PART 1

DESIGN THINKING AND BIM
1.1 INTRODUCTION

Despite the myth of the heroic architect, popularized by Ayn Rand’s novel *The Fountainhead*, whose Howard Roark–like designs spring entirely from personal inspiration, architects and engineers need information to design buildings. Few people today question the needs of the clients and/or users so at least a rough program of activity spaces is usually embedded within the design process if it doesn’t precede the actual building design. But there is a lot more information that helps architects make decisions during the design process. While it may not be possible to know everything involved in the design and construction processes prior to the completion of a building, there are assumptions that having information is better than not having it, that informed decisions are better than uninformed ones, and that design is a knowledge-based activity. If one does not object to designing with information that includes maximizing building performance, budgeting, and material optimizations, then building information modeling (BIM), almost by definition, has the potential to improve the products and processes of architectural design.

Building information modeling provides the implied promise of integrating all types of needed data into one file or model (perhaps with separate but linked files with easy bilateral information transfer). While the fulfillment of that promise depends, in part, on both the pace of commercial software development and academic researchers, any current lack of a single integrated information model is not a reason to avoid the process. Furthermore, as long as there are competing products for use by architects, the
features and ability to integrate different types of data are likely to vary. As architects are by nature and profession optimists, the type of integrated data and information in this discussion may not (always or currently) be ubiquitously available, but the information not available in the application of choice, may and probably will (or at least should) be part of and contained within any future development.

Tools are needed for form-making, simulation and analysis, and document production. Clearly these tools may be discrete, or they might be combined into one or more separate applications. A value of reducing the number of separate tools is to facilitate the ability to cyclically and iteratively move back and forth between tasks, especially between schematic design (of which form-making is a part) and analysis (which may rely on simulation). Note that none of these relationships assume an artificial intelligence or machine-determined decision-making process. While that may be possible at some point, its desirability is not assumed, and the purpose of using BIM in this case is to use the attributes of computational, information technology-enabled design to provide any member of the building design team with information helpful in making decisions. It is critical to understand, however, that success in the integration of BIM into the design and building delivery process relies, at least in part, on a combination of robust hardware and software.

Digital media in general, and building information modeling in particular, have the ability to inform the very beginning of the design process. The ability to associate data with geometry allows designers to begin to (1) integrate technical and performance criteria at early stages of design thinking while including advanced visualization capabilities and (2) algorithmically and/or iteratively test design implications. BIM starts redefining the way design ideas are generated by bridging formal creativity with design and technological innovation through a close integration of parametric generative tools, through the introduction of physically accurate digital materiality, and through intelligent database-enriched digital objects. Finally, BIM affords the architect (and client) an opportunity to include life-cycle assessment as part of the design process when considering alternatives. As design implementation in BIM becomes more tightly intertwined, there is the potential to combine multiple roles in the design process much in the way that “typists” have been replaced as authors write/type and compose with one tool. BIM also facilitates bridging across disciplinary boundaries.

It now remains to determine the kinds of tools that can facilitate creativity and innovative thinking within the design process. Creativity tools need to provide design feedback, help designers to gain new experiences, and allow for unexpected associations with pattern-breaking functionalities. They need to allow for inductive and lateral thinking, as well as to connect with broader expertise from other building delivery team partners.

Present BIM platforms have a legacy that derives from a combination of early CAD software and visualization applications—all of which are based on geometric logic. The software relies on shapes and forms to delineate architecture. Moreover, there is a proclivity to look at or define a building as a set of parts, components, or “families.” As such, it promotes mainly visually driven design validation in an additive design process. The other component of the current BIM platform, the database, is usually implemented as an extension of geometry, an attribute of a model. It is rarely a part of a broader datascape that considers user behaviors, functional patterns, relationships between the cost and performance, simulation of energy use, or life-cycle analysis. In a design context BIM may be used to evaluate
form, to look at generative abilities of parametric models, and as a tool to see how analysis can drive (or at least influence) the building delivery process.

### 1.2 Evaluation of Visual Information: Form

The attributes of BIM software allow it to be used for schematic “uninformed” design—a designer can do everything he or she wanted to do with “dumb software” (i.e., applications restricted to geometric modeling) or pen and pencil by:

- “Turning off” associated attributes and designing with geometry (e.g., rectangular solids or surface models rather than walls)
- Visualizing with rendering and ignoring realistic lighting (e.g., shadows as if the sun rises in the north) or actual material attributes (even visual attributes).

BIM applications have progressed to the point where they may be effectively used to visualize form with materials by adding realistic finishes with reflectivity, texture, and color, thereby enabling the designer to judge based on visual criteria (in or out of context) (Figure 1.1).

