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On the Visual Agency of Manufacturing Models

Sobre la capacidad de acción visual de los modelos de fabricación

investigación
pp. 130-139

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Abstract
Assuming that rapidly altering agencies and media of digital fabrication are only beginning to resonate in transdiscplinary research, innovation may emerge outside perspectives of efficiency and optimization. With a background of cultural technique research on the construction of drawing and distributed authorship, this paper proposes to read manufacturing models through the art historical notion of the 'image act.' Approaching the visual agency and suggestive power of this rather disparate topic, it suggests that authors pay renewed attention to the underlying conditions of their practices, corrective relations between the physical and digital and notions of brilliance and uncertainty. This is conceived as a tentative inquiry into the ontological foundation of digital workflows – eventually attempting to shift the discourse on CAD/CAM from 'possibility' to 'constraint' space.
Keywords: image act, CAD/CAM, digital ontologies, vagueness and brilliance, physical-digital interferences

Resumen
Al asumir que los rápidamente cambiantes acciones y medios de fabricación digital apenas están comenzando a hacerse sentir en las investigaciones transdisciplinarias, la innovación puede surgir fuera de lógicas de eficiencia y optimización. Con el antecedente de una investigación en técnicas culturales sobre la construcción del dibujo y la autoría distribuida, este artículo propone leer los modelos de fabricación a través de la noción de "acto de imagen" proveniente de la historia del arte. A partir de un acercamiento al potencial visual y al poder sugestivo de este tema –bastante dispar–, se sugiere que los autores presten renovada atención a las condiciones subyacentes de sus prácticas, a las relaciones correctivas entre lo físico y lo digital y a las nociones de brillantez e incertidumbre. Esto se concibe como una exploración tentativa sobre la base ontológica de los flujos de trabajo digitales, que eventualmente intenta cambiar el discurso sobre CAD/CAM y llevarlo del espacio de la "posibilidad" al de la "restricción."
Palabras clave: acto de imagen, CAD/CAM, ontologías digitales, vaguedad y brillantez, interferencias físico-digitales

Introduction

> There was the true continuity, San Narciso had no boundaries. No one knew yet how to draw them. [...] For it was now like walking among matrices of a great digital computer, the zeroes and ones twinned above, hanging like balanced mobiles right and left, ahead, thick, maybe endless. Behind the hieroglyphic streets there would either be a transcendent meaning, or only the earth.[1]

With the entrance of an increasingly paranoid Oedipa Maas into the fictional planned city of San Narciso in the dystopian ending to Thomas Pynchon's *The Crying of Lot 49*, the media theorist Friedrich Kittler concludes his 1994 "Stuttgarter Rede zur Architektur." In light of architecture's 'digital turn,' he writes that "cities, even if or even more so when named after Narcissus, are no longer reflections of the so-called human, but of microelectronics."[2] He expects neither augmented authorship nor potency from the infinite promise of computer-aided technologies, but increasing redistribution among techniques and practices, calling for a reinvention of architectural agency as a media system: "CAD for design, not only representation,"[3] reads a note below his manuscript – yet, if asked today, would he not add manufacturing[4] to his list?

Ever since the digital turn in architecture, the discipline has not only been reviewing its logbook,[5] but has been debating whether this was a slight bend, a blind curve or a complete turnaround. Optimistic and positivist rhetorics argue that the progress of CAD/CAM may allow architects to reinstate pre-Albertian logics of building, streamlining production workflows through the seamless integration of design, manufacture and assembly.[6] There is, however, rising criticism of prevalent notions of zero tolerance, control and optimization,[7] even fear of the dissolution of the profession, as technologies like Building Information Modeling (BIM) are reconfiguring authorship across all tasks, trades and disciplines.[8]

This paper compliments these disciplinary perspectives both from the core and the periphery of these discourses: the generation of manufacturing models[9] within CAD/CAM-driven workflows. Consciously choosing this rather disparate focus on simulation, data and notation, it directs readers less toward the endless potentials than the potential ends of computational processes: margins of error, convertibility, information bottlenecks, data interfaces and other frictions of fabrication processes – suggesting that we may conceive of them as a source of inspiration, a means to reinvent authorship in the digital age.

