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Digital Representation and Fabrication

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INTRODUCTION

In spatial design, digital technologies have prompted the development of a vast array of techniques for representing and fabricating the physical environment, from objects to landscapes. During the past twenty years, CAD/CAM software has afforded designers to conceive, visualize, develop, and construct their work in ways that were unimaginable only a few decades ago. While in some cases design professions have appropriated such technologies primarily to improve the efficiency of performing old tasks, innovative practitioners across multiple disciplines have engaged with computationally driven techniques in order to produce the kinds of material, formal, and spatial outcomes that would otherwise seem unlikely, if not impossible.[1] Digital technology continues to transform the procedures, sequences, feedback, workflow, and communication in the design process, and the designer's techniques[2]—the various specific ways of utilizing the given technology—profoundly impact the aesthetic, organizational, and performative character of contemporary environments, including building interiors.

A growing volume of contemporary interior spaces developed primarily through digital means from concept to realization—authored by designers, architects, decorators, and artists—suggests, as this chapter will explore, that the power of digital technology is neither in its sole capacity to represent spatial constructs in increasingly sophisticated ways nor is it only that it makes the fabrication of physical artifacts that are too complex or inefficient for analog production possible. Instead, the technology's transformative potential is in its ability to produce integrated relationships between representation and fabrication and to manage, through continuity, increasingly complex information that enters into and is generated by the design process. Framed in this way, representation[3] and fabrication—and by extension design and construction—are no longer understood as segregated pursuits but are rather interconnected entities that are a part of

a continuous workflow. Although the interior projects that result from digital practices are undoubtedly diverse and greatly vary in spatial strategy and sensibility, two common tendencies—continuity and pattern—provide the means of organizing a range of exemplary works and the discourse that surrounds them. Continuous surfaces and aggregate patterns have been prioritized in contemporary design as facilitators of program, negotiators of site, givers of form, order, atmosphere, and decoration, and their at times relentless activity and seemingly ubiquitous presence both inside and out of building envelopes is technologically rooted, as will be discussed, in the digital realm. How the desire for surface continuity is linked to digital design techniques and why complex patterns have more recently proliferated across surfaces will be addressed by examining specific interior projects in relation to advances in digital technologies that informed their design and material manifestation. The discussion will conclude with a sampling of experimental works that hint at the potential future trajectories in digital interior design, in particular in relation to environments' responsiveness to human factors.

CONTINUITY

In their pioneering book *Digital Design Media* from 1991, written as a comprehensive introduction to digital processes for architects and allied design practitioners, William Mitchell and Malcolm McCullough state,

> All practical computation is based upon the idea of letting numbers represent things that interest us—counts, measures, characters, words, sounds, positions, shapes, gestures, and so on. These things may, in turn, represent other things, which may represent other things, in potentially endless chains of reference. We often use computers to process very complex, multilevel representations of this sort, but these representations all reduce to collections of numbers in the end.[4]

Although relatively straightforward and obvious from the standpoint of computer science, the authors' observations nonetheless touch upon at least two issues that are significant and central to architectural design. First is the notion of representation as a system based on numeric quantity rather than visual resemblance; second is the fact of computation as a platform that transforms diverse and at times otherwise incompatible informational inputs into common mathematical code. Both have a tremendous impact on the conceptual underpinnings of the digital design process as well as its pragmatic technical logic. In predigital design—that is, the design process based on manual and mechanical means of conceiving—when developing and disseminating information about a product or project at stake, or what we may at times refer to as analog design, representation is primarily understood as a visual matter, a set of two-dimensional notations and three-dimensional artifacts that describe a vast range of information about design intent, from depicting qualitative characteristics and describing precise geometries to diagramming instructions for both fabrication and occupation. While the same could be said about digital design—it is still after all the resultant drawings, renderings, and images of digital

models that are produced for visual inspection, evaluation, and use—the difference is, as Mitchell and McCullough point out, that underlying such digitally processed artifacts is numerical data that can generate other types of output as well. For example, a line drawn on paper visually communicates its own geometry, direction, and dimension, but it requires additional acts of translation[5] such as measurement, scaling, or tracing before it can serve as a basis for material fabrication. A digitally drawn line, on the other hand, is essentially a set of numbers that can be directly processed in order to instruct digital fabrication machinery to produce the same line materially.[6] This is the core principle behind CNC—that is, the process of operating machinery not through manual or mechanical actions but rather through data, a continuous workflow that underlies all digital fabrication.[7] The power of digital representation is in large part in its ability to generate multiple modes of output, including the final product, without the additional interpretation or translation that is conventionally needed in analog production. Such a continuous process promises greater precision, increased efficiency, and a higher degree of customization and formal complexity; in other words, the technological links between representation and fabrication have presented designers with new opportunities for innovation.

