

BIM and Sustainable Design

Having established in the broadest terms the purpose and goals of this book in the Introduction, later chapters will discuss in detail the specific strategies the designer may employ to effectively use building information modeling (BIM) in the design of sustainable, skin-load dominated buildings. Beforehand, however, it is important to define BIM in greater depth, while considering its advantages and limitations (both perceived and real). We will also discuss BIM in the context of the design process, as well as consider its various other roles presented in later chapters. Finally, this chapter, like all others, will conclude with a relevant case study project.

The emergence of Building Information Modeling

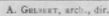
Historical context

For centuries, master builders and architects have relied on drawings as an inventive and analytical medium, and to convey instructions to building trades. Vitruvius mentions drafting in *De Architectura*: through geometry the architect's "delineations of buildings on plane surfaces are greatly facilitated." While little medieval construction documentation is extant, it is known that drawing was used to work out and illustrate the proportional system of cathedrals of the day. Models were apparently also not unknown: building models are depicted in medieval ecclesiastical art, and Brunelleschi had a 1/12th-scale model of the Florence Cathedral constructed prior to the construction of the actual building. The extensive technical expertise of historical craftsmen and

tradesmen, combined with established and fairly static vernacular building practices, reduced the need for extensive construction documents. Generations of buildings were constructed with little more than a few drawings and a pattern book of carpentry and masonry details. By the eighteenth century, drafting with specialized steel nibs on prepared surfaces, more or less as it had come to be practiced in my lifetime, had come into being. Such technical documents consisted of precisely constructed drawings executed on vellum, at times watercolored for aesthetic and communicative effect. Examine a Beaux-Arts elevation and marvel both at the beauty of its rendering and the remarkable paucity, by modern standards, of separate details.

The advent of computer-assisted drafting (CAD) did little to change the nature of drawing. It may seem surprising to claim that CAD is similar to eighteenth-century drafting, but consider that CAD drawings are, for the most part, manually assembled. The gestural tasks involved in their construction may be vastly different from those associated with inking vellum, but the cognitive and social processes remain largely the same. In both cases, the architect must manually construct and coordinate various orthographic views—plans, sections, elevations, and details—of a hypothetical building (Fig. 1.2).

Moreover, over a century ago, buildings had none of their construction budgets devoted to mechanical and electrical systems, simply because those systems did not exist; today it is common for about a fifth to a quarter of a building's construction



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SUPPLÉMENT AU N° 17

VILLA à LA CROISÉE (Marne)
M. ALBERT SIMON, ARCHITECTE (D. P. L. G.)

Albert Simon, architect, from the author's private collection.

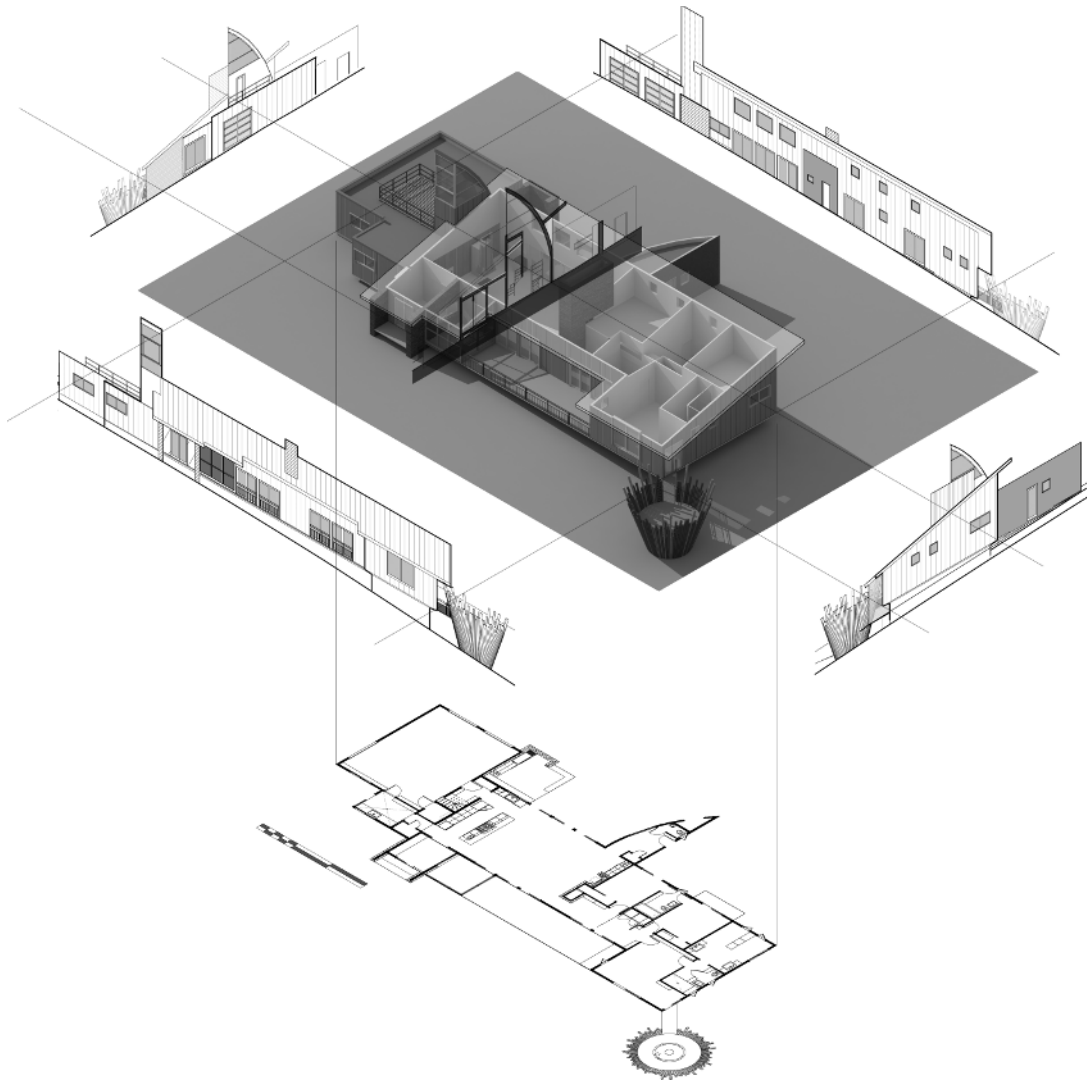


FIGURE 1.2 In traditional construction drawings, a comprehensive “model” of the building is a composite of a variety of 2D views, which are commonly called drawings. If a view is missing, there is a gap in the model.

cost to be for such systems. Specialized projects like laboratories or medical buildings may have as much as 60 percent of construction costs dedicated to mechanical, electrical, and plumbing (MEP) systems (Fig. 1.3). Furthermore, building materials and techniques are by now constantly and rapidly evolving. This, coupled with a tendency to mitigate risk through litigation, has contributed to the trend

toward more extensive, complex, and detailed architectural drawing sets. It is in this technological climate that BIM has emerged.

Defining BIM

Over the last decade, *building information modeling* has gained currency among growing numbers of building professionals and stakeholders, emerging

	pre-1900	since 1970	since 2000
Foundation	15%	15%	15%
Architectural	70%	35%	30%
Structural	15%	15%	15%
HVAC	0%	25%	25%
Electrical	0%	10%	15%

FIGURE 1.3 A greater portion of building cost over time has been dedicated to mechanical and electrical systems. Since structural costs remain somewhat fixed, architectural expenditures have proportionately decreased. These figures are approximated averages based on unpublished research by Steven A. Moore of the University of Texas at Austin School of Architecture in 1999, updated by Dason Whitsett, also of UT SOA.

from arcane obscurity to inescapable buzzword. Developments in building design and analysis software in recent years, coupled with advances in desktop and portable computational power, have engendered effective virtual buildings, or building information models. Gradually, use of BIM is replacing traditional two-dimensional drawing as an architectural design and documentation methodology. Such an approach can increase design efficiencies, foster an integrated design workflow, speed construction documentation and reduce errors, improve building construction and scheduling, and optimize operational performance.

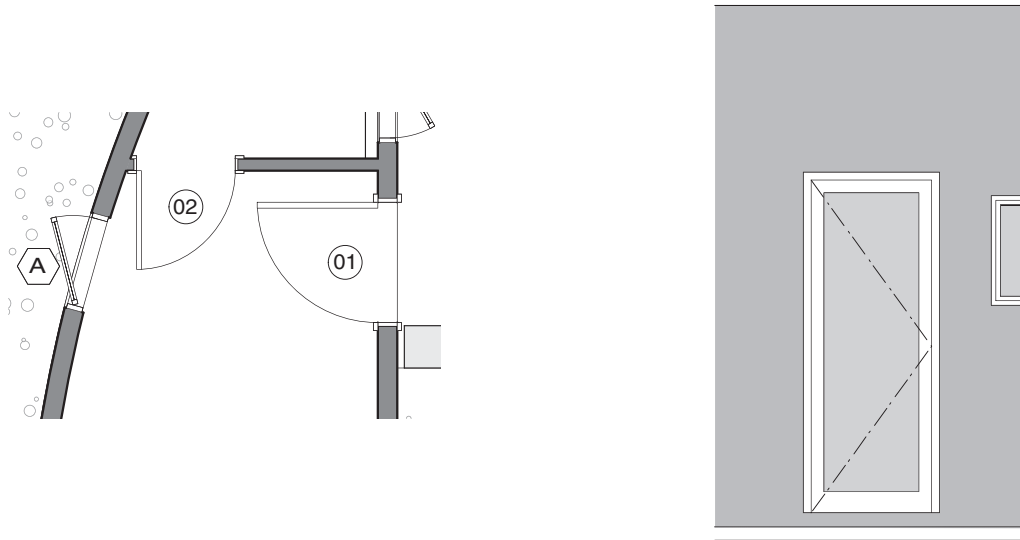
Along the way, BIM has been variously defined, according to the user's profession, perspective, or agenda. In their *BIM Handbook*, Eastman et al. (2008) define BIM as "a modeling technology and associated set of processes to produce, communicate, and analyze building models." They go on to distinguish building models as possessing contextual data-rich building components, whose data are consistent and non-redundant, and have coordinated views. While it is beyond the scope of this book to frame an exhaustive debate of BIM that will satisfy all practitioners, it's essential to clearly define the term in the context of sustainable design for small projects.