Initially, this means situating the related cultural techniques of modeling, notating, drawing and transmitting information within discourses on the construction of drawing and other forms of human and non-human agency. Secondly, its conceptual and methodological origin lies in the hypothesis of the 'image act' by Horst Bredekamp, an understanding in which models and their agencies are both probed by and are themselves probing formative and constitutive processes. Thirdly, it explores CAD/CAM-driven approaches through questions of underlying ontologies, physical correctives to brilliance and ways of dealing with vagueness. As a tentative inquiry, that may help us understand how design practices, software environments and production logics are inherently connected through the constraints and conditions of their emergence.

Manufacturing Models as a Cultural Technique

How should we approach the generation of manufacturing models from a cultural technique perspective? This paper suggests following its productivity from an instrumental and operative standpoint, exploring how it shares the foundational characteristics of other related techniques, "as virtually all design operations serve three basic functions: translation, processing and behavior in rehearsal."[10] In that respect, the art theoretician Barbara Wittmann offers an attempt to systematize the epistemic potentials of mechanisms for thinking and making, assembling an array of instruments, operations and corresponding practices. This allows her to apprehend how their evolution throughout modernity paralleled growing dependencies, whose redistributions of agency designers have often mistaken as outcomes of their own will.[11]

> Designing, as a cultural technique, starts with analyzing its material cultures and practices, its workshop conditions and storage devices. [...] Firstly, this implies reassigning that which is usually held to be artistic imagination toward hands, eyes and signs, and secondly, to conceive of such signs not as signs but as forms of media. How is the drawing used, how is it communicated, how do media for storing and distributing drawings affect their codes? This may open up a path toward different narratives of designing that do not simply celebrate artistic genius but deal with the exteriority of thinking, forming and designing.[12]

The media philosophers Bernhard Siegert and Lorenz Engell consider matters of communication, storage and distribution as desiderata of this discourse. Linked efforts in Science and Technology Studies (STS) and Actor-Network Theory (ANT) have revealed the roles of manifold human and non-human agents in distributed and collaborative processes of knowledge and design production.[13] Such anthropological interest in processes of creation puts manual techniques of notation, drawing and sketching at the forefront; this is mirrored in the series "Wissen im Entwurf," whose contributions on logics of ideation, notation and recording were fundamental to cultural technique research on these matters:

> This is how graphic construction functions as an intersection of knowledge and the ability to realize, practices of making […] and a kind of inventiveness, which cannot be anticipated but only developed situationally alongside its emergence.[14]

The literary and art historian Jutta Voorhoeve delineates how the operations and practices of drawing are constructional per se, as they are developed and construed on paper. Arguably, this is especially relevant for graphic thinking "because construction eliminates all that which is not truly relevant for the purpose of realization."[15] This is followed by explorations of how every physical realization encompasses epistemic operations, as they involve a change of media, shifts in scale and dimension or differences from an original sketch or concept. These notions of construction, from auxiliary lines to water lines, and their related actions of translation and alteration read as an archaeology of drawing and materialization.[16] In his summary of a project that approaches the 'digital turn' from a media-archaeological standpoint, the architect and critic Mirko Zardini demands these altered agencies of his readers:

> In all fairness, a fifth actor should be added to this list; an inanimate actor who takes different forms and names: machine, computer, manual, software, code, script, etc. This technological constituent – sought, found, tested, modified and even invented by the architects themselves in order to realize their ultimate vision – attained a life of its own and made the production of these projects possible.[17]

Both cases hint at multiple agencies which are embedded in their respective workflows. Clearly, manufacturing models revolve around this relationship between drawing and construction and may be a catalyst to approaching CAD/CAM from a cultural technique perspective. Their curves and codes are drawn and written to translate numbers into physical artifacts. As they have to take the material properties and constraints of machinery and data into account, they negotiate the constitutive aspects of digital production workflows. At the same time, we need a broader conception of drawing, one that is able to grasp the growing horizons of computational modeling and applications of manufacturing data and that specifically addresses its suggestive and self-determining qualities.

