Chapter 1

Digital Design

What is design? Is there a particular quality to digital design processes?

A question asked with the objective of obtaining a definitive answer is not a very interesting question. A question asked in an open-ended, indeterminate process of perpetual inquiry becomes a way of being. So when one thoughtfully asks "What is design?" what is really meant is, "How can I keep testing my assumptions about architecture and what it means to design?" Or, "How shall I keep questioning how and why I design what I design?"

Swimming in the waters of this type of inquiry will always be hard. For the young designer—looking for his voice, unsure about how to proceed, feeling the pressure of solving a design problem, and wandering away from a theory of design process—inexperience clouds the question. For the experienced designer—confident in her abilities, mature in her practice, technically knowledgeable, and sure-footed—the quick and possibly glib solution arises so quickly, seemingly magical in its effortlessness, that there's no time and certainly no incentive to question it.

Then there's the question of the cognitive quality of designing "by hand" as distinct from designing "digitally" ("computationally" would be more apt, as "digital design" has little to do with fingers). How does the modality of design affect the design outcome? Is an architect exploring a design solution by sketching with pencil and paper favoring a different design outcome than one immersed in a BIM workflow, by virtue of the haptic or cognitive nature of the design process? Does BIM lead to a particular architectural outcome?

Introduction

As a fruitful premise for inquiry (what Socrates in Plato's dialogues calls εικωσ μγθοσ—a "likely story"), let's consider that architecture (as a profession, though perhaps too as a human artifact) has been experiencing an evolving crisis for well over a century. And while we're in Greece, let's also ponder that "architect" is from άρχι and τέκτων: "master builder," or chief craftsman. While some architects may be capable builders, for a very long time the process of design has been divorced from the direct process of making. To be sure, in Europe some architects serve as *maître d'ouvrage* (master of the work), and their professional function is distinct from design architects. Even in the United States, many architects function as project managers. And as with *maîtres d'ouvrage*, their bailiwick encompasses project objectives, scheduling, sequencing, and budgets; they are not builders or craftsmen *per se*. Perhaps not coincidentally, very few architects come up through the profession with a background in building. For better or worse, ours is a profession rooted in the academy.

Arguably, the Viennese Secession, Franco-Belgian Art Nouveau, the British and American Arts and Crafts Movement, and their contemporary localized counterparts were a reformation against mechanized and industrialized fabrication methods coming online over a century ago. (Ironically, nowadays of course one can order Arts and Crafts furniture online, made in a factory overseas and delivered with two-day free shipping. I have no objections to such a convenience, but it does reduce an architectural and artistic movement to a mere style or fetish.) Mechanization has so pervaded our social expression of work that the handcrafted has lost the moral superiority assigned to it by the Arts and Crafts Movement, and is now commodified or fetishized. A century ago windows were produced by hand like custom millwork; now they are mass produced—and with good reason, too, as modern windows assembled with modern materials and manufacturing vastly outperform their historical counterparts.

So on the one hand we have master builders who do not build, and on the other we have building processes that are farther and farther removed from craft (Figure 1.1). In a philosophical context, it may not be a problem that architects do not build anything; it may merely be a needless obsession with an archaic etymology that would suggest that as a profession we should be builders. I for one am not trained in the act of building, nor do I have the urge to exercise it. Except that as the distance from design to execution lengthens, the constructibility of the design may suffer. Moreover, design can be instructed by construction. An architectural detail may be intricately drawn, but what if it cannot be achieved due to the dimensional tolerances required, or if the sequencing of its components would be impossible?

If anything, the abstract nature of architectural design processes only contributes to this gap between the design idea and its physical manifestation. The more abstract the design artifact, the greater the gap. The architect loves the hand-drawn line in part *because* it is so abstract: bearing almost no intrinsic information, an entire story may be inferred from a few accidental details. Is it perfectly straight (a firm decision has been made) or wavering (it describes a vague impulse, or perhaps a natural feature)? Is it ink (confident, authoritative), or soft pencil (tentative, or evocative)? Is it drawn on vellum (final) or trace (exploratory), or on a scrap of napkin (extemporaneous)? Note that all these

FIGURE 1.1 Automated construction of an architectural wall. If the craft isn't in the assembly in the field, where does it lie? In the programming of the automation?

Image courtesy Construction Robotics.

meanings are subjective: they are supplied by the observer, using certain cultural visual cues as a context for assembling a narrative out of a mere line drawn between two points. In other words, the observer infers the meaning (Figure 1.2).

By training moreover, for many architects and designers drawing is much more than merely a means of clearly communicating a comprehensive idea. The act of drawing itself is a cognitive process, an act of uncovering, an exploration. Just as the traveler may not fully see the building he is drawing until he actually draws it, so the architect may not fully realize a design idea *except by drawing it*.

Now consider a BIM assembly. With contemporary BIM-authoring software, it can of course readily be rendered in a hard line; in a sketch style with variable parameters to control wobble, overstrike, and so on; as a cartoon color rendering with graphic qualities reminiscent of Francis D.K. Ching; as a white rendering almost indistinguishable from a museum-board model; as a photo-realistic rendering with depth of field, blur, and complex lighting; and so on (Figure 1.3).

I assert that the modality of a BIM rendering, unlike that of the hand drawing, is a function of the communication of the completed design thought. As typically used, BIM is not as a rule an exploratory device. It may be that this fact contributes to experienced designers' contending that BIM is not a design tool, but only suitable to the refinement, coordination, or documentation of a

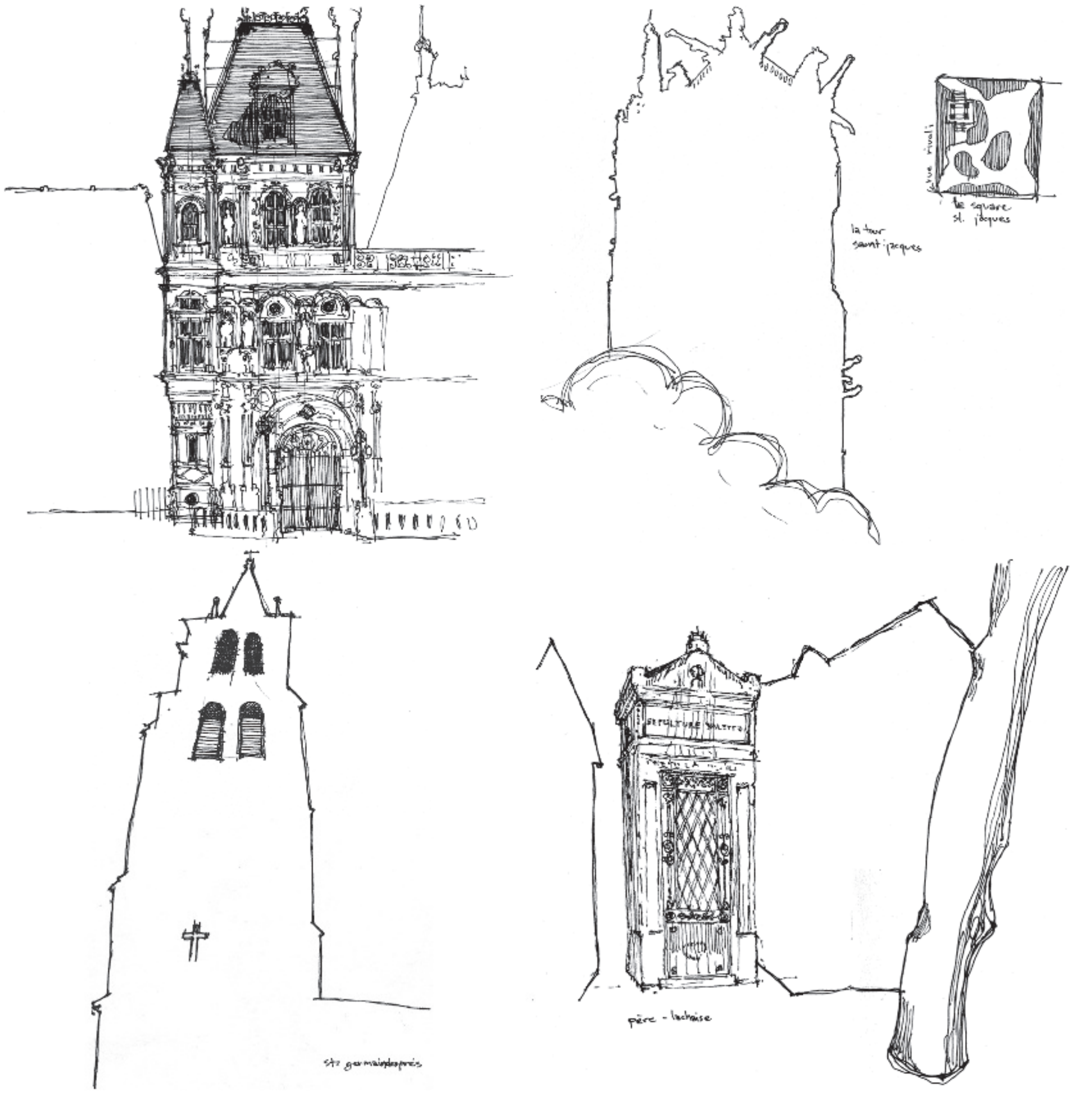


FIGURE 1.2 These travel sketches communicate as much with what they omit as by what is explicit. Moreover, the architectural elements of the drawing require that the user interpret the intended representation.

design derived by other means (Figure 1.4). This is a serious error, due perhaps to judging digital processes by analog standards and analog experiences. For the paradigm of the line is not the appropriate one for BIM. Rather, BIM inhabits the world of data, whether abstract or geometric, and should therefore be evaluated performatively and formally, rather than graphically.