Building information modeling: an architectural software environment in which graphic and tabular views are extracted from data-rich building models composed of intelligent, contextual building objects.

Thus, a BIM column is not merely depicted as a two-dimensional drawing or a three-dimensional extrusion, but as an intelligent object that "knows" that it is a column. As a result, various design disciplines can extract and manipulate relevant graphical or tabular building views. *Views* does not mean drawings only (in the form of plans, elevations, sections, isometrics, and perspectives). The term also includes reports: door, window, fixture, and finish schedules, for example, as well as various performance reports (Fig. 1.4).

BIM is a substantial departure from the traditional design methodology that architects have followed for millennia, thanks to both 3D digital modeling capabilities and the critical feature of view extraction. Heretofore, designers constructed multiple 2D drawings that, when viewed together, composed an implicit 3D representation of the building being designed. With BIM, the intelligent model is developed first, and drawings (views) are the result. This not only offers opportunities for greater production efficiencies, but also helps assure greater coordination between deliverables (again, drawings, schedules, and reports) and avoidance of conflicts and collisions. On the other hand, this methodology is to a large extent an inversion of the traditional workflow, with its emphasis on designing by drawing.

Of critical interest to designers is the opportunity to spend relatively more time on design, design more effectively, and capitalize on performance feedback from the virtual building to design for greater sustainability. Patrick MacLeamy, CEO of HOK, is credited with popularizing this graph



Door Schedule

Key	Width	Height	R.O. Width	R.O. Height	Operation	Leaf	Thickness	Manufact
01	2'10 1/4"	7'10 1/2"	3'1 3/8"	8'0"	Swing Simple	Glass	1 3/4"	Marvin Inte
02	2'4"	6'8"	2'6"	6'9"	Swing Simple	Panel	1 3/8"	Supado
03	2'0"	6'8"	2'2"	6'9"	Swing Simple	Panel	1 3/8"	Supado

FIGURE 1.4 A BIM object resides in a relational database, and is subject to a variety of views. In this case, the same door object can be viewed in plan with or without its identifier key, in an elevation, or in a door schedule. None of these is any more the “real” door than any other, and all are editable. Changes to one view affect all other views.

comparing the design team’s diminishing ability to control project costs and the increasing cost of making design changes over time, against the traditional architectural fee allocation (Fig. 1.5). Initially intended as an argument for integrated project delivery (IPD), the concept is equally applicable to BIM and sustainable design.

BIM among building professionals

BIM has a broad appeal to a wide variety of building professions throughout the planning, design, bidding and procurement, fabrication, construction, and operation phases of buildings. For many large projects, sophisticated building owners drive the adoption of BIM, perceiving it as an opportunity to reap greater value from Instruments of Service. In such cases, the owner may be motivated by opportunities for faster design and documentation

processes with the expectation of fewer errors, in addition to the benefits of coordinated, interoperable documentation for building operations.

Large construction firms also have been aggressively adopting BIM, finding benefits in faster and more accurate quantity surveying and cost estimating, a reduction in errors through improved 3D collision or clash detection, and more efficient construction scheduling thanks to 4D (sequence) modeling. Anecdotally, it seems to be commonplace for such builders to have in-house staff, who are often recent architecture school graduates and intern architects, to rebuild the architect’s CAD or BIM design documentation.

Architects, however, have met BIM with a certain degree of skepticism:

- Who pays for more service? There is the perception that with BIM the architect is providing

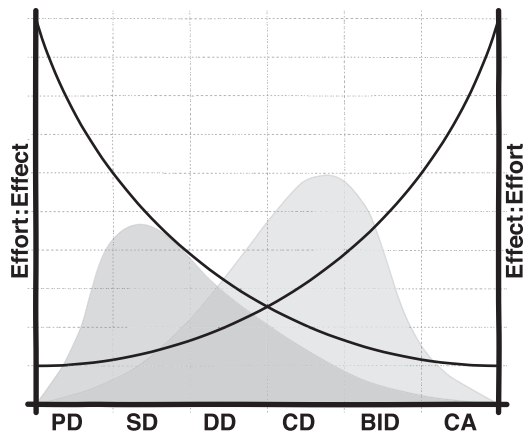


FIGURE 1.5 A version of the so-called MacLeamy curve, originally attributed to HOK's Patrick MacLeamy. As time progresses in the design process, it takes more and more effort to make changes that have a diminishing effect; the least effort will have the most significant impact early in the project. Typical project phases are listed left to right on the x-axis in chronological order: predesign (PD), schematic design (SD), design development (DD), contract or construction documents (CD), bid phase (BID), and construction administration (CA). The right-hand "camel hump" represents the traditional design process, with the bulk of work occurring in the CD phase. Note that a substantial portion of that effort lies outside the Effect:Effect curve. With BIM (and IPD), however, more work is "left-shifted" (the left "camel hump") and occurs when it is most effective—earlier in design. The shaded area lies under the Effect:Effect curve, which suggests that most work occurs when it has the most effect, and less work occurs when it has less effect on the design outcome.

a higher level of service and more useful Instruments of Service without commensurately increased compensation.

- Who is liable? There is a concern for increased liability. If a data-rich BIM model allows fewer construction errors and greater building performance, there might be the expectation that buildings designed with BIM would adhere to a higher professional standard, potentially increasing the architect's legal exposure.
- Who owns the Instruments of Service? In a world of document interoperability, some architects are uneasy with the potentially blurred line of intellectual property, and the questions arising from a potentially collective ownership of building documents. There is a substantial difference

between an MEP supplier basing shop drawings on prints or electronic backgrounds provided by the architect, and that same subcontractor accessing and editing files which originated with the architect and design team.

- Who pays for re-training? There are substantial retooling issues in making the transition to BIM. As a consultant, I'm acutely aware of the hardware, software, and, most significantly, the staff re-training and initial productivity losses involved in transitioning from CAD to a new way of working.
- How can the firm handle collaboration? BIM implies not just a different work methodology within a firm, but also a change in the nature of relationships with consultants and other project team members. Not all firms are ready to jump into the world of integrated project delivery (IPD) and design-build (DB).

It will be obvious from this brief discussion that many of the hurdles that confront a firm transitioning to BIM are fundamentally social, not technological, in nature (as is often the case with technology).

On the other hand, most *small*-project owners tend to be less concerned than their large-project counterparts with building operational opportunities due to data interoperability or longevity. At present, most have never heard of BIM. Similarly, small project contractors operate far more informally, and do not have the staff to leverage BIM models, mine them for data, or perform collision detection—much less implement 4D model scheduling. Many of the BIM features that are attractive to large organizations are barriers to entry for their smaller counterparts.

BIM for design

This book emphasizes the use of BIM as an architectural design methodology. It is, therefore, aimed squarely at architects and designers. Gallagher's oft-cited 2004 NIST report on CAD identified economic opportunities for the implementation of BIM. Such projected savings result in part from

construction scheduling efficiencies and reduced errors. In other words, BIM is potentially beneficial for documentation efficiencies. Indeed, the productivity gains due to automatically coordinated views of the virtual model are the most obvious benefit of BIM. But of the benefits ascribed to BIM, design is typically not the highest on the list. Indeed, many architects view BIM primarily as a documentation tool, rather than a design tool. This is a missed opportunity.

Design is a parametric process

Architectural design is both a forensic and a dialectic process. What could I mean by that? In architecture schools, it is not uncommon for instructors and students to refer to the design process, particularly in its early stages, as an *investigation*. This is not an inapt description, and is equally applicable to practice. Architects often begin a project by coming to an understanding of three overlapping realms: client, site, and program. In fact, in my first or second meeting with a client, I often sketch a little Venn diagram (Fig. 1.6), explaining that architecture occurs

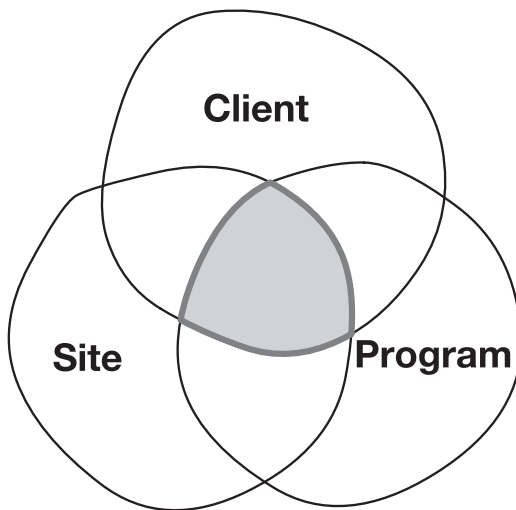


FIGURE 1.6 One way to frame a discussion of design is to think of it as the intersection of a particular client, a unique site, and a program. It might be drawn on the client's napkin, but the architect holds the pen.

in the common conceptual space mutually captured by these three diverse agendas.

An architect might ask, *Where do I fit in this diagram?* The architect profoundly affects the outcome of the project by influencing the framing of the issues. In other words, the architect “draws” the diagram, and thereby defines the boundary lines. Before we can get answers to our questions, we determine which questions to ask in the first place. Obviously, our choice of questions profoundly affects the answers we get (or don't). Will climate be considered, and if so, to what extent? Given inevitable conflicts in the client's program, how will they be prioritized? How much will we play to our client's aesthetic, functional, and financial expectations, and to what degree will we take it upon ourselves to challenge those expectations and educate the client? Will we argue for cost, or value? And so on.