Image Activity of Manufacturing Models

In his phenomenology of the visual agency of the 'image act', Bredekamp suspends the strict dualism of subject and object – tracing how images, creators and spectators mutually form and influence each other. As he foregrounds the practices and techniques through which images not only reproduce but produce meaning, he strengthens their active, self-determining qualities. From a conception of the image that "encompasses every form of conscious shaping,"[18] his work aims to overcome the primacy of the spectator and the prevalent demarcations of art history, inquiring into topics commonly external to its discourse – such as animal tool use[19] or the formative qualities of scientific visualizations:[20]

> Images do not derive from reality. They are, rather, a form of its condition. Images, through their own potency, empower those enlightened observers who fully recognize this quality. Images are not passive. They are begetters of every sort of experience and action relation to perception. This is the quintessence of the image act.[21]

Bredekamp differs between three *modi operandi* (schematic/body, substitutive/exchange, intrinsic/form) through which images become active: the schematic image act draws on the relationship between the image and life created from living things or evoking vigor through representations of the body (*tableaux vivants*, cell microscopy); the substitutive image act refers to the mutability and relationship of the physical body with its image, charged with religious or destructive acts (iconoclasm, relics); while the intrinsic image act describes instances in which forms acquire agency as their material presence enables or forces the spectators to reflect themselves. Putting the latter at the core of his theory,[22] Bredekamp presents models as being one of the most effective instances of the intrinsic image act in terms of its irresistibility as form.[23] The scripts, models and codes of CAD/CAM-driven processes arguably share this suggestive power – in spite of or because of their abstract, projective character. This may also answer the critique of their passivization as mere instruments by Engell and Siegert. Bredekamp himself explicitly hints at the formative potential of working and presentation models: their quality of shaping processes, constituting intent and creating precedents.[24] If one assumes that unrealized models are no less influential than realized ones, would there not be reason to argue that models not only become active in the moment of their realization, but many remain active through the long and painstaking processes of their virtualization, translation and adaption?

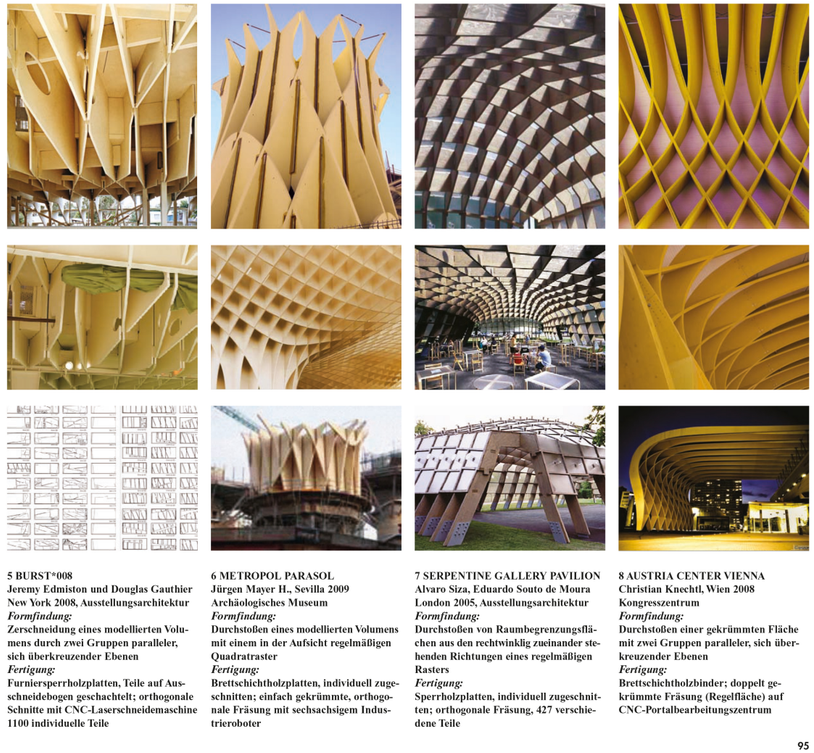
The following tentative analysis invites the reader to understand the models, scripts and notations of CAD/CAM-driven manufacturing workflows in their processes of creation, transmission and reception by applying the notion of the 'intrinsic image act.' The transition from CAD to CAM is an excellent opportunity to inquire into the suggestive, formative, autonomous logics of model agency: it is the moment the virtual model is operationalized when processual, material and artistic constraints enter into a productive dialogue.

The Ontologies of Manufacturing Models

> So even for architects who are not exposed to, or have no interest in coding, there still exists this secondary exposure to the logics of numerical representations and software development.[25]

Interestingly, these lines were not written by an architectural critic or a cultural historian, but a former Autodesk software engineer. Michalatos Panagiotis outlines how the ontologies of design software influenced the architectural aesthetics of our built and imagined environments and how ubiquitous logics of differential geometry and boundary representation in early modeling software resulted in a fetishization of the surface. His work outlines how these influences allowed geometric concepts and contents hitherto external to architecture to shape its forms and agendas.