Another kind of continuity is evident in contemporary digital design, one that addresses spatial, material, and formal connectivity through the articulation of smooth continuous surfaces. In the design of interiors specifically, this has resulted in the intensive questioning of the conventional distinctions between, floors, walls, and ceilings, as well as the blurring of the boundaries between architectural elements and furnishings. Branko Kolarevic traces the discussion of the "fluid logic of connectivity" in architecture back to Greg Lynn's essay "Architectural Curvilinearity" from 1993 and acknowledges particular theoretical and philosophical influences on designers' intentions, but also identifies a much longer and broader trajectory of the development of such a formal language based on continuous, curvilinear surfaces. For him, the precedent for continuous form can be seen by not only looking backward toward baroque, *art nouveau,* and the 1960s plasticity but also outside of architecture in the world of industrially produced toothbrushes, toasters, computers, cars, and airplanes.[8] Volumetrically manipulated surface continuity appears as a spatial strategy in numerous interior projects of the past two decades, from Diller+Scofidio's Brasserie (1999) and Rem Koolhaas/OMA's Prada Epicenter New York (2001), to GRAFT's KU-64 Dental Clinic (2005) in Berlin, and Noé Duchaufour-Lawrance's Galerie BSL (2010) in Paris (Fig. 82), with each project's individual characteristics undoubtedly informed by various factors, from the designers' theoretical positions to the influence and referencing of aesthetic precedents. Though explorations of surface continuity clearly predate, and at times sidestep, the use of digital tools in design and fabrication, digital modeling has undoubtedly contributed to the exponential propagation and development of surface-driven spatial strategies. Digital modeling techniques are fundamentally surface-driven, whereby what is perceived visually as a solid volume, thickness, or mass is in fact a collection of two-dimensional surfaces seamed together to describe a three-dimensional form. The value of digital models is not only in their ability to visually and graphically convey spatial information but rather that their geometries also exist as numerical representations, thus making them

readily editable, reproducible, and constructible. The computational logic and organization behind surface models varies depending on individual software packages as well as output formatting, but the most common types of digital surfaces are NURBS, polygon meshes, and subdivisions.[9] NURBS, the acronym for Non-Uniform Rational B-Splines, allow for what Kolarevic refers to as "rubber-sheet" geometries;[10] that is, the kinds of freeform surfaces that allow for a high degree of variation, while maintaining their overall continuity. While this has in many cases made NURBS surfaces desirable aesthetically—opening up a whole new set of formal possibilities in design—from the technical standpoint, what makes them valuable is the efficiency and accuracy with which they represent complex geometries, using a minimum amount of data and a relatively simple computational process.[11] Polygon meshes, on the other hand, approximate continuity of surface though tessellation (a point that will be addressed further in regard to surface patterning); that is, by constructing continuity not through smooth curvature but rather through the accumulation of flat polygonal tiles. Finally, subdivision models, too, are created using the logic of polygon modeling but have the added functionality of smoothing faceted curves and surfaces akin to NURBS construction. Whether spline-based or meshed, the digitally constructed surfaces have unleashed the technical ability of designers to generate and represent spaces whose geometries depart from the predigital Euclidian forms in Cartesian space.[12] Of particular importance for interior design,

FIGURE 82 Galerie BSL by NNoe Duchaufour Lawrance. Courtesy of Noe Duchaufour Lawrance/Eric Laignel.

however, are those projects that synthesize the formal innovation achieved through the manipulation of continuous surfaces with the procedural continuity of the workflow between digital representation and fabrication.

