Component-Based Design Approach Using BIM

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Abstract. *The promising directions in current design practice and teaching relate to creativity with digital tools in the context of building information modelling (BIM), performance analysis, and simulations as well as digital materiality (computational simulations of materials) and dynamics-based behaviour. This line of research combines spatial design with building and material technology in search of effective and efficient architecture. It reconstitutes questions of what to design by interrelating them with questions of how and why to design. This paper focuses on the appropriation of BIM tools for architectural curriculum teaching, from the design studio to building technology courses. It specifically focuses on BIM-based parametric modeling in discussing construction details, assemblies, and design explorations in the design studio context.*
Keywords. *BIM; building information modeling; parametric construction details; construction assemblies.*

INTRODUCTION

The renewed interest in creating-making in architecture, as evident in works of many contemporary designers, brings a new attention to materiality and process in design. While the interest in the design process is the legacy of last couple of decades of practice and teaching, the current version of this idea moves away from the conceptual and visual toward the actual and performative. It is closely connected with the physicality of architecture through understanding the performance and impact of constructions on user behaviour.

The component-based design approach for architecture, advocated in this paper, stands in contrast to past concept-centred design process as well as recent trends in which the weight of conceptual thinking, either in architecture or in the visual (fine) arts, has often taken precedence over tactile or material considerations. This has been evident both with traditional (analog) and with digital-based creativity. However, recent developments in fabrication, particularly in conjunction with the parametric BIM platform, create opportunities for balancing this emphasis on conceptual thinking by bringing material and assembly considerations to the forefront of architectural discourse. Architecture returns to the realm of making, rather than conceptualizing. Traditional or digital form making not only considers the structural behaviours of particular geometries, as was the case with Antonio Gaudi's or Frei Otto's works, but also starts considering material properties that could only be partially accounted for in Otto's soap-bubble models. Computational environments not only allow for readdressing materiality that is often missing from the design process, but also allow for asking speculative "What if…" questions. Material properties can be parametrically investigated in similar ways to tectonics or building performance characteristics such as lighting or an envelope thermal behaviour.

Deployment of performance-based design, with its quantitative and qualitative considerations, in the early design stages is particularly critical in the context of sustainable design. If, indeed, we want our buildings to be defined by their performance and respond to current environmental expectations such as zero-energy architecture, we need to include these parameters as design- and form-makers during initial design stages.

Due partially to their CAD legacy, BIM-based tools lack significant generative design modules with fully operational bidirectional data connectivity and thus become peripheral within the creative process. BIM also lacks specificity in programming and planning areas that could be effectively used in the predesign phases of a project. The user interface does not adapt to various design tasks or software competency levels that would require an intuitive interface. It often feels too technical for senior (seasoned) designers who are occasional and casual users. At the same time, general-use, generative design software lacks the database dimension and material-based knowledge associated with its digital models. It often provides an ease of use and quick tool adoption, but it does not grow with the user's increased capabilities. Even though architects may be able to develop visually interesting designs, it is impossible to verify whether these designs correspond to anything physically constructible, nor can they be associated with a particular scale or with particular material characteristics. These designs often exist purely as visual or conceptual propositions with no ability to advance into physical realization. This discontinuity between generative and implementive design stages exemplifies a significant limitation of digital tools. (Wallick and Zaretsky, 2009)

ANOTHER APPROACH

To bridge this gap between "design" and "production" tools, this paper investigates generative qualities of the BIM platform through a relatively narrow but potent set of examples of parametrically controlled constructional details and physically accurate material simulations. It looks at the overall design as the sum of its well-functioning component parts. It proposes extending BIM interoperability and parametric qualities into early, generative design phases, thus introducing two-directionality to a traditional process that follows a general-to-specific way of conceptualizing.

To connect generative creativity with professional practice and building technology education, courses used BIM software. However, working with BIM software has proven difficult for many designers because of the narrow range of designs that are possible with the applications. To overcome BIM's limitations as generative software, the course approach was to focus on selected software capabilities that allow for unrestricted creativity in the context of suitable design language.

