

# Architectural Acoustics

Christopher Jaffe, Ph.D., Hon. AIA, and Russell A. Cooper

*Architectural acoustical services encompass investigating, problem identification and solving, and designing solutions for matters dealing with sound and vibration in buildings.*

## Summary

### ARCHITECTURAL ACOUSTICAL SERVICES

#### **Why a Client May Need These Services**

- ▶ To achieve sound quality appropriate for a building space
- ▶ To address facility environments in which sound quality is paramount
- ▶ To control sound in facilities located near high-noise areas
- ▶ To rectify sound problems in existing facilities
- ▶ To include acoustical information in environmental impact studies

#### **Knowledge and Skills Required**

- ▶ Fundamental understanding of acoustical theory and concepts
- ▶ Background in science, math, and engineering
- ▶ Knowledge of architecture, music, theater, and construction techniques
- ▶ Knowledge of noise in mechanical equipment
- ▶ Ability to operate equipment used to measure sound
- ▶ Ability to clearly communicate technical information

#### **Representative Process Tasks**

- ▶ Develop acoustical objectives and criteria
- ▶ Develop recommendations for meeting acoustical objectives
- ▶ Develop details for acoustical treatments
- ▶ Prepare specification language for required materials and products
- ▶ Ensure conformance to acoustical details during construction
- ▶ Conduct on-site sound measurements for existing buildings

The acoustical consulting profession developed rapidly following the end of World War II, when architects and government agencies engaged individuals and firms to research and study practical applications for various fields related to transportation, housing, and electronics. The field has now matured but is still growing as the population increases and people become more sensitive to and selective about sound quality.

Architectural acoustics embraces acoustical analysis, design, and control in new and existing buildings. Acoustical services that architects may be involved with can be categorized into one or more of the following groups:

- Product and materials testing, measurement, and reporting
- Control of noise related to transportation systems
- Control of noise from building systems
- Environmental noise control within and near buildings
- Vibration and seismic control
- Electronic reinforcement and enhancement of sound (electroacoustics)

## CLIENT NEEDS

Acoustical services involve all kinds of spaces in and around buildings and are needed when clients are, or should be, concerned about the quality of sound throughout a completed building. Recent areas of concern are the effects of noise on office workplace performance and on classroom teaching and learning. More traditional engagements are for auditoriums, courtrooms, performing arts facilities, broadcast and recording studios, worship spaces, and the like. Specific reasons clients may need acoustical services include the following:

- They are designing spaces specifically for audience listening (e.g., theaters, auditoriums, concert halls, rehearsal halls, education rooms in music and theater facilities, dance theaters, etc.).
- They are designing a school building in which speech intelligibility in auditoriums and classrooms is paramount.
- They are designing facilities for which a satisfactory acoustic environment is perceived to be important to the project's success (e.g., restaurants, libraries, trading floors, dining rooms, executive offices, research facilities, nightclubs, etc.).
- They are designing multiple-use spaces.

---

**CHRISTOPHER JAFFE** is president of *Jaffe Holden Scarborough Acoustics*, a 41-year-old consulting company in Norwalk, Connecticut. Jaffe received the AIA Year 2000 Institute Honors for Collaborative Achievement Award. **RUSSELL COOPER** is director of architectural acoustics for *Jaffe Holden Scarborough*

- They are designing flexible, expandable spaces.
- A feasibility study is being conducted for a building located near a noisy site (e.g., highways, airports, industrial complexes, etc.).
- There is a requirement for an environmental impact statement that includes a noise assessment component.
- Complaints are being received about excessive noise or vibration in a building (e.g., lack of acoustical privacy, acoustics not suitable for the programmed activity in the space due to echoes or other acoustical anomalies, etc.).
- They are in need of conformance testing to meet applicable standards, codes, or specifications, such as residential noise codes or industry standard marketing ratings.

▶ **“From the very outset of any building development, the selection of the site, the location of buildings on the site, and even the arrangement of spaces within the building can, and often do, influence the extent of the acoustical problems involved. The materials and construction elements that shape the finished spaces will also determine how sounds will be perceived in that space as well as how they will be transmitted to adjacent spaces.”**

*William J. Cavanaugh and Joseph A. Wilkes, Architectural Acoustics, Principles and Practice (1999)*

The chief benefit of acoustical services for an existing problem is the assurance of a solution that works from the outset, thus saving time and money because a client won't have to try multiple unsatisfactory solutions. In the case of new construction or a building renovation, acoustical analysis can result in recommendations that avoid surprises once the building is in use.