This is why I claim that design is forensic in nature: we investigate and uncover a project's constraints. But there is perhaps another way in which designing is a forensic process. Constraints give life to the project itself, or as Nadia Boulanger said: “*Great art likes chains.*” In this act of uncovering constraints, we effectively uncover the building itself. Michelangelo's famous quote, too, is apt: “*Every block of stone has a statue inside it and it is the task of the sculptor to discover it.*”

What about my second assertion, that design is dialectic, or put another way, that architecture occurs in a conversation? Superficially, this may seem to contradict the inherent monumentality of our work. I expect that most of my work will outlast me, and I'm probably not the only architect who at times indulges the conceit of buildings as enduring testaments. This seeming permanence of our work, then, would tend to suggest that buildings are like monologues, impervious to their inhabitants. Yet I contend that buildings carry on lively conversations with us, on several levels. A good building exists as a variety of spatial and temporal expressions, creating for the occupant a correspondingly rich range of experiences. But more to my point, the *process* of designing consists of engaging in an almost Socratic inquiry. We ask the site about its

topography and the flora that inhabits it, how the sun dances across it throughout the day and in the course of the seasons, and which way the wind caresses it. We engage our clients in long conversations about their aspirations, hopes, and needs, teasing from them (and from ourselves) what is appropriate for this client, this site, and this project. We push and pull volumes and strain materials, probing their limits.

And why is this relevant? BIM, it turns out, follows a similar Socratic and dialectic logic. A BIM model is assembled and populated with data, from which views are extracted. Architectural relationships and conditions that might not have been obvious, or emphasized, come to the fore. The model is queried; data are organized to tell a meaningful story; the model is changed to tell a different story, or one with a different ending. We ask, *What if . . . ?* and then ask it again. And again. The process of critically examining alternate design options, preferably balancing subjective and objective criteria, is *parametric design*.

It is precisely this parametric design ability to ask, *What if . . . ?* that makes BIM such a powerful *design* tool. This may come as a surprise to those who assume that BIM is only good for documentation once all high-impact decisions have been made, or that it forces premature project decisions due to over-specificity, or that it is an inappropriate medium to address architectural details. We've already looked at BIM's capability beyond mere documentation; let's challenge these other assumptions.

"BIM forces premature project decisions due to over-specificity"

The Government Services Agency (GSA), the United States' largest single landlord, has been a driving force in the adoption of BIM. This has in part been a reaction to the potential for reduction of inefficiencies outlined in the NIST report. Of greater concern to the GSA, however, are the advantages accruing to building owners who have at their disposal intelligent 3D models of their properties. The GSA has therefore required that BIM files contain Space objects, which are intelligent volumes that

represent not a particular building component, but the spaces within the building. Occupancy type, code characteristics, internal energy loads, and other parameters are attributed to the Space object. Occupancy can be more easily planned and scheduled using such components, a clear benefit to the GSA and other building owner/occupants.

As a result of the GSA requirement, Space objects exist in every major BIM application. In some cases, as with Revit, the standard procedure is to "fill" a modeled volume bounded by floors, walls, and ceilings with a Space object. (In energy modeling, it is important that the Space object be exported to an energy modeler, as it contains critical energy load data. Such programs can also often ignore some of the BIM's more complex geometries for the sake of computational economy.) In other BIM workflows, the Space object can also be created first, and then "skinned" with walls, floors, ceilings, and roof components. This is the case, for example, with Vectorworks.

This seemingly innocent GSA-mandated component can become a powerful tool in conceptual and schematic design. Occupancies, room sizes, and other program-driven criteria constitute some of the earliest information gleaned or developed in the design process, and an early requirement of the conceptual design phase is the determination of spatial adjacencies and the development of building massing. Space objects are a useful tool in the BIM arsenal when used as intelligent building masses, providing quantitative data in support of design analysis and decisions. Here are a few early design operations involving Space objects that will be covered in greater detail in later chapters:

- ❑ Adjacency matrices that score spatial configurations in real time can help the designer develop more efficient building arrangements. Vectorworks and others have such tools built in.
- ❑ Since Space objects are intelligent volumes, competing concepts' ratios of envelope to effective floor area can be readily analyzed, providing preliminary material and cost optimization of early massing models.

- BIM Spaces combined with a topographical model and a 3D maximum building envelope can be visually or automatically analyzed for clash detection, depending on the BIM software used. Even in small projects, there are often complex zoning and solar rights codes that demand a 3D analysis of setback planes and terrain topography as they interact with the building mass. In Austin, where I practice, the so-called McMansion ordinance stipulates a building “tent” whose geometry is site-dependant and beyond which building elements, with some exceptions, cannot penetrate (Fig. 1.7). This tent can have a complex shape depending on topography and metes and bounds geometry, and an early envelope check is critical to avoid catastrophic problems later in the project.
- Site-indexed massing models can be analyzed for solar exposure and solar rights. In developing massing models for skin-load dominated buildings, early attention must be paid to sun

angles for solar exposure and shading, and solar rights impacts on adjacent properties. A massing model that is informed by correct orientation, the site’s global position, and the massing of adjacent structures, can be analyzed for solar optimization through automatic surface analysis or the creation of sun studies and solar animations (Fig. 1.8).

In addition to Space objects, most BIM applications allow the user to create generic walls (Fig. 1.9) and slabs (floors and roofs). Such components can be deployed early in schematic design when materials and perhaps even structural systems are as yet undetermined. The designer can specify wall thickness, for example, without concern for the exact particulars of the wall’s components:

- Characteristics such as cost per linear foot or overall thermal resistance factor (U-factor) can be assigned to such a generic wall for preliminary cost estimating or thermal envelope performance evaluation.

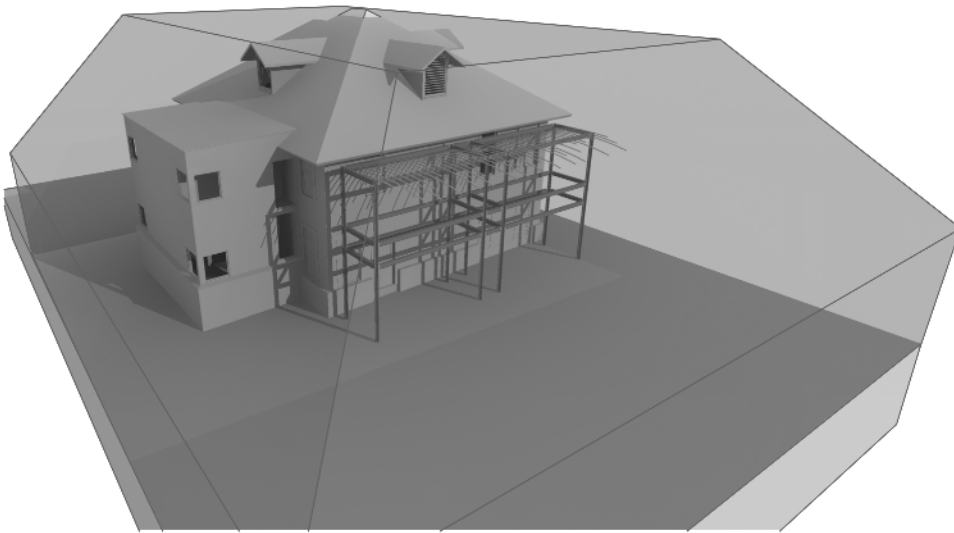


FIGURE 1.7 Form-based codes have been in existence for at least as long as New York stipulated solar access rights, but they are becoming increasingly popular tools for municipalities to govern growth and development. Sites may be straightforward, but even so, careful modeling can be a useful tool in verifying compliance. When sites are challenging with irregular metes and bounds, a model may be the only way to validate an allowable maximum design envelope (see also 3.19).

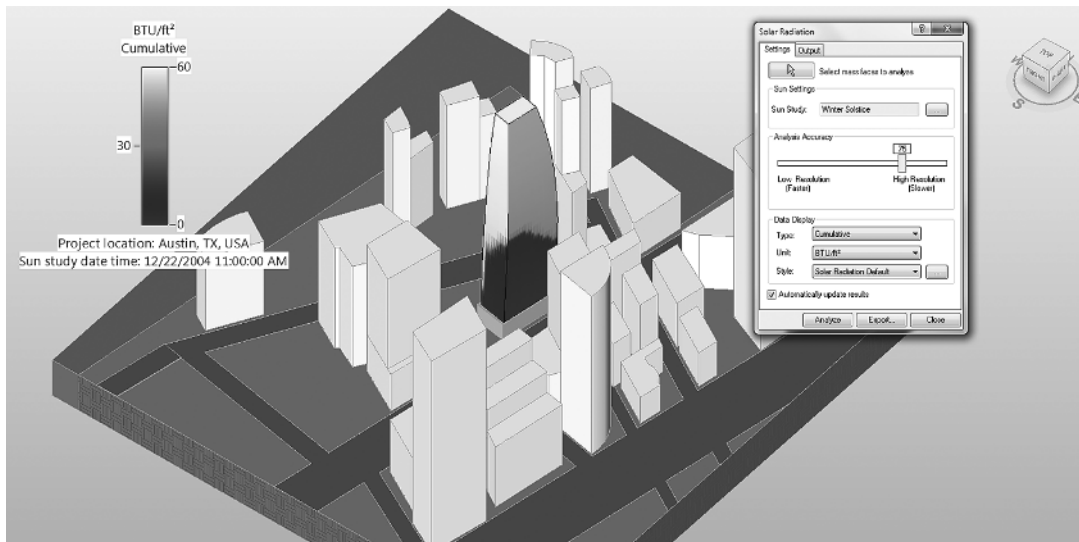


FIGURE 1.8 There are a growing number of BIM or BIM-compatible energy tools targeted for the conceptual design phase. Autodesk's Project Vasari, for example, allows preliminary energy performance analysis at the massing model stage.

Image courtesy of Justin Firuz Dowhower, LEED AP.

