Institute of Environmental Sciences and Technology

IEST-RP-NANO200.1

Contamination Control Division, Nanotechnology Committee
Recommended Practice 200.1

Planning of Nanoscale Science and Technology Facilities: Guidelines for Design, Construction, and Start-up

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1 SCOPE AND LIMITATIONS

1.1 Scope

This Recommended Practice (RP) is an overview of factors involved in the design, start-up, and operation of facilities in the field of nanotechnology.

The overview focuses on the unique considerations related to planning, design, construction, and start-up that typically confront owners, designers, and users of the advanced-technology facilities supporting research or production at the nanometer scale.

Intended as an executive-level summary, this document provides guidance in the planning and decision-making processes required for establishing facilities involved in nanoscale research and production as well as subcellular-scale biological research.

Specifications for ranges and criteria recommended within this RP form a framework intended to stimulate further discussion between the owner and the design team.

A series of supplementary RPs will cover specific topics in expanded detail. These RPs will provide recommendations on the following subjects as they relate to nanotechnology facilities:

- Planning
- Design
- Construction
- Start-up
- Operations

In addition, technical RPs will expand upon more complex topics that cross the above subjects, such as:

- Safety
- Quantitative aspects of environmental definition and evaluation, including vibration, acoustics, electromagnetic interference (EMI), and temperature

1.2 Limitations

Although this RP provides guidance for establishing performance criteria for operations at nanoscale levels, specific topics or details are not necessarily universally applicable to all nanotechnology facilities. Each facility is unique, and the general approach of the RP should be tailored to meet the operational needs of the facility of interest.

This RP does not specify environmental conditions in detail, as these conditions are driven by the requirements of research and process equipment and instrumentation unique to each facility.

This RP does not address laboratory animals or small-animal facilities.

This RP does not impose requirements that would supersede existing standards or requirements established by recognized regulatory bodies at any level.

Issues of safety (toxicity) of nanoscale materials lack consensus. It is beyond the scope of this document to define limits or provide recommendations with regard to toxicity and design of nanotechnology facilities. The most current information available at the time of the design should be taken into consideration.

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2 REFERENCES

The following documents are incorporated into this Recommended Practice to the extent specified herein. If no specific edition is cited, the most recent edition should be used. Where specific editions are cited, subsequent revisions of these publications do not automatically supersede the cited editions, and users should investigate the applicability of revised editions.

2.1 Institute of Environmental Sciences and Technology (IEST)

IEST-RP-CC003: Garment System Considerations for Cleanrooms and Other Controlled Environments

IEST-RP-CC006: Testing Cleanrooms

IEST-RP-CC012: Considerations in Cleanroom Design

IEST-RP-CC018: Cleanroom Housekeeping: Operating and Monitoring Procedures

IEST-RP-CC026: Cleanroom Operations

IEST-RP-CC027: Personnel Practices and Procedures in Cleanrooms and Controlled Environments

2.2 International Organization for Standardization (ISO)

ISO 14644-1: Cleanrooms and associated controlled environments—Part 1: Classification of air cleanliness

ISO 14644-2: Cleanrooms and associated controlled environments—Part 2: Specifications for testing and monitoring to prove continued compliance with ISO 14644-1

ISO 14644-3: Cleanrooms and associated controlled environments—Part 3: Test methods

ISO 14644-5: Cleanrooms and associated controlled environments—Part 5: Operations

ISO 14644-8: Cleanrooms and associated controlled environments—Part 8: Classification of airborne molecular contamination

ISO 14698-1: Cleanrooms and associated controlled environments—Biocontamination control—Part 1: General principles and methods

ISO 14698-2: Cleanrooms and associated controlled environments—Biocontamination Control—Part 2: Evaluation and interpretation of biocontamination data

ISO/TR 12885:2008 Nanotechnologies—Health and safety practices in occupational settings relevant to nanotechnologies