Fees for professional acoustical services vary according to geographical region, facility type, length of time services are provided, and, of course, scope of the project. When the detailed scope and time frame of the study are known, acoustical studies are generally conducted on an hourly or per diem basis plus direct costs for travel, instrument use, and so on. Long-term projects are individually priced based on a percentage of the cost of construction or of the cost of the equipment that may be specified.

## SKILLS

Unfortunately, people still consider acoustics—especially architectural acoustics—to be more art than science. Successful acoustical consultants generally are experienced practitioners who know how to apply acoustical science to real buildings and understand how people respond to various acoustic environments. Since acoustical success is based on both objective measures and subjective impressions, guarantees cannot be made that all users will come to the same conclusion regarding the acoustic quality of a particular design. However, just as in judging the quality of architectural design, the risk of dissatisfaction is greatly minimized by applying good acoustical analysis and design in collaboration with the entire project design team.

Individuals in the field of acoustics have backgrounds in science, math, and engineering. However, architectural acoustics is an interdisciplinary field involving many aspects of both the arts and sciences. A broad background is needed, including understanding of music, theater, architecture, building construction techniques, and other disciplines inherent to the building design process. Noise and vibration control requires specialized knowledge of mechanical equipment, how noise is generated, and how it is propagated in the air or through a structure. Electronic sound reinforcement and enhancement design requires further background in electrical engineering or electronics.

Experience is a critical factor in determining the qualifications of acoustical consultants for a particular assignment. Also, architects seeking acoustical consulting services should consider the ability of the consultant to effectively communicate technical information—orally, in writing, graphically, or with physical or computer modeling—to the architect or client.

Acoustical consultants are familiar with the use of both simple and complex sound-measuring instruments such as sound level meters. Some employ highly sophisticated equipment such as real-time analyzers that measure, store, and analyze a sound's frequency, time length, and intensity or level. Some instruments are hand-held, while others are the size of a small suitcase.

Occasionally the best architectural acoustics solution for a space is to supplement the natural acoustical deficiency of a space with electroacoustical enhancement. The concept of enhancing the sound quality of a space through electronic means has been well understood since the 1970s. However, not until recently has digital technology been able to provide cost-effective, electronically stable systems that musicians and audiences are willing to accept. When this technology is needed, the architect should seek acoustical consultants who are experienced in its application.

▶ **Postoccupancy evaluations may uncover acoustical problems, among others.**

▶ **AIA continuing education programs periodically offer workshops and other courses on architectural acoustics. Check the continuing-education page at the AIA Web site, [www.aia.org](http://www.aia.org).**

## PROCESS

Numerous project factors affect the scope of acoustical services, such as whether a project is new construction or a renovation and whether it will include design only or comprehensive services from initial design through construction administration. To the extent needed for a particular assignment, architects should seek out consultants or specialists in acoustics to bring acoustical expertise to the project team.

An acoustical consultant's staff is typically set up in the same way as an architect's and consists of a principal consultant in charge, a project manager, and various staff consultants working together as needed on each project. The principal in charge is usually responsible for establishing the acoustical criteria and initial acoustical design concepts. The project manager is the day-to-day point of contact for the architect and client. The project manager may also provide acoustical design in keeping with the principal's concept. Project consultants provide assistance to the project manager and principal for specialized expertise and for calculations, measurements, detail drawings, submittal reviews, and the like.

**Consultant selection.** Before engaging an acoustical consultant, the architect should determine to the extent possible what services are warranted. Some questions to ask are:

- Does the client understand the need for and desirability of having acoustical services?
- Would having acoustical expertise on the project be beneficial or even essential to the desired end result?
- Does the client prefer to engage the acoustical services of a consultant located in the same region as the project?
- What level of architectural and/or acoustical quality is the client (and ultimately the building tenant) looking for?

Answers to these questions will determine if it is beneficial to have an acoustical consultant on the team and give guidance about what type of consultant would be suitable.

Often due to an insufficient budget for consultant services, acoustical expertise is brought on board well after a project begins. It is preferable, however, to bring acoustical expertise into a project as early as possible. It can be extremely difficult to undo decisions that have been accepted by a client and architect. When brought in at a later point, a consultant may have to critique or evaluate a design instead of participate in its creation. The introduction of a new team member late in the process may also produce a poor working relationship among project team members. For performing arts projects, qualified theatrical consultants should be considered for the team as well. A close working relationship between all consultants on a project is essential for proper coordination and the success of the overall design.