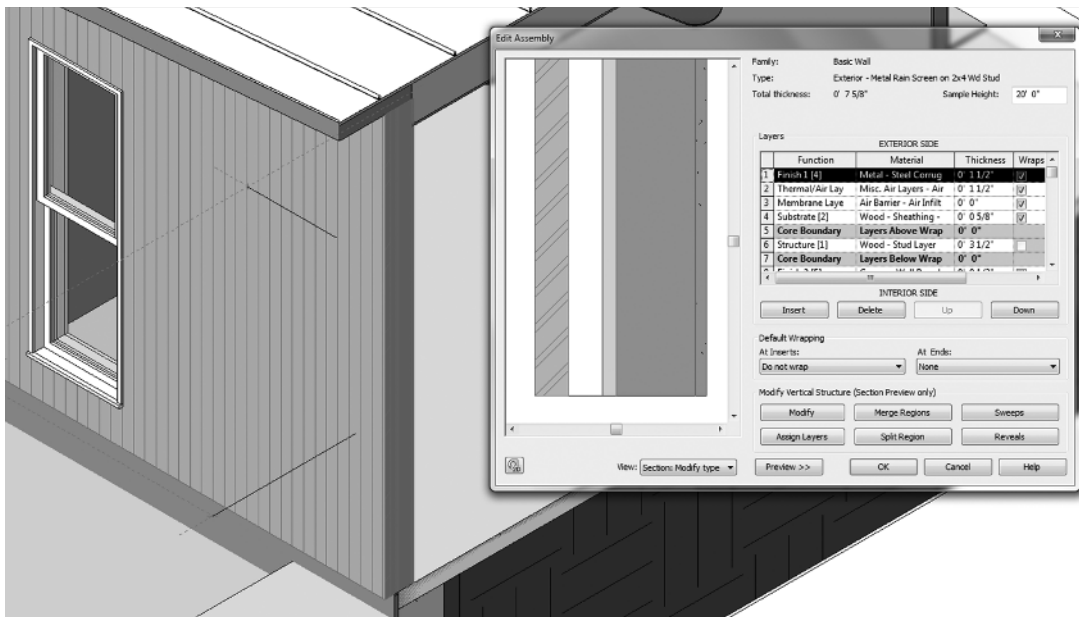


FIGURE 1.9 BIM walls are more than mere extrusions with penetrations for windows and doors; they are potentially composed of components with individually assigned characteristics (data and geometry).

Image courtesy of Justin Firuz Dowhower, LEED AP.

- Doors and windows may initially be modeled with little or no detail, to the point of being represented as simple openings. Optionally, the designer may assign code-specified minimum performance standards (U-factor and SHGC) or cost assumptions.
- BIM software can calculate percentage glazing, to optimize thermal performance based on rules of thumb. The model can be queried for total glazing area, which may be compared to gross or net exterior wall area, even when no specific window system has been selected.
- A total U·A limit (U-factor, times exterior wall assembly area) can be calculated for the BIM model in real time as the design progresses, beginning in schematic design. Commonly, projects are verified for energy code compliance through the use of applications such as the US Department of Energy's free ResCheck and ComCheck software. For thermal envelope performance, a total U·A must not be exceeded. If such code compliance is verified late in Design Development or, worse yet, just prior to permitting, design changes to insure compliance in the event of failure are time consuming and expensive—and undermine the designer's credibility.
- For projects where architectural controls govern, such as in deed-restricted subdivisions, calculating compliance with exterior material percentages is readily accomplished when the exact nature of wall materials is unknown. A homeowner's association might stipulate 75 percent masonry for exterior walls, for example; as the schematic design progresses, walls may be assigned generically as masonry or nonmasonry, to assure compliance throughout the design process.

It should be clear from the above examples and discussion that BIM does not inherently require the designer to make final material or design decisions early in the design process. In fact, the opposite is true: BIM allows the designer to quantitatively and qualitatively test design assumptions about

the project from an early stage, without being constrained regarding design-decision outcomes.

"BIM doesn't address designing details"

BIM relies on standard construction components (e.g., open web bar joists, standard steel profiles, conventional window sash configurations and profiles). As software applications develop, they tend to add larger libraries of standard building components. While such ever-growing libraries of building elements streamline design and documentation, they do not necessarily contribute to fully custom design. This is most evident in architectural detailing, where the designer may require an extremely flexible software environment in order to model conditions where standard components and connections may not be appropriate (Fig. 1.10).

While it's true that conventional components may not lend themselves to unconventional applications, most BIM software permits custom or free-form modeling (Fig. 1.11). Revit allows the creation of families: user-defined parametric objects whose geometries can be controlled by relational algorithms governed by spreadsheets. Vectorworks includes robust 3D modeling, including non-uniform rational Bézier splines (NURBS), curves and surfaces with variable curvature, and potentially few vertices for computational efficiency. With some scripting, Vectorworks users can create their own custom parametric tools. And ArchiCAD, too, readily permits custom-created parametric objects.

Such user-defined elements can be assigned data, and exported for analysis and collaboration in buildingSMART's, the International Alliance for Interoperability, neutral and open Industry Foundation Classes (IFC) format. With IFC, components can be created in one BIM application, assigned a taxonomical label and data, and exported to another IFC-compliant BIM application, even if the receiving application does not natively support the object type (Fig. 1.12).

Drawing the line

Architects who are new to BIM understand the necessary abstraction of architectural communication

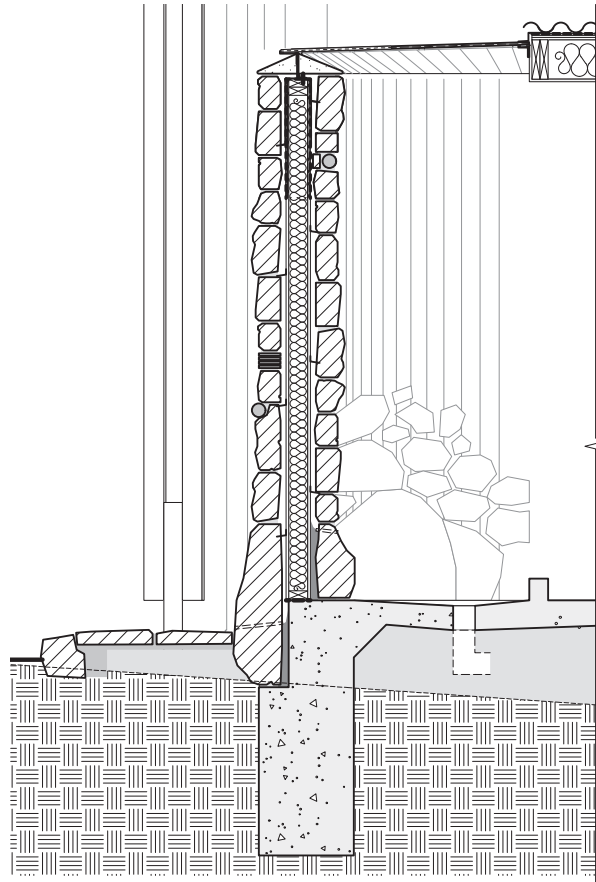


FIGURE 1.10 A wall section detail drafted over the geometry of a BIM model. While certain components (steel sections, dimensional lumber, repetitive materials, and conventional hatches) are quite typical and are considered “standard” 2D or 3D BIM elements, others are custom modeled, or drafted.

and may be concerned by BIM’s potential specificity. Architectural drawings specifically but representations generally have always entailed a certain level of abstraction. This is not only necessary, but also desirable. Take for example the case of architectural scale. There is a certain level of information that is presented on a 1/4" (or roughly 1:50) scale plan that is omitted on a site plan or is inadequate for a plan detail at 1" (1:10) scale. In part this convention evolved from necessity: one could not realistically draft every stud, every piece of trim, and every wall component on an architectural layout plan. More importantly, however, architectural documents must communicate, and do so appropriately.

The architectural floor plan is not intended for the trim carpenter except in the most general terms; the finish carpenter is particularly interested in interior elevations and millwork details, whereas the carpenter in wood-frame construction is keenest to understand the 1/4" (1:50) plans and attendant elevations and sections. We omit information from the architectural floor plan in part because it is not feasible to show it there, but also because we are directing the drawing toward a particular trade, or trades, who will execute their portion of the work from it.

Indeed, with the advent of CAD, it has become possible to draw every building component, regardless of size, limited only by the resolution of current

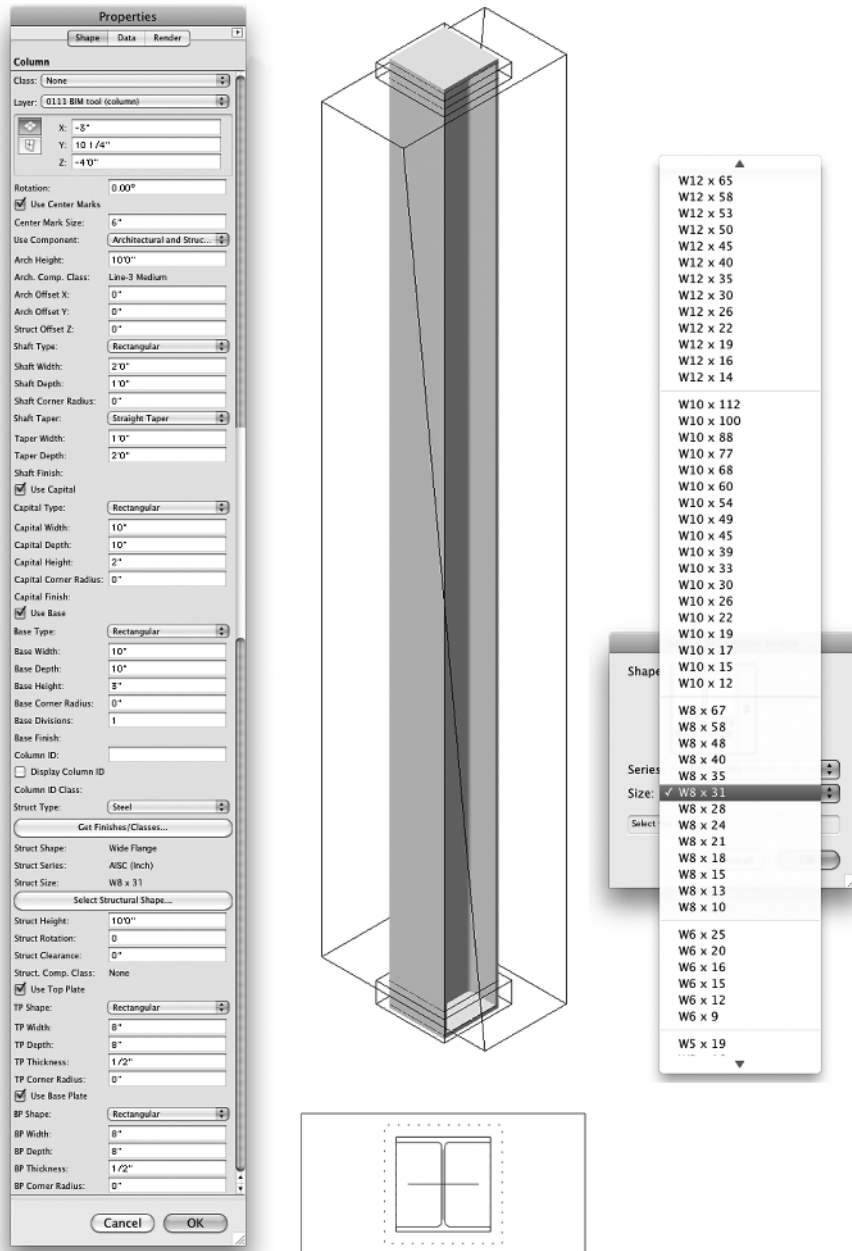


FIGURE 1.11 A BIM column—like walls, doors, windows, beams, roofs, and foundations—is controlled by a variety of settings that are germane to its nature. Columns may contain structural and/or architectural graphical and numeric data.