It is possible in both BIM and non-BIM geometric visualization applications to parametricize components so that not all repetitive elements are one-off objects (e.g., provides the ability to change all or one window at a time when evaluating a façade based on visual criteria/composition). This ability facilitates smooth interaction in an iterative design process that is essential for any tool and saves time over the use

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**FIGURE 1.1** BIM models account for material properties, lighting levels, and furniture layouts. While providing a visual feedback to designers and clients, they also keep track of types and schedules for construction components, finishes, and furniture.

[Images courtesy of Mina J. Liba—left, and Peter Fritzky—right. Designed, modeled, and rendered with Autodesk Revit. Grayscale conversion and image processing with Adobe Photoshop and/or Corel PaintShop Pro]
of traditional media, which effectively improves creative operations. For example, associative attributes of parametric models allow for autonomous resolution of the edge condition between various elements and are imperative in relieving designers from continuous verifications and modifications of design changes.

1.3 GENERATIVE ABILITIES OF PARAMETRIC MODELS

Parametric relationships offered by current BIM platforms facilitate generative processes by allowing design versioning while maintaining integrity of an overall assembly. Figure 1.2 shows a number of design variations of a column-to-space frame detail. Through parametrically defined interoperabilities within the connection, a design can morph between multiple states and at the same time preserve the logic of the construction detail. This is an important associative quality that distinguishes BIM from CAD models. However, while this approach provides an effective tool for design versioning and assembly resolution, it also lacks broader validation criteria such as performance, costs, and material usage that would provide designers with other than just visual feedback. This limitation is characteristic of most generative software applications that utilize algorithmic and geometric procedures without physics-based form-making mechanisms.

1.4 HOW LIGHTING, THERMAL, AND STRUCTURAL CONSIDERATIONS CAN DRIVE THE DESIGN

The ability to add technical information specific to components, context, and/or place can provide valuable information during the design process. The ability to apply this information during the design process does not require the elimination of traditional visual evaluation, but does imply that the designer should consider multiple criteria when making decisions. The following three lists on lighting, thermal
performance, and structure provide some examples of data that can/should be added as part of a true building information model.

1. Lighting
   - Using exterior location data to test illumination inside a building when looking at the size of windows.
   - Adjusting design elements based on site data (e.g., exterior shading devices, interior light shelves).
   - Specifying luminaires and lamps and testing light distribution visually (interactively test against surface reflectivity and color; change lamps within luminaire; add, remove, modify reflectors).
   - Associating calculations for lumen levels on surfaces (Figure 1.3).
   - Providing life-cycle assessment of lighting.

2. Thermal performance
   - Modifying the wall construction to compare thermal performance, and other wall attributes: thickness, weight, space, details, finish options, cost, and more.
   - Interactive calculation of internal loads (large buildings) may be tied into engineering decisions that affect space allocation (e.g., lighting loads, HVAC equipment, heat sinks/cooling towers).

3. Structure
   - Modifying structural system at different levels (e.g., concrete vs. steel; size of structural bays/distance between columns) and visually seeing different implications (e.g., heavy vs. light).
   - Detailing parametric variation with visual results (note that this is the kind of work architects and designers did in traditional structures classes).

**FIGURE 1.3** (Left) photorealistic image, (right) the same image with luminance mode showing the levels of surface illumination in candela per square meter (cd/m²).

[Images by Travis New. Designed, modeled in McNeel & Associates Rhino and rendered with Autodesk 3DS Max. Image composition and grayscale conversion and image processing with Adobe Photoshop and/or Corel PaintShop Pro]
An important feature of future BIM platforms would be to provide multiple modes of data visualization, both quantitative and qualitative, that can relate to diverse types of communications and user's needs. Decision making may be heavily influenced by way information is represented. Creativity and new ideas are often triggered by an unconventional look at the already known problem. Solutions emerge when various perspectives are considered.

1.5 Limitations of Current Parametric Models

A number of current BIM packages allow for establishing parametric relationships between various model components by feeding values from one object into another (Figure 1.4). However, they still function within limited scope without bi-directional feedback loops. Parameters are passed along established routes in a linear manner that reinforces the hierarchical and didactic design processes rather than providing opportunities for unexpected discoveries. With most of modeled components functioning as inert geometries and deprived “smart” behavior, they relay data “down the stream” rather than allow for a multidirectional dialog and interoperability. While they work effectively in producing outcomes based on initial assumptions (operands), they are incapable of reversing the reasoning sequence and using the outcomes as starting points to examine initial design assumptions.