Alongside such influences and imprints, an ever-growing number of outside references, vocabularies and morphologies have augmented the discourse (emergence, material system, continuity, performance, complexity, mimetics). It is striking how concise and systematic studies on the effect of such logics on the discipline, however, largely remain to be made. According to Bredekamp, these would have to trace how the intrinsic logics of modeling are never passive, but instead engage with their



Inventory of CAD/CAM carpentry by Sabine Kraft and Christoph Schindler in the *ARCH+* 193 Holz issue. Source: Kraft and Schindler, "Digitale Schreinerei," (2009), 95

5 BURST°008
Jeremy Edmiston und Douglas Gauthier
New York 2008, Ausstellungsarchitektur
Formfindung:
Zerschneidung eines modellierten Volumens durch zwei Gruppen paralleler, sich überkreuzender Ebenen
Fertigung:
Furniersperrholzplatten, Teile auf Ausschneidebogen geschachtelt; orthogonale Schnitte mit CNC-Laserschneidemaschine 1100 individuelle Teile

6 METROPOL PARASOL
Jürgen Mayer H., Sevilla 2009
Archäologisches Museum
Formfindung:
Durchstoßen eines modellierten Volumens mit einem in der Aufsicht regelmäßigen Quadratraster
Fertigung:
Brettschichtholzplatten, individuell zugeschnitten; einfach gekrümmte, orthogonale Fräsung mit sechsachsigem Industrieroboter

7 SERPENTINE GALLERY PAVILION
Alvaro Siza, Eduardo Souto de Moura
London 2005, Ausstellungsarchitektur
Formfindung:
Durchstoßen von Raumbegrenzungsflächen aus den rechtwinklig zueinander stehenden Richtungen eines regelmäßigen Rasters
Fertigung:
Sperrholzplatten, individuell zugeschnitten; orthogonale Fräsung, 427 verschiedene Teile

8 AUSTRIA CENTER VIENNA
Christian Knechtl, Wien 2008
Kongresszentrum
Formfindung:
Durchstoßen einer gekrümmten Fläche mit zwei Gruppen paralleler, sich überkreuzender Ebenen
Fertigung:
Brettschichtholzbinder; doppelt gekrümmte Fräsung (Regelfläche) auf CNC-Portalbearbeitungszentrum

respective workflows, whether theoretically, through their assumptions and suggestions, or practically, through their affordances and presets. Instead of portraying seamless transitions from thought to material, they would dissect the manifold steps and how they manage, alter and filter the outcome. Such an interest in actual and tangible mediacy, not some abstract immediacy of designing, would also put the narrative of the 'digital chain' into perspective.

This call for a systematic inquiry into the readability of modeling logics, software environments and production workflows may go beyond the scope of the present approach. Among the rare points of reference,[26] the 2009 survey by Sabine Kraft and Christoph Schindler stands out as an attempt to link larger matters of architectural cultures of research and practice with realities of digital fabrication. On the basis of 14 compared projects (see image in the previous page), they delineate how foundational logics of designing and modeling across various typologies (egg slices, double egg slices, folds, panels, braids) appear as fundamentally detached from matters of material organization (fiber direction, choice of material), function (use, inner organization), construction (connections, statics) and fabrication, delimiting the role of the architect as author: "Bluntly said, her/his role seems to be confined to picking an apt metaphor or decorative gesture, that is, creating formal complications, while largely masking any fabrication constraints."[27] It is in the irresistibility of these metaphors, guiding and shaping their project outcome through models and processes of manufacturing, in which the 'intrinsic image act' reveals itself.

In recent years, some have begun asking that contemporary practices develop more adaptable, resilient and open-ended processes.[28] While doing so, however, one may conceive of the 'image act' as a reminder to consider the filters, scripts, plug-ins and interfaces as much productive parts of realization processes as their respective machinery of production – "because the complex and highly variable contemporary environments of software and hardware introduce a distance – not a void, but perhaps a filter or membrane – between designer and object,"[29] as the scenographer Sean Keller has said. Architectural histories of the model are told elsewhere, namely how their recurrent role as an *idea materialis*[30] repeatedly challenged the discipline to redefine itself.[31] Yet it is precisely this faculty to provoke, challenge and constitute the processes of their generation which appears as an atemporal feature. To the extent that these presumptions prevail today, architects cannot afford missing out on fully authoring the generation of manufacturing data within their CAD/CAM-driven projects. It is this moment in which all remaining questions need to be resolved by the authors, before other human or non-human agents resolve them for them.

