I, James D Bayless, hereby submit this original work as part of the requirements for the degree of Master of Architecture in Architecture (Master of).

It is entitled:
Digital Gothic: Integration and Material Experimentation in Contemporary Architecture

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DIGITAL GOTHIC

INTEGRATION AND MATERIAL EXPERIMENTATION IN CONTEMPORARY ARCHITECTURE

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF CINCINNATI IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARCHITECTURE IN THE SCHOOL OF ARCHITECTURE AND INTERIOR DESIGN OF THE COLLEGE OF DESIGN, ARCHITECTURE, ART, AND PLANNING

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ABSTRACT

Gothic construction was an experimental, material practice. Buildings were not preconceived in drawn plans and elevations, but were continuously shaped by multiple authors in close proximity to the building site. If drawings were used, they were secondary to the physical work. They had not yet assumed the same self-sufficient quality or institutional hold that has characterized architectural practice from the Renaissance to the present day. According to a number of contemporary theorists, architectural practice may be returning to a Gothic model of construction. Since the development of CAD/CAM in the late twentieth-century, the building industry has been confronted with a series of technological changes that threaten to displace the conventional means and methods of construction. The ‘rapid adoption’ of new technologies continues to challenge traditional assumptions about representation, production, and division of labor, all of which refer back to certain features of Gothic construction. The following paper examines current systems of mediation between architects and other building professionals. It explores how these technologies are being used to redefine traditional workflow, and what opportunities are presented by its change. While digital design is often used to support an immaterial formalism and visualize physical impossibility, a number of interdisciplinary offices demonstrate that it can be used to create poetic, material spaces. The product of this research is a proposal for a history museum in Cincinnati’s historic Over-the-Rhine neighborhood. The design begins as a response to the site’s material context, and is developed in an associative digital environment.
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The computer is not just another tool. This oft-invoked analogy assumes that the tool has no effect on the conceptual or aesthetic agenda of the user. The conservative attack against the computer in architecture would thus seem to have some justification, as there is indeed a difference and something is lost. While this may be true, the question is not to hold onto what is lost, but to begin to take advantage of what is gained and to attempt to understand where threads of continuity with the past can be found.1

Michael Young, *Technologies of Mediation*

Why is this change occurring? The fundamental underlying motivation is the desire for the building process to achieve predictable results in an environment plagued by systematically unpredictable outcomes...Traditionally, industry participants have used fairly abstract, two-dimensional orthographic projections in the form of drawings to represent the very complex three-dimensional phenomenon of a building. The rapid adoption of new digital tools for building delivery is a clear indication that these traditional orthographic technologies are reaching the end of their useful life in the building industry.2

Phillip Bernstein, *Thinking Versus Making*

Architecture as a material practice implies that making, the close engagement of the material, is intrinsic to design process. Making, however, is increasingly mediated through digital technologies: today, it is the CNC machines and not the hands of the maker that mostly shape materials and their properties. Digital making - the use of digital technologies in design and material production - is blurring the sharp discontinuities between conception and production established in the twentieth century. New techniques based on close, cyclical coupling of parametric design and digital fabrication are restructuring the relationships between design and production.3

Branko Kolarevic, *The (Risky) Craft of Digital Making*

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INTRODUCTION

The Gothic master-builder is commonly perceived as an ideal, an early architect that embodies both design and construction. Since at least the nineteenth-century, architectural theorists have appropriated this ambiguous figure to suit their own contemporary analogies. While the precise definition of master-builder and the type of work he performed varied across Western Europe, historical accounts suggest that these craftsmen functioned as architect, contractor, and administrator on the Gothic construction site. Master-builders worked anonymously, “layering” construction over successive generations to produce huge church complexes such as those at St. Denis, Reims, and Chartres. Given the length of time it took to complete these massive projects, construction required the collective work of many master-builders over several “discontinuous” building campaigns and fundraising cycles. The final work was not predetermined. Rather, it was continuously shaped by multiple authors in close proximity to the building site.

Construction began by drawing the footprint of the intended building on the ground at full scale with stakes and chains, and “proceeded by rhetoric and geometry, raising the elevation as discussions about the building’s face continued, almost until the end.” If drawings were used to communicate design intent, they only served as preliminary guides, or diagrams. Gothic construction drawings were not self-sufficient, nor legally binding. They were merely “one element in the wider social and legal context that allowed a Gothic architect to design and build.” As demonstrated by the Sansedoni elevation, an illustrated building contract from the thirteenth-century [see fig. 0.01], medieval construction documents lacked detail. They were momentary, graphic references to the physical work that was to be completed by the master-builder. These “ephemeral” working drawings had no artistic value in themselves. They were valued more for the vellum on which they were drawn. Most were consequently broken down and turned into glue.

Stone templates were the more valuable tool; adjustable wooden devices that could be used to create a wide variety of architectural form. Templates served as “accepted, concrete, local, or indexical solutions that [could] be applied to other problems… portable solutions as opposed to fully articulated and consistent plans.”

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5 Ibid.
9 Toker, “Gothic Architecture,” 89.
10 Pérez-Gómez and Pelletier, Architectural Representation, 8-9.
13 Ibid., 319-320.
14 Ibid., 324.
Gothic templates are an example of a flexible representational technology—geometry given “material manifestation.” Cathedrals functioned as early laboratories, in which master-builders tested and applied material knowledge at full scale. Structural solutions were developed through experimentation. As a result, buildings were often over-structured or had to be reinforced at a later time. According to Farshid Moussavi, Gothic construction was a flexible model of construction: “The Gothic approach could be described as non-essential, focusing instead on assembling forms that were tied to specific material components… Gothic church architecture was based, not on an ideal geometric system, but on a protogeometry that was anexact (precise, but not metrically so).”

In this sense Gothic construction constitutes a material, constructive practice. Buildings were realized through full-scale experimentation and flexible technologies of representation. If drawings were used, they were secondary to the physical work. They had not yet assumed the same self-sufficient quality or institutional hold that has characterized architectural design from the Renaissance to the present-day. Design and construction were linked more by material experimentation than by abstract projections alone.