The goal is a platform where members of the building delivery team could reexamine initial design decisions at any point in the process, including topics such as construction types, budgetary constraints, site placement, and/or program adjacencies, and substitute them with new priorities. This would facilitate the inquisitive “what if . . .” explorations with building performance data, carbon footprint, or material substitutions as design informing factors.

FIGURE 1.4 Parametric relationships are passed between various assembly components. (Images by Alexander Merlucci, Nicholas Giuliano, and Aidan Migani. Designed, modeled, and rendered with Autodesk Revit. Grayscale conversion and image processing with Adobe Photoshop and/or Corel PaintShop Pro)
The bi-directional interoperability is particularly important when considering multiple, often competing, design criteria and the need to solve for the most optimal collective solution, not a single variable. Additionally, clients’ priorities change and so do the site and marketplace conditions. Consequently, an effective computational design delivery platform needs to accommodate the volatility and uncertainty of the design process.

1.6 PHYSICS AND MATERIALITY

What other input will be critical for future BIM models to support the design process? In addition to associative quality of geometry and parametric relationships, the physics-based behaviors, materiality, and more intuitive user interface are among the most pressing needs for an effective computational design platform. The lack of materiality considerations hinders the creative process when considering current digital or analog design tools. With the ability to generate complex forms, designers sometimes operate within scaleless and etherlike environs that bear little resemblance to actual built designs. Materiality and physics-based behavior brings a scale and “bite” into otherwise abstracted forms. Emerging design BIM platforms need to consider physicality of the final product and be able to account for it in all design stages. This physical awareness needs to be both quantitatively expressed in units and costs and qualitatively contributing to a designer’s intuitive understanding of performance and informing his/her tacit knowledge.

While materiality and physics-based behavior is critical, in understanding design implications, assembly and manufacturing processes as well as a broader impact on material usage and life-cycle analysis are equally important. Current tools allow designers to model more complex designs than those that can be effectively built or solved. When digital fabrication combined with NURBS surface modeling results in fabrication strategies that produce a significant amount of material waste, the issues of material usage optimization and zero-waste designs become critical. The project in Figure 1.5 investigates this condition by analyzing design methodologies for form-making and form-solving. Unfortunately,

**FIGURE 1.5** Initial form-finding exercises led to the discussions on material usage in fabrication and zero-waste strategies. Form-finding for pneumatic design with generative/algorithmic tools (right). Unrolled and fragmented surface of the pneumatic form (center). Finding complementary unrolled components to optimize material usage (left).

(Images by Gayatri Desai, Edward Perez, and Joseph Ribaudo. Designed and modeled with McNeel & Associates Rhino, Grasshopper, and Kangaroo. Graphic layout with Adobe Illustrator and/or Corel Draw. Grayscale conversion and image processing with Adobe Photoshop and/or Corel PaintShop Pro)
in this particular case, the zero-waste part of the project relied significantly on the analog try-and-see method to optimize material layouts. Computer tools provided limited value in addressing this important design consideration.

Future BIM platforms need to account for fabrication and manufacturing processes in order for designers to consider them in their design process. This is a particularly pressing issue since many current designers empowered by fabrication technologies expand the traditional definition of an architect into the maker (master builder) of architecture. This is evident in emerging innovative practices such as SHoP where architects assumed a broader role similar to what was historically considered a master builder. These new practices not only take responsibility for building design but also are aspects of fabrication and oversight of the overall construction delivery. Furthermore, their contribution toward a project goes beyond design intent and often involves industry research and technology/tool development. These practices are the next step in the evolution of the traditional integrated team delivery (ITD) project with much closer collaborations between thinkers and makers. As with the traditional ITD projects, the success of these emerging practices depends on the unified building information platform that guarantees a high level of integration and efficiencies due to the greater level of building delivery control. However, with such highly interconnected and finely tuned design-build pipelines, there is a question of system adaptability, and continuous creative evolution remains to be explored for best possible outcomes.

1.6.1 Solving for Multiple Criteria

Most simulation and optimization approaches such as genetic algorithms allow for a single variable optimization and usually solve for a local optimal solution rather than a global one affecting many variables. This limitation applies to both analog and digital design process where designers address a limited, and often narrow, number of variables without fully investigating all possible scenarios. Architectural design requires solving for multiple criteria based on a particular value judgment. Solving for multiple variables, developing higher-level evaluation mechanism, and going beyond genetic algorithms would provide more effective creative tools. Furthermore, the ability to adaptively reprioritize evaluation criteria during the lifespan of the project would provide a better fit with real-life situations.