One of the earliest and widely published interior architectural projects realized almost entirely through digital means from concept to construction is Ost/Kuttner Apartments by Kolatan/MacDonald (1997).[13] The project, sited on New York City's Upper West Side, deploys surface continuity as a connective tissue between and across a series of intended and potential microprograms. It occupies the footprint of two adjacent residencies in a 1933 building, and though it is designed to primarily serve as a single apartment, it can also be compartmentalized to function as two separate spaces to accommodate the occasional need for additional privacy between units. Within the prewar envelope of the existing building, a series of chromatically saturated volumes are inserted into the space—larger than single pieces of furniture but smaller than the size of a whole room—that merge the conventional distinctions between floor and wall surfaces, building and furnishing, object and paint but also blur the clear boundaries of use (Plate 40). In this way, a bright orange surface cascades down the wall to become the platform for a bed, only to spill out further and turn itself into an indented volume that serves as a bathtub before it completes its footprint as a floor finish. In another such volume—this one rendered in brushed metal—a sink is transformed into a vanity, which then swells up smoothly to form a full-height wardrobe (Plate 41). A plush upholstered windowsill only makes more sense as it continues across the wall, past the window, and grows out to form the back of a built-in settee. Together, these interventions create an interior that has been stripped of most residential associations and yet highlights the sensual, informal, and voyeuristic aspects of contemporary domesticity.[14]

In the design process, Kolatan/MacDonald began with two-dimensional sections that index spatial occupation at the scale of the body as an initial input from which larger surfaces were digitally generated. Unlike conventional interior design practice in which standardized ergonomic proportion, shape, and scale are applied to the design of specific objects or spaces, the designers employed sampled sections from a variety of furnishings and household objects in order to embed them within surfaces that are typologically ambiguous yet rich in their potential to be occupied, engaged, and interacted with. In other words, while the presence of originally selected profiles alludes to certain conventionally understood uses, it is but a point of departure for the digital blending, lofting, extruding, and joining that produce a continuous terrain within which new relationships between the architectural form and the human body unfold. The designers state, "The ambivalence towards form and programme as relational constructs provides for the possibilities of appropriating, adapting and adopting those structures for the particular needs and desires of its inhabitants."[15] Kolatan/MacDonald took advantage of modeling software's ability to generate new data (the resultant surfaces) through the interpolation of information within a range of known limit conditions (the initial sectional curves). To physically construct the interior, the surface model is digitally contoured into serial sections that provide templates for the fabrication of the plywood ribs that structure the overall installation. In order to maintain the monolithic quality of the volumes, a

thin skin of rigid fiberglass is draped over the structure, rendering the surfaces seamless, continuous, and with limited detail about the tectonic properties. The space visually transmits many of the aesthetic qualities one is more likely to encounter within a virtual environment produced with software such as Maya than in a conventionally conceived architectural interior. While Kolatan/MacDonald regard fiberglass as a material without qualities[16]—perhaps not unlike NURBS surfaces themselves–Kolarevic explains the effectiveness of such a material as a key ingredient in the physical construction of digital forms not because of the material's lack of qualities but rather because of its specific character. He writes, "The physical characteristics of fiberglass make it particularly suitable for the fabrication of complex forms. It is cast in liquid state, so it can conform to a mold of any shape and produce a surface of exceptional smoothness—a liquid, fluid materiality that produces liquid, fluid spatiality."[17] Embedded in the discussion about the relationship between digital forms and material properties is the significant degree to which digital representations have shaped designers' desires and aesthetic sensibilities. In this particular project, choices of material, color, and finish work to reinforce the strategy of blurring distinctions across programs and uses, while at the same time fulfilling the visual desires generated by design software.

Whereas the surfaces of Ost/Kuttner Apartments seek to reterritorialize the activities that occur in the private realm, Restaurant Georges by Jakob + MacFarlene (2000) deploys surface continuity in order to inscribe a particular programmatic footprint within the larger institutional framework of a public museum (Plate 42). The restaurant occupies 15,000 sq.Ft. (1,400 sq m) of the top floor at Centre Pompidou in Paris. The project's primary feature is a set of irregular, bulbous volumes clad in brushed aluminum, each of which strategically reveals an interior of a different color and contains a specific part of the restaurant's program. The largest volume contains the kitchen, while the smaller ones contain house coat-check and restrooms, a video bar, and a semiprivate dining area. Between, around, and extending out from these four defined forms is the matching aluminum floor surface that extends past the glass curtain wall onto the outdoor terrace, carrying most of the seating that accommodates the museum restaurant's diners. There is a clear contrast between not only the existing building's envelope—featuring exposed structural and mechanical systems designed by Renzo Piano and Richard Rogers and organized within a rigorous Cartesian grid—and the aluminum surfaces that define the restaurant but also between the luminous, yet achromatic, character of the aluminum and the richly saturated hues of rubber sheathing that lines the interiors of the volumes.