According to a number of contemporary theorists, architectural practice may be returning to a Gothic model of construction. Since the development of CAD/CAM in the late twentieth-century, the building industry has been confronted with a series of technological changes that threaten to displace the conventional (or rather, classical) means of architectural production. Many designers are looking beyond traditional methods of project delivery, and developing alternative models of construction within a digital environment. The “rapid adoption” of these new technologies continues to challenge traditional assumptions about representation, division of labor, material, and production, all of which refer back to certain features of Gothic construction.

In the opening pages of Digital Culture in Architecture, Antoine Picon states that architecture is now beyond “initial reactions of enthusiasm or concern” for the presence of the digital in the profession. The more important question is rather:

About the direction architecture is taking under its influence. Confronted with a series of technological innovations, the only certainty we have is that the change they are bringing is profound. It might prove as radical and enduring as the transformation that gave birth to the architectural discipline at the beginning of the Renaissance.

The following paper examines current systems of mediation between architects and other building professionals. It explores how these technologies are being used to redefine traditional workflow, and what opportunities are presented by its change. While digital design is often used to support an immaterial formalism and visualize physical impossibility, a number of interdisciplinary offices demonstrate that it can be used to create poetic, material spaces. The product of this research is a proposal for a history museum in Cincinnati’s historic Over-the-Rhine neighborhood. The design begins as a response to the site’s material context, and is developed in an associative digital environment.

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**DIGITAL GOTHIC**

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19 Ibid., 323.
16 Ibid., 321-323.
18 Pérez-Gómez and Pelletier, Architectural Representation, 8-9.
19 Dayem, “Drawing Futures,” 236.
CHAPTER ONE: (RE)MEDIATION

Drawing has served as the primary form of communication between architects and other building professionals since at least the eighteenth-century. The development of descriptive geometry systematized “the reduction of three-dimensional objects to two dimensions, and permitted the control and precision demanded by the Industrial Revolution.”25 Over the long history of architectural representation from Gaspard Monge to the present day, drawing has remained firmly embedded in professional culture. Contemporary architects continue to exchange a set of manually-drawn construction documents with builders, consisting of orthographic plans, sections, and elevations. Alberto Pérez-Gómez and Louise Pelletier provide a concise summary:

“The process of creation prevalent in architecture today assumes that a conventional set of projections, at various scales from site to detail, adds up to a complete, objective idea of a building. Whether or not the architect is effectively or legally responsible for the production of construction documents (working drawings), the assumption remains. These projective representations rely on reductive syntactic connections; each projection constitutes part of a dissected whole.”26

The development of CAD/CAM in the second half of the twentieth-century brought with it profound changes to the building industry, but the classical language shared by its different professions was relatively unchanged. The computer was used more as a “drawing tool” than as a “true partner in the process of conception.”27 Computer-aided drafting replaced drafting by hand, which “made creating great swaths of detailed drawings first easy, then expected.”28 Within architectural offices, “there evolved a technical and administrative infrastructure designed to support the production and construction document sets using 2-D drafting software that simulated manual drafting techniques with ever-increasing complexity and sophistication.”29 Three-dimensional modeling tools adopted from other industries “allowed new user to proliferate topological surfaces in unending measures,”29 but these technologies were generally used for visualization and formal experimentation, rarely for construction.29 For the most part, architecture and construction proceeded by traditional means and methods.

This relationship has changed within the last fifteen years. Although CAD/CAM was first used to reinforce analog modes of production, digital technology has had an influential role in design practice. One crucial (and controversial) subject that begins to explain this change is the transition from drawing to modeling. In recent years the digital model has evolved from a tool for visualization into an information management system that regulates all aspects of design and construction. For many contemporary offices, the digital model has effectively replaced the drawing as a shared language between building professionals:

“Never has the practice of architecture been less dependent on the traditional means of drawing architecture than today. Compared with software that fully integrates all aspects of construction into a single digital model, drawings that were once used to convey information to builders are no doubt less expedient.”30

One measure of this transition is the adoption rate of Building Information Modeling (BIM). In a BIM work environment, all members of the project team communicate through a shared digital model that not only contains three-dimensional geometry, but additional information related to the building’s cost, assembly and construction schedule. In other words, the digital model becomes a “systematic constitution of a common pool of data… to be shared by the various actors in a project.”31 According to a recent study on the business value of BIM in North America [see fig. 1.01], 28% of architects, engineers and contractors reported using some form of BIM in the year 2007.32 The percent of building professionals using BIM grew to 49% in 2009. By 2012 this figure was 71%. In that same year, more contractors reported using BIM than architects. The United Kingdom has witnessed a similar adoption rate.33 Only 13% of the UK building industry was using BIM in 2010. Two years later, this number had grown to 39%. In a relatively short period of time, the digital model has established itself as the primary form of mediation between architects, contractors, and engineers.

The historic shift from drawing to modeling must be understood as a response to traditional systems of mediation in the building industry. According to Phil Bernstein, an architect, theorist, and vice-president at Autodesk: “Methods like BIM and Integrated Delivery, which operate at the heart of the intent-to-execution gap, have been developed not to support and encourage design but rather to address

25 Pérez-Gómez and Pelletier, Architectural Representations, 84.
26 Ibid., 5.
27 Porta, Digital Culture in Architecture, 8.
28 Bernstein, “Intention to Artifact,” 68.
31 Stephen Kieran and James Timmerlake, Refraeting Architecture: How Manufacturing Methodologies are
well-known inefficiencies of the building industry.” 36 The use of the digital model as a notational system resolves a number of problems exacerbated by the drawing in traditional practice.