To guide students in their applications of digital tools, it was necessary to define appropriate architectural precedent. As precedent, students investigated contemporary designs representing high quality accomplished practices, which naturally translated into parametric thinking and could be effectively deployed within BIM platforms. Projects by Nicholas Grimshaw, Norman Foster, Renzo Piano, and Santiago Calatrava were just a few of the designs that fit well into the class methodology and were relatively easy to handle using digital tools.

In each case, structural system and expression were clearly delineated with visually interesting and structurally accurate logic. Waterloo Station, by Nicholas Grimshaw, was given as such an example, with trusses naturally morphing their shapes and thus responding to the overall design of the station . Such designed trusses, while each of them has a slightly different confiuration, all of them follow the same parametric logic. This shared parametric logic allows for design efficiencies associated with modular or adaptive components. Another discussed with students example was the Centre Pompidou Metz designed by Japaneese architect Shigeru Ban. In this case the wooden laminated timer roof structure was seen as a dynamic deformable surface that creates diverse localized conditions of a single tileable element.

Figure 1
Parametric variations of the roof/skylight assembly (BIM model).

All chosen buildings had well-integrated and architecturally expressive structural components. The components performed clearly defined functions with multiple variations present in a building that allowed for relating them parametrically with one another. After selecting projects and particular assembly components or construction details, students were asked to study these precedents, model partial assemblies, and test them as a three-dimensional BIM models.

CLASS METHODOLOGY

In selecting projects and construction details, students were asked to study these precedents, model partial assemblies, and test them as a three-dimensional BIM models. Projects discussed here follow a design methodology that starts with a construction component or material properties and pursues designs that naturally emerge out of the assembly of initial components.

While this is not an established approach , this study broadens this method by considering a broader set of design solutions resulting from parametric alterations and alternations of original components. It discusses the use of simulations as self-normalizing design validators that in some instances allow these components to exemplify their inner constructional logic, as is the case with physically behaving materials and assembled components. The final design projects emerge through a series of explorations with fragments informing the entirety of the architectural design solution.

CONSTRUCTION DETAIL CASE STUDIES

The first part of the assignment—knowledge building—focused on research and modeling of a precedent. Through the modeling students became familiar with construction detail, assembly, and the interface between architectural and structural systems.

In this phase of the assignment, students learned about the spatial organization of various members and system components, their interconnectivity and interdependencies. Studetns were able to relate separate structural members into a single assembly and define construction details as a series of imbedded parametric relationships that interoperate on numeric values. These imbedded parametric relationships allowed for scaling up designs from smaller and simpler assemblies to larger and more complex ones. These parametric hierarchies, discussed earlier, facilitate inductive design thinking with individual components informing an overall design. Students also focused on identifying flexibilities associated with particular designs and attempted to define them. They were able to manipulate parametric components and to explore interactively design variations [fig.1].

The second part—design formation—used the intrinsic ability of parametric objects (details) to de-