The material and formal continuity between the restaurant floor and the blobs that appear to emerge from it provides a conceptual framework for the design informed by the project's strict parameters. The primary site-based requirement that the designers had to address was the prohibition to intervene on or touch any of the building's interior surfaces but the floor. Their point of departure was a flat floor surface divided into a 31.5 in. (80 cm) grid—a dimension that echoes Centre Pompidou's architectural module—digitally deformed to create the three-dimensional interior volumes. By collaborating with a boat-building company from design to fabrication, Jakob + MacFarlane developed the project through a series of digital models that interpreted the

continuous surfaces as a set of monocoque structures, constructed from intersecting ribs whose contours follow the deformed pattern of the initial grid. The models examined multiple technical properties of the system, from gravity and lateral loads to the contouring of the surface and fastening details, and served as a basis for templates from which structural ribs were digitally fabricated from 3/8 in. (10 mm) thick aluminum. Brendan MacFarlane refers to the ribs as the pure part of the construction because they were constructed entirely through digital means from modeling to fabrication. In contrast to the digital integration through which the structural ribs were developed and delivered, the process of constructing the aluminum skin ultimately required a strategic engagement with more traditional fabrication methods. The double-curved aluminum panels that make up the overall continuous skin were fabricated mechanically through a process borrowed from boat-building and their surfaces brushed on-site to produce the desired matte finish.[18] The strategy of deforming the floor surface, as if it were bubbling up from the pressure underneath, in and of itself produced an impenetrable volumetric condition that required another set of techniques for generating apertures with which to reveal and access the spaces within. The first technique was to truncate the form where necessary by slicing it across the surface with a flat cutting plane. The second was to cut an incision by following a curved path projected onto the continuous form, not unlike a knife that cuts through a material by moving perpendicularly to its surface, tracing the contours of the desired aperture.[19] Both follow a certain logic of surface editing inherent to digital modeling, resulting in formal effects that refer less to conventional doors and windows and are closer in resemblance to the arm and neck holes of a garment. In this way, the fluid geometry of the restaurant is experienced as a new layer between the surface of the body and the structure of the building, one that is seen as internal to the building, while at the same time containing, concealing, and framing its own interiority (Plate 43). The openings are crucial for other reasons, too: they impart a sense of scale and a depth of field by choreographing the occupants' movement and arranging the relationships between the foreground and the background. Furthermore, they provide evidence of the meeting between the project's digital and material means by revealing the profiles of the otherwise hidden structural ribs and exposing the material thicknesses of the aluminum and rubber surfaces, acknowledging the transpired transformation of the continuous NURBS surface into corporeal matter.

The two interior projects, produced at the turn of the century, capture the creative ambition as well as the technical limits that defined what might be considered the first wave of digitally produced architectural constructions. These designers and their peers sought to overcome, through digital fabrication, the limitations of formally extravagant but unbuildable digital architectural representations, while attempting to retain in their physical constructions—both the quantifiable geometries and the aesthetic qualities produced in computer models, drawings, and renderings. While the computational continuity between representation and fabrication is central to the transformation of the image into material and space, the projects also reveal the amount of human judgment required along the way. Digital tools allow for the automation of processing and outputting information, but as the two discussed projects show, how the information is

interpreted and deployed in architectural terms is still largely up to the designer. Both Ost/Kuttner Apartments and Restaurant Georges may be experienced as types of total immersive environments in which the surface acts as an omnifunctional entity capable of transforming itself in order to perform the work of any architectural component or piece of furnishing, yet they both also reveal the limits of a single homogenous system as the primary means of space-making. As it has been seen, the projects' encounters with materiality, structure, and use in the physical realm motivated the development of further design strategies to supplement the primary logic of the continuous digital surface. This is true of not only these two works but also can be understood as a broader trajectory in digital design, one that resonates in a wide range of realized interior projects from the first decade of the twenty-first century.

PATTERN

Parallel to and expanding the repertoire of continuous, curvilinear, and glossy digital environments first produced in the 1990s is the increased prevalence of patterns—graphic, material, structural, ornamental, and organizational geometries with varying degrees of repetition and difference within.[20] Such pattern-driven projects, in particular those for which the architectural surface is the primary carrier of repetitive geometries, intricate textures, and highly crafted reliefs, are as much a product of digital design techniques as are their smooth and blobby predecessors. The aesthetic qualities of these works have not only reinvigorated the once dormant discourse about ornament and decoration in architecture—a development particularly meaningful for the design of interiors—but also, to a large extent, reflect many of the pragmatic concerns related to the transformation of digital representations into viable material constructions.[21] As the previous case studies demonstrate, the continuous digital surfaces frequently require additional ordering devices or strategies before they can be fabricated and assembled at full scale. While for the projects preoccupied with surface continuity and seamlessness such strategies are secondary with their byproduct typically concealed by thin veneers of homogenous materials and layers of paint, the obsession with patterns yields works in which surface patterns that define material, structural, and scalar distribution of parts in fabrication are conceptually and technologically embedded into the design process from the onset of digital production. In this way, patterns provide a link between computation and construction and a means of continuous feedback between digital and material parameters in design.