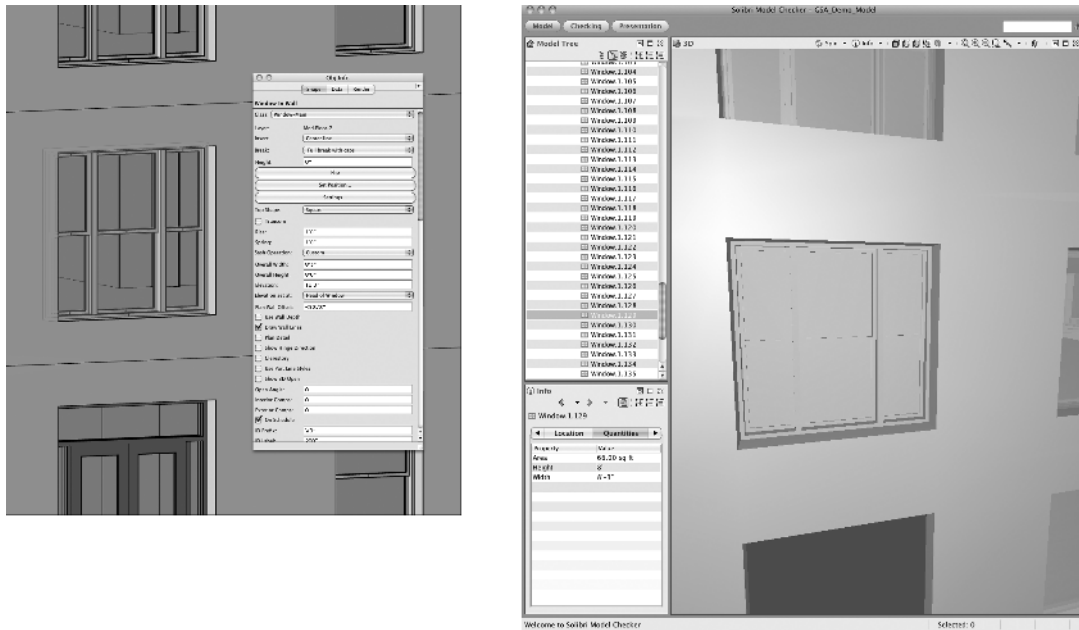


FIGURE 1.12 Two views of the same BIM object: the window at left is in its native Vectorworks format, and is a fully editable parametric and data-rich object. At right, the same model exported as IFC 2x3 is inspected in Solibri Model Checker. The geometry and IFC data are preserved ensuring interoperability, but the window is no longer an easily editable parametric object.

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printing technology and by the visual acuity of the user. Yet abstract drawing conventions are still observed (Fig. 1.13). For example, at a 1/4" (1:50) scale plan:

- Walls are shown *poché*. Studs are not delineated, and only major components (structural core, veneers on the order of 4" [100 mm]) are shown, with thinner materials (plaster, wall-board, sheathing, vapor barriers, flashing, air spaces) typically omitted;
- Doors are generally shown as rectangles open 90°, with swings indicated by arcs, and sometimes trim is indicated (the prevalence of the latter is a more recent development). Hardware is never shown at this scale;
- Handrails are often depicted as double lines, and brackets and connection details are omitted.

We still deliver drawings at set scales with certain abstract drawing conventions, in order to clearly and appropriately communicate the particular intent of a given drawing. To that end, it is at least as significant which information a particular drawing omits as which information it includes (Fig. 1.14). In fact, this process of abstraction is the foundation of the craft of architectural documentation, a craft whose fruits are no less necessary now: the trades at present still need drawings, even if this may someday change.

In architectural detailing, the abstraction of graphic information is taken a step further. Details often depict typical conditions (from which similar conditions are to be inferred), special conditions, or critical conditions (Fig. 1.15). Details are not intended to represent all conditions, for several reasons. First, even in a modest project it would be unfeasible to do so. Further, many conditions may be commonplace, whether industry-wide or regionally.

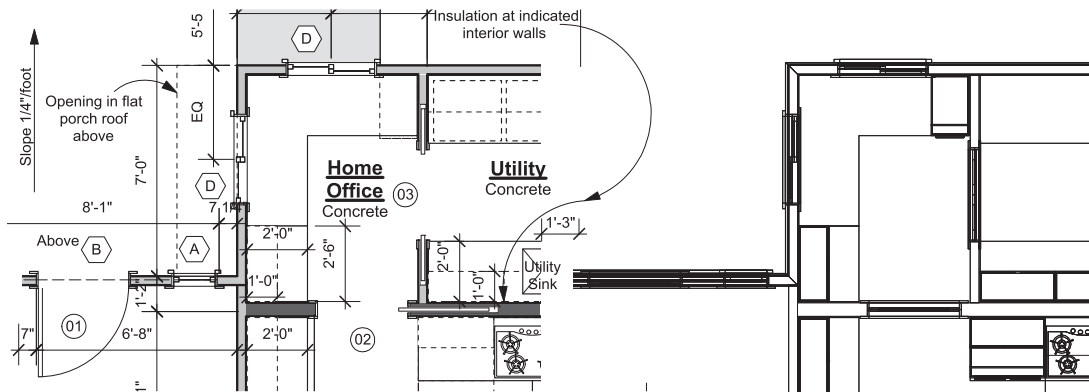


FIGURE 1.13 Compare a portion of a traditional plan view at 1/4" scale (1:50; left) with a model view from above of the same file (right). The usual plan view is an abstraction, intended to convey only the requisite information and nothing more. The model view dispenses with the graphic conventions that building professionals expect from a plan drawing—door swings, abstract window representations, depth-cued line weights, and so on.

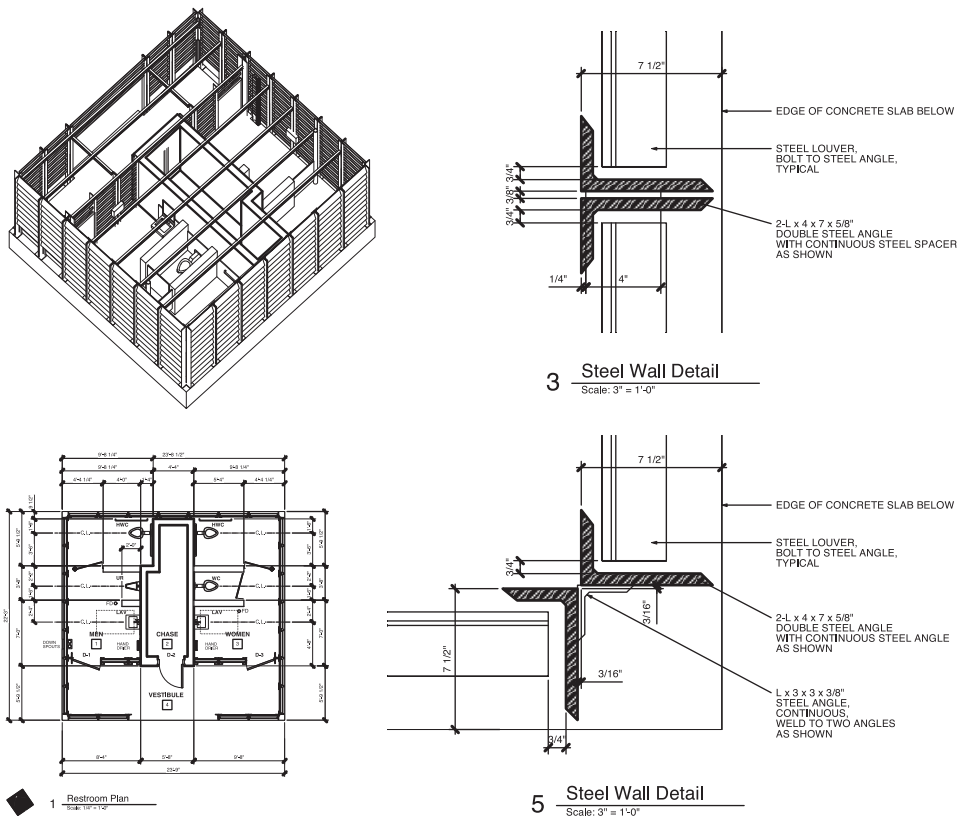


FIGURE 1.14 In this small BIM project, every deliverable drawing is a view of the model; nothing is drawn in the conventional 2D, CAD sense.

Image courtesy Limbacher & Godfrey Architects.

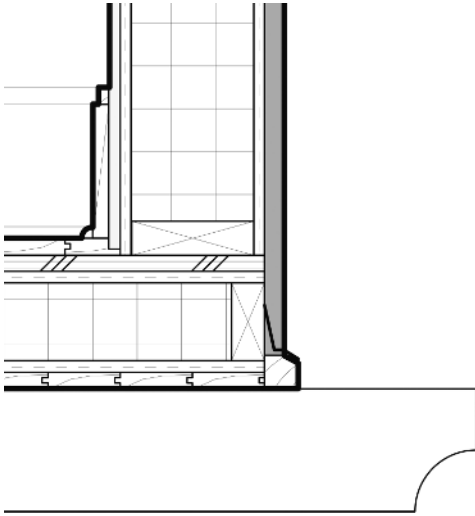


FIGURE 1.15 A flashing detail is a common condition depicted in a set of construction documents that would not usually be modeled in BIM. This case is one of many where the abstraction of a 2D drawing representing a typical condition is appropriate, but not every variation is necessarily drawn, nor modeled.