Orthographic projection is a reductive technology that fractures a three-dimensional object into a series of two-dimensional, partial views. In order to describe the totality of the architectural work in three-dimensions, the author must render the image from multiple perspectives. This classical system enables its user to represent the object on two-dimensional media, and allows him or her to measure its proportions at a certain scale, but requires the deconstruction of the conceptual whole. "Any complete representation of a complex solid (or hypersolid) in a single drawing involves disruption... A comprehensive graphic description necessarily destroys coherence. In pictures, totality and incoherence are synonymous." 37

The digital model however, does not require multiple projections to describe the entire work. The object is held in a single, dynamic projection that is divorced from the procedural working plane. Depending on the software, this may be called the sketch, the construction plane, or the "plane of measurement."

The digital model no longer requires the plane of projection to be coincident with the plane of measurement. This is a significant conceptual and aesthetic change for architectural design. It does not negate the disciplinary discourse and history of drawing conventions, nor does it negate gravity and the organization of horizontal movement. But it does shift the pragmatic necessity that previously required the drawn view to also be a measurable projection.38

In a traditional design environment, changes to the overall work within one projection are manually traced through the entire drawing set, and updated accordingly. The potential for human error multiplies exponentially between different drawings, and between different authors. The digital model however, automates these changes. Individual drawings are continuously updated and extracted from the larger representation.39 Ray Crotty compares the traditional coordination of drawing sets to a single building information model:

From the point at which an element first appears on a designer's drawing... all the information, every transaction and every event in its life-cycle is recorded and managed manually. Every transaction requires human intervention. Every piece of paper, every CAD drawing and printout must be checked, at least once, before being acted upon or reused. This is the nature of untrustworthy information – it cannot be taken as being true without being checked and validated. Besides being enormously wasteful, every one of these checking

36 Bernstein, “Intention to Artifact,” 66.
38 Young, “Technologies of Mediation,” 235.
and validation exercises is in itself a compounding source of error. BIM on the other hand, generates inherently trustworthy, computable information. It offers the possibility of more or less completely automating these transactions, eliminating the waste they introduce and the errors they generate.40

More than a question of representation, the digital model allows for the lossless transfer of information between its users. Whereas drawing is an ambiguous, graphic language that allows for the possibility of human miscommunication, digital exchange is inherently unambiguous:

Even within a single domain, one line on a plan or one number on a spreadsheet could have a multitude of different meanings, depending on the interpretation. Like any other (natural) language, the language of architecture was ambiguous. But as those who read and understood this information were more or less successful at performing plausibility tests all the time - depending on their knowledge and experience - they were able to interpret the given data more or less adequately. Computer languages, on the other hand, are unambiguous, formal languages.41

The recent success of the digital model in the building industry can be understood as a solution to the historically inefficient flow of information between building professionals [see fig. 1.02]. Bernstein suggests that “the rapid adoption of new digital tools for building delivery is a clear indication that these traditional orthographic technologies are reaching the end of their useful life in the building industry.”42 Digital exchange however, does not invalidate the drawing as a design tool. The ambiguous quality that accompanies drawing (that is, the distance between the intended object and its representation) continues to be generative and desirable.43

In a recent article on the future of drawing in architecture, Neil Spiller writes: “Indeed, while one might expect the computer to have fully vanquished what might at first seem an arcane medium - the hand-drawing - in fact paradoxically the reverse is true. We are currently seeing a renaissance of the drawing, albeit in new forms.”44

The following paragraphs explore what opportunities are presented by the use of the digital model in practice, but this argument is not made at the expense of drawing as a relevant design technology.

The more important question concerns the professional culture that has accompanied digital exchange, and the implications that it holds for design practice. Given the new realities of construction, what opportunities are presented by working through the digital model? For many architects, the result of these shared, lossless tools has been an increasingly collaborative and integrated practice.

43 Rowen, “In Praise of Orthographic Projection.”
CHAPTER TWO: INTEGRATION

Contemporary architects work in an increasingly complex digital environment. The limits of this environment are best defined by architect Michael Young in an essay entitled "Technologies of Mediation." Young adopts the language of media theorist Friedrich Kittler to explain digital exchange as a single, automated system of mediation:

It is not even ‘the computer’ that we should be discussing, but instead the conglomeration of hardware components, software environments, interface dialogues, graphics and codes, display monitors, printers, routers, mills, and cutters. These all combine to form the technological system of mediation for contemporary architectural design, and it is crucial that the entire assembly be understood as part of a single technology of mediation.45

According to Kittler, "the computer is the first technology of mediation that automatically combines storage, manipulation, and transmission into a single system."46 Young builds on this theoretical framework, and presents the possibility of a comprehensive digital environment, characterized by the lossless transfer of information between digital design and production tools [see fig. 2.01]. While the link between architectural design and construction through digital technology is by no means new, it has only begun to influence the building industry as a whole.

For many practicing architects, engineers, and contractors, the instrument most often used to manage this complex network of relationships is the digital model. As mentioned above, the digital model not only contains three-dimensional geometry, but can be endowed with additional information related to its cost, assembly and schedule during construction. It connects the software, hardware and various interfaces outlined by Young, and serves as a shared form of communication between the building trades. It facilitates both design and construction, and by doing so, blurs the professional boundaries between the two. Christopher and Coren Sharples, principals at SHoP Architects, argue that the digital model has become a "basis of collaboration" between building professionals:

Three-dimensional visualization tools not only allow physical coordination of multiple building systems, they become a basis of collaboration, and encourage early participation of design disciplines and construction trades.47

Collaborative relationships with both builders and owners demand shared platforms of communication. Technologies that facilitate and promote such communication, such as building information modeling (BIM) and direct digital fabrication, are having a profound impact on the inner workings of the

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45 Young, “Technologies of Mediation,” 234.
46 ibid.
architectural office, both in terms of organizational structure and the nature of the labor force.48

A model is collaborative in the sense that its digital construction anticipates physical assembly. Developing a functional three-dimensional model requires input from all specialized members of the project team, including the architect, engineer, and builder (see fig. 2.02). In a traditional design-bid-build project delivery system, the contractors and fabricators are not involved until late in the design process. Digital exchange through a shared model however, encourages practitioners to enter into this dialogue earlier (see figs. 2.03):