Ongoing advances in software development, mainstream availability of once specialized digital tools, and the rapid distribution of digital scripts, plug-ins, and other means of generating, evaluating, and outputting digital designs have all contributed to the proliferation of pattern-based strategies from computer screens to buildings and beyond. Current digital tools expand the capacity of surfaces to address external demands that range from programmatic performance to material resolution, and through the use of patterns complex surfaces are able to be subdivided into smaller buildable elements on the one hand, or they can be generated through the multiplication and aggregation of predefined repeatable components on the other. Algorithmic scripts and parametric models allow

for the dynamic exchange between digital data and form, with the resolution of design intent tested through an automated or live iterative process. That the embedded patterns have aesthetic consequences is undeniable; conceptually, however, it is also necessary to understand their role as highly organizational, as their geometries negotiate material limits (sizes of available materials and tooling tolerances based on their properties), labor distribution (how the components will be fabricated and assembled), human interaction (ways in which their geometries suggest use and occupation), and so on.

In the architecture of building interiors, digitally produced patterned surfaces take on the role of paneling, cladding, screens, suspended ceilings, and flooring systems, and their influence also permeates the realm of freestanding furnishings, decorative off-the-shelf products, even apparel. Their presence registers through various figure-ground relationships as well as in more nuanced topographic manipulations. Ranging from highly ordered matrices to intricate lace-like formations, and varying in depth from thin veneer to thick poché, the patterns are manifested as seams, reveals, gaps, edges, joints, apertures, perforations, protrusions, and reliefs across surfaces. Such conditions reflect not only the relationship between the cutting templates extracted from digital models and the cutting paths made by CNC tools but also the computer's capacity to generate and manage the levels of geometric complexity and variation unthinkable in the analog realm. Unlike the conventional patterns of assembly bound by the limits of standardized repetition on the one hand and laborious, resource-intensive customization on the other, digitally produced assemblies allow for high degrees of nonuniformity, while maintaining the production efficiencies otherwise associated with high degrees of repetition and standardization. This is commonly referred to as mass customization, a term originally coined to refer to competitively priced but highly customized goods and services tailored to their specific consumers' needs and desires in the information age,[22] but one that in architectural production primarily stands for the ability to serially fabricate uniquely differentiated material artifacts such as building components with the efficiency levels compatible to those of mass production.[23] The nonuniformity of patterns enables surfaces to respond to and accommodate a variety of conditions, while maintaining the overall continuity of the system. The variation of such patterns responds to programmatic requirements and site conditions, as well as environmental and performative criteria, and produces rich atmospheric effects through highly differentiated modulations of light, view, material, and texture.

In the past decade, the commercial availability and relative affordability of small-scale fabrication machinery such as laser cutters, CNC routers, and 3D printers, along with the earlier mentioned software developments, have allowed young designers to experiment with the development and delivery of digital projects from conceptualization to construction. Such experiments have resulted in gallery installations, temporary structures, and full-scale prototypes in which the use of pattern-based strategies is significant as the scalar limitations of fabrication machinery is negotiated vis-à-vis ambition toward full-scale constructability. In other words, because the machinery produces artifacts of limited size, in order to construct an installation at the scale of a building, the overall digital form must be subdivided into much smaller components that can be