ISO/TS 27687:2008 Nanotechnologies—Terminology and definitions for nano-objects—Nanoparticle, nanofibre and nanoplate

2.3 Semiconductor Equipment Manufacturers' Institute (SEMI)

SEMI E33-94: Specification for Semiconductor Manufacturing Facility Electromagnetic Compatibility

2.4 Additional references

ANSI/ESD S20.20: Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)

ANSI/IESNA RP-7-01: Lighting Industrial Facilities ANSI approved

FDA Code of Regulations, Title 21, Parts 210 & 211 "Current Good Manufacturing Practice"

FDA Code of Regulations, Title 21, Part 820 "Quality System Regulation"

IEEE Std 1100-2005: IEEE Recommended Practice for Powering and Grounding Electronic Equipment

NEBB "Procedural Standards for Certified Testing of Cleanrooms, Second Edition" (1996)

NFPA 70: National Electrical Code (NEC)

NFPA 318: Standard for the Protection of Semiconductor Fabrication Facilities

2.5 Sources and addresses

ESD Association
7900 Turin Road, Building 3
Rome, NY 13440-2069 USA
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Fax: 315-339-6793
www.esda.org

IEEE
3 Park Avenue, 17th Floor
New York, NY 10016-5997 USA
Phone: 212-419-7900
Fax: 212-752-4929
www.ieee.org

IESNA
120 Wall Street, Floor 17
New York, NY 10005-4001
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ISO
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www.iest.org

All other ISO Standards:
ISO
1, ch. de la Voie-Creuse,
Case postale 56
CH-1211 Geneva 20, Switzerland
Phone: 41 22 749 01 11
Fax: 41 22 733 34 30
www.iso.org

NEBB
8575 Grovemont Circle
Gaithersburg, Maryland 20877 USA
Phone: 301-977-3698
Fax: 301-977-9589
www.nebb.org

NFPA
1 Batterymarch Park
Quincy, Massachusetts 02269 USA
Phone:617-770-3000
Fax: 617-770-0700
www.nfpa.org

SEMI
3081 Zanker Road
San Jose, California 95134 USA
Phone: 408-943-6900
Fax: 408-428-9600
www.semi.org

US FDA
10903 New Hampshire Avenue
Silver Spring, MD 20993
Phone: 1-888-463-6332
www.fda.gov

2.6 Additional resources

ASHRAE
1791 Tullie Circle, N.E.
Atlanta, Georgia 30329
Phone: 800-527-4723
Fax: 404-321-5478
www.ashrae.org

ASTM
American Society for Testing and Materials
100 Barr Harbor Drive
West Conshohocken, Pennsylvania 19428-2959
Phone: 610-832-9585
Fax: 610-832-9555
www.astm.org

Factory Mutual
Factory Mutual, Global Headquaters
500 River Ridge Road
P. O. Box 9102
Norwood, Massachusetts 02062
Phone: 781-440-8000
Fax: 781 440 8742
www.fmglobal.com

ICC
International Code Council
500 New Jersey Avenue, NW, 6th Floor
Washington, DC 20001-2070
Phone: 888-422-7233
Fax: 202-783-2348
www.iccsafe.org

3 TERMS AND DEFINITIONS

See Appendix B for a glossary of terms used in this document and related terms.

4 BACKGROUND AND PURPOSE

Prior to commencement of work on this document, many nanotechnology facilities had been completed or were under construction. The lessons learned by those involved in these projects have been shared at workshops and conferences. In nearly all cases, university and governmental planners and decision makers expressed that the plan/design/build/start-up process would have been much more straightforward if a source for guidance had been available. In most cases, the facilities were far more complex than any project these owners had attempted previously.

This document represents a collaborative effort of representatives from the design, construction, and user communities, along with equipment providers and owner groups.

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Facilities established for operation at the nanometer scale are among the most complex in existence. This complexity is based primarily on their breadth, not the complexity of individual components. Such facilities are inherently interdisciplinary and require interface of design requirements rarely addressed in the design of other types of facilities.