Design based on creation of parametric models, however, means more insight into how to create the building must be deployed early in the design process, and the use of these models to facilitate fabrication is, in fact, a proxy for the larger question of the knowledge necessary to put a building together. If your model presages a digitally fabricated building assembly, it is best if you fully understand that assembly in a very concrete way; you can’t wait for your contractor to figure it out for you. Conversely, if that model will become the basis for the contractor’s construction strategy, perhaps he or she should be at the table while it is created.49

As delivery methods are increasingly integrated, the constructor sits at the same table as the traditional design players, and highly detailed construction analysis and planning models operate in parallel with evolving design models, providing yet another stream of feedback.50

The case studies presented at the end of this chapter demonstrate the capacity of the digital model to create a more collaborative, interdisciplinary practice. Design/production and UNStudio, among others, provide alternative approaches to architectural design where the digital model is central to office workflow.

These experimental delivery methods have been codified in the building industry under names such as design-build,51 and integrated project delivery (IPD). They establish more collaborative contractual relationships between traditional project members, and often involve some degree of shared financial risk and reward.52 They provide an alternative legal framework based on existing definitions for architect, engineer, and contractor. A number of contemporary theorists however, have questioned whether the professional definition of architecture itself has begun to change, given the realities of an integrated, digital environment. In 2004 Kieran and

50 Bernstein, “Invention to Artifact,” 68.
Timberlake envisioned architects as the "overseers of the exchange of information...as a twenty-first century maestro." Their organizational model places the architect in a central position between the other disciplines [see fig. 2.04]. The realities of working in a digital design environment however, suggest that other professions might take on this role:

Given this evolution, one may wonder whether the traditional identities of architects and engineers will not have to evolve in order to adapt to the new context created by the computer. Various conflicts of competencies may arise in the meantime. The very existence of a Building Information Model raises the question of who will ultimately be in charge of its management. Beside architects and engineers, there are other candidates such as professional project managers.54

This question as to who assumes responsibility for the shared system of mediation between building professionals is also raised by architect Peggy Deamer. Deamer anticipates the dissolution of professional titles in the building industry. She presents an organisational scheme that is radial and collaborative, rather than regulatory [see fig. 2.05]:

Here, the traditional definitions of designer, architect, and builder come under attack as the relationship of each to the other shifts. Design is no longer equated with architect, fabricators, engineers, and software programmers can lay equal claim to authorial designation. The architect has access to all the economic/organizational parameters originally known only to the builder; hence, control of the critical path is mingled with control of form.55

This strategy could perhaps be described as an "empathetic model," or a "design engineering" model, that acknowledges professional differences and specialized training within a collaborative environment.56 Regardless, the opening in the professional definition of architecture presents an opportunity to re-evaluate design practice. In contrast to the historical image of the architect as a singular artist, prioritizing form and representation over structure and material, the design of buildings can become collective work, realized through flexible systems of mediation. These collaborative relationships, developed through the shared use of a digital model, can also be used to create a more material practice.

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53 Kieran and Timberlake, Refabricating Architecture, 22.
54 Picon, Digital Culture in Architecture, 165.
CASE STUDY: UNSTUDIO
MERCEDES-BENZ MUSEUM, STUTTGART

UNStudio is an Amsterdam-based practice founded by Ben van Berkel and Caroline Bos in the late 1980s. The role of the diagram and the design model is central to the office’s work. Van Berkel explains these organizational strategies in an interview with Scott Marble:

We see design models as packages of organizational or compositional principles, supplemented by constructional parameters, which act as a more sustainable and reusable guide to architectural projects. The design model does not include site-specific information but rather exists at a more abstract level and may be implemented in various situations and projects.57

Although Picon compares UNStudio’s use of the diagram to a Beaux-Arts parti58, van Berkel emphasizes the flexible nature of a design model. Whereas a traditional diagram might proportion mass, a model proportions information.59 It not only contains spatial information, but additional project parameters that can be dynamically valued or devalued as-needed. The abstract design model leads to a set of objective goals and criteria, which is further developed into a geometric mother model.60

The Mercedes-Benz Museum was UNStudio’s first implementation of a mother model, which effectively served as an early version of BIM [see fig. 2.06]. The office worked with the workflow consultancy Designtoproduction to manage the digital model. The client and all members of the project team “buy-in” to the mother model at the beginning of the project.61 Through the integrated digital model, UNStudio assumes a more direct control over the design. The office functions simultaneously as architect, software engineer, and management office:

We will request part of the management fee and then add four or five people to the team, who are only doing the digital exchange between all of these different specialists. When a project moves to construction, we are also able to play a more central role. Because we have so much 3D information in the model, contractors will often come to us and request detailed production drawings. They often ask us to produce the fabrication drawings from our 3D model, for which we get an additional fee.

In the case of the Mercedes-Benz Museum, the mother model becomes the central point of collaboration between designers, consultants, and builders. Overall form and concept are developed alongside construction details and individual components. The office is leveraging this relatively new way of working to take a more active role in design and construction.

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58 Picon, Digital Culture in Architecture, 82.
59 Van Berkel, “Diagrams, Design Models and Mother Models,” 77-78.
60 Ibid., 79.
61 Ibid., 82.
CASE STUDY: DESIGNTOPRODUCTION
EPFL ROLEX LEARNING CENTRE, LAUSANNE

Designtoproduction is a workflow consultancy located in Zurich, Switzerland, and led by Fabian Scheurer. Trained as an architect and computer scientist, Scheurer and his office manage the digital exchange between designers and fabricators on large-scale projects of high complexity. They have worked with UNStudio, Zaha Hadid, Renzo Piano Building Workshop, LAVA, SANAA and many other clients to organize, optimize, simplify and materialize architectural form for digital production. According to Scheurer, Designtoproduction fills a “niche [that] has opened up in the building workflow that lacks a name but is nevertheless full of opportunities.”

