WHAT IF? WHAT NEXT?

SPECULATIONS ON HISTORY'S FUTURES

SESSION 1C

MODES OF ARCHITECTURAL HISTORY

Architectural History in the Digital, Virtual and Gaming Age/Space

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ENCODING MATERIAL CULTURE

Santiago R. Pérez | University of Western Australia

This essay attempts to resituate material practices as complex systems embedded within, and encoded by, multiple technological, cultural and social parameters. The goal is to 'unpack' modes of production affecting material culture, in relation to the rise of the post- digital artisan[1], and "Encoded Materiality."

The term 'material' is used interchangeably in this paper, within the broader context of material-practice or material-culture. The intent is to focus on the abstract conceptualization of materiality in architecture, rather than the physical attributes or properties, etc. of 'material.'

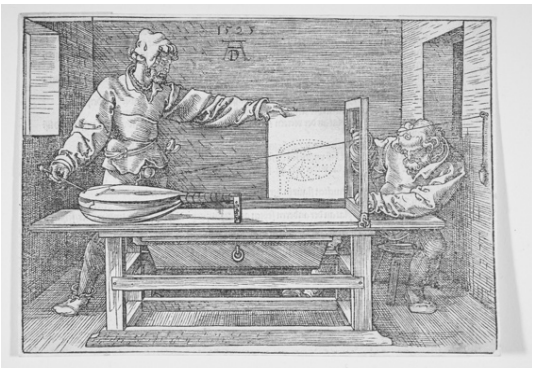
What is the role of the designer in a Post-Albertian, Post-Notational or Post-Digital era collapsing the distinctions between design and making? How do we reframe the conceptualisation and production of materiality in architecture, from the perspective of a renewed understanding of material-practice, dominated by the rise of the Post-Digital Artisan? An underlying aspect of contemporary material culture is the unresolved tension between both the suppression and elaboration of detail. Emerging material practices utilising parametric design and fabrication, implicitly question nineteenth and twentieth century conceptions of artisanry or craft, the relation to art, and the ensuing separation of design from production. By examining these relations, a more complex, non-binary configuration between design and making emerges as the hallmark of contemporary practices.[2]

In the context of SAHANZ, these questions examine the shifting relations of architecture as a hybrid mix of allographic practices, dominated by notational systems, with the re- emergence of (autographic) craft practices, guided by computational & robotic systems. This is relevant as a means to consider the evolving trajectory of architecture as a discipline informed by theoretical, economic, cultural and material systems, affecting both the conceptualisation and production of built work. The recent confluence of emerging technologies, in particular Robotic Fabrication, with modes of production incorporating specific material properties, workflows and practices, suggests a need for rethinking the historical relations between design + making, abstract notation and crafting. These developments suggest a new physical-digital conception of materiality, collapsing or combining the notational (drawing), the computational (model or script) and the material (tooling- workflow + material properties).

Methods

This paper presents both historical examples and references pertaining to the primary research topics, and case studies of the author's recent creative output, teaching and research, focused on the confluence between design, material-practices and digital crafting.

The methods employed in the author's work strive to maintain a critical engagement of the digital crafting process, combining hardware development, coding or parametric design of workflows, and specific material and tooling constraints. The examples illustrate the connections between abstraction of pattern, procedural or algorithmic control, and their relation to material resistance.



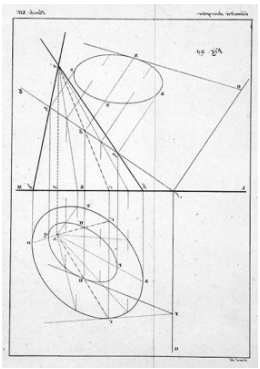


Figure 1. (L) Albrecht Dürer Draughtsman of the Lute c. 1525. The Draughtsman of the Lute MET DP816495.jpg via Wikimedia public domain license (CCO 1.0Universal).

Figure 2. (C) Monge, G. Géométrie Descriptive, 3é edition, Paris, 1811. Plate 14 from the 1811 edition of the *Descriptive Geometry* of Gaspard Monge (1746-1818), illustrated in Frank J. Swetz and Victor J. Katz, "Mathematical Treasures - Gaspard Monge's Descriptive Geometry," *Convergence* (January 2011).

Figure 3. (R) Alvar Aalto's wood bending experiments c. 1934. https://commons.wikimedia.org/wiki/File:Aalto_wood.jpg via Wikimedia Attribution 2.0 Generic license (CCO BY 2.0).