Brilliant Models and Physical Correctives

> For the boon of its sparkling clarity is accompanied by the danger of its power to seduce. By virtue of the compelling brilliance of their construction, models may become fetishes in the fields of research that in reality comprise utterly indigestible masses of data.[32]

On the case of Darwin's *On the Origin of Species*, Bredekamp exemplifies the epistemic power of scientific model practices as being both guide and shackle in the hand of a researcher. He outlines how his branching illustrations of natural selection had to be deceptive – partly due to their teleological implications of growth and direction, partly due to their exclusion of dead, fossil-like structures – and uses sketches in Darwin's notebooks to suggest how an encounter with a Patagonian coral (which turned out to be an algae) may be the actual, figurative origin for this theory.[33] To Bredekamp, this stands as an example of how models function both as container and symbol of their underlying theories and how

A difficult chair, fragment of *Remote Impressions* by Thomas Pearce and Gary Edwards, 2020. Photograph by Thomas Pearce. Source: Pearce and Edwards, "Remote Impressions," 3

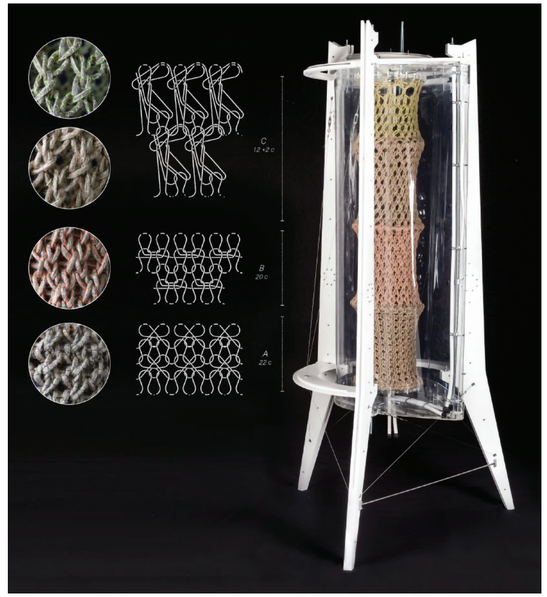
they may gain authority over the reality they are describing. To us, it is also an example of how a physical reference may reveal an alternate, corrective pathway to those fetishes of modeling.

Building history has been one of loosening such physical grips on reality and precision has more than once served both as rule and workhorse to these ends. Craftsmanship long measured distances in relation to parts (foot, ell, cubit, palm) or ranges (bow shot, stone throw) of the body, which were eventually replaced by metric working units connected to the reality of material processing[34] – and related customs of dimensioning masonry in decimeters, carpentry in centimeters and metalwork in millimeters. Later still, a whole culture of postwar architectural representation was founded upon the ISO 128-compliant nib widths of Rabidograph technical pens (0.13, 0.18, 0.35 mm), which still populate our tool bars today. When the science historian Norton Wise reflects on "why and how precision has become the sine qua non of modernity,"[35] he illustrates how the 'values of precision' form a specific Western disposition toward self-asserting qualities, a tautological quest.

According to current critics of architectural discourse, "the clichéd immaculate offices and pressed white shirts of the quintessential modern architect were just the tip of a redundant precision iceberg":[36] a contractor may build a 5 m long concrete wall at a German construction site with 16 mm tolerance to meet DIN standards, the finest print layer of the Stratasys J750 amounting to 0.014 mm and Autocad calculating its data set to even 16 decimal places. While the primacy of drawing required the utmost draftsmanship, the same rigor now weighs heavily upon the standards of digital representation, models, layer structures and their rendered manifestations. Paradoxically, such obsessions with ever-smaller margins of tolerance eventually appear as detached from sense perception: the two-point discrimination of our fingertips, as applied to Braille writings, is assumed to be around 2 mm.[37]

Linking the precision of computational workflows back to human and non-human points of reference thus takes on special importance. The *Remote Impressions* project by Thomas Pearce and Gary Edwards is one example of such practices. Merging recording, scanning, modeling and making processes, its authors create a processual, functional and narrative wall as part of a mobile artist's studio. They draw on 3D scans of existing objects and merge them with body-related equipment designs and motion studies; the hybrid outcome instructing the Single Point Incremental Forming (SPIF) panels (see image on this page). What they describe as a form of "cross-contamination between bodies, objects, skins and code"[38] is an example of such strategies where the physical and the digital augment each other: as glitches and artifacts from the physical realm are not erased or flattened, but adapted and altered through the following steps of mediation, they remain active contributors to the process until its end.