The office demonstrates the extent to which digital workflow is redefining traditional practice, and blurring the boundaries that separate professional architecture from other disciplines. For the EPFL Rolex Learning Centre project, Designtoproduction occupied a middle position between SANAA, Bollinger Grohmann, Lasinger Construction, and the various fabricators [see fig. 2.07]. They rationalized the geometry from both the architectural and structural models, and used it to digitally fabricate the 10,000 formwork tables for SANAA’s massive concrete landscape. These multiple models were parametrically linked to a custom Rhino script and updated throughout the project. Like scripting in many contemporary design practices, these “disposable” scripts are discarded at the end of the project as custom solutions to unique design problems.

The integrated workflow represented by Scheurer’s office supports the notion that digital design should be balanced by early consideration for a building’s physical assembly. Digital fabrication does not absolve the architect of responsibility to a materiality and production:

The idea of just sending a 3-D model to the fabricator and receiving a few containers full of mass-customised components some days later is downright utopian. At least for all non-standard projects... the mass-customisation system that translates the design input into production data has to be developed first.

Rather than developing a complex, non-standard work of architecture and hoping to rationalize its construction late in the design process, Scheurer advocates an integrated approach to design. He promotes early collaboration between disciplines, and developing functional, “minimal” models. Simplicity during early design - that is, developing straightforward models that anticipate construction logic - translates into less complexity during construction.

64 “Organize / Optimize / Simplify / Materialize,” 410.
66 Scheurer, “Materialising Complexity,” 95.
CHAPTER THREE: MATERIAL EXPERIMENTATION

Although digital tools have led some offices to develop more integrated, collaborative practices, many architects continue to use these technologies in ways that reinforce traditional design methodologies. Despite early hopes that the computer would affirm the “predominance of structure and tectonic in architecture,” CAD/CAM has in many ways strengthened formalist tendencies in architecture.68

This culture remains embedded within the discipline:

> Since its emergence in the 1960s, computer-aided design (CAD) in its many transformations has afforded the designer an almost effortless manipulation of shapes generally detached from their fabrication in material form. Such processes promote the application of material subsequent to the generation of form. Even when supported by high-fidelity analytical tools for analysis and optimisation, these processes are predominantly linked to geometrical manipulations in three dimensions.69

The tendency to prioritize form over materiality is related to what Picon describes as a “striking distance between architectural imagery and the reality of building techniques.”70 Projects conceived in a digital environment do not easily reveal their tectonic, and the processes by which they are designed and built. To some extent, recent advances in computer-numerical-controlled production have only complicated the issue. The promise of digital fabrication has led to the expectation that any three-dimensional form can be (post) rationalized and constructed. Digital technologies do not, in themselves, challenge the “sequential development of ‘form, structure, and material’” that has characterized architecture and architectural engineering.71

Another design approach, or rather an ideology, has evolved alongside traditional form-based culture in architecture. It is apparent in the work of Neri Oxman, Barkow Leibinger, Buro Happold, SHoP Architects, Adams Kara Taylor, Kennedy Violich Architecture, and numerous other offices that use digital tools to emphasize material, rather than immaterial, design solutions. Gramazio and Kohler [see fig. 3.01] write that “the digital realm is generally misconstrued as being antagonistic to the analogue or physical realm. Our intention is to unite these seemingly opposite realms.”72 These integrated practices approach digital design as an act of making:

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68 Picon, Digital Culture in Architecture, 127.
70 Picon, Digital Culture in Architecture, 128.
The point here is that the tectonic data of the digital core model can function as information for the fabrication and construction processes. In a reversal of this process, it is possible that the tectonics of material systems can, in fact, drive the design process, a condition which is the epitome of architecture by performative design.\textsuperscript{73}

The underlying logic of computation strongly suggests such an alternative, in which the geometric rigor and simulation capability of computational modeling can be deployed to integrate manufacturing constraints, assembly logics and material characteristics in the definition of material and construction systems. Far beyond the aptitude of representational digital models, which mainly focus on geometry, such computational models describe behavior rather than shape. This enables the designer to conceive of material and construction systems as the synergetic result of computationally mediating and instrumentalizing the system's intrinsic logics and constraints of making.\textsuperscript{74}

The methodologies described above make use of performative, computational models to study material, structure, and assembly logic. Designers then use these parameters to develop architectural form and space [see fig. 3.02]. This type of workflow challenges the traditional use of the digital model as a representational tool in architecture, and is explored more thoroughly in the case studies below.

The precedents suggest an emerging design practice, closer to a Gothic model of construction. Architectural spaces are realized through flexible technologies of representation and material experimentation at full scale. In a profession increasingly mediated by digital technologies, these offices demonstrate how architects can maintain a relationship with the built environment. This relationship between contemporary architects and physical architecture is not merely an analogy, but an imperative. Other professions have proven as capable of performing the tasks traditionally carried out by the architect within an emerging digital context.\textsuperscript{75} The risk is perhaps best described by Tom Mayne in his remarks to the AIA convention in 2005. When asked what message he had for practicing architects, Mayne replied:

> My office doesn’t resemble what it did fifteen years ago. It’s a completely different office. Different staff, different skill sets, different time sequences, different services. It’s going to put us back as builders, which is absolutely key. I graduated in 1969. Since then architecture has been eviscerated. We’re cake decorators, we’re stylists. If you’re not dealing in the direct performance of a work and if you’re not building it and taking responsibility for it, and standing behind your product, you will not exist as a profession.\textsuperscript{76}

\textsuperscript{73} Rivka Ossman and Robert Ossman, “Introduction,” 20.


\textsuperscript{75} Picon, Digital Culture in Architecture, 165.