Finally and perhaps most importantly, there are often conditions where the trades' expertise and experience may exceed that of the architect, and a good construction set should allow some latitude in those conditions.

In BIM as in CAD, however, there is the potential to model building components beyond the needs of the deliverables, or extracted views. While it may be *possible* to include every fastener and length of flashing in a building model, it is hardly desirable, if only for computational economy. The question therefore arises: What should be modeled, and what should be omitted in a building model? Three tests can be applied to answer that question:

- Is the feature represented in more than one view? Arguably, features that occur only once might be drawn (as opposed to modeled) for the sake of economy. A foundation footing, for example, will appear in a foundation plan, but will appear in building sections as well. Light fixtures may only appear in a single graphic view, the lighting plan, but they also populate lighting

fixture schedules and a variety of performance reports (power budgets, general illumination calculations). Generally, building components that populate more than one view should be modeled. Consider, too, that the number of views that a component may populate may increase as the project progresses.

- Is the designer responsible for designing or coordinating the component? A building component that the architect is neither designing *nor* coordinating may be omitted from the model. The assumption is that another discipline may later contribute to the overall project model as required.
- Is it more appropriate to model the component, or specify it? The model indicates the location, placement, quantity, and extent of any given portion of the project; specifications define the standards of installation and specific materials and products, in addition to referencing portions of applicable building codes. By this standard, for example, drywall fasteners are covered by the specifications (their kind and spacing is governed by code), but a handrail bracket may not be (Fig. 1.16). The latter might therefore be modeled.

Components that fulfill all three of the above criteria should be modeled.

High-performance architecture

Architectural design for performance necessarily requires quantitative building data, and therefore BIM is a natural and appropriate methodology to support performance architecture. For architects who aspire to have the form of their work informed by and expressive of performance, BIM may be particularly apt. Conceptually, the underlying methodology proposed seeks to dynamically link building geometry with data, in order to satisfy performance criteria according to sound design practices.

Most BIM applications are not, per se, performance analysis software, except in specialized instances. The software may detect for collisions

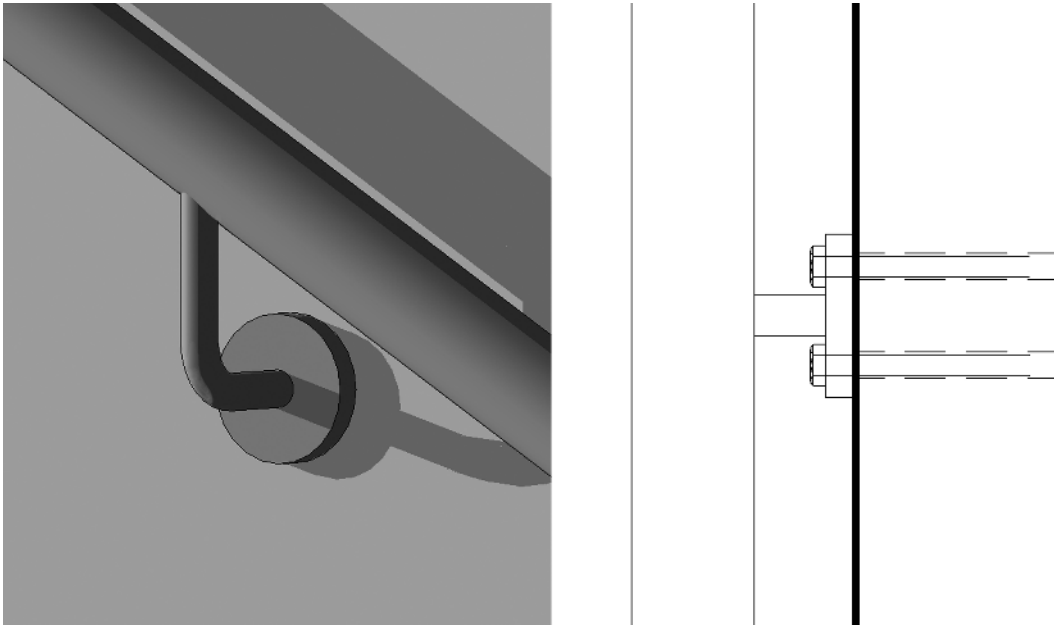


FIGURE 1.16 Where to draw the line? The ability to draw or model every component of the building is hardly an excuse to do so. One could model every fastener in this handrail, but it may be sufficient to model the rail and supporting brackets and leave the bolted connection to a detail drawing.

Image courtesy of Justin Firuz Dowhower, LEED AP.

(clash detection), or verify basic code compliance (alerting the user, for example, when a 20-minute fire-rated door is placed in a one-hour fire-rated wall assembly), but in general BIM applications are not energy modelers, for example. On the other hand, BIM modelers can and routinely do produce user-specified reports (tabular views) of the virtual building.

The designer is therefore faced with a decision. In reductionist terms, the architect may either apply proven geometric relationships (“rules of thumb” and approximations) in real time early in the design process, or perform more precise modeling based on more refined data later in the design process. The first is a “parametric design,” and the other is “design validation.” In reality, the architect is free to choose both methods; the dichotomy is an artificial one for argument’s sake.

Design validation has distinct advantages, the most obvious of which is that it is presumably more

accurate. In addition, it is the required method for demonstrating compliance with applicable building or energy codes. On the other hand, validation requires detailed data to be meaningful. Any experienced energy modeling specialist will attest that without accurate data—accounting for specific internal loads, climate data, and building parameters—an energy model is extremely prone to error. Much of that data cannot be provided until the building has largely been designed. Exporting BIM data to specialized modelers certainly yields more accurate results, but once design is well underway it may be too late to make a substantial difference. Referring to the MacLeamy curve above, it’s clear that by mid to late design development, the designer has reached a point where significant changes come with significant expenditures of effort (read: scheduling delays, work hours, and money). *Round-tripping* is a term that describes exporting a building information model to a performance modeler (such

as an energy modeler or computational fluid dynamics modeler), analyzing performance, and then making design changes based on the results of the detailed analysis. Even with round-tripping, however, there may be significant effort required to prepare a model for export—in some cases involving data re-entry in the performance modeler due to translation data loss. As a result of the potentially labor-intensive nature of round-tripping, as well as file format translation pitfalls, this process has nontrivial barriers to entry. Finally, most small projects will not have provision in the design fee for intensive performance modeling, and clients may be reluctant to pay additional fees for what they may perceive, rightly or wrongly, as a basic service. In short, as necessary as design validation may be in many cases, detailed performance modeling may be too much, too late.

On the other hand, *parametric design* is intended to inform decisions as they are being made. This requires that assumptions be made about building characteristics from the onset. Those assumptions are then tested and refined based on direct feedback from the model. Building performance thereby potentially becomes an architectural form-giver, insofar as the designer allows it to be so. Parametric design is advocated as a means to empower the architect, and therefore by extension the client, to make informed tests of building technology choices before becoming committed to those choices.

Thermal design of the building must fit into the design process that evolves from the general to the specific as an integral part of the process. In recent history, thermal design usually has been relegated to the final construction documents phase . . . By then it is too late to mold a passive building—the commitment to passive design must be made in . . . schematic design . . .

Many times I have said something to the above effect to students, clients, or fellow architects. Unwittingly I was quoting Doug Balcomb and his colleagues (1980), authors of the *Passive Solar Design Handbook*, who wrote the above passage three decades ago. While the building design professions have made many advances, the relevance of this quote even today is a clear admonition that as a profession we must further evolve our early design work practices to incorporate sustainable design. Below is a cursory listing describing some specific BIM parametric design strategies for sustainable performance architecture. The reader is referred to the relevant chapters for more detailed discussions.

Site indexing (Chapter 3)

BIM can produce dynamic data-driven site models with editable 2D contours and 3D topography (Fig. 1.17). Such models are parametric in that they may be regraded and recontoured either through

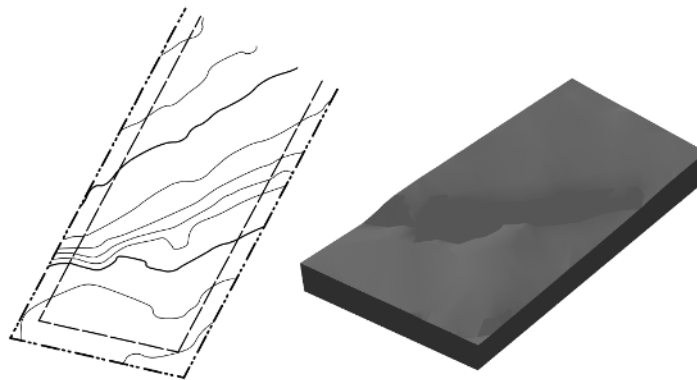


FIGURE 1.17 Two views of a dynamically editable BIM site model. Both the 2D topography and the 3D solid model (in this case rendered with smoothing) are different views of the same object.

the use of area tools (imagine a level building pad or paved area with a user-defined slope) or contour lines (similar to the traditional manual method of site design). Once created, such a site model can report (and dynamically update) site conditions for either existing or proposed conditions:

- Net cut and fill volumes. This is highly useful for reducing project costs and limiting environmental impact. In some jurisdictions or sensitive areas, soil may not be removed from the site.
- Buildable envelope. Most jurisdictions impose building setback limits. In an increasing number of cases, a maximum building envelope or tent will also be imposed by ordinance, in addition to floor area ratio (FAR) limitations. Such form-based code restrictions may be quite complex depending on the boundaries and topography of the site, and cannot be feasibly analyzed without the use of 3D site models. A BIM site model can greatly streamline such analyses.
- Slope analysis. Net buildable area is sometimes jurisdictionally limited by excessive slopes, such as when water quality ordinances reduce FAR for steep portions of a site. In addition, excessively steep portions of a site may not be legally or feasibly buildable. Some BIM applications color-code portions of the site by slope value, to obviously signal buildable and unbuildable areas.
- "Viewsheds." Some BIM software, such as Vectorworks, can automate the process of determining those portions of a site visible from a given point. Even in cases when such analysis is performed manually (the user sets the location and direction of a particular view), perspectives establishing viewsheds are critical to design programs with desirable or undesirable views, or for refining solar orientation.