1.6.2 Other Data Types

Parametric relationships should go beyond geometric properties and include other data types such as building performance or user behavior. These data types need to feed into form- and space-making while considering constructability, assemblies, and user experience. Whereas solar or lighting analyses are effective tools to inform a designer’s thinking and are helpful in justifying a particular course of action, they often do little to quantify design in terms of the actual performance particularly from the multiple criteria perspective.

For example, the following question is not uncommon when designing a curtain wall. What are the benefits and drawbacks of a large glazed façade from the standpoint of solar gains, thermal losses, natural lighting, and possible condensation issues? While it is common for designers to latch on to a single
criterion to justify their preferred design directions, an actual quantification of the competing design objectives would provide designers and clients with a broader understanding of their decisions and ultimately with better performing buildings. While the current state-of-the-practice assumes that all these are part of mental validation processes designers consider when designing a building, these processes are often based on intuitive thinking and unquantified experience rather than on sound and current data. This also limits clients’ ability to understand a design decision process and shape it in an informed way.

1.6.3 Soft Constraints

While parametric definitions can be effective design aids in relating multiple assembly components, their binary state functionality (works or does not work) sets a serious limitation for design explorations. Designers experimenting with parametric systems may get overconstraint messages from BIM software when there is a conflict between various competing parameters. However, this does not provide constructive feedback that can help advance the design. What is needed is a soft constraint platform that communicates to the designer the degree to which the design is working. The qualitative message “you are 95 percent there” is more effective from the design process viewpoint than the mechanical response “overconstrained; it does not work.”

The case study shown in Figure 1.6 demonstrates such functionality achieved with chipboard models of kinetic assemblies using scissor mechanisms. In this case, the physical material used for the
mock-ups provided enough flexibility and strain to allow for the soft constraint functionality. Students were able to use interactions with physical models to understand kinetic movements of their designs and later bring them within a computational platform for further design explorations and resolutions. What was learned from this case study was that while physical interactions were helpful, materiality of a model was critical in providing the desired design feedback. Using acrylic glass or other rigid material would not provide the same results as chipboard models. This suggests that computational materiality employed in a similar manner could also be an effective response for soft constraint system.

1.7 DESIGN AND CONSTRUCTION 2.0

Analogous to Web 2.0 functionalities that utilize context-awareness, track user interactions and preferences, and incorporate crowd-sourcing, the future BIM platform may find it worthwhile to break away from a single data node mindset and become a part of a broad data-sharing network. This raises several questions:

- Can the experience of one designer contribute to the success of another one?
- Can data make the design process and design knowledge modular enough to be quantified, compared, and shared?
- What is required of the BIM platform to facilitate broader collaboration, knowledge transfer, and experience building?

Of course, this may posit a somewhat different business relationship between owner, architect/interior designer, contractor, and facilities management personnel as well as a redistribution of liability. Nevertheless, “turf wars” aside, there are opportunities that could be technically feasible that would benefit future designers. It is possible, for example, that the collection and (re)distribution of data (with appropriate identity protections) may create an entirely new area for employment. For example, some architects could specialize in development of fully integrated digital prototypes (virtual prefabs) that can be used as parametrically flexible design modules. These design assets could be reused by others and franchised as long as the digital building models would allow for easy and flexible parametric reconfigurations, thus leading to genetic standardization of architecture and formatting it into universalities that go beyond the traditional one-off designs. Additionally, this could lead toward considering designs as forms of intellectual property, not unlike the situation with tangible objects.

1.7.1 Context-Aware Data

With the exponential growth of datasets and design models, the question of filtering information, just-in-time, and just-in-place functionalities is critical. Having access to relevant information at the appropriate level of abstraction or detail would streamline design process and eliminate unnecessary trial-and-error attempts. While often criticized for the requirement of too-much-data-too-early in the design process, future BIM platforms could adapt its dataset into the level of the design resolution. While this is a representational rather than systematic issue, the initial data required by a BIM model would not have to be input by a
designer, but it could be intelligently guessed based on the past or similar projects. The key consideration is how the data and knowledge developed on the past projects or by other designers could feed into new work.

Other aspects of context-aware data refer to associative qualities of BIMs that would develop lateral connections between various design components as well as the contextualization of design within a particular locality (environment, codes, process, and construction culture), culture (human factors), and types of users. Furthermore, with the “Internet of Things” on the horizon, the building information models need to include a persistent monitoring, data gathering, and connectivity with everyday objects.

One note, however: It must be acknowledged that there could be a danger in creating formulaic algorithmically derived design with information that would actually work against lateral thinking that leads to conceptual breakthroughs and innovation. To avoid this, designers must still be educated in and facile in the ability to manipulate all of the criteria traditionally associated with good design and architecture.