\textsuperscript{76} Thom Mayne, “Change or Perish,” AIA Report on Integrated Practice: May 20, 2005.
CASE STUDY: BARKOW LEIBINGER
TRUMPF CAMPUS CAFETERIA, STUTTGART

Barkow Leibinger’s design methodology begins with its research division, often led by student interns [see fig. 3.03]. The research division has relative autonomy in the office, which is made possible by fabrication sponsors. Each researcher explores a particular tooling process, or tooling action, and studies its material possibilities through experimental prototyping. The experiments are compiled in the office’s Atlas of Fabrication, which is made available to all designers within the practice. When the office begins a new project, the appropriate research is “activated from the archive, or a new line of research is developed specifically to address the new project.”

The Trumpf campus cafeteria is one instance of this workflow. In collaboration with Werner Sobek and the wood fabricator Holzbau Amann, Barkow Leibinger developed a laminated structural beam system that balances daylighting and acoustical needs with structural requirements. The overall geometry is the result of experimental prototyping, which was then simulated in a digital environment and optimized according to the desired parameters.

Although the digital model is vital to the design process, it is no replacement for the physical architecture. Frank Barkow emphasizes the importance of material experimentation in the office’s workflow, more than its digital simulation:

We refute the tendency toward representing architecture virtually or digitally, conceived as a superior alternative to the physical prototype. We maintain a commitment that the experience of material, effect and haptic workability cannot be adequately simulated.84

For Barkow Leibinger, the practice of architecture is primarily an act of making. Design is “enabled by a production tool,”85 which in turn prompts material and then space. The physical is assigned more value than the representational. Software merely serves as a guide to its production.86 Within this design approach, the architect (or rather, the designer) assumes the role of what has traditionally belonged to the fabricator, or materials scientist. This ideology is placed in direct contrast to the historical role of the architect as described by Michael Young, in which “the drawings, models, notations, texts, and calculations that the architect produces are not secondary to the building, but constitute the primary acts of architectural design.”87 For Barkow Leibinger and similar integrated practices exploring digital design methodologies, priority belongs to the built work and its tectonic - not only its representations.

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78 Barkow and Leibinger, “Designing Assembly,” 97.
80 Barkow and Leibinger, “Designing Assembly,” 97.
81 Young, “Technologies of Mediation,” 235.
CASE STUDY: MATERIALECOLOGY

MATERIAL-BASED DESIGN COMPUTATION

Whereas Barkow Leibinger has developed a material practice through digital fabrication and experimental prototyping, Materialecology explores materiality through computational design. Led by Neri Oxman, Materialecology inverts the “usual sequence of the design process - form-structure-material.” Material and structural parameters are embedded within a computational model, and used to develop formal solutions to a design problem. Oxman compares this methodology to natural processes, and biological growth. She has defined this workflow as “material-based design computation” and “variable property design.”

Material-based design computation is developed and proposed as a set of computational strategies supporting the integration of form, material and structure by incorporating physical form-finding strategies with digital analysis and fabrication. In this approach, material precedes shape, and it is the structuring of material properties as a function of structural and environmental performance that generates design form.

Material computation is therefore a design approach, a methodology and a technical framework, by which to model, simulate and fabricate material organizations with varying properties designed to correspond to multiple and continuously varying functional constraints. Such framework includes processes of modelling, analysis and fabrication.

This design approach is evident in much of Oxman’s work, including a custom wrist splint designed for patients with carpal tunnel syndrome, and a conceptual chair that adapts its “thickness, pattern density, stiffness, flexibility and translucency to load, curvature and skin-pressed areas respectively.” One of her more recent projects, entitled Minotaur Head with Lamella, is a flexible helmet with variable thickness and heterogeneous materials [see fig. 3.04]. In many of Materialecology’s projects, the formal design adapts to the individual specifications and performance criteria as defined by the end user. The result is digitally fabricated. These experiments lead Oxman to the conclusion that “materials are the new software.”

Although the selection of Oxman’s work described above is realized at a small scale, it has significant implications for a performance-based architecture - material and structural requirements used to generate form. The digital is no longer a means of representation, but used for full-scale material experimentation. Similar to a Gothic model of construction, priority belongs to the physical work.

82 Oxman, “Structuring Materiality,” 76.
86 Ibid., 85.
CHAPTER FOUR: MATERIAL CONTEXT

This thesis research has examined the contemporary systems of mediation between architects and other building professionals, and how these systems are being used to redefine architectural practice. It has also examined one opportunity presented by this change - that is, how digital design and computation can be used to support a more material practice. The following design proposal explores this last subject. It occurs as one moment within the larger body of research concerning contemporary digital culture.

A material approach to design must not only address the composition of the material itself, but also its history and function. The methodology must be understood within an appropriate context. This design proposal began as a search for a project with a strong historical and material context in the nearby community. This search led me to Cincinnati’s Brewery District.

At the turn of the twentieth-century, Cincinnati, Ohio was one of the largest producers of beer in the nation. In 1889 there were at least twenty-three breweries in operation within the Greater Cincinnati area, rolling out tens of thousands of barrels each year. These breweries were concentrated in Over-the-Rhine, a neighborhood inhabited by a predominantly German population. Drinking beer was deeply embedded in the local culture:

Roughly three-fifths of beer produced in Cincinnati in 1890 was consumed here by its 297,000 residents. In 1893, Americans consumed an average sixteen gallons of beer per capita, but in Cincinnati the average was forty gallons for every man, woman and child in the city - two and a half times the national average.

The production and consumption of beer at this scale had a significant impact on the local economy. By 1889 Cincinnati had “1,841 saloons, four hilltop resorts, [and] hundreds of restaurants that also served beer” [see fig. 4.01]. Brewing also supported a “large number of related industries,” such as malt houses, cooperages and cooperage suppliers, bottlers and bottle-makers, metal foundries, grain suppliers, hops suppliers, refrigeration specialists, and architects.