Climate indexing (Chapters 3–5)

Consideration of climate and orientation is obviously critical to the design of any sustainable skin-load dominated building. Not only do general climatic

conditions (or climate zone) profoundly affect the appropriate design response, but also building orientation, with respect to solar geometry and prevailing winds, will determine the effectiveness of a host of passive cooling and heating strategies. Building information models can be analyzed for these conditions to a large extent, even before exporting for further analysis in software like Ecotect and Green Building Studio.

- Sun studies. These may range from fixed shade and shadow renderings (Fig. 1.18), to interactive renderings depicting shadows at different times of day or year, to solar animations exported as separate files. It is also possible to set views to "what the sun sees."
- Determining daylight factor. Reducing electric lighting increases a project's sustainability for two reasons: less energy is consumed directly by electric lighting, and cooling loads are reduced due to (inefficient) heat generated by such lighting. Daylight factor, a ratio of interior illumination to exterior illumination, can indicate when adequate natural light is provided, and is directly related to room geometry. It is thus another opportunity to use the intelligent modeling of BIM.
- Capturing prevailing winds. Wind roses are available for major locations, and informal surveys of prevailing breezes can be graphically represented in the BIM file and appropriate responses designed.

Energy efficiency (Chapters 5–8)

Well before the energy modeler stage of design (design validation), the designer will make critical decisions that will irrevocably affect the building's overall energy performance (Fig. 1.19). The building's aspect ratio and orientation will largely be determined at the massing model stage, and can have a profound affect on building performance. Obviously, not every building can be optimally oriented due to limitations of site and zoning ordinances. Nevertheless, the architect has a great deal

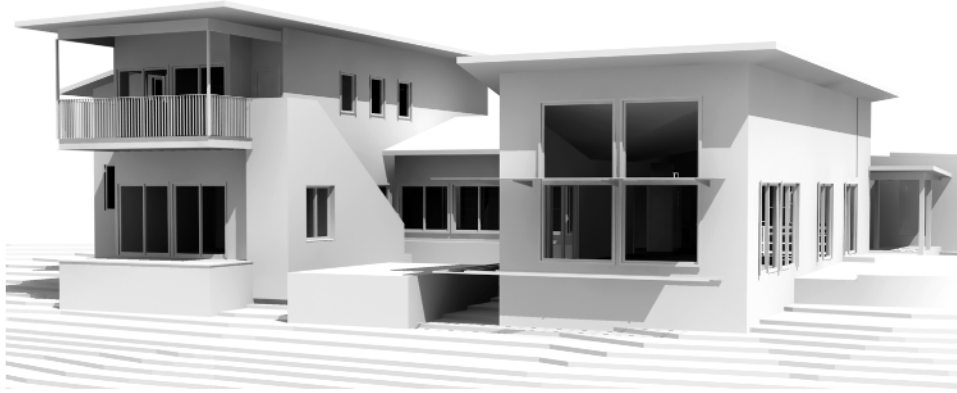


FIGURE 1.18 Sun shading models are invaluable BIM tools. In this case, glass, color, and material textures have been selectively turned off; the parametric site model is displayed as extruded contours; diffuse ambient lighting supplements the virtual sun. At first glance, the resulting rendering could be mistaken for a photo of a physical museum-board model. More importantly, it clearly communicates the degree to which the design's shading devices are effective.

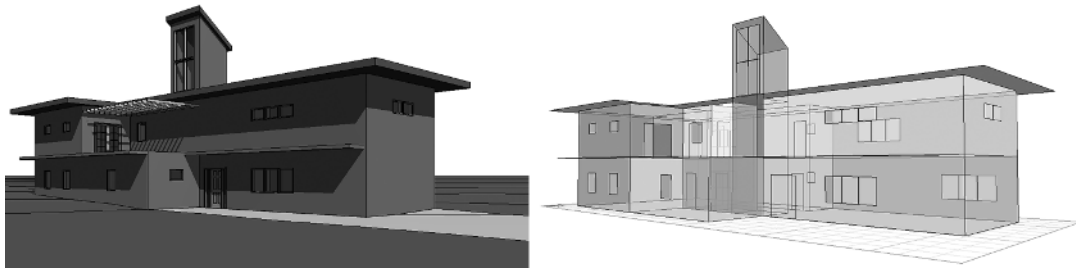


FIGURE 1.19 A BIM model (left) is divided into zones (right) in preparation for energy modeling analysis.

Image courtesy of Justin Firuz Dowhower, LEED AP.

of latitude in making early decisions, which, if well informed, will result in better buildings.

- Heat gain and loss. Envelope energy code compliance for buildings in the United States in many jurisdictions can be verified with the DOE's ResCheck and ComCheck. These free applications calculate total heat loss through the envelope, as well as lighting power density and mechanical systems compliance. Unfortunately, there is currently no common file format that allows direct exporting of BIM data to these applications. However, calculating

total building thermal conductivity, $U \cdot A$, is possible within the BIM modeler itself. This allows the designer to make rapid global changes to envelope systems and determine their effectiveness in meeting or exceeding energy codes in real time.

- Passive cooling (ventilation, thermal mass). Depending on the climate zone of the project, various passive cooling strategies are appropriate. For hot, humid climates, natural ventilation is most effective, whereas projects in hot, dry climates respond more favorably to adiabatic

cooling and thermal mass. The effectiveness of these strategies can be determined directly from the building geometry and certain basic climate assumptions, such as ambient temperature. BIM allows those geometric relationships to be linked to calculations that return dynamic information to report the relative effectiveness of design configurations.

- Passive heating (solar orientation, net glazing area, and thermal mass). As with passive cooling, factors determining the effectiveness of passive heating strategies are largely orientation- and geometry-driven. How much south-facing glazing is present in the current design? What is the area of available thermal mass? How much sun does the building face receive over the year? BIM can readily answer these questions, supporting the optimization of the building design for improved thermal performance.

Effective building hydrology (Chapter 9)

For a variety of reasons, ranging from water conservation, water quality, and erosion control, a building's response to water is critical. BIM allows several approaches to designing for these issues:

- Rainwater harvesting. Growing in popularity despite the lag in recognition by local jurisdictions for potable water, rainwater harvesting is a viable alternative to wasteful residential irrigation with treated (potable) water, as well as a potential source of safe drinking water. In many municipalities, the water department is the largest single consumer of electricity, as massive pumps are employed to provide pressurized water supply throughout the community. Increasing reliance on site-generated water supplies supports sustainable communities. Correctly sizing major system components, the roof catchment area and the cistern, is possible using established formulas and dynamically linking them to the appropriate roof area and cistern geometry.
- Site grading for proper surface water flow. Site model analysis of the triangulated irregular network (TIN), just as with slope analysis, can determine direction and intensity of surface water flow. Such surface flow studies not only help confirm positive drainage at building perimeters, but also guard against inadvertently shedding water onto adjacent properties.
- Roof, gutter, and downspout sizing. Similarly, gutter sizes and the number and sectional areas of downspouts are determinable from basic climate data and roof areas. The drawn or modeled roof elements are sized according to those relationships as reported by the building model.

Waste stream (Chapter 10)

Generally, over a building's useful life, operating costs will exceed construction costs by roughly a factor of ten. Reducing the operational environmental impact of buildings is therefore logical and should be a priority for any sustainable design. Whenever possible, materials use (and therefore cost) should also be reduced, particularly when such reduction leads to improved operational efficiency.

- Reducing waste through alternate building techniques. Dimensional lumber framing enjoys widespread use in the United States (although rare elsewhere). Forest Stewardship Council (FSC)—certified forests are sustainable, and wood is a renewable resource. Even so, embodied energy, represented by transportation and processing costs, can be reduced if materials are used wisely. Framing techniques like advanced framing not only use less material, but avoid “wall washing” and other mold-encouraging conditions. BIM can be used to quantitatively compare conventional and advanced framing in order to better determine cost benefits of the latter for a particular project. While some BIM modelers may model unit takeoffs, even gross quantity surveys can help the architect make appropriate decisions.

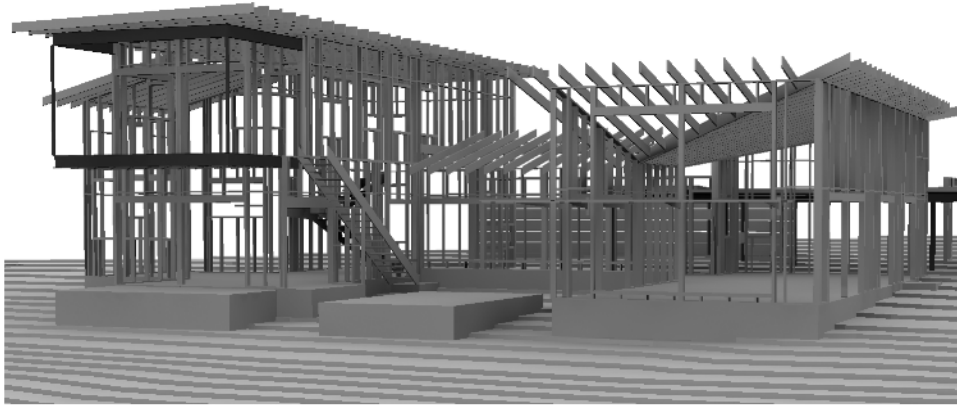


FIGURE 1.20 A BIM model after having been decomposed and the walls' continuous structural core converted to discrete studs, headers, and blocking. The roof has likewise been framed according to user parameters for framing member size and spacing.

- Accurate, dynamic quantity surveys. BIM software does not necessarily model every individual component of a wall (individual CMU, length of lumber, sheet of plywood, etc.), but tends to represent assemblies more abstractly (wythes of masonry, depth of stud wall, layer of sheathing, and so on). Some applications allow modeling and reporting

of every individual length of framing lumber (Vectorworks's Wall Framing and Roof Framing modules do so, for example). It is often sufficient for takeoffs to be more abstract, limited to area takeoffs of a particular material, rather than unit takeoffs. Such reports are possible with BIM, with or without specialized modules (Fig. 1.20).