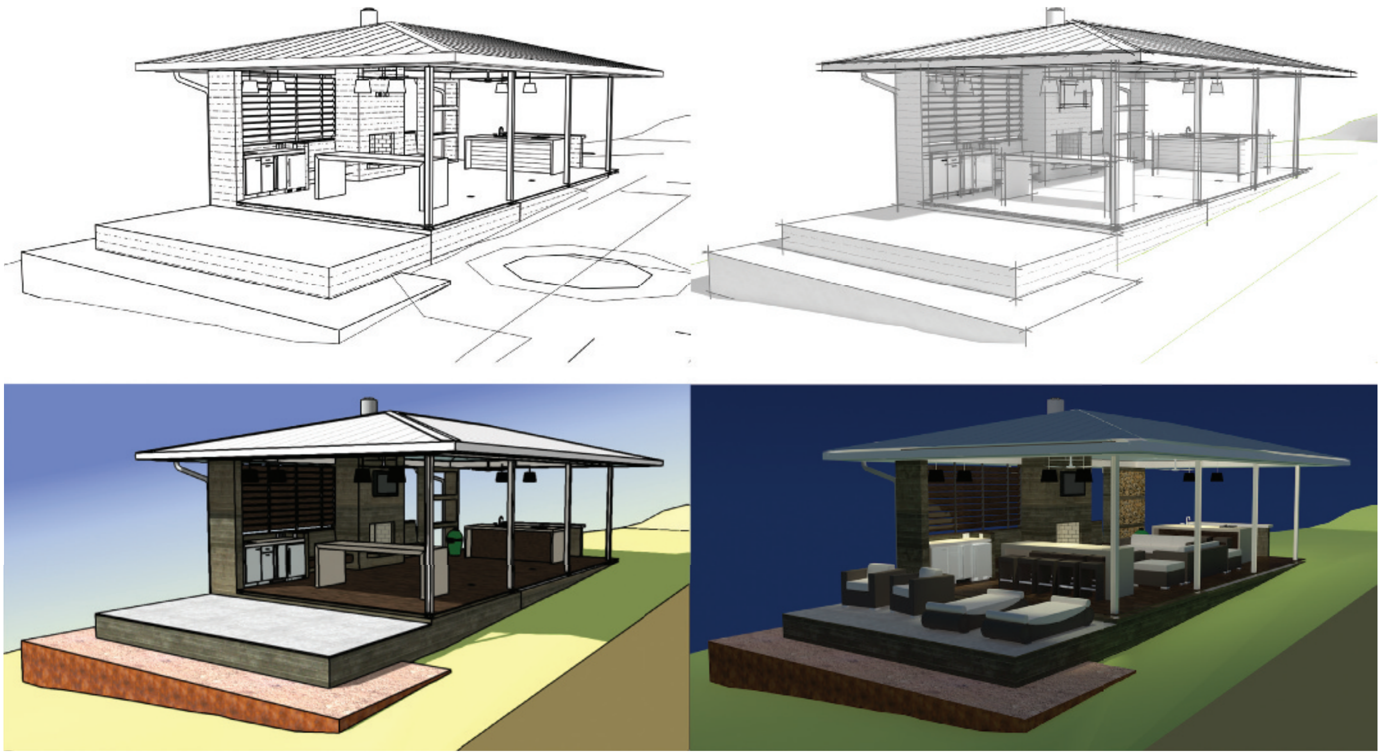
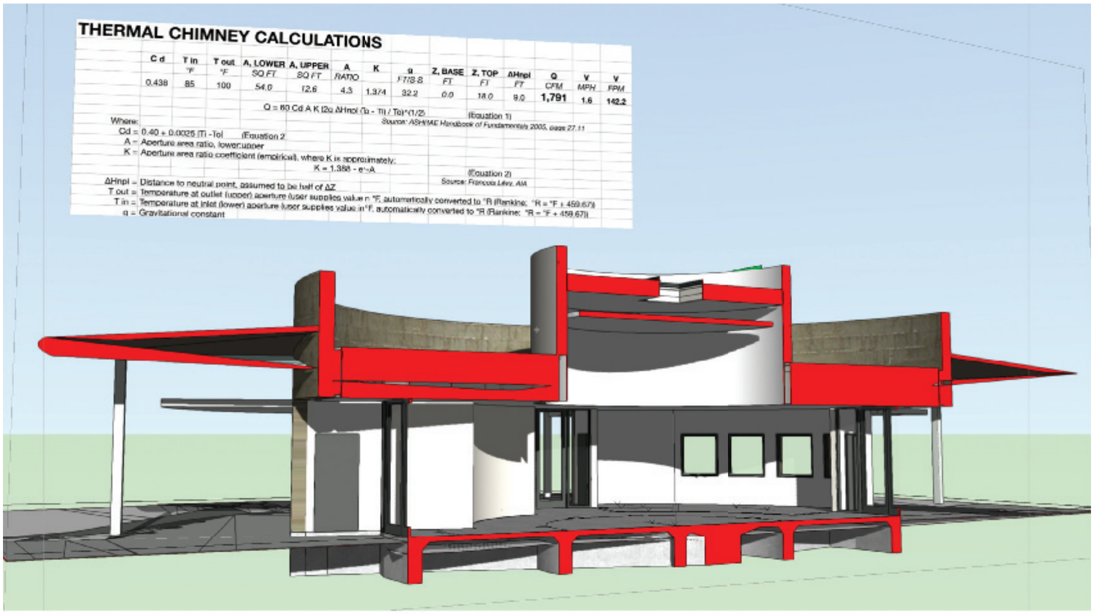


FIGURE 1.3 A series of renderings of the same BIM assembly, illustrating just some of the variety of rendering styles available when rendering in BIM.



Wind-Driven Cross Ventilation Calculation

	C v	A	v	v	V
Doors	0.25	27.0 SF	7.5 MPH	660 FPM	4,455 CFM
Doors	0.35	27.0 SF	7.5 MPH	660 FPM	6,237 CFM
Doors	0.5	27.0 SF	7.5 MPH	660 FPM	8,910 CFM
Doors	0.6	27.0 SF	7.5 MPH	660 FPM	10,692 CFM
Average:					**7,574 CFM**
Transoms	0.25	12.0 SF	7.5 MPH	660 FPM	1,980 CFM
Transoms	0.35	12.0 SF	7.5 MPH	660 FPM	2,772 CFM
Transoms	0.5	12.0 SF	7.5 MPH	660 FPM	3,960 CFM
Transoms	0.6	12.0 SF	7.5 MPH	660 FPM	4,752 CFM
Average:					**3,366 CFM**

V = Cv A v *Equation*

Where:
Cv = effectiveness coefficient: 0.25, 0.35, 0.50, 0.60, depending on wind orientation to window
A = inlet area, square feet
v = prevailing wind velocity, feet per minute (miles per hour · 88)

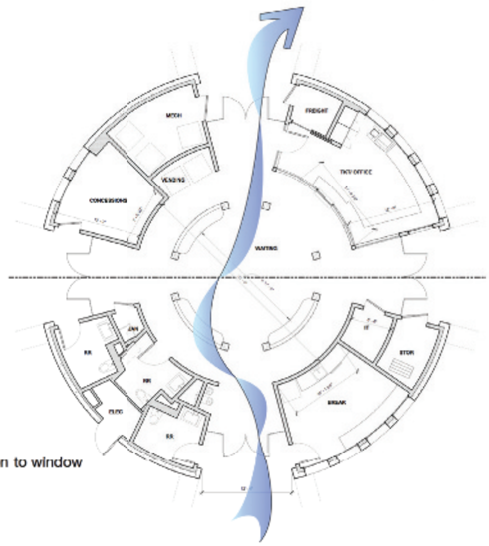


FIGURE 1.4 Design investigation in BIM. A single BIM model is used to evaluate a host of performance-based design decisions. Capital Area Rural Transportation System (CARTS) East-side Bus Plaza project design by McCann Adams Studio and Jackson McElhaney Architects; energy and sustainability analysis by the author.

What's Wrong with BIM?