Nanotechnology facilities typically require cleanrooms for research and fabrication, but the cleanroom is not the primary focus of the facility. Nanotechnology facilities also have high-performance spaces within laboratory environments, in which environmental controls of parameters such as electromagnetic interference (EMI), temperature, and vibration far surpass the requirements of a typical research facility.

The nanotechnology processes undertaken in manufacturing plants and research and development (R&D) labs require facilities with extremely stringent environmental control. Conventional environmental control has dealt primarily with air cleanliness. In nanotechnology applications, however, environmental controls include: temperature and humidity level; air and water quality; purity of chemicals and gases; sound and vibration; electromagnetic and radio frequency interference (RFI); electrostatic discharge; materials outgassing; safe grounding; assurance of personnel health, safety, and security; and prevention of biohazard.

The needs of nanoscale science will dictate the makeup of the facility, such as spatial relations among cleanroom, laboratory, and high-performance operations. Generally, the technological requirements of the facility are the most critical.

This RP provides a tool for use by those who are approaching the planning, design, and construction of a highly sophisticated facility, possibly for the first time. It is not intended to provide step-by-step instructions for how to design, construct, and operate a facility, but it can help to alert decision makers to potential roadblocks during the project phases.

4.1 Objective

The objective of this document is to address the following considerations:

a) Planning

- Philosophical balance within design process between capital and life-cycle costs, design and construction schedule, and long-term building performance
- Regulatory issues regarding science and research focus
- Composition of the owner's technical guidance team
- Optimum design and construction teams for the particular set of applications
- Project delivery method and the appropriate process for successful implementation
- Site features appropriate (or inappropriate) for an advanced technology facility, including vibration, EMI, radio frequency interference (RFI), acoustic noise, and air quality
- Parameters of site evaluations
- Programming

b) Design

- Site considerations
- Overall building considerations (e.g., design by phases, architecture, sustainability)
- Safety considerations
- Building engineered systems (e.g., mechanical systems and electrical infrastructure)
- Building technical systems (e.g., vibration, acoustics, EMI/RFI/magnetics)

c) Construction

- Contractor selection
- Construction means and methods
- Commissioning, certification, and validation
- Training
- Project close-out

d) Start-up and Operation

- Building operations manual
- Safety
- Operational systems
- Controlled-material handling
- Process equipment and tool installation

4.2 Intended audience

The intended audience for this document includes:

- Decision makers, owners, and other stakeholders involved in facilities for nanoscale work

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- Planners, designers, architects, and engineers at universities, government agencies, manufacturing organizations, and other institutions
- Equipment and service suppliers
- Design and construction community
- Standards and professional organizations (AIA, ANSI, ASCE, ASHRAE, ASME, ASTM, IEEE, IEST, ISO, NFPA, USP, and other organizations)

Insurers and underwriters

- Regulatory bodies (BSI, CDC, DIS, EN, EU, EPA, FDA, ICH, JIS, NIOSH, OSHA, and other agencies)

5 PROJECT PLANNING

All architectural projects involve activities that occur prior to formal design. However, highly sophisticated technical buildings may require adjustments to certain traditional activities as well as special planning activities related to the technology involved.

5.1 Project definition and programming

This section addresses the critical, early aspects of the design process involving a sophisticated, high-technology building. The programming phase consists of a systematic evaluation to identify and address the goals and requirements of the project. A well-developed program plan will help the remainder of the project proceed smoothly. During the programming phase, the project team will meet for the first time to discuss their research and educational needs. The goal of this process is to perform an objective analysis while limiting subjective influence.

It is recommended that the owner and users employ this process to establish clear goals and objectives, clarify constraints, project realistic space and infrastructural requirements, and deliver a holistic and succinct problem statement that will serve as the departure point for design.

This process occurs early, sometimes before funding or final approval from the governing bodies, and offers the greatest opportunity for building owners and users to fully express their needs and visions for their new facility. An effective programming process is structured to unite the building owner's creativity with that of the design firm.