Architects may contact the National Council of Acoustical Consultants for a directory of acoustical consultants by country, region, state, or discipline. Experience is best judged by word of mouth; references, friends, and associates in the business may be helpful. When contacting acoustical consultants, an architect should request the overall firm biography and a list of pertinent completed project types. Resumes for individual consultants who may be involved should also be requested.

**Work plan.** If the scope of work encompasses the entire design and construction process, the first step is to establish acoustical criteria for each space within the facility. This can be done in the programming phase with input from user groups or in a separate document, prepared by the acoustical consultant, based on an assessment of the architectural program (especially if there are no users involved at this point). After the acoustical criteria have been established for all spaces and the quality of the sound as it relates to the budget has been determined, schematic design commences.

**Programming.** The acoustical criteria depend on the program uses for each space. An example of this for a dedicated concert hall would be that the background sound level must be very low noise criterion (NC-15) and the reverberation time relatively long (RT about 1.8 seconds). If the space is to be used for Broadway musicals that have reinforced sound systems, the criteria could be NC-25 with RT of 1.3 seconds. However, a concert hall with a very low tolerance for extraneous sound and a sufficiently reverberant quality may be far more costly to construct than a Broadway house, which could tolerate a higher level of noise and have a less reverberant acoustical characteristic.

▶ **AIA Document C141, Standard Form of Agreement Between Architect and Consultant, is suitable for use when an architect contracts with a consultant for acoustical services.**

## ACOUSTICAL DESIGN PROCESS STEPS

<b>Programming</b> <i>Discovering client needs</i>	Conduct user interviews Perform acoustical survey, including measurements Determine uses—single or multiple Determine number of seats Identify audio system needs Establish acoustical criteria <ul style="list-style-type: none"> <li>• Background sound level (NC), (RC), (NCB)</li> <li>• Volume per seat (V/S)</li> <li>• Reverberation time (RT60)</li> <li>• Adjustable acoustics? Orchestra shell?</li> </ul>			
<b>Schematic Design</b> <i>Establishing a design direction</i>	<b>ROOM ACOUSTICS</b>	<b>SOUND ISOLATION</b>	<b>NOISE AND VIBRATION CONTROL</b>	<b>AUDIO SYSTEMS</b>
	Determine volumes and dimensions	Identify acoustic doors, windows, floating floors, sound control ceilings	Identify mechanical equipment locations	Develop preliminary audio systems description
	Determine room locations and adjacencies	Provide outline of partitions, floors, and ceilings	Provide noise and vibration control guidelines	Establish budget for audio systems
	Determine amount of adjustable acoustic material	Determine the structural system and acoustical requirements (acoustic joints?)		
	Broad discussion of room finishes			
<b>Design Development</b> <i>Developing the design</i>	<b>ROOM ACOUSTICS</b>	<b>SOUND ISOLATION</b>	<b>NOISE AND VIBRATION CONTROL</b>	<b>AUDIO SYSTEMS</b>
	Determine adjustable acoustic material and locations	Provide partition details	Review mechanical duct and pipe distribution and sizes	Provide preliminary locations and sizes of audio system speakers
	Discuss room finish options	Provide acoustic door, window, floating floor, and ceiling details	Provide penetration details	Refine audio systems budget
	Provide layouts for orchestra shell and risers	Provide intersection details		
<b>Construction Documents</b> <i>Detailing the design</i>	<b>ROOM ACOUSTICS</b>	<b>SOUND ISOLATION</b>	<b>NOISE AND VIBRATION CONTROL</b>	<b>AUDIO SYSTEMS</b>
	Provide guideline specifications for acoustic materials and constructions	Provide guideline specifications for acoustic materials and constructions	Perform acoustical calculations and provide recommendations for acoustical treatments	Prepare audio systems bid documents (drawings and specifications)
	Review theater consultant's documents Review architect's documents	Review structural engineer's documents Review architect's documents	Review mechanical engineer's documents	Review bids
<b>Construction Administration</b> <i>Implementing the design</i>	<b>ROOM ACOUSTICS</b>	<b>SOUND ISOLATION</b>	<b>NOISE AND VIBRATION CONTROL</b>	<b>AUDIO SYSTEMS</b>
	Prepare submittal review list	Prepare submittal review list	Prepare submittal review list	Monitor audio contractor's progress
	Review submittals and shop drawings of acoustic materials	Review submittals and shop drawings of acoustic materials and construction	Review submittals and shop drawings; perform site inspections, and prepare punch lists	Perform site inspections and prepare punch lists
	Perform site inspections and prepare punch lists	Perform site inspections and prepare punch lists		
<b>Postconstruction</b> <i>Tweaking the design</i>	<b>ROOM ACOUSTICS</b>	<b>SOUND ISOLATION</b>	<b>NOISE AND VIBRATION CONTROL</b>	<b>AUDIO SYSTEMS</b>
	Tune adjustable acoustic systems for each program use	Measure sound isolation for conformance to criteria	Measure background sound levels for conformance to criteria	Tune the audio system and verify speaker aim and positioning, settings, and controls
	Set the orchestra shell for each program use	Make recommendations if necessary to resolve problems	Make recommendations if necessary to resolve problems	Train system users
	Measure RT <sub>60</sub> and other architectural acoustical parameters			