The infamous 2004 NIST study, which "conservatively" identified an estimated $5.3 billion cost to designers and builders in the capital facilities industry in the United States for 2002 alone, helped set the stage for adoption of BIM in construction. The push for adoption was largely led by large-scale construction companies, building owners, and facilities managers. The latter stakeholders especially saw the benefits of the BIM artifact (the building information model), as a tool to potentially more efficiently manage building operations. Contractors were perhaps more sensitive to the possibilities for error reduction in a data-rich 3D building model federated from submodels contributed by the various design disciplines (architecture and civil, structural, and mechanical engineering), but contractors tended to completely rebuild the building information model in-house rather than simply reuse the federated design model. This astonishing apparent inefficiency flies in the face of the collaborative spirit of BIM and has been justified by contractors' differing set of operational parameters. For example, sequencing concerns might suggest that concrete be modeled in discrete divisions based on the maximum concrete volume per pour (Figure 1.5).

Architects, on the other hand, were often reluctant to adopt BIM for a variety of reasons. BIM seemed to expand the architect's services and deliverables with no corresponding increase in fee. BIM required new software,

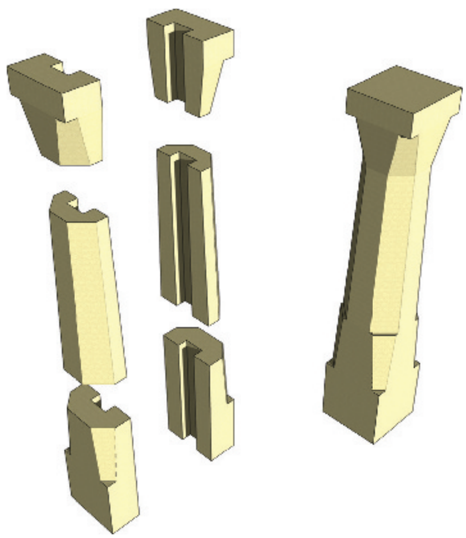


FIGURE 1.5 Two BIM models of architectural concrete components of a project, in this case a cast stone column. The instance at right is modeled as the architect would, in terms of the desired final geometry. The exploded view at left illustrates the cast stone clad elements segregated into individual castings, as the contractor and fabricator would consider it.

hardware, and training—again with no correlation in remuneratioin. Moreover, the claim of increased efficiency was met with some skepticism. BIM at its worst is just another file format requirement, and one with high overhead costs. In short, BIM was seen in many cases as a benefit to building owners and contractors at the expense of architects.

Missed Opportunities

And this may be true if in fact the sole or primary objective of BIM was "better, faster, stronger" computer aided design and drafting (CADD, commonly shortened to CAD. One might rightly wonder whether it's the "design" or the "drafting" that got dropped). But to see BIM as CAD+ is frankly shortsighted and misses important and fundamental changes in design approaches enabled by BIM.

BIM [Re]defined

There has already been quite a lot written on the nature of BIM; anything more than a brief definition here might be considered superfluous. Moreover, intentionally or not, definitions tend to be self-serving, advancing the agenda of the author or promulgating a particular view. Nevertheless, it's important to the context of a discussion specifically about BIM for design to consider the following:

- **BIM is a social construct** at least as much as it is a technology. For many, underscoring that "BIM is not a technology" actually means that BIM is not a particular, proprietary technology (i.e., Revit). To suggest that BIM is not technological could not be farther from the truth. Moreover, acknowledging the social aspect of BIM is crucial to discussions of BIM's interoperability. That is, one must consider that a BIM workflow is one that allows multiple authors and stakeholders to share graphical (geometry) and tabular (numerical data) project information. Furthermore, BIM is not an island, and it can accept and transmit (import and export) non-BIM data.
- **BIM has cognitive implications** for the participant. BIM requires designers and project stakeholders to think differently about the processes of designing, coordination, collaboration, and verification. The relationship between tool and user is not one-directional; the chosen design tool influences that design outcomes are harder, which are easier, and which are virtually impossible. Our tools influence us (see Chapter 3).
- **BIM is data driven.** The BIM file is a comprehensive database of information regarding building components and activities, and boundaries. BIM objects are data rich. For example, a wall contains geometric information (e.g., length, height, thickness, location, surface area, volume, etc.). It is also contextual, able to accept a penetration like a door, window, or louvered vent, and can be

tagged with data identifying it as load bearing, with a particular fire rating, STC (sound transmission coefficient), R-value, density, cost per given unit, or any user-defined information desired. This is critical, not merely because it happens to be a historical feature of BIM, but because the inherent data of **BIM gives the designer opportunities to make richer design decisions.**

To summarize: BIM is an architectural digital environment and work process in which data-rich 3- and potentially 4- and 5D building models, composed of contextual building objects, generate dynamically linked graphical and tabular views.

Leveraging BIM Workflows in the Design and Delivery of Complex Projects

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Introduction

GRO Architects is a multidisciplinary architectural office working on projects of varying scales from interiors to planning proposals (Figure 1.6). Over the past decade, we have increasingly utilized technology to realize projects, initially through digital fabrication and ultimately with BIM as projects have grown in size and complexity. Our use of these technologies has expanded beyond design, document execution, and fabrication to the development of a collaborative process for building delivery. To accomplish this, we have become interested in the design of a *workflow* that encompasses as much project scope as possible.

By shifting to a workflow process, as architects we not only control how our work integrates with others on the design and construction team but are also able to expand the territory within which our profession has traditionally operated. Namely, the workflow process moves architectural production from primarily preconstruction phases to ones that directly engage the physical matter of building. It is useful to note that such a tradition of architects working remotely was established by Leon Batista Alberti and others following a period when the architect was intimately involved in building activities on a project site. As BIM continues to impact design practice, both in terms of *novelty* and *efficiency*, it is no coincidence that new modes of production are being likened to a time when architects were known as master builders, such as Filippo Brunelleschi.

Workflow

In a contemporary context, one cannot help but compare a workflow process for architectural design and construction with those that revolutionized business practice some 25 years ago, contemporaneously with 3D modeling

FIGURE 1.6 Harrison Mixed-Use Transit Oriented Development, Harrison, New Jersey. GRO Architects is using BIM in the early design stages of large-scale planning projects. By linking variables like program, assigned by material; number of stories; and metrics for unit and parking count, our practice is exploring way to scale BIM technology to urban plans.

Image courtesy GRO Architects.

software's initial broad foray into our profession. Referred to as business process reengineering (BPR), these processes relied heavily on information technology (IT) to lessen the importance of individual tasks and refocus the flow of work on the achievement of value. Interestingly, a term being used both in the architectural profession and in business and enterprise development is that of "continuous improvement," defined as the cumulative addition of both breakthrough and continuous enhancements to a product or process. By allowing for more design iteration and integration during preconstruction activities, BIM has allowed architects to expand the territory within which they operate while allowing for better buildings.

Unlike methods of production in the twentieth century, which privileged the linear and rote repetition of tasks by relatively unskilled workers, these BIM-enabled improvement flows can be discontinuous. Following the work of W.E. Demming and others, an integrated design and construction team can bring differing approaches covering separate but related areas of building. These are merged and refined within a single or federated digital model shared across a large team responsible for design and construction. What is at stake is not the architectural design process becoming overly codified, but rather its being technologically and technically rationalized to be both novel and efficient—two sometimes oppositional goals in architectural practice.

To illustrate a varied design process utilizing digital tools, the case study that follows utilizes a workflow that, through BIM, engages a variety of stakeholders and team members in the actualization of projects of different scope and scale.

Case Study: Harrison Mixed-Use, Transit-Oriented Development

GRO is designing a mixed-use development between the PATH Station and Red Bull Arena, opened in 2010, in Harrison, New Jersey, that will expand retail, hospitality, and entertainment opportunities and brings residential, office, and structured parking programs to a commuter hub some 20 minutes from Lower Manhattan (Figure 1.7). Bound to the south where the Passaic River flows to Newark Bay is a major nexus of railway (Amtrak, NJTransit, PATH) and roadway (Interstate 280, NJ Turnpike) infrastructures; the site, a portion of a 250-acre (101.1 ha) former industrial waterfront area has been declared an area in need of redevelopment. Since 2012, the municipality has intended to see its

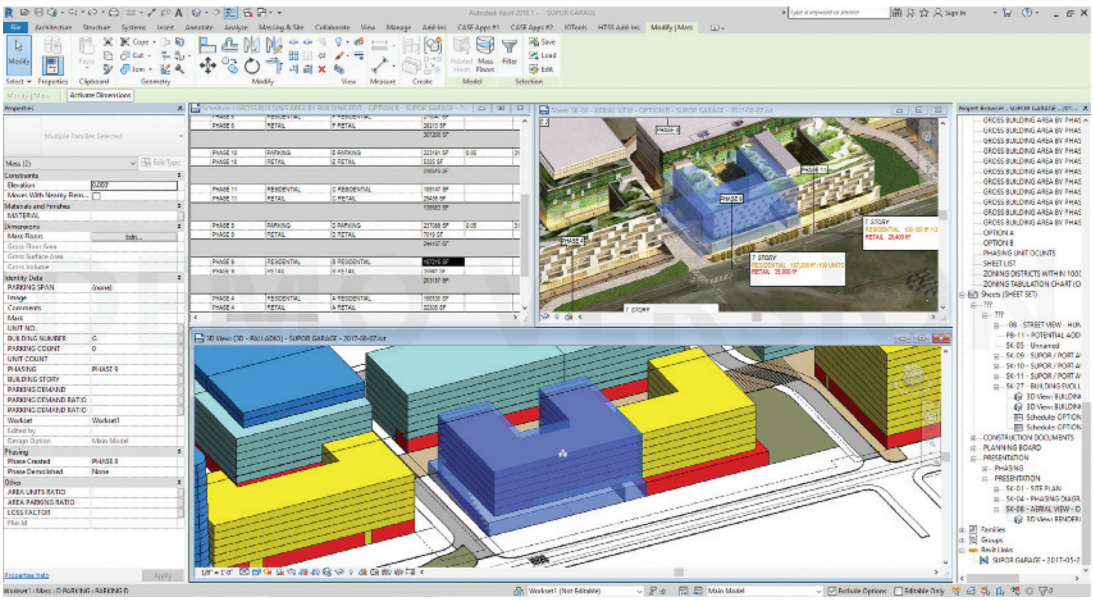


FIGURE 1.7 Harrison Mixed-Use, Transit Oriented Development, Harrison, New Jersey. The process of manipulating the BIM based on real-time input allowed the team to see metrics change automatically. Through this process, GRO was able to forecast better design options that remain financially feasible.