Other critical voices call on us to distance ourselves from the drive toward perfection instilled by computational tool sets, calling for an architecture of tolerance that harnesses precisely the spontaneous, imprecise and even the erroneous.[39] They remind us that, sooner or later, even the "ultimate digital description becomes subject to the issues of tolerance, irregularity, approximation, human error and the unpredictability of materials, to name just a few of the many contingencies of building."[40] Projects like *Remote Impressions* interestingly revert these logics, and treat such deviations and adaptions not



Finished softknitted column inside the bioreactor, pattern distribution and material hierarchy, *Column 21* by Bastian Beyer and Daniel Suarez, 2017. Source: Beyer, Suarez and Palz, "Microbiologically Activated Knitted Composites," 547

as limitations but potentials for authorship. They stand in line with other examples, where experiments with error-driven process chains have revealed the prospects for innovation of glitches and imperfection.[41]

> The more precise and reliable we consider the model to be, the more it blends with its object. This process generates its own form of indeterminacy and ambiguity because it is no longer possible to distinguish the two. […] What appears to be exact, faithful and isomorphic has the peculiar qualities of ambiguity, uncertainty, non- or under-determination.[42]

In continuation of Bredekamp's 'image act,' the art historian Reinhard Wendler labels such tendencies to confuse model and subject as the 'brilliance problem' of modeling, referring to the moment when an (over)definition on the part of the model begins to blur the borders constituting their difference. From science to the arts, Wendler follows historically-contingent interplay and transitions between certainty and uncertainty, precision and imprecision, which he frames as a cultural technique take on the uncertainty principle.[43] In order to avoid such pitfalls of brilliance, CAD/CAM strategies need to remain conscious of the respective degrees of certainty or uncertainty in their work, embracing –in a way– their margins of error.

If they do not, their endless hunt for precision and exactitude runs into a dead end at the very moment when the represented and its representation collapse into one, as illustrated by Jorge Luis Borges's famous 1946 short story.[44] Some have raised concerns about how the infinite promises of digital visualization[45] and BIM[46] may run into the very same ontological paradox of complicating the building and its digital alias. And it will remain unresolved here to what extent the introduction of computation into architecture and design has fostered this Borgesian moment. In any case, however, an architectural culture of manufacturing modeling may learn from related fields and ways of dealing with similar epistemic dynamics that have also undertaken considerable efforts to underline their legitimacy, reliability and quality, the brilliance of their endeavor.

Modeling Vagueness

Wendler contrasts the uncertainty of precision with its opposite, the precision of uncertainty, which he sees in the instantaneous, self-actuating and performative logics of abstract sketching techniques: from Renaissance drawing to contemporary architectural sketches, he outlines how reverse logics of indeterminacy, ambiguity and vagueness leave space for interpretation, as they are characterized by their inability to deliver exhaustion and completion.[47] According practices of modeling would consciously employ their options and limits in terms of mutual potentials for knowledge production, using precisely their operative latitudes and instrumental openness to render them potentially productive. This may involve epistemic operations that are contrary to the logics of brilliance: abstracting, complicating, hypothesizing, relativizing, etc., the very reverse of finiteness.

If one refers back to Panagiotis, he states that "the more elaborate and specialized the ontology, the less suitable the software becomes for the early stages of design where ambiguity can be more productive."[48] Such bias toward openness also prevails at the other end of the spectrum, in which manufacturing data is permeated by the digital ontologies of its generation, storage and translation – and in which the conscious embedding of process- and material-based factors gains growing importance for speculative, open-ended contemporary practices.[49]

Column 21 by Bastian Beyer and Daniel Suarez may serve as an example of such a workflow. Its authors install a multi-actor fabrication system which exposes the textile microbiome of a hand-woven jute structure to bespoke treatment with urea and calcium chloride. In line with the structural simulation and optimization of these processes, this designed conglomerate converts from a tensile to a compressive system, as it solidifies into a column (see image on this page) through biochemical reactions – realizing what Wendler frames as an "*optimized* uncertainty"[50] in a structurally complex material hierarchy and performance. In its blending of transdisciplinary and temporal knowledge, the resulting workflow "operates between and utilizes the inherently different domains of binary and biological computation."[51]