The team should review and analyze the data collected and develop a detailed document to be used as a baseline for further planning efforts. Areas of internal inconsistency or conflicts are identified for special investigation and resolution. Senior decision makers representing the owner should be closely involved in the drafting and review of the resulting programming document, or program.

The program should address how the facility should interact with the contextual surroundings of the site and the overall master plan. While the program is function driven, statements of image, massing, connectivity to surrounding buildings and grounds, and long-term sustainability should be defined. Other issues for consideration include the long-term life-cycle operational strategies and costs of the facility, expansion opportunities, site utilization, and access. The movement of people, chemicals, and equipment should also be examined.

Recommended deliverables at the end of the programming phase are:

Written Program Document
Clear and concise program goals, issues, facts, concepts, and relationships delivered within a written program document.

Conceptual Cost Estimate
Perhaps the primary issue in facility design and construction that cuts across all factors is economics. Maximum flexibility, quantity, quality, and sophisticated systems demand rational decision-making and establishing priorities to maintain a fiscal balance.

Comprehensive Site Survey
Evaluation of the site for geotechnical, vibration and electrical influences, acoustic noise, and ambient outdoor air quality should be considered during the programming phase to identify the best site and siting options prior to the design phase.

5.1.1 Goals and objectives

Clear communication is particularly critical with technology buildings, where many of the environmental requirements pose a significant impact to project cost. The communication process should start with a definition of the project goals and objectives. Otherwise, the design team may be forced to make assumptions. As part of this effort, the owner and stakeholders should address key issues and reach consensus regarding the following questions.

Why is this facility being built?

Is the project intended to provide interdisciplinary space that does not already exist, in order to facilitate collaboration between disparate research groups? (For example, an organization may wish to support collaboration between biology and physics, but may have no appropriate lab facilities.)

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For whom is the facility being built?

This question is more complex than it appears to be. There are two major categories of researchers for whom a facility can be designed, and most facilities involve a combination:

- **Established research groups:** The organization has one or more well-established research groups, and the facility is intended to provide these groups with collaboration space or laboratory space, or both, that is more sophisticated than currently available.
- **Potential users:** The organization has a growth plan that involves establishing a presence in a particular facet of nanoscale research, but does not currently have an established group around which the facility can be designed. The organization hopes to use the new facility to attract researchers and faculty. (Some in the design community have referred to this as a "build it and they will come" facility, after the famous line from the movie, *Field of Dreams*.)

The latter group poses the greater challenge, as the design team must make assumptions regarding interior environmental characteristics and technical priorities in building systems that will have a significant impact on cost as well as on the potential for performing certain types of research. Budgetary constraints typically do not accommodate a "one size fits all" nanotechnology facility. Furthermore, the programmatic needs are derived from the unique mission and goals of each project.

What are the project constraints?

- Site contextual constraints
- Physical limitations, including space constraints
- Financial limitations
- Regulatory requirements
- Schedule

In addition to goals and objectives, certain philosophical considerations will weigh heavily on the design process:

- What will be the philosophy of the owner and the design team for balancing competing factors of cost (capital and life-cycle), schedule, and performance considerations when making decisions?
- What will be the philosophy regarding balance between operational efficiency (e.g., energy production, consumption, and efficiency) versus the initial cost of construction? Is it desirable to spend more money initially on a facility that produces its own power and consumes less power over the life of the building?
- What will be the philosophy regarding future flexibility, which may have a greater initial cost?