Image courtesy GRO Architects.

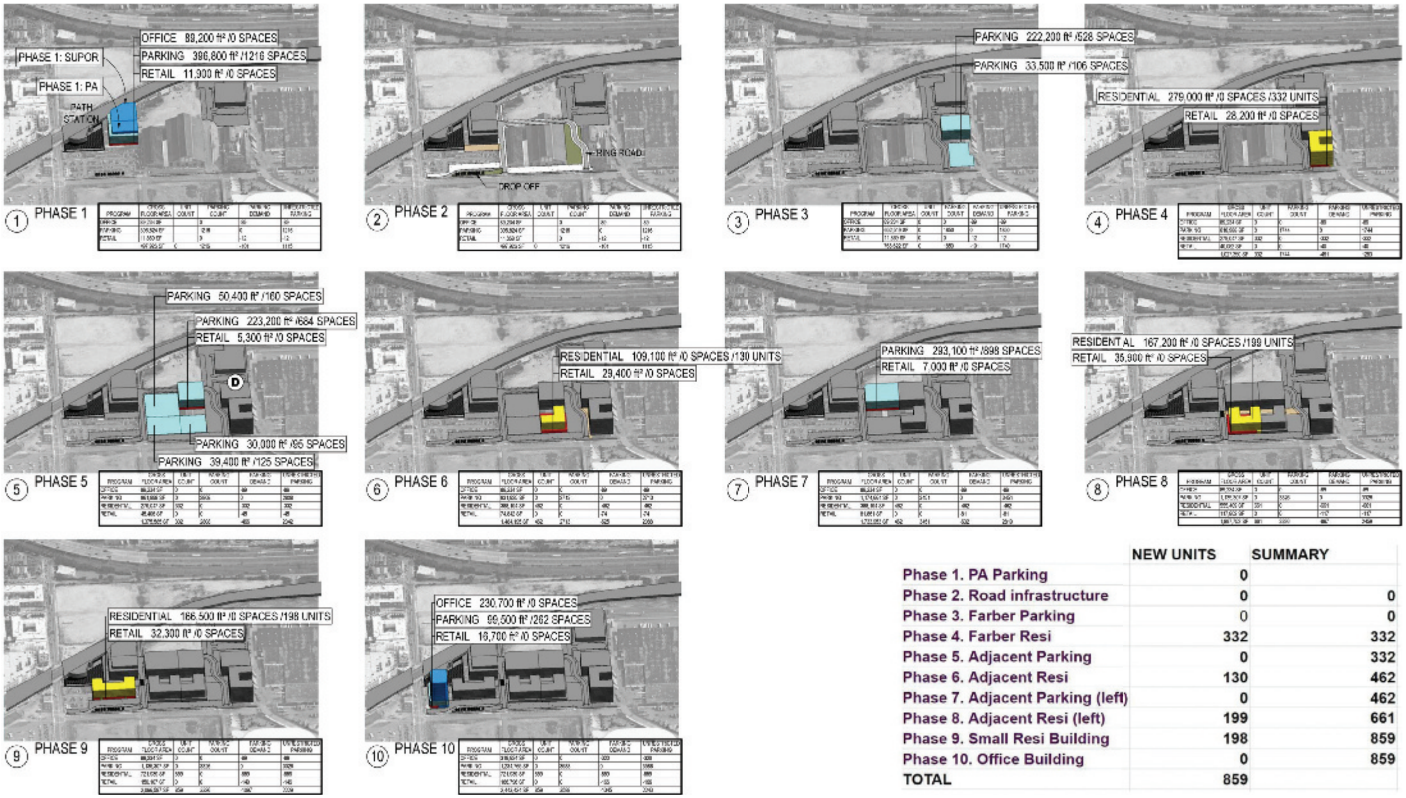
transformation into a walkable and transit-oriented development. The vision for the area, elaborated by Susan Gruel of Heyer Gruel & Associates, the municipality's community planning consultant, is to "create a vibrant mixed-use, transit-oriented, pedestrian-scale development that will make Harrison a regional destination for years to come."

For GRO's plan, a series of 10 phases have been imagined to bring 1.3 million square feet (120,774 m^2) of development as well as 3,500 new parking spaces to the commuter hub, over 2,200 of which will be unrestricted. Interestingly, the project metrics were driven by parking, with the municipality needing to satisfy the requirements of a subway expansion plan that will increase ridership from 7,300 to 13,000 between 2012 and 2022, between Newark, New Jersey (the last stop immediately west of the project), Jersey City, and finally New York City to the east. The design team has imagined a dynamic mix of pedestrian-friendly programs and uses that will activate the area bound by the PATH station to the west and the arena to the east (Figure 1.8).

Following the construction of a new looping roadway, a series of phased buildings are proposed. Key elements of the plan include a retail base under many of the buildings for a total of 166,800 square feet (15,496 m^2) of retail. This brings a walkable aspect to the proposed plan that will link the new station with the arena by a 60′0″ (18.3 m) wide dedicated pedestrian street (Figure 1.9).

At GRO, we have had an interest in studying how digital tools, which we originally used in exhibitions and small-scale buildings, could scale to the level of urban planning. While a modeling system was not used in the same manner it would be in the development of, say, construction documentation of a single structure, BIM was heavily utilized to understand real-time development metrics of the group of structures imagined for the site as they related to a redevelopment plan being undertaken by the municipality. Specifically, BIM's ability to parametrically update data ensured that the design team was able to share current information with all interested parties ranging from the municipality to investors. Changes to the overall plan ranging from revised radii requirements in the plotting of the new road to revised metes and bounds for specific sites within the plan were accounted for in real time. By establishing typical loss factors and unit sizes for the residential and parking programs, both gross floor area and unit counts were maintained. Shadow studies were developed so that appropriate heights for buildings could be proposed and incorporated into a revised redevelopment plan. A temporal understanding of the sequencing of phases was understood through the BIM as well.

The model was also linked and shared via CSV-format data to populate a development term sheet used to establish project worth to investors, and a running preliminary cost estimate for the design team. As a result, a precise



	NEW UNITS	SUMMARY
Phase 1. PA Parking	0	
Phase 2. Road infrastructure	0	0
Phase 3. Farber Parking	0	0
Phase 4. Farber Resi	332	332
Phase 5. Adjacent Parking	0	332
Phase 6. Adjacent Resi	130	462
Phase 7. Adjacent Parking (left)	0	462
Phase 8. Adjacent Resi (left)	199	661
Phase 9. Small Resi Building	198	859
Phase 10. Office Building	0	859
TOTAL	859	

FIGURE 1.8 Harrison Mixed-Use, Transit-Oriented Development, Harrison, New Jersey. GRO's BIM for this urban planning project included temporal phasing data. This data was critical in illustrating to the municipality that parking demand would be met while still demonstrating the project's financial viability, which was of high importance to the development group.

Image courtesy GRO Architects.

FIGURE 1.9 Harrison Mixed-Use, Transit-Oriented Development, Harrison, New Jersey. A 60′0″ wide dedicated pedestrian corridor that links the Harrison PATH Station to the Red Bull Arena is a critical component to the project. The walkway, which is programmed with retail along its entire expanse, will ensure that both commuters and soccer fans will have retail and hospitality options to explore while spending time in Harrison.

Image courtesy GRO Architects.

financial dossier was assembled so that project work and cost per phase could be established.

One of the most remarkable things about this process was how BIM allowed an expanded team to come together and make decisions to drive the direction of the project. While the architects remained the designers and purveyors of the data, the data was parsed and translated to allow the team to expand beyond designers and engineering consultants to include planners, attorneys, financial consultants, developer's representatives, traffic experts, and municipal officers—all speaking a related, if not common, language contained within BIM.

While potentially increasing the architect's scope and role in project design and delivery, the building information model, as precise data, can be parsed in a variety of ways to increase the knowledge of stakeholders. While the intent is not to adopt a "design by committee" schema—the architect should always retain an authorial role—the notion of being more inclusive in the design workflow, especially during preconstruction activities, can lead to more effective communication and a better-informed team during actual building delivery.