The breweries themselves were large complexes with highly specialized programs. A single brewery might consist of several buildings, including the brewhouse, bottling facility, icehouse or stockhouse, offices, worker accommodations, and stables. Given the technical knowledge needed to design and build these structures, nineteenth-century brewery architecture was a relatively integrated practice:

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88 Michael D. Morgan, Over-the-Rhine: When Beer was King (Charleston: The History Press, 2010), 68-74.
89 Ibid., 71.
90 Ibid.
91 Ibid., 69-71.
The first breweries were built without detailed plans; the builder would have worked directly with the brewer to layout the building. However, as both building and brewing technologies advanced, and the importance of style grew, architects became integral to developing these projects. Due to the specific technologies and processes involved, brewery architects were usually specialists in the design and construction of similar building types. Many of these brewery architects also designed mechanical refrigeration systems.92 Because of the flammable materials involved in production, the buildings tended to be of concrete or brick construction.93 The early breweries adopted a "Romanesque Revival" style that was "heavily influenced by the popularity of the German Rundbogenstil style from the 1830’s and 1840’s. The German immigrant lager brewers would have been familiar with this architectural style, and their architects translated it to be the ‘American round-arched style.’"94 The original Christian Moerlein Brewhouse [see fig. 4.02], the Bellevue Brewery, the Jackson Brewery, and the Windisch-Mühlhäuser Lion Brewery [see fig. 4.03] are all examples of this early architectural style.

One unique feature of these late nineteenth-century Cincinnati breweries was the use of felsenkeller, or stone cellars, to cool and store the wort as it fermented [see fig. 4.04]. Before advances in mechanized refrigeration, Cincinnati brewers built extensive networks of underground tunnels and cellars to store their lager, and cooled these spaces with blocks of natural ice:

These stone cellars mimicked the natural caves where lager beer was first made. The consistent cool underground temperature, around 55˚ F, provided an ideal environment for lager yeast. The cellars were built as a series of smaller rooms with communicating doors. These cellars were of stone construction with barrel vaulted ceilings. They were often two levels deep, extending to 40 feet underground or deep under a hillside.95

These lagering-cellars are located below most brewery-related structures in Cincinnati, and are usually connected by a series of tunnels. The sub-basement below the Kauffman brewhouse alone is approximately eleven thousand square feet [see fig. 4.05], and may have been connected to another sub-basement underneath its workers’ apartments on Vine Street.96 An article written for the Cincinnati Enquirer, dated May 11, 1889, describes the extent of underground cellars below the Lion Brewery:

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93 Morgan, Over-the-Rhine, 68.
94 "Bricks, Barrel Vaults & Beer" Exhibition.
95 Ibid.
It will astonish many Cincinnatians to know, as did the reporter, to learn that the most wonderful structures as well as the most costly and expensive in the Queen City are under ground. The buildings above ground, vast and imposing as they are, only represent a small portion of the capacity, cost, and capital of the Lion Brewery. It was like going down into a mine... all was neat, tidy, fresh, and cleanly as a Yankee kitchen. The floor of the lowest sub-cellar is forty-two feet below pavement.97

By the 1880s and 1890s, more efficient refrigeration technologies had replaced the traditional, underground lagering-cellars. Above ground stockhouses proved more economical,98 and enabled Cincinnati brewers to produce lager throughout the year. Workers pumped wort directly from the brewhouse to the stockhouse, where it was chilled in a series of settling tanks and coolers instead. The Christian Moerlein stockhouse, commonly referred to as the Apex Building, still stands between W. McMicken and Henry Street.

Prohibition however, had a “devastating” impact on Over-the-Rhine.99 Saloons were forced to close on Saturday, May 24, 1919.100 Few of the city’s breweries survived past the mid-1920s. The historic buildings were sold, and the entrances to the lagering cellars were sealed with concrete or filled with trash.100 Over the past hundred years, many of these spaces have been intentionally closed and forgotten:

Many of the lagering cellars and tunnels became obsolete while the breweries were still in operation because of the advent of artificial refrigeration in the mid-1880s. In subsequent years, the spaces would have been of limited use, and after Prohibition they would have been little more than a liability - particularly in residential properties. When different parts of brewing complexes were sold to different owners, it would have been undesirable to have tunnels connecting them... Over-the-Rhine’s underworld was sealed off, forgotten and may have been intentionally hidden during the 1920s.102

Since Prohibition, Over-the-Rhine has suffered from economic decline, crime, and deterioration. Many of its original buildings have been demolished, leaving a lasting impression on the city. Scheer and Ferdelman offer a summary of the neighborhood as it changed during the twentieth-century:

In the 1930s Over-the-Rhine was officially declared a slum, and planners called for much of it to be cleared... Absentee landlords refused to maintain old buildings and poverty became deeper. From 1960 to 1990, the decline of

97 “Bricks, Barrels, Valets & Boats” Exhibition.
98 Morgan, Over-the-Rhine, 65.
99 Ibid., 160.
100 Stephens, Cincinnati’s Brewing History, 70.
101 Morgan, Over-the-Rhine, 17-21.
102 Ibid.
the neighborhood accelerated, with substantial numbers of the nineteenth-
century buildings being lost.103

In 2006 the neighborhood was designated as one of the “Eleven Most Endangered
Places in America” by the National Trust for Historic Preservation, but has continued
to see its historic buildings demolished.104 By 2010, Over-the-Rhine had lost over
50% of the original buildings that stood during Prohibition.105

In recent years however, there has been a movement to protect Over-the-
Rhine and its historic buildings from continued destruction. The southern half of
the neighborhood below Liberty Street has seen significant redevelopment, but the
northern half with its warehouses and large brewery buildings is perceived as unsafe
and under-utilized.106 In 2005 a group of local residents, business owners, planners,
and architects formed the Brewery District Community Urban Redevelopment
Corporation (BDCURC), a non-profit aimed at redeveloping Over-the-Rhine.107