Similar criteria are established for determining how much sound can enter a space. Again, the program use of the space dictates this. An outdoor rock-and-roll amphitheater next to a residential complex would require an extreme amount of sound mitigation, while an office building next to the same residential complex might not require any noise control measures. Music practice studios may need to be isolated from each other, but in the corridor it might be quite acceptable, even pleasant, to hear some music emanating softly from the rooms. For a multipurpose space, with varying programmatic needs that require different acoustical qualities, an acoustical consultant may recommend using an adjustable acoustic system to vary the reverberation time to suit the different programmatic requirements.

If a project is a renovation, an acoustical survey may be desirable to assess the quality of the existing acoustics. This usually involves equipment for measuring and analyzing sound as well as interviews with key user groups.

An assessment of facility audio system needs is also undertaken, through interviews or a survey of existing equipment (if applicable). If the end user is not yet available, the acoustical consultant develops an audio system description and budget based on experience and requirements for each space.

**Schematic design.** In the schematic design phase, recommendations for achieving the acoustical criteria are provided in broad terms. For example, information about the following may be specified: volumes of spaces; dimensions; location of spaces and their adjacencies; structural concerns; mechanical equipment locations and guidelines; and a brief outline of major partition types, special floor or ceiling assemblies, area requirements for variable acoustic elements, identification of need and budget for an orchestra enclosure, and other items that may affect the budget in an extraordinary way. An experienced acoustical consultant is highly valuable at this stage because he or she can identify items that will affect the budget long before a concerted design effort has reached a detailed level.

Electroacoustical design services during schematic design usually include a schematic audio systems description and an installed-systems cost estimate for various options.

It is useful for project team members to have a schematic design acoustical report prepared at this point. This document can become the basis for further acoustical design development. There is nothing more frustrating to an architect and client than to be surprised by new acoustical requirements late in a project. Although it is impossible to foresee all potential problems in advance, an experienced acoustical consultant should be able to identify and document most of the issues early in the process.

**Design development.** Deliverables include partition details, penetration details, and sketches for acoustic doors, windows, and floating floors. Room finish options are also developed. Mechanical duct and pipe sizing and distribution are discussed. Preliminary location and sizes of speakers and adjustable acoustic systems and layouts of orchestra enclosures or shells are shown on drawings.

**Construction documentation.** Construction document services usually include many reviews of drawings and specifications to ensure that the acoustical recommendations have been incorporated correctly. The electroacoustical consultant prepares a set of plans and specifications to be bid. However, it is important to understand that the architectural acoustics consultant does not provide a set of drawings and specifications that go into the bid documents.

Instead, the consultant provides recommendations in the form of sketches, drawings, reports, memorandums, letters, meetings, and so on for the architect and engineers to incorporate into the documents. Even when a consultant prepares CSI specifications, these should be

reviewed by the architect or engineer before they are incorporated in the bid documents. Since most acoustical consultants are not licensed professional engineers, the burden of professional responsibility lies on the architect and engineers whose documents bear their name and stamp.