■ Case study: Moonrise Ranch, Hill Country, Texas

By François Lévy

Design Firm: Mark Winford and François Lévy (Studio Mosaic)

Client: Jan Gauvain and Stanley Tartakov



FIGURE 1.21 The project seen from the south. The roof's curved ridge and level perimeter created a complex curved surface that was more readily analyzed and represented with BIM. Note a portion of the original cabin visible behind the ladder, well-protected by the generous roof overhang.

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Several years ago, my design partner at the time and I were approached to design a private residence on a ten-acre riverfront site in the rural Hill Country of central Texas—near the town of Wimberley, a 40-mile drive from Austin. Our client had a highly artistic sensibility and had been hiking and camping in the area for years before acquiring the property a year prior to commissioning us. As a result of her experiences, she desired an idiomatic home strongly connected to the site that would heighten the experience of the land's natural beauty. Eight years prior, the previous owner had moved a nineteenth-century two-room dogtrot cabin onto the site (Fig. 1.22). This building, with its remarkable mud plaster interior, was gradually succumbing to the elements.

(Continued)



FIGURE 1.22 The original cabin structure as it was prior to being relocated and integrated into the new house.

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Design Intent

We suggested to our client that the cabin be relocated on the house site to a bluff line just within earshot of the Blanco River. The historical cabin would constitute two rooms of the new house, with the rest of the structure designed around and cradling it. At that location, the new house would capture prevailing breezes and command a view over the riparian meadow below—future site of her gardens.

We developed this idea into two competing design themes. On the one hand, we conceived the project as a “village of spaces,” each room articulated by form and material to distinguish it from the others (Fig. 1.23). As a result of this articulation, most of the house would be “one room deep,” and most rooms would have access to natural light from three sides. In addition, we designed a corrugated metal, parasol roof both metaphorically and literally sheltering the historic cabin and the assembled spaces. The form of the boat-like roof invoked the gurgling Blanco River, and also the nearby rounded central Texas hills. Tree trunk columns would support the roof’s gently arched spine, inspired by the tall cypresses growing in the Blanco and on its banks.

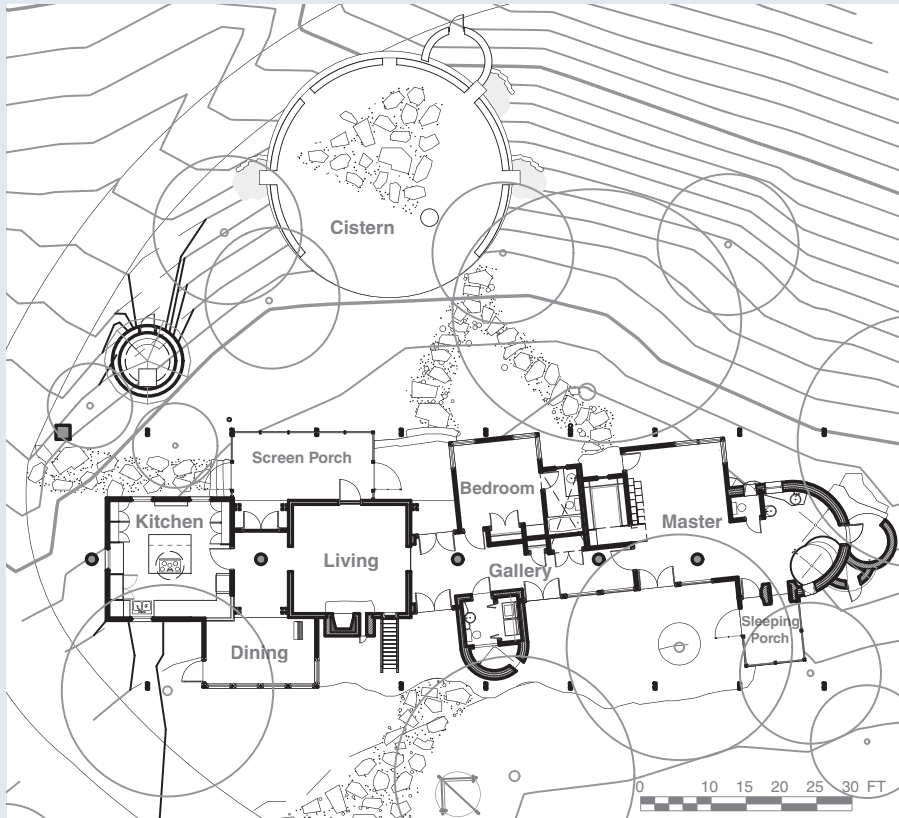


FIGURE 1.23 The precinct plan of the project indicating the relationship of the covered cistern to the site topography and internal arrangement of spaces.

Drawing by the author and Mark Winford, AIA.

We included a tall tower to create a dramatic viewing platform. Prevailing breezes, tempered by the deep shade porches, would be naturally exhausted through the dual-purpose observatory and thermal chimney. Harvested rainwater would be stored in a covered cistern dug into the bluff just below the house. Our architectural approach maximized the building's exposure to appropriate natural light, views of the extended site, and opportunities for natural ventilation. The design exposed and celebrated these natural passive systems, making them didactic and legible.

BIM Solutions

There were several challenges that a BIM approach helped address, not all of which were strictly technical. At the outset of conceptual design, the project had an indeterminate budget. As the conceptual design evolved—beginning as early as our conversations on-site with the

(Continued)



FIGURE 1.24 A sketch rendering of the BIM model. Completed a decade ago, the project's early use of BIM was key to resolving qualitative and quantitative design decisions.

Model by the author and Mark Winford, AIA.

client, and even before the development of preliminary sketches—it became clear that the design goals of client and architects might prove unusual and outside the experience of many local builders in this remote area. From the beginning, therefore, we negotiated a fee structure that was weighted more heavily toward construction administration (CA) than is typical, and correspondingly tilted away from construction documents, reducing our fee sans CA by 20 percent. (In the end, our final total fee was lower than typical for our firm.) As designers, our expectation was that we would produce a more forgiving drawing set that had built-in design tolerances such that construction inaccuracies, if any, would be less noticeable. This fee arrangement was fortuitous, as it encouraged us to leverage the design and production advantages of BIM without sacrificing design and documentation quality (Fig. 1.24).

The non-orthogonal and compound geometry of the project was a form that would have been challenging to construct as a series of two-dimensional drawings. The roof's shape was particularly challenging: the curved ridge beam and level parallel perimeter beams created a hyperbolic paraboloid surface; each pair of straight rafters was set at a different pitch than adjacent rafters. Modeling the structure allowed us to verify its constructability, as well as to rationalize the rafter spacing and symmetry to simplify construction for the framers as much as possible.

Given such a roof shape, and that the walls were arranged non-orthogonally to the column grid, constructing interior elevations as 2D drawings would likewise have been time-consuming and prone to error. In this case, fitting the BIM walls to the roof model in 3D was relatively simple. The interior elevations could then be readily derived from the fitted walls. The same held true of other elevated and sectional views: building elevations and sections were more easily and accurately derived from the 3D model than constructed as 2D drawings.

As might be expected from her deep connection to the site, our client was interested that the project emphasize sustainable systems as much as practicable. This emphasis on



FIGURE 1.25 The curved roof shelters conditioned, enclosed, and open spaces, and is peeled back to admit mature live oak trees. 3D modeling the complex geometry resulting from the interaction of curved forms was more direct and accurate than constructing 2D drawings.

© Paul Bardagjy.

sustainable systems suggested an analysis of an intelligent 3D model to help derive and validate our design decisions (Fig. 1.25). In this case, there were several opportunities for a BIM design process to advance our green agenda.

Water wells in developed areas a few miles away were gradually being drilled deeper and deeper as consumption pressures were lowering the tenuous water table, and we were all acutely aware of the water problems that future, neighboring development might bring. We therefore elected to incorporate a rainwater harvesting system in the project, and offered perspective renderings for a variety of different cistern designs, from a single low tank some distance from the house to a scalable array of smaller tanks. In our research, we had determined that cistern costs were roughly comparable regardless of the size and number of tanks; all solutions were about a \$1 per gallon of storage. We thus decided to use the cistern as an architectural feature, setting it into the hillside and covering it with a walkable surface. We were able to dynamically calculate the cistern size as our roof design evolved, thanks to

(Continued)

our ability to quickly query the roof plan area and use it to inform the cistern geometry. As a result, we could readily determine which roof areas should be guttered for drainage and which for catchment. (Chapter 9 discusses BIM and building hydrology: roof catchment sizing and rainwater harvesting design.)

For sun studies, our model allowed us to verify the shading of certain windows at various times of the year, and we could adjust their placement and size accordingly (for an in-depth discussion of solar modeling with BIM, see Chapter 5). Even with coarse tree models, we could establish shading patterns on exposed windows, such as the southwest-facing dining room windows. Similarly, diagonal views through the model from a high elevation sighting to a lower one could be mapped out in three dimensions, helping to refine our window placement in some instances.

Passive cooling of the house was best achieved through natural ventilation, given the climate (see Chapter 6). The observation tower doubled as a solar chimney, and we used open bar grate for the upper flooring to allow upward air movement and light penetration down into the tower. Due to the stack effect, in a thermal chimney, the rate of air movement is predicated on air inlet and outlet sizes, the difference between their respective heights, and inlet and outlet air temperatures. All the geometric information in this relationship, including window elevations and aperture sizes, was readily and dynamically determined from the BIM model as the design evolved. Inlet and outlet temperatures were estimated based on experience and climatological data. The owner currently reports that the thermal chimney is highly effective, and cools the house well on all but the very hottest Texas summer days.

Nationally published and a popular destination on the 2001 Austin AIA Homes Tour, Moonrise was successful, in large part, thanks to an extraordinary client. Given the design intent, sustainable program, and constructability constraints, I am convinced that this project would have not been feasible for our firm at the time without the use of a BIM design process.