Very clearly, then, their approach favors the distributed and the complex over self-contained and determined logics – setting the stage for a large number of natural-textile, biochemical, computational, dexterous and environmental actors, leaving space for a well-rehearsed 'improvisation' as a crucial part of the script – which may be linked to how Bredekamp frames drawings by Charles Peirce as "self-generating, arising in part by chance, but, precisely on that account, symptomatic – of a nature to be found in continuous physical and mental movement."[52] Not only do they activate the column as an architectural archetype, that is, reactivate an analogy to the human body which has been effective since ancient times, as it instigates an active, bidirectional relation between spectator and metabolising 'object'; they also transcend the notion of the object in a form that is itself the result of the active process of its own generation. Referencing Alexander Cozens's *Blot Landscapes* and dynamic sketching methods from Leonardo da Vinci to Frank Gehry, Wittmann has acknowledged such play with openness as an elemental technique in drawing practices.[53] While, to her, drawing logics and practices become productive at the beginning of design processes, as they open up preconceptions and self-contained workflows and release creativity through spontaneity, the given project makes it reasonable to seek their formative power also at the other end of the spectrum: in the realization of computational workflows.

Conclusion

> Why would we leave behind the spline-dominated environment of the first digital turn to embrace what appears to be a new style of digital disorder, messiness, complexity, patchiness, disjointedness and even – once again – angularity and aggregation?[54]

Carpo gives three answers to his own question: an exposure to rising computational capacities, the detachment of such excess and ornament from its postmodern provenance and the unflattened look of Big Data, which we are only beginning to visualize, literally and figuratively.[55] He encourages us to conceive of related work as a technological and computational proof of concept, renovating baroque complexity and working toward multifaceted or voxelated structures and spaces.[56] Or, to go back to Schindler and Kraft, "'Anything goes': it appears as if one could build virtually anything – and if one had to exhibit such technological potency, such capacity to realize the most intricate forms."[57]

In order to avoid such pitfalls of brilliance, authors of CAD/CAM-driven processes may acknowledge how the scientific quest for brilliance and the architectural quest for precision both imply their respective logics of fetishization. This application of the 'image act' suggests how both comparably handle an excessive amount of information in comparable ways, detaching matters of interest from the analog world. All of a sudden, the open question of an 'archaeology of the digital' may then soon become a question for an archaeology of the author, if not its prophecy. Through a cultural technique perspective, such forms of encapsulated knowledge on the part of developers and programmers necessarily result in a redistribution of agency and authorship – a situation designers can only face by embracing technical constraints, physical contingencies and distributions of agency.

There is reason to suspect that the rapidly altering instruments, media and processes of digital fabrication are still yet to be fully penetrated across disciplines. The practice may be somewhat haunted, the routines of our new toolsets concealed behind artistic and rhetorical eloquence.[58] Notions and concepts from art history can serve as vehicles to open up these rather self-contained discourses of computational design and manufacture, while matters of manufacturing modeling may serve as an external, peripheral and largely unexplored approach and a catalyst to discussions of agency within the discipline.