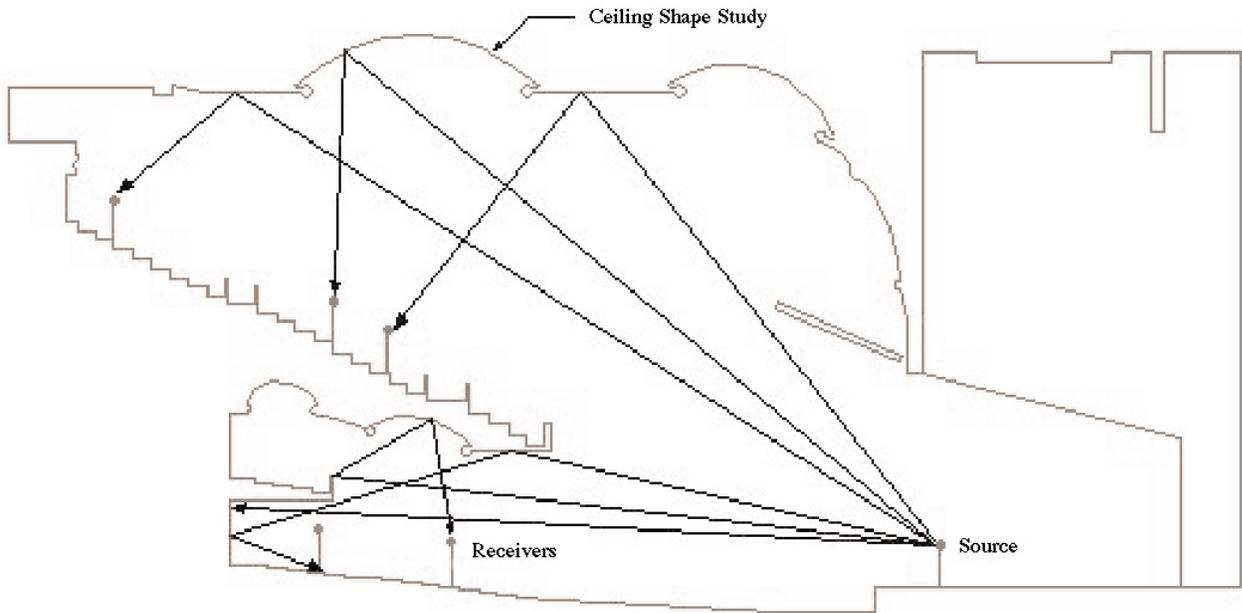
An exception to this is in electroacoustics, in which consultants do provide drawings and specifications to be bid by an audio contractor. This is acceptable, since most audio systems are low-voltage and do not require the license of a professional electrical engineer. However, close cooperation and coordination between the electroacoustical designer

and the electrical engineer is necessary to ensure that the full scope of the work (low and line voltage) is properly documented.

▶ **The acoustical consultant reviews construction drawings prepared by the architect and the architect's consultants to ensure that recommended acoustical measures are addressed. For more on documentation services, see Construction Documentation—Drawings**

▶ **Materials associated with the acoustical criteria and benchmarks recommended by the acoustical consultant are defined in the specifications. The development of these specifications is coordinated with the development of project drawings as described in Construction Documentation—Specifications**