individually fabricated and then reaggregated into the larger whole.[24] The puppet theater at the Carpenter Center for the Visual Arts at Harvard University (2004), a temporary pavilion tucked underneath the Le Corbusier–designed building, features a structural envelope defined by a tessellation of approximately 500 diamond-shaped components, each uniquely shaped in response to the distribution of forces across the overall surface. The tessellated pattern takes on the graphic form of seams between the components and contributes to various optical readings of the envelope depending on given lighting conditions. Brennan Buck's gallery installation *Technicolor Bloom* (2007) exploits surface subdivision as a technique for constructing a series of vibrant visual effects, distributing intricate voids across the plywood material so as to repress the material's original planar state (Plate 44). What is leftover appears like an elegant web of fragile edges, its thinness and layering amplified by selective use of color. The spatial effects of the ornate latticework, not unlike those found in Andrew Kudless's cellular honeycomb experiments, are amplified by deliberate lighting. The intricate nature of Kudless's *C_Wall* (2006) is, for example, as evident in the physical construction of the paper cells of the porous Voronoi surface as it is in the cast shadows collected on the gallery floor. Although experimentalin nature, such projects are nonetheless engaged in an exchange with commercial practice, undoubtedly expanding into and influencing more conventional modes of design, fabrication, and construction.

Japanese architect Kengo Kuma's interior design of a boutique for the fashion label Lucien Pellat-Finet (2009) deploys a three-dimensional honeycomb-like system as a primary spatial and tectonic element. Occupying 1,430 sq.ft. (133 sq m) divided into three stories of a compact building in the Shinsaibashi district of Osaka, the boutique also contains a café and a small library. From outside, the building appears as a thickened billboard, which visually blurs the distinction between the two-dimensional pattern imprinted onto the solid exterior surfaces of the building and a three-dimensional system within that is partially seen through two horizontal bands of frameless glass (Plate 45). In this project, the honeycomb pattern is based on irregular polygonal cells that include both pentagonal and quadrilateral shapes, a combination that suggests a degree of geometric order and repetition but also a level of flexibility and improvisation. Upon entering, visitors encounter the core of the boutique, a space where plywood honeycomb cells define most of the vertical wall surfaces as well as the ceiling. Along the walls the honeycomb has the depth of a typical storage shelf, acting both as a screen that filters views and a display system for merchandise. The vaulted ceiling appears as if it were designed by cutting a curvilinear incision into what would have been a solid mass of extruded honeycomb pattern, revealing as a result an array of irregular tessellated geometries (Plate 46). Upstairs, the program of the boutique continuous, as does a similar spatial strategy with the exception that along the exterior façade much of the pattern is removed to clear a direct panoramic view of the street framed by a band of glass. On the building's top floor, the pattern is further eroded, revealing more of the white background surfaces, with what is leftover of the pattern acting as strategically placed book displays for the informal library. In the basement, where the café is located, the pattern reappears again but is shallower and—with the exception of the fact that its depth is calibrated to house glassware

at the bar area—appears tentative about accommodating program. Instead, the polygonal pattern is distributed as a decorative layer atop the neutrally painted background.[25]

Despite its high-end nature, the design achieves a richness of spatial experience with an economy of means. This is as evident in material and fabrication choices as it is clear from the deft deployment of pattern. The honeycomb pattern is entirely fabricated from ordinary plywood sheets and utilizes only three standard types of aluminum fasteners to address all the connections among the parts. The system's cells, with variant shapes and a range of depths, play multiple roles in the space, from defining overall wall and ceiling surfaces to acting as storage and display devices, see-through screens and surface-applied decorative wallpaper. In that sense, the nonuniform nature of the pattern is tailored according to variable site conditions, programmatic needs, and aesthetic desires and provides a sense of unity across the multiple levels of the building despite the embedded spatial differences and competing functional demands. Given its multifunctional nature, the system appears as efficient, but at its limits one also perceives its relentlessness and excess. This is most evident at the edges of the pattern where more ordinary, nearly ad hoc, devices are introduced to reinforce the utilities promised, but perhaps underdelivered, by the system. Conventional shelving and hanging rods introduce a tension between that which is programmatically essential and what is aesthetically and experientially desirable. The project nonetheless demonstrates the potential with which patterns that are ordinarily seen as graphic devices can be transformed into robust spatial constructs and does so by deliberately constructing a precise sequence of movement that leads one from the graphic exterior of the building to the immersive interior within.