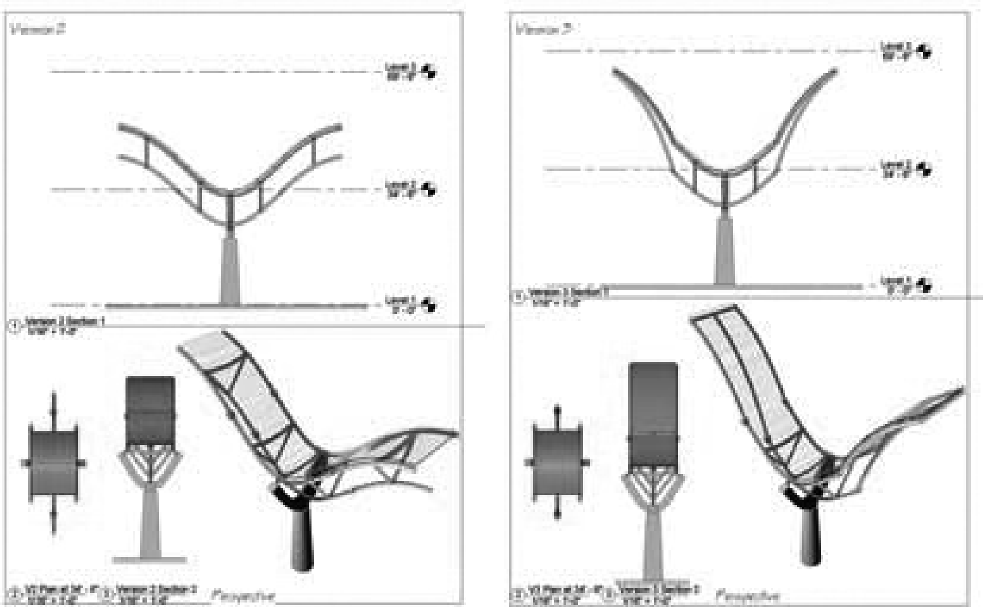


Figure 2
Parametric details allow for alternative design explorations and creating larger assemblies.

velop variations--design scenarios that allowed for new design formation. When choosing examples for their explorations, students were asked to consider the open-endedness of their particular designs and their ability to develop meaningful variations. In this design modeling/design phase, students explored the generative possibilities of parametric BIM models [fig.2]. Three-dimensional, parametrically resolved architectural details served as speculative, idea-generating devices for design. Students were expected to demonstrate the creative possibilities of their BIM models and to document their parametric explorations through images, digital models, and a text narrative (final report).

Another design strategy for the realization of flexible structural systems used an idea of a surface-based patterns as design generators for space frame design. This approach looked at the adaptability of individual space frame modules as defined by underlying surface geometry. In this particular exercise, students did not test the structural performance of a system but rather focused on ways to define a design system that could allow for maximum flexibility and ultimately would lead to generating qualitatively new designs. A primary visual reference for this group of projects was the Centre Pompidou Metz, designed by Shigeru Ban and Jean de Gastines, where a roof surface, a wooden lattice, naturally adapts from being a roof into elements such as columns. Such a system uses construction components in a similar way as the parametric definitions discussed earlier. However, the focus is not on a parametric change but on the adaptation of an assembly to a new function it plays while preserving its integral character.

The aim of this exercise was to help students to develop the technical knowledge necessary for the pre-comprehensive and comprehensive studios. Specifically, it addressed the integration of building systems and their appropriateness to the design intent. Additionally, this assignment facilitated material, dimensional, and construction detail inves-

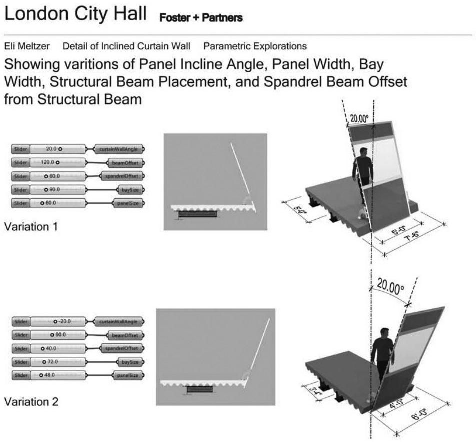


Figure 3
Digital construction detail with parametric relationships achieved with visual scripting (Grasshopper).

tigations in the context of contemporary architectural practice. The level of the applied constructional knowledge for this assignment matched that of the comprehensive studio work and of professional architectural practice. Furthermore, students were exposed to an alternative way of designing, with technical knowledge and a constructability-based idea, not an abstract concept, as the design generator.