BIM in Academia: How BIM Is Taught

As one might expect, there exist varied approaches to the integration of building information modeling in the professional pedagogy. These methods lie on a spectrum from a full acknowledgment and teaching of BIM to a tacit implication that BIM is "merely a tool" and need not be part of the curriculum. In some architecture schools, students are given technical instruction in BIM as a distinct curricular subject, much as they might learn visual communication, statics, or environmental controls. In other academic programs, BIM is considered just another kind of software, not explicitly addressed in the formal curriculum at all, and students are expected to pick it up along the way, just as they might learn Photoshop from YouTube videos. It's been my anecdotal experience that the more a school considers itself a mainstay of high design, the more BIM is seen as "just a tool" and the less it is considered to be a legitimate academic endeavor. Naturally, even in "design-oriented" programs one will find academics with progressive views on BIM as a design environment, just as one may encounter Luddites in more technically oriented programs.

Karen Kensek, an assistant professor at the University of Southern California School of Architecture, teaches computer applications for architecture, is on the Facade Tectonics Institute steering committee, and with her colleague Douglas Noble organizes the annual USC BIM Conference. She relates that, currently, USC has a dual approach to introducing both graduate and undergraduate students to BIM in the architectural curriculum—offering instruction in both required and elective courses. First, BIM is incorporated into the second semester of the required professional practice course, with an emphasis on the use of drawings to communicate between the various stakeholders in the design and construction process. The comprehensive projects the students develop also incorporate mechanical and structural components while highlighting the importance of coordination within design and documentation drawings. Guest speakers from architecture, construction, and fabrication firms also speak to the class about innovative uses of BIM in the industry.

In the elective undergraduate BIM class, there is typically a secondary theme that changes from year to year; in the past it has been the use of BIM with analysis software, specifically for sustainable design, but for collaboration as well. Students in this class are often architecture students, but also several are from the geodesign major. The graduate version of the class includes a strong BIM visual programming (or graphical scripting) element, where students learn how to customize software and create new tools. This class also attracts an academically more diverse group of students, from architecture, building science, and engineering programs. Interested students are encouraged to take the BIM graduate course in construction management as it covers a very different set of issues.

The USC program offers elective courses in BIM or BIM-related topics at both the undergraduate and graduate level, including Advanced Computation, Advanced Fabrication, Architectural Technology, Computer Applications in Architecture, Descriptive and Computational Architectural Geometry, Digital Tools in Architecture, Media for Landscape Architecture: 3D Design, and Theories of Computer Technology.

In addition to coursework, graduate students have the opportunity to focus on BIM for their thesis projects. Recent topics have included interoperability between BIM and energy software, BIM and virtual reality, and potential uses of BIM in heritage conservation. As with the advent of CAD and then 3D modeling in the past, there is a progression in the curriculum where more fundamental ideas are incorporated into other classes, and the "BIM" courses evolve to focus on more advanced and innovative topics (see Figure 1.10).

In almost any academic environment, there is a tension between students' concern with learning skills with direct employment applications, potentially in opposition to—and at times at the expense of—gaining a deeper understanding of the appropriate use of technology. Kensek acknowledges that there is a clear desire by students to learn specific software skills for their résumés. That does not necessarily sacrifice deeper thinking, however. Ideally, a teaching approach is designed for both of these tendencies to build on each other. Her homework assignments are very much software based, and yet are grounded in concepts she wants her students to learn, as well as augmented by appropriate readings. For example, one topic she stresses is the use of data in the building model and how it can or cannot be transferred to other software programs; while students are using the software and learning commands they think are of practical value, they learn processes through successes and failures that are even more important in the long term. Sometimes students learn things that they may not think of as BIM or even valuable; one semester Kensek spent a couple weeks of C# programming with the expectation that her past coding experience is applicable to student learning.

According to Kensek, students who attend the USC BIM Conference are truly amazed that topics they have learned in class from their professors and guest lecturers are not mere academic exercises but have real-world applications. They recognize that BIM is bigger and more exciting than they ever thought,

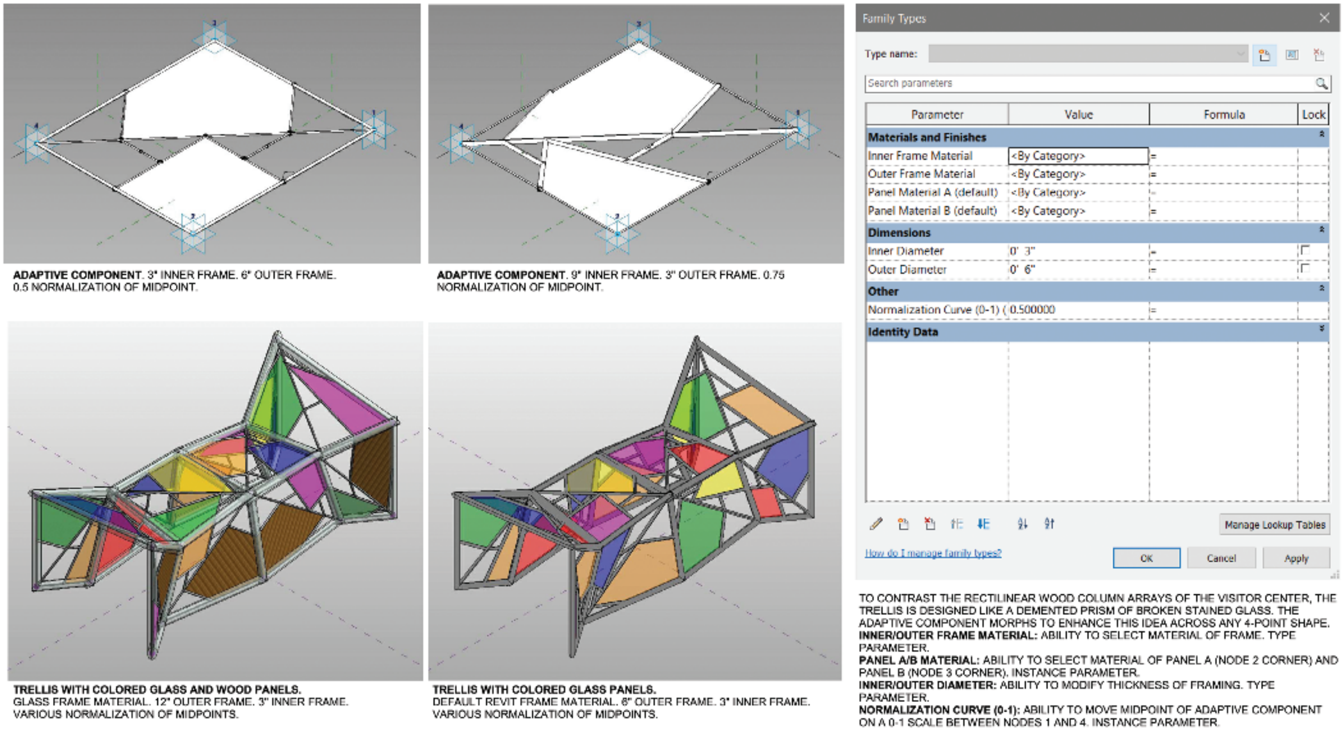


FIGURE 1.10 An example of graphical scripting, generating a 3D model from a series of inputs and algorithmic operations.

Image credit: Noah Cherner, USC School of Architecture student.

and rather than being one piece of software or one narrow topic, it is a broad field that covers a profuse area of design, construction, and even facilities management. Students see that expanse and want to be part of it.

Students seem very engaged in graphical scripting, far more so than most practicing architects (older professionals may think that Grasshopper is a passé cocktail rather than a popular graphical scripting module for Rhino, a 3D surface modeler). While visual programming may be the next wave in design technology that younger designers are eager to embrace, it may be a niche design process with limited relevance in the prosaic world of kitchen remodels, health care projects, K–12 schools, and building permits. For Kensek, programming and scripting are important, as they allow for another type of designer to contribute to the design process. Moreover, coding is freedom: it allows those who understand it to customize their digital world and not be trapped by tools a software developer decided to provide.

In her graduate BIM course, Kensek's current approach is to assign relatively simple exercises that are not discouraging or frustrating. One assignment, for example, was to change the size of an opening based on the sun's location. She then gives an open-ended team project for student groups to explore their own interests. Sometimes the student projects are exciting or surprising; one year, a team of students demonstrated using Alexa to have their 3D model respond to voice commands to open and shut shading devices, a wholly unexpected approach. A few students conclude that coding isn't for them, and those are balanced by a few who have found a new career option that they previously did not even know existed.

Looking forward, Kensek sees several emerging or recently emerged technologies that can fit under a "big tent" definition of BIM: big data, simulation, additive manufacturing (3D printing) and rapid prototyping, graphical scripting, data-driven design, and the use of drones, robotic construction, and virtual and augmented reality (Figures 1.11 and 1.12). Kensek has published on another emerging technology: the integration of environmental sensors with BIM, using Arduino or comparable devices to program the built environment. This simple, mono-chip microcomputer executes programs created in the Processing programming language. It can be adapted as a software interface, a robotic control system, a data recorder in conjunction with an array of available sensor types, for kinetically responsive art installations, as well as for other applications. In spite of an expanding ecosystem of technology in architectural practice, Kensek sees more optimism that technology can be appropriately applied, and that her school and others are exploring exciting new possibilities. One has only to look in on architecture studios for inspiration!