In contrast to Kengo Kuma's boutique and all its exuberance, and with a remarkable restraint and rigor toward the integration of interior surfaces and patterns through digital means, is Marble Fairbanks' design for the Toni Stabile Student Center at Columbia University's School of Journalism in New York (2008). The project, completed in multiple phases, includes 9,000 sq. ft. (835 sq m) of renovated interior space spread over two floors and a new 1,000 sq. ft. (93 sq m) addition at the street level. In shaping the new interior spaces, the architects identified three particular surfaces and their individual roles in the project relative to programmatic and environmental requirements. The largest space within the project, the Social Hub, a multipurpose room for studying, meetings, and special events, contains two of the surfaces, a ceiling and a window wall. The ceiling is charged with the task of eliminating existing acoustic reverb and echo in the space, while the wall lends a new image to the space by graphically negotiating representational content (i.e., a photographic image embedded into its thickness) and abstract patterning. There is a third surface, another ceiling, that is a part of the new addition and acts as a rigid solar shade underneath a structural glass roof but is also a carrier of graphic content similar to that of the wall. Together, the three surfaces share common materiality, finish, and overall pattern geometry. All the paneling is fabricated from sixteen-gauge steel sheets, powder-coated white and perforated with an array of round apertures, ranging in size and shape from circles to ellipses.[26]

The central premise of the design for the Social Hub ceiling is that metal paneling conceals a layer of acoustic insulation and that it is perforated to expose the insulation

wherever acoustically necessary. In addition, perforations for recessed lighting and a sprinkler system are integrated into the overall pattern. The overall form of the ceiling was manipulated through the introduction of strategically placed folds in order to maximize ceiling heights wherever possible. The design of the pattern was achieved digitally involving two related processes. First, a digital acoustic model was developed to evaluate sound conditions within the space. The model identified areas in the ceiling where the exposure of acoustic insulation aids the correction of existing reverb and echo issues in the space, thus requiring larger perforations in the metal surface. Second, through algorithmic scripting the exact distribution and size of perforations were determined along with the additional placement of lights and sprinklers. The script provided possible iterations based on preset rules: the overall pattern grid, the allowable range of perforation sizes and shapes, and various parameters for dealing with boundary conditions, such as the pattern's responsiveness as it encounters surface edges, creases, and preset fixture locations. The result is not just a highly differentiated gradient pattern but also the very patterns that are used, without the need for additional construction documents or shop drawings, for digital cutting and bending of the steel. The Social Hub wall, while similarly perforated, is different in its intent and process. Sited parallel to the tree-lined street outside, the intent was to transpose the view of the street, concealed by the solid walls of the building, as a virtual view on the inside but to do so with a level of abstraction that would allow the image to go in and out of focus, or rather, whose legibility would vary depending on the subject's distance from it. The process started with a digital image of the elevational view outside, which was then processed through another algorithmic script in order to transform tonal values of the image into apertures and convert that information into another set of cutting templates for fabrication.[27] The result is a cladding system whose pattern not only oscillates between abstraction and representation but also juxtaposes the virtual image of the street with the actual views framed by the existing windows inset into the paneled wall. The third surface, the café ceiling, is designed to eliminate 80 percent of the new addition's solar gain, while providing, not unlike the wall in the Social Hub, an aesthetic experience derived from graphic imagery. Through a combination of digital solar analysis models that quantify specific, maximum, and overall solar loads based on site information and, again, algorithmic scripting that automates pattern distribution according to preset criteria, the architects arrived at the final solution, which reduces solar gain but also produces a nuanced dappling of natural light as it is filtered through the ceiling and distributed to the space below. Together, the three surfaces deploy digital means not as methods for extravagant form-making but instead focus on the technology's ability to integrate, with high levels of precision, multiple sources of information, pragmatic demands, and aesthetic intentions in order to transform existing spatial conditions into preferred ones.

EXPANDED PERFORMANCE

As the case studies demonstrate, the significance of digital media in spatial design lies in its ability to connect generative, representational, and manufacturing tasks into

continuous processes. Increasingly dynamic in nature, such projectsexceed the efficacy of static representations and artifacts in favor of dynamic relationships and reciprocal feedback. This means that the relationships between numerical inputs, digital geometries, and material outcomes are interdependent and adjustable, producing potentially infinite iterations and possibilities for fine-tuning and customization. The dynamic nature of digital processes has been exploited in ever-expanding facets of spatial design practices, from the mainstream integration of Building Information Modeling (BIM) in corporate architecture to the exploration of interactive technologies in more experimental contexts. What such digital projects have in common is the increased attention to performance in design; that is, how designed artifacts work in relation to their given tasks as well as ways in which digital technologies negotiate the responsiveness of those artifacts relative to the data that defines the performance criteria. As a result, contemporary digital models are dynamic in nature, only made static by their authors' judgment and will, and digitally fabricated material artifacts too frequently embody the kinetic properties of their virtual predecessors.