Notes

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1. Thomas Pynchon, *The Crying of Lot 49* (London: Pan Books, 1979), 122–125.
2. Friedrich Kittler, "Stuttgarter Rede über Architektur," *Zeitschrift für Medien- und Kulturforschung 3-1 (2012)*: 104, doi:10.28937/1000106357. This and all further translations by the author.
3. Friedrich Kittler, "Stuttgarter Rede über Architektur," 104.
4. It should be stated that the notion of manufacture applied in this text draws on the English use of the word: on making processes of trades and industries and, notably, their furthering in the Industrial and Information Ages, such as developed, for instance, in the architect Branko Kolarevic's foundational text. See Branko Kolarevic, "Introduction," in Branko Kolarevic, ed., *Architecture in the Digital Age: Design and Manufacturing* (London: Spon Press, 2003): 1-16. It is to be differentiated from its German connotation, which remains closer to its etymological origin (Latin *manu*, "a hand," and *factura*, "a making").
5. See Mirko Zardini, "Eight Million Stories," in Andrew Goodhouse, ed., *When Is the Digital in Architecture?* (Berlin: Sternberg, 2017), 111–112.
6. See Stephan Rutishauser, "Zukunftspläne. Von der grafischen Darstellung zum digitalen Code," in Annette Spiro and David Ganzoni, eds., *Der Bauplan: Werkzeug Des Architekten* (Zurich: Park Books, 2013): 282–283.
7. See Bob Sheil, "High Definition: Negotiating Zero Tolerance," *Architectural Design* 84-1 (2014): 8–19, doi:10.1002/ad.1697.
8. See Ekkehard Drach, "Einführung," in Ekkehard Drach, ed., *Das Verschwinden des Architekten: Zur architektonischen Praxis im digitalen Zeitalter* (Bielefeld: Transcript, 2016), 11–27.
9. The notion of the model applied in this paper pays special attention to the formative qualities of developing, using and interpreting models; modeling is conceived from its material and immaterial basis, its founding in techniques and materials on the hand and an ability to display and construe abstract matters on the other hand. See Nathalie Bredella, "Modell," in Barbara Wittmann, ed., *Werkzeuge des Entwerfens* (Zurich: Diaphanes, 2018), 107–109.
10. Barbara Wittmann, "Denk- und Werkzeuge. Ein Entwurf," in Barbara Wittmann, ed., *Werkzeuge des Entwerfens*, 21.
11. See Barbara Wittmann, "Denk- und Werkzeuge," 13–14.
12. Lorenz Engell and Bernhard Siegert, "Editorial," *Zeitschrift für Medien- und Kulturforschung* 3-1 (2012), 6.
13. See Bruno Latour, "Why Do Architects Read Latour? An Interview with Bruno Latour," *Perspecta* 44 (2011): 64–69.

14. Jutta Voorhoeve, "Technische Zeichenmanöver. Verfahren der Konstruktion," in Jutta Voorhoeve, ed., *Welten schaffen. Zeichnen und Schreiben als Verfahren der Konstruktion*, vol. 4, Wissen im Entwurf (Zurich: Diaphanes, 2011), 8-9.
15. Jutta Voorhoeve, "Technische Zeichenmanöver." 9.
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21. Horst Bredekamp, *Image Acts*, 283.
22. See Christopher Wood, "Iconoclasts and Iconophiles: Horst Bredekamp in Conversation with Christopher Wood," *Art Bulletin* 94-4 (2012), 527.
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30. See Werner Oechslin, "Architekturmodell – 'Idea Materialis,'" in Wolfgang Sonne, ed., *Die Medien und die Architektur* (Berlin/München: Deutscher Kunstverlag, 2011), 131–156.
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32. Horst Bredekamp, *Image Acts*, 249.
33. See Horst Bredekamp, *Darwins Korallen. Frühe Evolutionsmodelle und die Tradition der Naturgeschichte* (Berlin: Wagenbach, 2005), 50–61.
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36. Francesca Hughes, *The Architecture of Error: Matter, Measure, and the Misadventures of Precision* (Cambridge: MIT Press, 2014), 5.
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38. Thomas Pearce and Gary Edwards, "Remote Impressions: Roboformed Prototypes for a Nomadic Studio," in *Distributed Proximities. ACADIA 2020*, 2021, 4, https://discovery.ucl.ac.uk/id/eprint/10118462/1/PearceAcadia.pdf
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43. See Reinhard Wendler, "Zu einer Unschärferelation der Modelle," 140-141.
44. See Jorge Luis Borges, "Of Exactitude in Science," in *A Universal History of Infamy* (London: Penguin, 1946), 131.
45. See Francesca Hughes, *The Architecture of Error*, 251.
46. See Mario Carpo, "Vom Handwerker zum Zeichner. Das Alberti'sche Paradigma und die Erfindung des Bauplans in der Moderne," in Annette Spiro and David Ganzoni, eds., *Der Bauplan*, 280.
47. See Reinhard Wendler, "Zu einer Unschärferelation der Modelle," 134-136.
48. Michalatos Panagiotis, "Design Signals," 110.
49. See Kathrin Dörfler, Romana Rust and Florian Rist, "Moderation der Unschärfe. Experimente zur Verschränkung physischer und digitaler Formfindungsprozesse," *GAM* 10 (2014): 196–205.
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56. See Marjan Colletti, "The Awesome and Capricious Language of Past, Present and Future Digital Moods," *Architectural Design* 86-6 (2016): 118–125, doi:10.1002/ad.2120.
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