The BDCURC released a revised masterplan in April 2013 that defines the
Brewery District, identifies some of its problems, and proposes several strategies to
create a more walkable, urban neighborhood. The objective is to use momentum
from successful redevelopment along Vine Street and Main Street, and carry it north
to the Brewery District, connecting the two divided parts of Over-the-Rhine.108 The
masterplan consists of eight initiatives that guide future development in the Brewery
District, organized by degree of partnership with the BDCURC109:

1. Creating a Brewery Heritage Trail to encourage tourism and raise awareness
2. Developing a neighborhood brand identity and gateways
3. Developing existing parks and recreation facilities
4. Adaptive reuse of historic buildings for a new mixed-use economy
5. Investing in Brewers’ Triangle as a commercial anchor
6. Establishing new zoning districts to protect historic structures
7. Creating new street-level amenities and restoring the broken street edge
8. Creating public plazas and additional structured parking

The defining feature in this set of masterplan initiatives is the Brewing Heritage Trail,
an urban trail system that connects many of the historic pre-Prohibition breweries in
Over-the-Rhine [see fig. 4.06]. Tour guides take groups of 15 to 30 people through
the former brewery buildings, and down into the historic lagering cellars, to learn

103 Brenda C. Scharf and Daniel Forshlitz, “Inner-City Demolition and Survival: the Case of Over-the-
otrfoundation.org/Why_OTR_Matters.htm
105 Morgan, Over-the-Rhine, 165.
106 Brewery District Community Urban Redevelopment Corporation “Brewery District Master Plan: A
107 “Our History,” Over the Rhine Brewery District Community Urban Redevelopment Corporation,
109 Ibid., 29.
about Cincinnati’s history before Prohibition. The BDURC began to offer these guided tours in 2006, and hopes to use their success to encourage future economic development. Similar strategies have been used in Boston, St. Louis, and Detroit.

Many studies have determined that well marketed heritage trails attract not only visitors but also investment in real estate development and business... Heritage trails have been successful in otherwise economically depressed areas - especially where historic buildings are part of the trail experience. Visitors are willing to accept that they may have to go to a neighborhood they perceive as 'rough' in order to see the trail. In fact, heritage trails are one of the few reasons people visit economically challenged neighborhoods.110

More than an attraction, the Brewing Heritage trail can be used to raise awareness about the other issues presented in the masterplan. Tour guides usually end the walking trail with a few words about the proposed initiatives, and their vision for the Brewery District in the future. Cincinnati’s brewing history provides an easily marketable image for the neighborhood, which can be used to promotes tourism and new business opportunities. The heritage tour offers an incentive to preserve Over-the-Rhine’s historic buildings, and has the potential to create more walkable, desirable public spaces along its path.

The following design proposal is for a Brewing History Museum, developed in response to these masterplan initiatives put forward by the BDURC. The initiatives provide a framework to guide the project and a set of criteria against which to measure its success. A new museum for Over-the-Rhine has the potential to reinforce the Brewery Heritage Trail and other objectives identified in the masterplan. It can be used to develop neighborhood brand identity, encourage parks and other existing public spaces, create new street-level amenities, contribute to the adaptive reuse of historic buildings, and expand current the historic district to cover a number of unprotected spaces in Over-the-Rhine.

110 Ibid., 31.
CHAPTER FIVE: DESIGN PROPOSAL

Instead of a single site, the museum is conceived as a series of sites in Over-the-Rhine. The museum occurs as several moments within the broader experience of the Brewery Heritage Trail. These sites were selected based on shared typology. Each one is a vacant property, or small pocket park, adjacent to a historic brewery building with underground lagering cellars or sub-basements. As visitors follow the tour, they learn about the local history of each brewery and the future plans outlined in the BDCURC masterplan. The site at 1315 Vine Street, near the former Peter Noll Brewery, is illustrated at right [see fig. 5.01].

The brewery history museum is a transitional space between the public park above and the unused lagering cellars forty feet below street level [see fig. 5.02]. Rather than siting the museum within an existing building, this strategy allows for the simultaneous development of the park, the historic brewery building, and its underground cellars. Local businesses can occupy the building, while the public and museum visitors use the nearby park. The cellars themselves are transformed into useful spaces, now opened to future development and protected by new historic district zoning. This design reinforces the objectives of the masterplan to create new public spaces, infill vacant properties, create new street-level amenities, and protect historic structures. One local developer has plans to develop the sub-basement at 1315 Vine Street. The proposed use is distinct from the business that occupies the rest of the building. For the purposes of this thesis project, it is assumed that the lagering cellar will be developed into a restaurant or biergarten [see fig. 5.03].

The early design made use of custom scripting to create an open brick enclosure at the museum’s entrance [see fig. 5.04]. While this initial strategy addresses the broken street edge with infill construction, it does so at the expense of the public park - another important aspect of the masterplan. The final design however, turns the museum from a vertical, positive intervention within a negative space, into a horizontal landscape. This landscape is a reference to the masonry construction in the barrel-vaulted lagering cellars below. A visitor progresses through a series of structural shells embedded within the ground, moving from gallery to gallery, until he or she reaches the stone-vaulted cellars below the park. The topmost structural shell is a walkable surface that begins and ends at street level.

The vaulted geometry was created using structural form-finding software in Rhino. The design begins with a base surface that is allowed to develop into a catenary surface, following structural and material parameters. These forms are nested to create the multiple exhibition spaces.

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111 Brewery District Community Urban Redevelopment Corporation, “Brewery District Master Plan,” 52
112 The form was generated using the Kangaroo plugin for Rhinoceros, and studied with Karamba finite element analysis. A number of similar plugins have been developed in recent years, most notably RhinoVAULT by Matthias Rippmann and Philippe Block of the BLOCK Research Group. Building on the work of Frei Otto and Hans Scharoun, Rippmann and Block have worked with numerous academic groups to explore the material possibilities for funicular structures in a digital environment. Their work contributes to a growing body of research on digital form-finding.
fig. 5.04
An early sketch for the brewing heritage museum using custom brick scripting.