Marc Goulthorpe/dECOi's installation Aegis Hyposurface consists of tens of thousands of triangular panels connected by an elastic rubber membrane and a system of digitally controlled pistons that allow the overall surface to respond, through movement, deformation, and bulging, according to environmental stimuli such as light and sound.[28] The precedent-setting project, realized in 1999, is both continuous surface and pattern and its flexible, shifting form is a result of both physical and computational constraints. Exploiting the qualities of animate form is also evident in Ammar Eloueini's design for CoReFab chair.[29] Though static in its material state, Eloueini's chair is based on the fundamental premise that with digital fabrication, making a series of unique objects is as efficient as making reproductions of identical ones (Plate 47). As such, the chair is conceived as an animated lattice of interconnected members that is perpetually in motion, smoothly repatterning the chair as the animation unfolds in time until it is paused and 3D printed directly at full scale using a selective laser sintering machine.[30] Although the functional performance of the chair is not redefined—Eloueini intended CoReFab chairs to be used just like any other side chair—the design nevertheless seeks to redefine the status of uniqueness in product design relative to digital fabrication and addresses the value of one-off objects in the consumption of contemporary design. Also at the scale of furnishings is Neri Oxman's Beast, an experimental prototype for a chaise lounge that synthesizes continuous surface and pattern in response to material and digital processes.[31] Designed as a monocoque surface, or a single structural skin, the chaise is modeled and patterned according to the structural requirements as a freestanding object as well as in response to the body's needs for comfort. The synthetic structure—also 3D printed and filled in with acrylic materials of varying levels of density, flexibility, stiffness, and translucency, depending on localized requirements—focuses on the issues of material performance at the scale of the body, zooming in, in order to address human factors at microscale.[32] The act of sitting, in a social context and aggregate form, is also addressed through digitally designed and fabricated furnishings in the Fleet Library at the Rhode Island School of Design, a project designed by Office dA and constructed in 2006. Faced with the programmatic requirement

for multiple computer stations, the architects eschewed the standardized dimensions of workstations in favor of a parametric range that accommodates a diverse population of people of various sizes. In this way, the requirements for universal design are addressed not through rigid common denominators but rather through rule-based variation. Spatial and human performance is thus enhanced through customization, while maintaining and even increasing, as the architects acknowledge,[33] the economy of the project.

CONCLUSION

The notions of continuity and pattern have provided a useful framework for interrogating, relative to the design of interiors, the developments in digital representation and fabrication of the past two decades. It is hopefully clear, however, that despite the apparent aesthetic implications of these terms and the formal affinities among the discussed projects, the selection of the works is based primarily on the need to explain the crucial relationships between representation and fabrication in the digital realm in ways that are conceptually clear and visually explicit. Because the chapter focuses on these two areas of digital design as interrelated entities rather than separate areas of investigation and as such its ambition has been to examine the explicit continuum between specific techniques of visualizing and making, interior design has ultimately been treated primarily as a material practice. In the practice of interior design, whether as a specialization within architecture or within its own distinct disciplinary context, the use of digital tools is currently diverse and, in many cases, as compartmentalized as it is integrated in the discussed projects. The chosen examples deliberately demonstrate a degree of totalizing, allover design strategies that result in saturated, immersive environments, in part a reflection of the persistent dream in which a project is conceived in its entirety in the computer and then magically materialized with the touch of a button. While such visions of the future have undoubtedly shaped the ambitions that drive technological innovation, for interior design as a practice it may also be prudent to consider digital constructions as partial, incomplete, fragmented—in other words, not everything. The design of interiors after all requires a skilled synthesis of existing conditions, site-specific interventions, and off-the-shelf products as well as, inevitably, occupants' possessions.

In his essay "Relentless Patterns: the Immersive Interior," Mark Taylor discusses the work of Atelier Manferdini (Plate 48), known for its digitally crafted patterns embedded in everything from coffee cups and couture dresses to skyscraper curtain walls, and writes, "Operating at different scales, and cut into the material, this pattern is freed from the constraints of conventional ordering devices, and begins to take over, not to create an immersive environment but to immerse itself within the environment."[34] Contemporary interior designers, equipped with digital experience and with the drive to opportunistically co-opt technological advances unfolding around them, have the capacity to practice in ways that are at once expansive and focused. Equally fluent in site-specific interventions and industrial processes, and spanning multiple scales, markets, and media, the contemporary interior designer is positioned to influence material culture in ways that are perhaps, as of yet, unprecedented.