SOFTWARE ALTERNATIVES

A number of students used other, non-BIM, parametric software, such as Grasshopper, to work on the construction detail projects [fig.3]. Initially they were able to develop geometries with greater sculptural definition and with a broader range of shapes as compared to conventional BIM software,

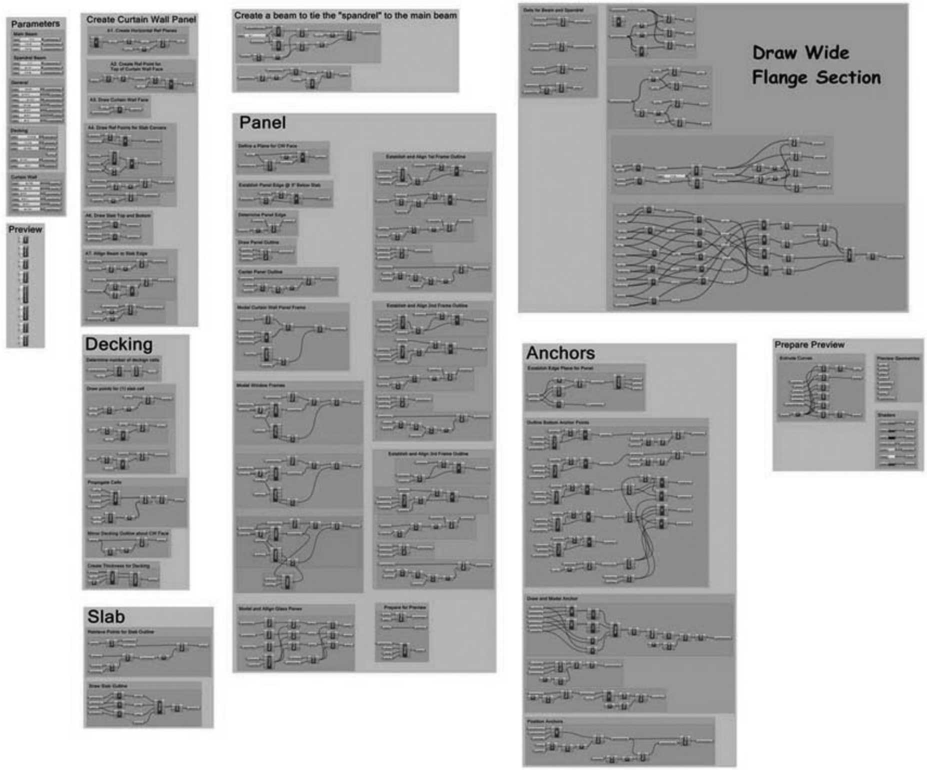


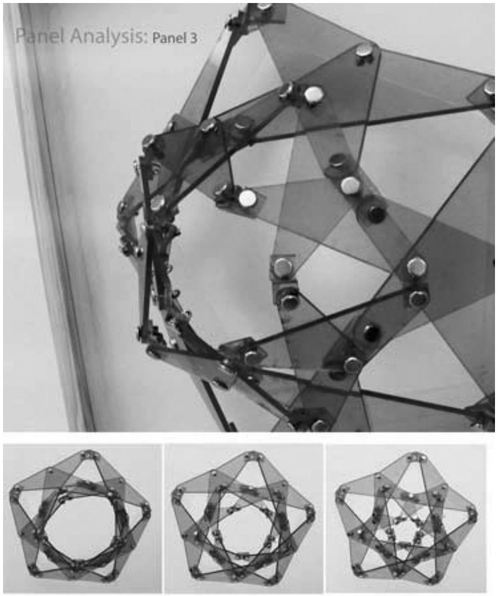
Figure 4
Partial Grasshopper script.

such as Revit or Vectorworks. However, their scripts became increasingly complex, which often led to reduced flexibility in design explorations as well as increasingly time demanding to maintain an ever-expanding definition. [fig.4] They often traded the design flexibility existing on the subcomponent level for the clarity and navigational ability of the overall design. While this approach gave students direct access to all the components with the ability to fully customize all interopperabiliites, these projects quickly became complex and difficult to scale up. Furthermore, the increased complexity of Grasshopper scripts made it difficult to pass the project to other collaborating students or revisit projects after a long period of not working on them.

However, in the long run, visual parametric environments such as those used in Grasshopper for Rhino allow more for the development of customer/user-driven features as compared with conventional, out-of-the-box BIM software. A number of third-party plug-ins and components are presently available. One of them, Kangaroo, is a physics engine with components that account for the simulation of a number of forces and material properties. This open SDK-like (software development kit) environment allows for dynamic development of the BIM platform.