5.1.2 Project team formation

It is important that the project team include representatives from the following teams (also see Figure 1):

- Owner's project management team (including administration, facility managers, users, technicians, building and maintenance staff)
- Integrated architect/engineering (A/E) design team
    - Programmers, architectural designers, sustainable building specialists
    - Engineering disciplines (mechanical, structural, electrical, costing)
    - Specialty consultants (e.g., laboratory design, EMI/RFI/magnetics, acoustics, vibration)
- Owner's technical guidance team
- Value engineering team
- Construction manager (CM) or contractors
- Commissioning agent (CxA)

All of these participants should be active throughout the design process. The participant that is often neglected—with dire consequences—is the owner's technical guidance team. This group should be drawn from technical staff within the research community for whom the facility is being designed. The purpose of this group is to represent that community, and the members should be prepared to communicate information to and from the researchers. Some of this information will be highly technical, and critical nuance may be lost if proper and direct communication channels are not established between researchers and designers.

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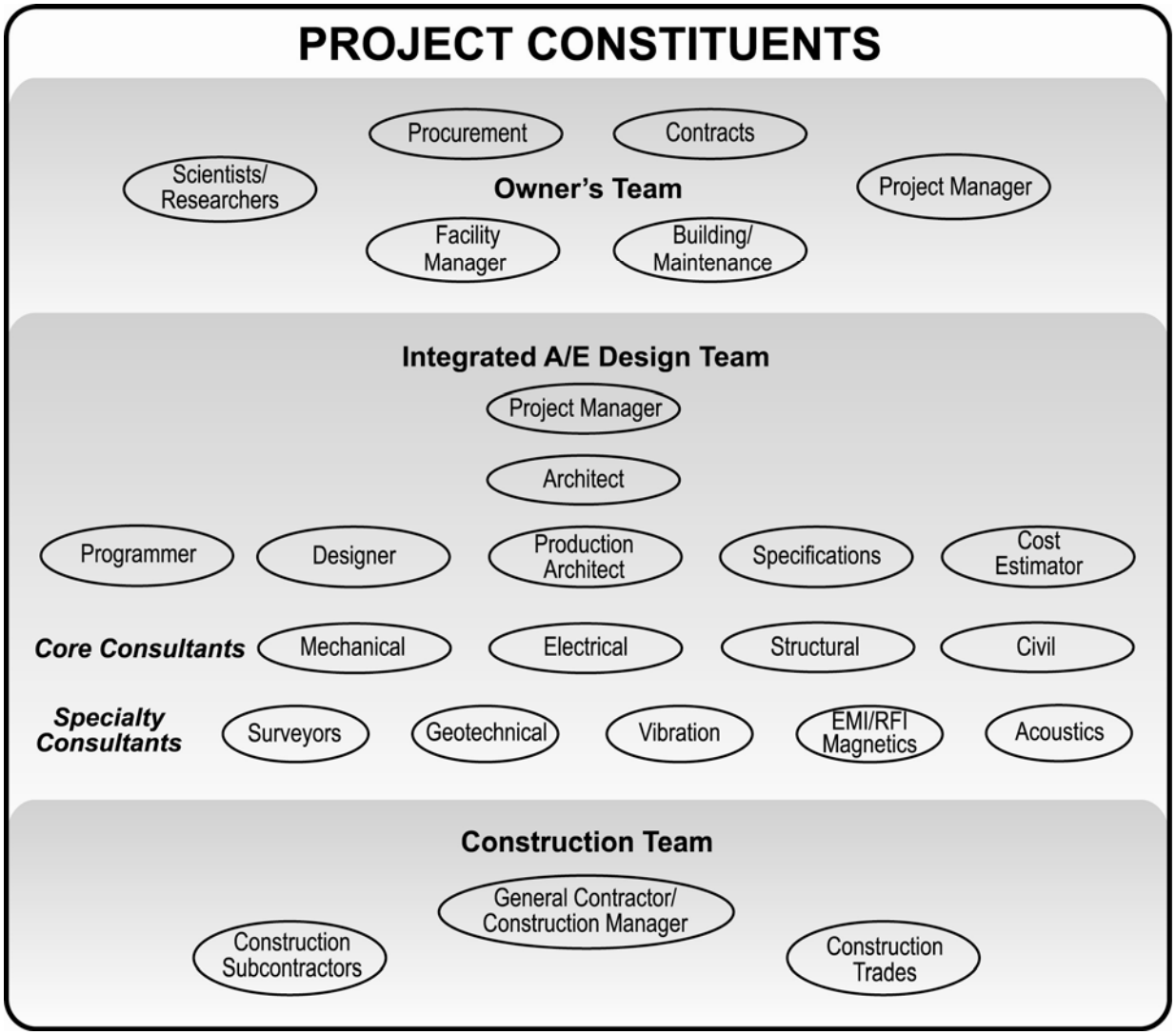