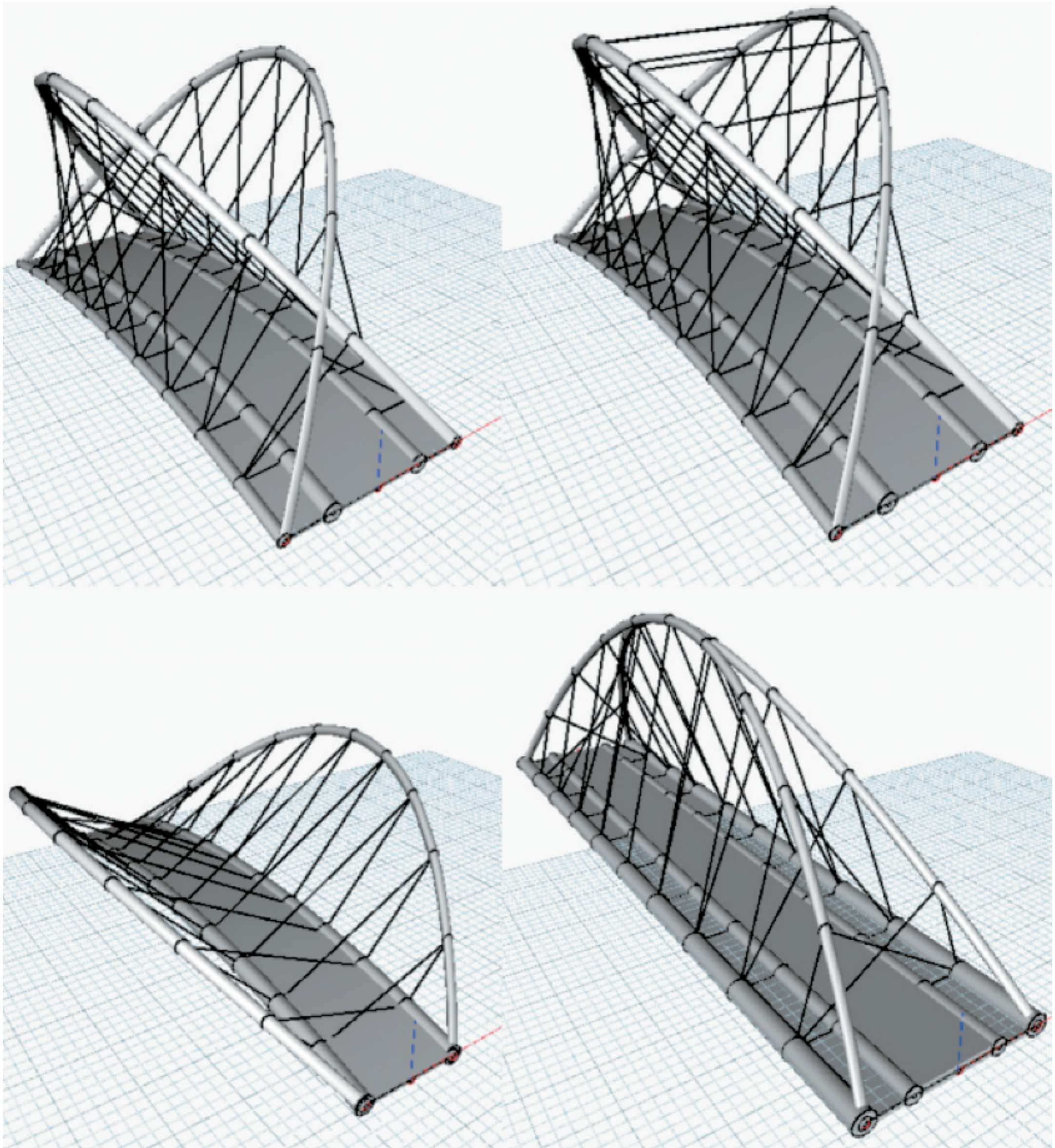


FIGURE 1.11 Design permutations of a parametric bow truss design altering input variables to achieve variation in modeling outcome.

Image credit: Noah Cherner, USC School of Architecture student.

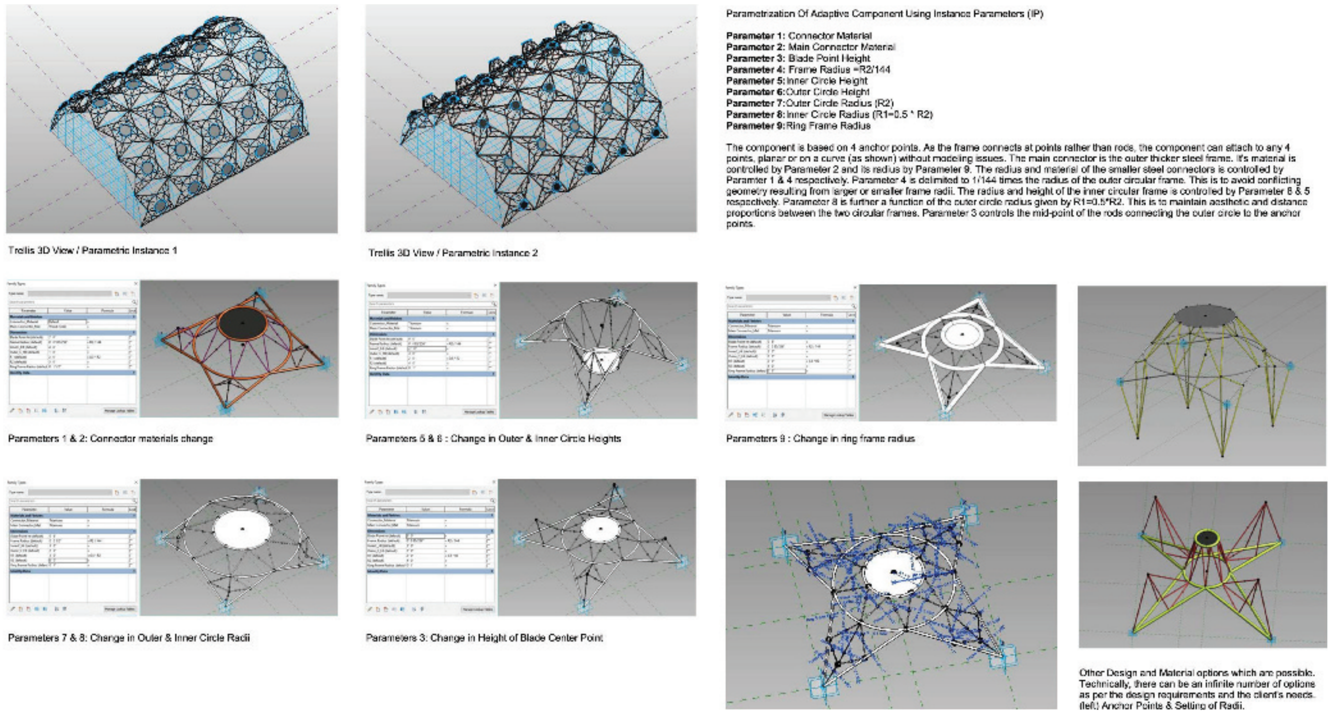


FIGURE 1.12 A computational BIM conceptual modeling exercise.
Image credit: Kushnav Roy, USC School of Architecture student.

Case Study: Guadalupe Parking Garage Green Wall Pilot Project

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This proposal (with co-primary investigator Mark Simmons and former UTSOA dean Fritz Steiner) for a green wall comprising plants either supported on a trellis structure ("green façade") or rooted in growing media attached to the wall itself (a "living wall" similar to a prototype designed and constructed on campus) has environmental benefit potential for buildings and structural partition walls. Green walls can be both beautiful and functional. They can be an effective air purifying system: the wall is a natural air filter, removing particulate matter, O_3, volatile organic compounds, and CO_2 from the air as it passes through or across the wall. Similarly, a green wall can cool building surfaces and interior space and even reduce ambient air temperature around the building—helping to mitigate the urban heat-island effect. Other benefits include storm water mitigation (through transpiration and soil infiltration) and habitat for beneficial fauna including pollinators (hummingbirds, butterflies), songbirds, and raptors (owls, hawks).

However, the design of extensive green walls in a hot, dry climate can pose some challenges, and appropriate systems and plants species have been poorly explored. Previous research conducted by Simmons and Briscoe on suitability of plants for green (vegetated) roofs and green walls has indicated that there are suites of plant species, tolerant of high root temperatures and limited water availability, appropriate for this application, although this has yet to be extensively tested for green walls in this subtropical climate.