ADAPTIVE STRUCTURE CASE STUDIES

While parametric variations of construction components, discussed in the previous section, can facilitate development of the meta-details able to define many, or all possible, design conditions relating to a particular assembly, they can also be used to study kinetic and adaptive designs. In this case a parameter represents a constraint or degree of freedom allowing for the movement, rotation, and scale of the assembly components. By changing a single parameter, such as the angle between two structural mem-



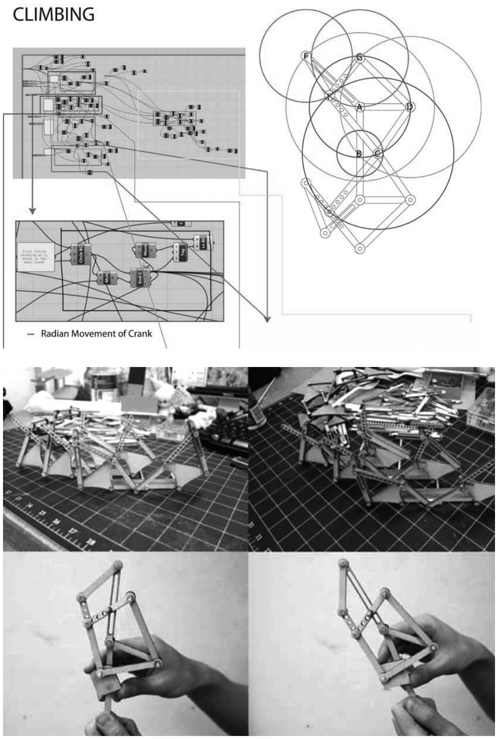


Figure 5 (left)
Adaptive structure—kinetic model.

Figure 6 (right)
Adaptive structure—parametric model.

bers or their spacing, the parametric model adopts to new parametric configuration. The overall design change is driven by numeric vales and can be easily tied to parametric feeds coming from other components or assemblies. When faced with unsolvable numeric input, software responds with an "overconstrained" message indicating the problem in the assembly. This becomes a hint for students to better understand mechanical and spatial relationships of their adaptive design.

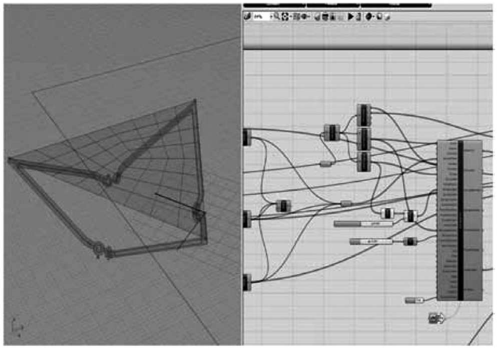
Since the construction detail examples discussed earlier [figs.1-3] can also be seen as adaptive designs, many students pursued this line of experimentation with BIM and parametric tools.

A student-developed example of such an adaptive assembly is a façade screen system that builds on the precedents of Chuck Hubberman's work and the façade screens of the Institut du Monde Arabe in Paris designed by Jean Nouvel together with Architecture-Studio. Students developed a number of physical and computational models to test design variations and ultimately proposed three-dimensional alternatives to the conventional scissor-like hinge assembly. Their design not only brought a certain level innovation into their investigations, but also prepared them for the tedious, yet successful, resolution of a relatively complex mathematical and mechanical problem. [fig.5]

Inspired by Theo Jansen's kinetic sculptures, students investigated the design possibilities of parametrically defined adaptive systems that mimic rigged or skeletal systems used in character animation software tools. Unlike the constraint-based systems used in VFX software, BIM and parametric packages allow for more direct and precise numeric operations, including operations that can both input and output numeric values.
Using a similar approach to that of Jansen, students focused on developing individual design components and testing them with parametric tools. They focused on resolving individual assemblies and on the ways these simple assemblies could be scaled up to form larger interoperable structural systems. BIM parametric capabilities were again an effective software tool to study and evaluate adaptive designs.