Figure 1. Typical project team organization.

The project team needs the ability to grow and shrink as appropriate during different phases of the project. Flexibility is important. The specialty consultants will typically be more active at particular times than at other times.

Parameters that should be considered by the owners and users prior to commencing design include:

- Composition of the owner's technical guidance team
- Qualifications of the design team for the particular set of applications (nano, bio, etc.)
    - Experience of prime design firm and consultants
    - Reputation
    - References
    - Workload
- Qualifications of the construction team to build a sophisticated advanced technology facility
    - Consider prime and subcontractors
    - Consider using a prequalification process
- Qualifications of commissioning team
    - Representation of the owner, users, building operating engineers, designer, contractor, and independent commissioning agent

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5.1.3 Advisory group

Complex projects require buy-in from a variety of stakeholders. It is useful to assemble an advisory group made up of researchers and staff to serve as liaison between the scientists, facilities group, and design team, translating needs and physical attributes between the various participants.

A common conundrum facing design teams is that of conflicting criteria. This situation arises when the solution to one stringent criterion violates another criterion. For example, one common means of achieving stable temperature is to increase airflow. However, the increased airflow may lead to more acoustic noise. Individually, temperature stability and low noise are moderate design challenges. When stringent control parameters are imposed on both simultaneously, the level of design challenge increases. The resolution could have cost consequences.

The advisory group can be advised by the design team of the possible design implications and cost impacts, and then facilitate communication with the researchers who can assess the implications to the science. In some cases, the advisory group alone may be able to resolve the conflicts without requiring input from the researchers.

5.1.4 Project delivery methods

A project delivery method is a system by which the project is organized, financed, designed, and constructed among building owner, designers, and constructors. There are various delivery methods, each having strengths and drivers that depend on the project goals with respect to the balance between scope, cost, and schedule.

a) Design-Bid-Build (DBB)
With the help of the designer, an owner develops contract documents consisting of a set of drawings and specifications. Based on these documents, proposals are called for and bids are submitted by constructors. The project is then awarded and contracted. The selected constructor is responsible for the overall completion of the project. This process is linear by design and therefore has a longer schedule than alternate delivery methods. This process affords the building owner ample time to define project requirements in a full set of construction documents before agreeing on a construction price based upon those documents.

b) Design-Build (DB)
In this method, the owner selects one responsible constructor to perform both design and construction of the project. Because the designer and constructors belong to one entity and work together from the beginning, it is not necessary to prepare detailed drawings and specifications before awarding the project. Time may be saved because it is not necessary to wait for the overall completion of detailed design. Change orders can be internally resolved within the DB entity.

In general, this is the fastest-growing delivery method; however, implementing DB within a nanoscale project poses both challenge and risk. Unlike the DBB method, the shorter DB schedule requires the building owner to sign a construction tender prior to full development of the construction documents.

c) Construction Management (CM)
The building owner hires a construction professional who works with the designer to assure that the design can be built for a reasonable cost and in a realistic amount of time.

In general, there are two types of construction management (CM):

- **The CM as adviser** serves as a consultant to the owner and has no legal responsibility for the execution of the actual construction work.
- **The CM as general contractor (CM at risk)** acts as a prime constructor and is in charge of the construction work. The CM is authorized to award subcontracts in the role of general contractor.