The critical factors in determining a structural proposal are soil volume, existing building right-of-way, and the desire for component variability to act as a trellis, container, and bio-habitat. As a means to growing plants at multiple levels of the garage, the project proposes the fabrication of "trough-like" soil containers to sit behind the existing concrete spandrel, reducing standard parking spaces along the west side of the building to compact spaces. The irrigation line and drainage will be incorporated into this system. This container will allow greater soil volume in the green wall, and is also self-shaded from the intensity of the west-facing sun. The proposed geometry of the trellis and living system will allow for the integration of detailed habitats, such as for birds or bats.

Advanced 3D fabrication. 3D printed cells in varying colors correspond to plant types in the BIM model and optimized pattern-making arrangement (Figure 1.13); BIM is integral to the design/fabrication process in that the initial modular studies could very easily translate to STL files for 3D printing. Color-coded 3D prints express the plant pattern. Advanced data monitoring for a year of four cells on the wall would allow the wall to interactively report its

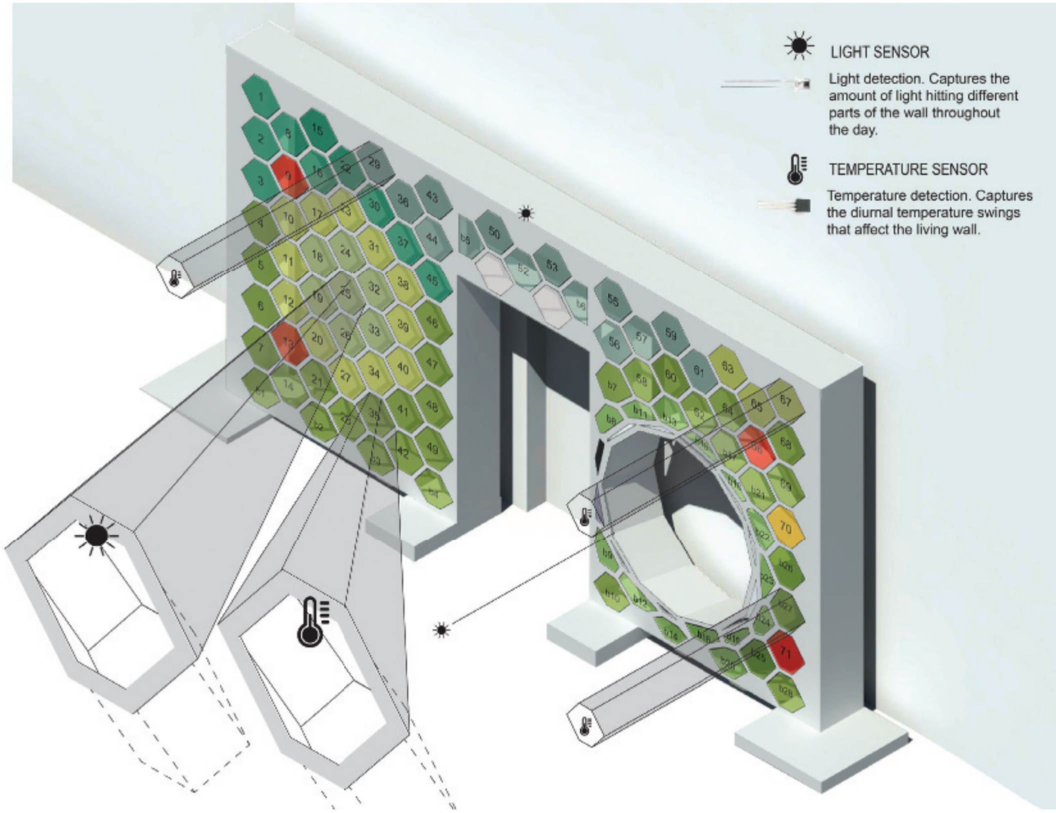

FIGURE 1.13 Axonometric rendering of the planting, and light and temperature sensor of a BIM modeled green wall prototype installed at the University of Texas at Austin School of Architecture.

Image courtesy of Danelle Briscoe.

full physical state through a QR code and the Smart Water system established by UT facilities maintenance director for water, Marcus Hogue. A novel approach to BIM modeling is achieved by through his software to detect the activity of selected cells, primarily through monitoring water distribution and temperature.

Advanced coordination. Beyond merely improving documentation and coordination, BIM assisted in the exchange among stakeholders regarding the depth of the planter component, one of the biggest determining factors (Figure 1.14). Several competing agendas had to be resolved: the wall is near a power line on San Jacinto Street that would be cost-prohibitive to bury; on the other hand, ecologists and landscape designers preferred as much soil as

FIGURE 1.14 The completed and operational green wall prototype on campus at the UT Austin School of Architecture.

Photo credit: Whit Preston Photography.

possible (primarily for root temperature). By working with the angle of inclination (i.e., skewed geometry) of the component, a self-shading cell was designed that is estimated to decrease the root temperature by 30° F (17° C) on a 100° F (38° C) day, based on past experience with cacti.

Novel pattern making. Particular design opportunities are to be found through scheduling and data-rich "material" capabilities in BIM. Each cell is assigned a given color and corresponding plant species (and all its attributes specified by Lady Bird Johnson Wildflower Center ecologists) in Revit's Material Editor. Plant parameters are embedded within each type's Properties menu, which can then be scheduled as a material take-off quantity from each generated pattern, as if it were a sum of building material. By having each plant type read as a single, abstract color, the information model allows for greater legibility of the patterns, reducing memory usage, yet retains all the information from the plant data sheet (Figure 1.15). The pairing of hexagons begins to strategize a nested solution for developing a reduction in file size and reducing the computational generation time of each potential pattern. Managing processing and rendering time is critical for increasing interoperability solutions between the different components of the project. In order to establish a construction budget, plant types and quantities must be accurately known, and they influence factors such as water use and soil hardiness.

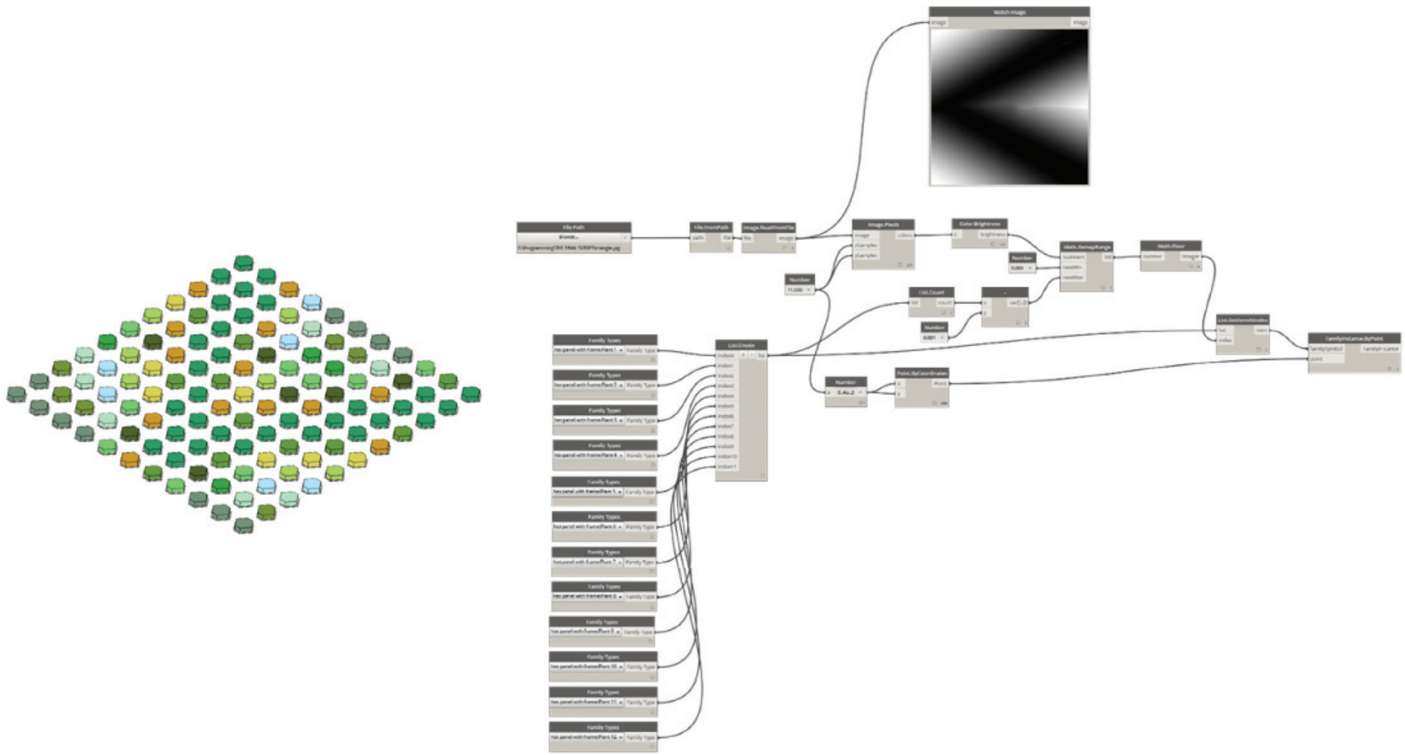

FIGURE 1.15 A graphical script used to generate color-coded planter cells. Gray blocks bearing Dynamo scripts are arranged in a visual flow chart; “wires” show the flow of data and operations left to right. The automated model output can be quickly varied and iterated by changing input variables.