One student team started by creating an exact replica, both physical and digital, of Theo Jansen's Strandbeest kinetic sculpture mechanism. They investigated the parametric possibilities of this constrained-based kinetic system. In this particular case, students looked at how specific dimensions and radii impact the kinetic behavior of the system. The final deliverable was an adaptable vertically climbing mechanism. [fig.6]

The presently available architectural BIM and parametric software were not optimal tools for this kind of investigation as compared to engineering tools such as Inventor. A combination of both as a single fully integrated tool would provide a better design environment.



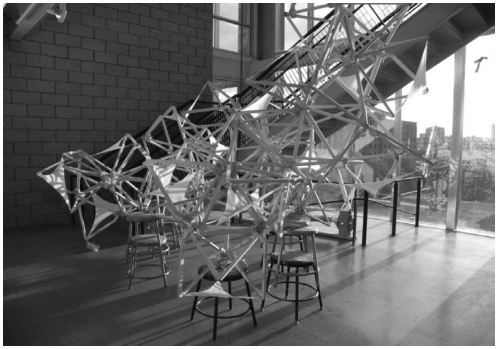


Figure 7 (left)
Testing cloth-tensile behavior with a Kangaroo component in Grasshopper.

Figure 8 (right)
Final installation.

Explorations focused on parametric constraint systems without the ability to understand acting forces. However, it was still a meaningful and knowledge-building experience for students involved in the project.

Depending on the team size and individual student abilities, some teams also developed a physical mock-up to interrelate between digital and physical designs. This was the case with the digital-versus-physical mock-up project.

PHYSICAL MOCK-UPS

While parametric design is a potent and creative approach, it reaches its full potential when combined with physically based behavior. When parametric definitions address not only expressions of inert geometries but also, or perhaps primarily, material properties and physical behavior, architecture responds to actual design drives and acquires broader relevance. In a number of projects, students experimented with computational form-emergence derived through performance simulations [fig.7]. They explored material behavior with computer analysis—designing—and later fabricated their designs using CNC machines—making. This combination of simulating-designing-making mirrors the traditional "learning by doing" approach.

Students investigated a number of designs by parametrically manipulating their geometry. This is the point where many design studio projects end. However, in this case, considering the requirements of a building technology course, students continued their investigations by bringing a model geometry into Kangaroo, a dynamics-based component in Grasshopper. Students used a Kangaroo component for form-finding and developing a form that considers material properties and physical forces. Since this approach combines parametric functionalities with physical behavior, it allowed students to practice the interactive form-making that mimics and extends that done in a traditional context. Students could parametrically fine-tune their designs and instantaneously observe how their designs are reshaped by the impact of physical forces [fig.8].

With parametric analysis, designers can immediately trace design changes and see how they impact other components in the assembly. Combining or nesting parametric components not only allows for an ease of modeling and a greater flexibility, but also allows understanding of how individual changes impact an overall design. Once a single parameter was changed in an overall, often complex, assembly of individual components, students were able to trace the propagation of changes throughout the database model and immediately evaluate the consequences of this particular change. Also, they could propose new designs through interactive manipulations of parameters and see changes propagated through the entire assembly. This dual use of parametric digital models—for understanding of a significant architectural precedent (construction knowledge building) and for speculative explorations of design propositions—allows for greater integration between building science courses and the design studio. This is particularly applicable in the upper-level comprehensive studios where generative and implemental aspects of design need to be reconciled. In parametrically defined BIM environments, students can explore designs that are native to the world of construction—that do not have to be translated or reinvented as a result of the progression from a conceptual idea to a real product.

As a result of new digital tools and developments in professional practices, students increasingly develop designs that exceed their technological knowledge. This has the potential to further fragment expertise and weaken design practice by driving it toward paper-based architecture. It also has immediate implications for the education process and specifically for changes in technology teaching methods.