The CM process not only affords the building owner ample time to define project requirements in a full set of construction documents before agreeing to a construction price, but also provides a secondary reviewing body to the cost estimates and a contractor perspective on the constructability.

d) Integrated Project Delivery (IPD)
This delivery method entails a concentrated team effort of all parties involved under a single contractual umbrella. IPD is less hierarchical than other traditional methods. The trade subcontractors are typically embedded within the design team and work closely with the engineers in developing the concepts.

5.1.5 Cost, budget, and value engineering

The terms *cost*, *budget*, and *value engineering* have well-defined relationships, but in the context of building design (especially buildings for technology) these terms are often misused.

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The building cost is the amount of money required to produce the facility, including the cost of acquisition, materials, and labor. Prior to construction, the cost is estimated by professionals using the design documents and assumptions. The budget is the amount of money available to the owner to spend on the facility. The cost must be kept to an amount equal to or less than the budget.

The terms *function* and *scope* in the context of a facility refer to the environments provided or to the aesthetic qualities exhibited. The environments are defined by the criteria for the project. *Value* is commonly defined as the ratio of function to cost. Thus, value can be increased by either improving the function or reducing cost.

Value engineering (VE) is a methodology intended to increase the value of a facility. The use of VE is often motivated by a need to reduce the cost of the facility, but a fundamental principle of VE is that function not be reduced as a result of VE. In other words, VE is not the same as a reduction in scope, but may have a similar effect on cost.

A cost estimate may determine that the cost to construct a building, as designed, will exceed the budget. VE may be applied to determine if such options as alternate materials or construction methods might reduce the cost without compromising the function (as defined by the technical criteria). If, after VE, the cost still exceeds budget, then the scope of the building should be addressed and may be reduced.

In some instances, the concept of VE is applied to the criteria themselves, by re-examining basic functionality. This approach addresses whether a specific criterion is necessary for a particular instrument or process, or another, less expensive criterion might be used. For example, a questions might be addressed such as, "Does instrument (or process) X really require limiting temperature fluctuation to ± 0.01 °C, or would it function equally well if temperature fluctuation were limited to ± 1 °C, which represents a significant cost difference?" In some cases, the response may be fairly straightforward, but in other cases, the response may require evaluation by a researcher.

The cost and budget of a facility should be determined based on the building technical requirements, classification of space, equipment, and safety. The engineering systems typically represent 50% of the total capital cost of the building, and careful consideration of the design and requirements should be accounted for within the allocated budget.

VE should consider the following factors:

- Cost of land acquisition
- Cost and availability of utilities
- Design of building construction
- Construction completion date
- Financing terms and depreciation cycle
- Availability of support staff
- Research requirements
- Equipment environmental requirements

5.1.6 Commissioning

Commissioning not only encompasses a number of activities that are mainly carried out at the latest stage of a project, but also includes ongoing activity, to be systematically managed and modified from pre-design to post-completion.

According to the National Institute of Building Sciences (NIBS), commissioning is "a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets defined objectives and criteria. The Commissioning Process assumes that owners, programmers, designers, contractors, commissioning team members, and operations and maintenance entities are fully accountable for the quality of their work. The Commissioning Team uses methods and tools to verify that the project is achieving the owner's Project Requirements throughout the delivery of the project. The Commissioning Process begins at project inception (during the Pre-Design Phase) and continues for the life of the facility (through the Occupancy and Operations Phase). The Commissioning Process includes specific tasks to be conducted during each phase in order to verify that design, construction, and training meet the owner's Project Requirements." (NIBS, 2006)

The commissioning agent(s) (CxA) should be selected at the project definition and programming stage so the agent(s) can attend planning meetings and be present during the design process. The presence of the CxA during the design phase will give the agent(s) a working knowledge of the form and function of the facility during the commissioning phase, and allow the agent to provide input that may save effort and reduce post-construction cost.

More information about commissioning, including guidance for the selection of the CxA, is provided in section 7.2.

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