Image courtesy of Danelle Briscoe.

Novel design workflow. We experimented with Revit family files containing Rich Photographic Content (RPC) for each plant, in an effort to assist in the visualization of the pattern generation and to produce renderings of each pattern iteration. In effect, 2D and 3D views were able to display plant entourage images using simple line drawings as placeholders. In pursuit of data-to-vector relationships, some placeholders were found to "misbehave" by inconsistently changing their orientation. When rendering a 3D view, the photo-realistic plant entourage was displayed in the rendered image, but proved to be item-consuming to calculate and render and the quality of the renderings could suffer. A possible alternative that could reduce data redundancy per component would be to create more populous nested components, each acting as a single agent in the pattern generation.

The algorithm to create patterns of planters assigned each distinct hexagonal component type to a corresponding pixel's grayscale value of a bitmap. This methodology stands apart from (what has become) a very common practice in visual programming as each pattern results in a material take-off schedule for ecological relationships or other aspects of feasibility testing. For example, in one bitmap test pattern, the black-to-white gradient application was reversed, thereby changing the aesthetics of the pattern due to plant color allocation. Such a simple shift of correspondences in the bitmap dramatically influenced both the cost of the tested scheme and the ratio of Lepidoptera (butterfly) linkages due to plant combinations created. In this particular case, the quantity of sideoats grama grass doubled, with both cost and performance implications as ecological optimization is linked to plant distribution in the visual pattern.

Species selection. Plant selection is based on a number of factors: known survivability on green roofs or pots, broad ecological niche (e.g., wet or dry soils) and habitat value. Those faunal species that can be encouraged by a green wall are easily found in the urban environment or can be induced to use food sources or constructed habitat. These include the anole lizards, Mexican free-tail bat, numerous butterfly species, and hummingbirds. A BIM has been modeled to parametrically control and schedule planting options as design schemes of the selected species (Figure 1.16). A partial version of one of the planting plans will be utilized in this pilot. For the intent of a design feedback loop, specific information on plant relationships can be flagged from the pilot as ones that enhance and help establish the bio-habitats for the full install. This then will be further explored and research within the simulation of the BIM model.

FIGURE 1.16 A detail of the campus prototype wall, showing the integration of a bird shelter in one of the hexagonal planter cells.
Photo credit: Whit Preston Photography.

BIM milestones. This project has established several procedural landmarks:

- Exploration of the potential of graphical scripting (Dynamo in this case) to handle visual programming for design iteration at the scale of landscape and building.
- Emphasis on BIM data process, not merely BIM drawings or modeling process, representing a shift away from treating BIM as merely a CAD documentation tool.
- Use of Revit/Dynamo as an ecological and landscape design tool with collaborative databases between multiple disciplines; more specifically, the deployment of BIM to support design, scheduling, and future tracking of ecological behavior through a 4D and 5D platform like Navisworks.
- Further insights in BIM design process refinement and streamlining. Current methodology requires at least three to four software applications, and this may be an area of innovation.

- Further research will investigate the manner in which components correspond to visual patterns, where beneficial relationships are flagged (analogous to flagging of clash detection instances). For example, two plants with a high ecology rating in proximity could trigger a graphical indication, alerting the designer. In other words, the pattern's optimization is legible.

Conclusion

There is and always has been a natural tension between "architecture" as the thing designed and eventually built, and "architecture" as a practice. We even call our firms, "practices." One is about an external experience, whether objectified as a sculptural object ("I like it as a thing") or experienced as a phenomenological place with particular qualities of spatial organization, light, views, materials, textures, and acoustics. The other is about a generative process that is part invention, part analysis. Even if it were possible to fully disambiguate the two architectures, building and design, it's not evident that that would be for the best.

The experience of architecture as physical artifact is enriched by the perception, understanding, or imagination of the processes that have brought it to life. Kant speaks of the beautiful and the sublime. The former is merely aesthetically attractive; the latter inspires awe and ennobles the viewer by shrinking him before the majesty of the scene. For Kant the sublime can only be found in the domain of nature, which dwarfs human beings with its awful majesty. But I would argue that great architecture (even if modest in scale) can also be sublime in the sense that as we experience it we know, perhaps instinctively or subliminally, that someone gave a great deal of thought, attention, and effort into its making. The care in the designing of a thing increases its value.

For its part, the design process is a mere intellectual or conceptual exercise without an artifact to birth. More pragmatically, the design process is informed and honed by construction. Knowledge of material properties, norms of construction techniques, the sequencing of assemblies, and even the relative costs of building materials are a critical foundation of good design. Moreover, we learn from our mistakes, even (especially) if those can be painful or expensive once executed in the field. I recall drawing details as a young designer fresh out of school, learning by emulating others in the office. But it wasn't until I spent time on job sites that I really understood what I was doing and could meaningfully contribute new solutions to construction detailing problems. The architectural artifact exists in the context of a preexisting reality (site, environment, social milieu) and the realities of construction processes (materials, labor, time, and costs). In order to fit or transform those realities, the designer must understand individual elements and their relationships, often through simulation,

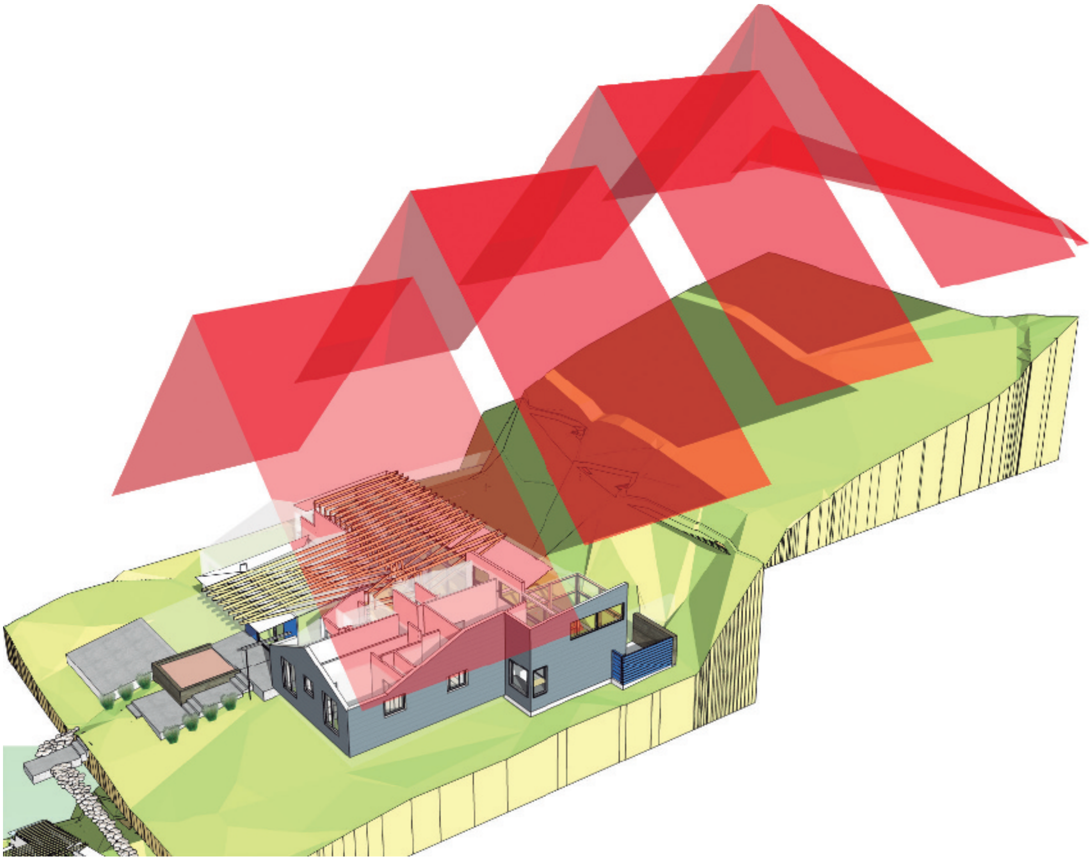

FIGURE 1.17 Site and programmatic investigation are a fertile source of design inspiration; BIM particularly and computational design generally are rich methods of discovery.

experimentation, and trial and error. That understanding is achieved through a process of investigation.

Such a process of investigation is thus fundamental to the design process and to architecture as practice. Nondesigners may labor under the impression that architects are artists, designs springing from their heads fully armed like Athena. Maybe for a few of us that is the case. But in my experience, a design arises out of a process of inquiry into the nature of a site, the needs and means of a client or user, and the realities of construction. BIM offers an opportunity to inquire or investigate in a variety of interdependent modalities: modeling in three dimensions existing and proposed conditions, and analyzing data or information inherent to or attached to that geometry. In some cases BIM gives rise to computational design, simulating the performance of components or assemblies, and/or algorithmically generating responses to variable inputs (Figure 1.17). At the heart of that is investigation.