Parametric design follows an interesting paradox. A common argument for BIM, and for digital design in general, is that it allows for early decision making. Thus, BIM facilitates effective design progression from the conceptual to more concrete development and implementation stages. The other argument that is often put forward is that BIM allows for deferral of design decisions exactly because of its parametric properties. This paradox can be solved with real bidirectional interoperability of BIM software. However, the real answer may lie in the way designers use software, not in its capabilities. Are we able to commit to early decision making, or would we rather procrastinate and delay thinking about details?

While both arguments are reasonable in their particular rationales, they also seem to exemplify both blessings and impediments to the design process. Depending on circumstances, early decision making may limit the procrastination and idle versioning common in architectural production, where a lack of direction or infinitesimal small variations in design alternatives effectively loop a designer into a closed design circle. Early decision making allows an experienced designer to validate his or her scenarios by introducing the constructability component into design.

At the same time, it is evident that the parametric capabilities of digital models allow for deferring specific design decisions while still considering a parametric component as an interdependent element of an overall system. In this application, parametric objects serve as intelligent placeholders for design. These placeholders can be changed if necessary, but, independent of the accuracy of their numeric values, they still function effectively as active elements of a larger interdependent system.

This property of parametric objects becomes a critical characteristic of BIM construction models, not only in understanding the models' assembly but also in applying them as explorative and generative tools for architectural design. This dual ability of BIM models—allowing designers to introduce constructional considerations in the early design stages, and later, due to the components' parametric definition, to develop variations and generate alternatives at the very end of the design process—reunites the act of conceptualizing with the act of making. It also renegotiates the boundary between design generation and design implementation. This renegotiated boundary will impact architectural practice and design team dynamics by increasing the requirement for each team member to contribute equally to the design and constructability of the project. Since design and implementation in BIM become more tightly intertwined, the separation into designer and detailers becomes meaningless. The next level of the design production integration removes architectural drafters from a design team structure.

SUMMARY

Digital tools provide a unique capability to speculate creatively and simulate physically within a single design framework. Creativity is seen as both an abstract proposition and an actual implementation with a problem-solving value. Simulation and analysis tools allow for contextualizing design with real-life physical and construction considerations. While often criticized for its overemphasis on formal expressions and its pursuit of the spectacular, digital creativity begins to account for a multiplicity of design factors that define architecture. These factors relate to performance simulation and analysis, fabrication, and BIM. Usually associated with the back end of the design process (implementation), BIM could also redefine the way design ideas are generated by bridging formal creativity with design and technological innovation. This is achieved through a close integration of generative tools with parametric capabilities, through the introduction of digital materiality with physical behavior, and through intelligent database-enriched digital objects.

The introduction of parametric thinking into building technology and design courses promotes qualitative and analytic thinking in lieu of the descriptive or metaphorical. Transcoding conceptual design into highly interdependent and parametric sets of relationships confronts us with the need to understand design in a comprehensive way. While there is still a space for the imaginary, unknown, and unspoken, these are often predetermined by initial design assumptions in discrete ways defined by performance expectations. This not only allows for understanding the interdependencies between various elements of a building assembly, but also opens doors for "What if...?" speculative exploration. This second aspect of parametric thinking encourages students to bridge technical knowledge with creativity. These new creative factors reflect technical, functional, programmatic, or code knowledge as necessary competencies feeding into the design process.

With bidirectionally interacting parameters and dependencies, the cause-and-effect sequences can be reversed and tested for new possibilities. The initial design criteria (ideas) can be defined in the context of the ultimate design goals and performance values. Design becomes a logical, cause-and-effect sequence that can be executed in both didactic (general to specific) and inductive (specific to general) ways.

Parametric definitions of architectural components become fluid modifiers that facilitate exploring designs and testing design assumptions against established validation criteria. BIM in conjunction with physically based parametric design allows for the alternative design process that parallels traditional creating/making processes.

These new tools create opportunities to expand the conventional design process characterized by the hierarchical (didactic) thinking that starts with the general and gradually progresses towards the specific. With the parametrically defined BIM, broadened by physically behaving components and materials, there is an opportunity to establish the interoperability of data, or a bidirectional design process with designers simultaneously working on the general and the specific, within all phases and scales of the project.

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