1.7.2 Beyond a Single Lifespan of the Project

Future building information models need to facilitate the extension of the dataset use beyond single project or a single designer. While there is a significant discussion about extending the use of BIM into early design stages and into the post-occupancy, these are not sufficient. Certainly, building information models can help in the management of facilities, maintenance, and operations especially when coupled with mobile technologies such as an augmented reality platform (Figure 1.7).

FIGURE 1.7  Augmented reality (AR) environments provide a location-awareness platform for combining data and video camera feeds to facilitate more effective construction and facility management.
(Image by Andrzej Zarzycki. Image composition and grayscale conversion and image processing with Adobe Photoshop and/or Corel PaintShop Pro)
However, a more significant repositioning of BIM and the design process is necessary. Design by its nature is a proposition (intent) that is realized by a contractor erecting the building and later tested by the owner and users. In any effective design process one would expect a number of feedback loops connecting users, builders, and designers to validate initial design assumption and techniques used to realize them. This design-build-test approach is prevalent in other design disciplines and is effective in improving product quality. Unfortunately, architecture does not follow this model, and when it claims it does, it does so in a very loose and unsystematic way, relying on scattered information gathering and sharing. This situation creates an opportunity and necessity for future BIM platforms to address the need for validation of assumption, simulation, and projection used to design the building. When done properly, designers will be able to learn from past projects in a clear, quantified way and transfer this knowledge into future designs (Figure 1.8).

Imbedded sensors monitoring buildings’ operations could feed data gathered back into the BIM model and verify this against initial simulation models. This would not only provide an opportunity to verify design assumptions and simulations but also to reflect upon the construction techniques and material quality. In such a scenario, the BIM platform would emerge as a broader virtual building model that parallels its physical counterpart and is continuously used to fine-tune building performance throughout the life of the building. In this new role, virtual models become software components that operate physical hardware of an actual physical structure. Digital models that were used to design, analyze, and simulate performance continue their existence as a building operating software.

The predictive value of current simulation tools is limited unless it can be closely tied to actual building performance monitoring and is later used to refine future BIM-driven designs. Iterative design processes that include feedback from constructed buildings incorporated into future designs are important for good design practices. Presently, the architectural profession depends on human designers to accumulate knowledge about specific building efforts. However, in actual practice, designers, architects, and engineers often are not involved in post-occupancy lives of their project. They may lack the time or expertise to comprehensively evaluate their design.

Finally, information modeling and data sharing refocuses the design process from the one-of-a-kind creativity to an iterative and sequential process of prototyping and knowledge building. It facilitates the
development of design(er) memory encoded into data model that can be passed from one building into another, from one designer to another, continuously and progressively refining the outcomes.

1.8 CONCLUSION

Emerging computational technologies are the latest in the long line of agents informing the way we work, innovate, and ultimately how we think and who we are. Creativity is perhaps the most cherished and unique of all human attributes. As such, an intersection of creativity and technology becomes a critical opportunity that informs design professions and provides great promise toward our future.

While technology redefines the surrounding world, it also needs to reflect/consider it with its various intricacies, physical behaviors, and materiality. Designers not only need to model materials, energy usage, or lighting but also follow up on built designs and learn from previous work.

Remote building monitoring interconnected with building information models can provide an effective creative feedback loop to improve designs we build and help us to understand a broader impact on the environment. It can quantify the quality of construction labor and material performance as well as our own designs.

This accumulated knowledge can benefit all members of the building delivery team if it persists beyond the life span of a single project in the form of a shared experience that can be passed between various individuals asynchronously and feed into other construction disciplines and the outside world. The experiences gained by clients, architects, engineers, contractors, and facility management personnel throughout the project can be useful to policy makers, residents, or first responders. A recently constructed building may become an important player in the neighborhood for the resource sharing and providing new services for other buildings.

The emerging common denominator to these propositions is a broader unified building information modeling platform that reflects the complexities and aspirations of professionals involved in the building delivery process as well as the social and cultural roles. Current BIM products represent early stages of the ultimate platform that are progressively advancing their scopes and the role they play in practice.

DISCUSSION QUESTIONS

1. What criteria should/could be considered in a building information model to improve its usefulness in the design phase of a building?
2. What are some of the dangers of relying on single-optimization or algorithmically generated solutions to building design?
3. What long-term opportunities may arise from extending BIM beyond the life of a single project and sharing data?
4. What opportunities are there to integrate augmented reality into building information models and in what ways could this prove useful?
BIBLIOGRAPHY