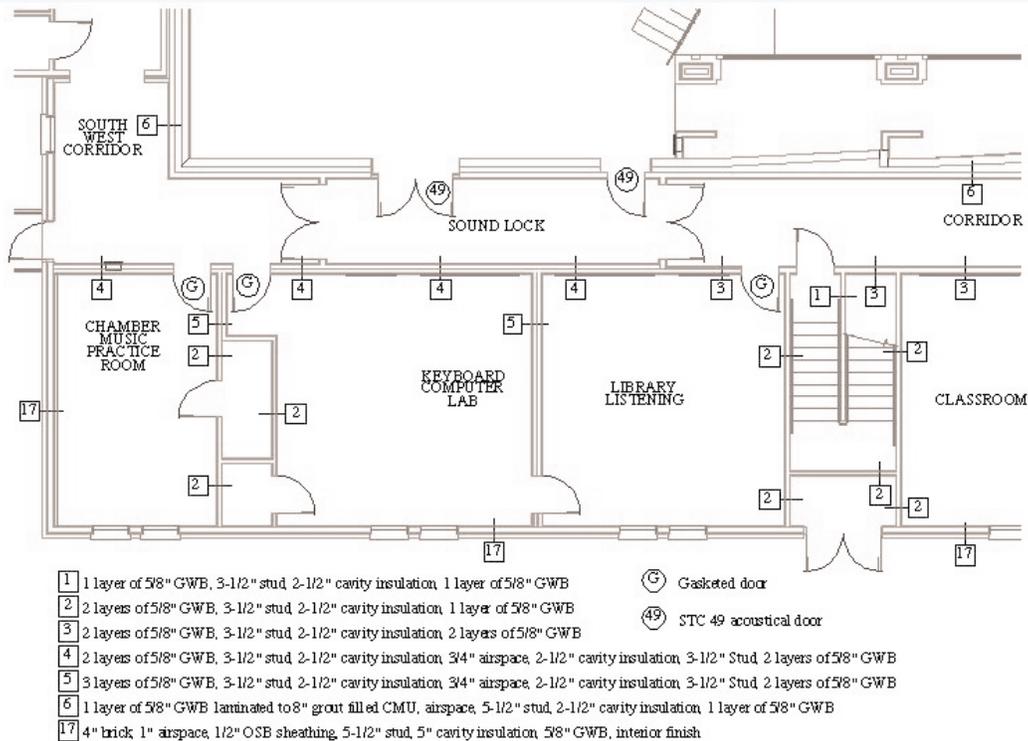
## Sound Reflection Study



Illustrated is a ray tracing or sound reflection study of a ceiling shape proposed by an architect. Sound "rays" are traced from a source on the stage along a surface and then, according to the formula stating that the angle of incidence equals

the angle of reflection, reflected to areas in the audience. The study is conducted to ensure there are few areas that do not receive reflections and that sound isn't focused in any individual area.

## Sound Isolation Constructions



Illustrated are partition and door markups of an architectural plan for a music school. Acousticians often communicate sound isolation requirements by creating partition details rather than using single-number acoustical requirements such as "STC-50 wall," which leaves the construction open to interpretation. The acoustician has determined the placement for these partitions by

comparing the expected sound pressure levels to be generated in the source room to the background sound criteria in the receiving room. Each of these partitions has a laboratory-rated performance and must be weighed with the deficiency that will occur in the real-world construction process.

▶ During construction, the acoustical consultant monitors the installation of materials, components, and systems to determine if the intent of the acoustical design is being met.

▶ Noise and related acoustical problems may be revealed during a commissioning process that includes on-site performance testing and evaluation of building systems.

**Construction administration.** This phase of the project is a very important (and on some projects essential) part of the scope of architectural acoustical services. Site visits for inspections are necessary to help contractors understand how the construction details coordinate with the proper acoustics end product. Most contractors are less experienced in buildings for which acoustics are of major concern, so it is important to communicate to them why in acoustically critical projects some of the details are complex and what can go wrong if the designs are not properly implemented. For example, strategically scheduled site inspections are necessary to inspect construction that is vital to sound isolation but may be covered up early in the construction process. For example, a small connection of two steel members across a structural isolation joint may short-circuit the acoustical isolation for a music hall. Experienced acoustical consultants know when to visit a site to examine these types of sequencing issues.

**Postconstruction.** Acoustical services can and often must be part of building commissioning services. This usually involves verifying acoustical criteria and establishing the initial setting of adjustable acoustic systems. Where adjustable acoustic systems have been employed, postconstruction services may involve tuning to achieve the proper acoustical balance. For performance spaces, the consultant must work with performance groups in rehearsal to determine the most agreeable settings. In addition, the consultant may have to train users in the use of the audio systems or adjustable acoustic systems.

“Architectural Acoustics” was originally published in *The Architect’s Handbook of Professional Practice*, 13<sup>th</sup> edition, ©2000 by the American Institute of Architects, published by John Wiley & Sons, Inc.

---

The AIA provides a contract document designed especially for alternative architectural services.

**B102–2007, Standard Form of Agreement Between Owner and Architect without a Predefined Scope of Architect’s Services.**

AIA Document B102–2007 is a standard form of agreement between owner and architect that contains terms and conditions and compensation details. B102–2007 does not include a scope of architect’s services, which must be inserted in Article 1 or attached as an exhibit. Special terms and conditions that modify the agreement may be included in Article 8.

The separation of the scope of services from the owner/architect agreement allows users the freedom to append alternative scopes of services.

AIA Document B102–2007 replaces and serves the same purpose as AIA Document B141–1997 Part 1.

For more information about AIA Contract Documents, visit [www.aia.org/contractdocs/about](http://www.aia.org/contractdocs/about)

*May 2011 The American Institute of Architects*