Parallel Trajectories: Material Systems + Geometric Description

Alberto Pérez-Gómez has suggested that *"Tools of Representation are never neutral."*[3] This may be extended to include Tools of (Material) Production, exposing the latent instrumentality of both architectural representation and material engagement, within contemporary creative practices. He goes on to elaborate on this statement, in what can be construed as a prescient indictment of emerging practices:

> Today we recognise serious problems with our post-industrial cities and our scientistic way of conceiving and planning buildings. Even the most recent applications of computers to generate novel (and structurally "correct," i.e., "natural") architectural forms, assume an instrumental relationship between theory and practice in order to bypass the supposedly old-fashioned prejudice of "culture," i.e., the personal imagination, with its fictional and historical narratives. It is imperative that we do not take for granted certain scientific assumptions about architectural ideation, and that we redefine our tools in order to generate meaningful form.[4]

The culture of architecture may be described as having parallel trajectories, one based on geometric description, the other, based on material systems, intuition, economy, and logic. The relation between Allographic practices (drawing + notation), and direct manipulation of material, as an Autographic method of discovery or tacit learning, has a long historical record in architecture. The diminishing separation between notational practices and physical, embodied material processes associated with artisanry, is a primary aspect of (Digital) material culture. Within a post-Albertian and post-notational culture of making, both the role of the designer, and our conceptualization of what constitutes 'material' must be rethought. Encoding Material as a product of direct interaction with the *immaterial* scripts and programs driving machines for

making requires a new conceptualisation of material-practice, collapsing the distinctions between the physical artefact and modes of representation, notation and control.

As contemporary theorist Mario Carpo observes, the shift to digital technologies called into question the difference between the 'autographic' craft-based original, conceived and made by the designer/builder, and the 'allographic' art-form relying on notational transmission of "scripted" original drawings, designed by an author, and executed by others. Allographic forms can be replicated, based on notations, scripts, etc. that precisely communicate the author's intent, and may be produced remotely without the embodied engagement or direction of the author.[5]

Dürer's drawing illustrating the *Tactile* construction of perspective (Fig. 1), embodies the latent relation between geometric description or notational practices relying on projection, and the physical transference of (spatial) information with the use of an instrument or *Tactile Process*. Pre-Digital (Albertian) modes of practice relied primarily on the translation from drawing to building (Fig. 2) using descriptive geometry and projection, however we may observe a parallel trajectory of *Tactile* learning and empirical modelling of form, with direct engagement of material.

Alvar Aalto's wood experiments (Fig. 3) suggest a different type of information transfer, through direct manipulation of material. Aalto's experiments provided practical information regarding the limits of bending with respect to specific properties. This mode of tactile learning influenced the development of an intuitive technical and geometric foundation for Aalto's furniture designs. The encounter with material also influenced, perhaps indirectly, the development of a language of form applied from the scale of material to the large scale of architecture.

The translation of notational practices based on projection, to contemporary CAD / CAM models, provided a means towards the full implementation of Notational or Allographic processes in early digital culture or the "First Digital Turn." In *The Projective Cast,*[6] Robin Evans documented the historical reciprocities between abstract notation systems and material practices, in the shift from a pre-digital to a contemporary mode of translation from drawing to building. His writing anticipated the imminent shifts occurring in architecture, regarding the transference of information between the abstract regime of notational practices, and the "encoding" of information from material practices such as ruled surfaces, or the complex *Traits* or drawings used to fabricate complex forms in stone.[7] These shifts re-introduced a pre- Albertian or artisanal mode of material practice in architecture, as Carpo, McCullough and others have documented in detail.

Two simultaneous modes of engagement with material emerged from a union of the allographic or notational, and the autographic or artisanal, as a result of Digital Fabrication. On the one hand, a shift is observed from the sequential iteration of form based on geometrical transformations (Eisenman), to the scripted, procedural (continuous) transformations made possible by parametric design and computation. This procedural, rule-based approach was thoroughly documented in Mitchell's *Logic of Architecture*, and forms the basis of contemporary algorithmic design.[8] The second mode of engagement stems not from the abstraction of rule-based iteration, but rather from the physical properties, limitations and possibilities of material itself. If Computation released the designer from the tyranny of repetition, Digital Fabrication created the opportunity for variation or *Versioning*,[9] based on specific workflows or *Tooling*, establishing both new Material Economies, and languages of form derived from specific material processes.[10] As Aranda and Lasch noted:

> Tooling is about what rules exist within this hypothetical "pre-material" state that influence its movement into the realm of the material. [11]

These new relations between rule-based design or code and material suggest a capacity to transmit embodied material intuition previously found in Autographic practices such as Sculpture or Painting, towards the production of architecture influenced by a shift from (geometric)

representation, towards a conceptualisation of form relying on continuous feedback or engagement with material.[12]

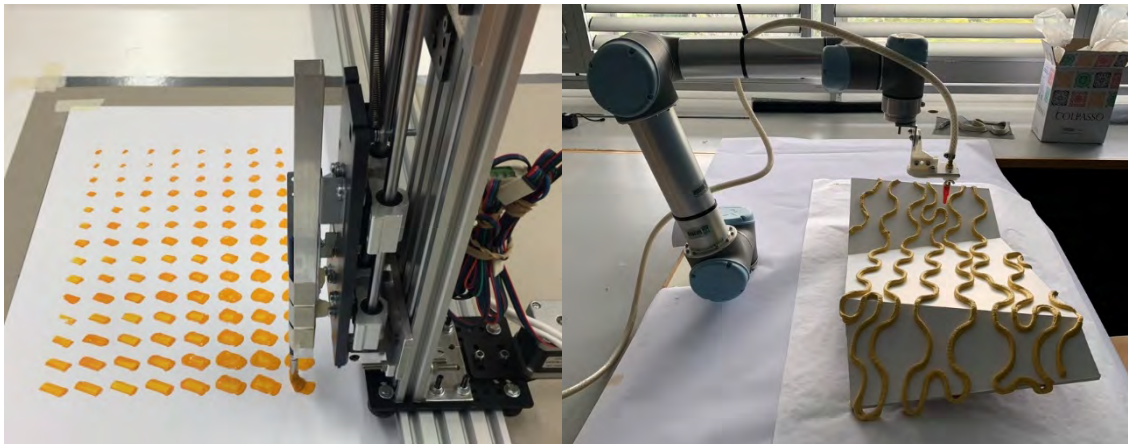


Figure 4. (L) Parametric Pigment Painting Series, S. R. Pérez 2019.
Figure 5. (R) Robotic Polymer-Clay Printing on Folded Plane, S. R. Pérez 2020.

The "Post-Digital Artisan"

The emergence of the Post-Digital questions both the emerging protocols of representation or *drawing codes,*[13] and digitally mediated crafting, as illustrated by the recent use of the term across multiple contexts involving both representation and making. The emergence of the "Post-Digital Artisan" is made possible by the confluence between (Procedural) codes, with the empirical and intuitive understanding of material (Figs. 4 and 5).

Two examples from the author's research illustrate both the algorithmic control of pattern, and the encounter with the viscosity or physical resistance of a (material) medium. In the Pigment Painting Series, the pattern is controlled by the parametric variation or spacing, and the micro-control of the brush, in response to the fluid medium. In the Folded Plane Printing, the robotic control must respond to both the geometry of the folded plane, and the need to maintain a constant speed in response to the viscosity of the robotic extrusion.

The relation between design and making evolved in response to the evolution of "craft" beyond the limits of unmediated hand-making, and the shift from a notational to an algorithmic culture heavily influenced by computation and digital fabrication. This in turn has led to the rise of the "Post-Digital" artisan, critically examining the limits of technical innovation, and no longer adopting new technologies merely as novel tools for invention. The coupling of digitally mediated design and making is in itself not a recent phenomenon- the emergence of CNC and digital fabrication has been a central aspect of experimental practices for at least the past two decades.[14]

Contemporary material culture maintains a nuanced relation between design and making, beyond the initial novelty of parametric scripts and "tooling" workflows, towards a "Post-Digital" artisanal culture, critically examining the potential of both code and material. This topic has a deep lineage, from the (pre-digital) writings of David Pye, and the critical reflections of Juhani Pallasmaa, to the understanding of digital cultures of making by Malcolm McCullough (Abstracting Craft) and Mario Carpo (The Second Digital Turn, The Alphabet and the Algorithm). Early examples of digital craftsmanship introduced the concept of a continuous *"Digital Chain"* [15] connecting design and material from conceptualisation, modelling, to fabrication. The emergence of robotic fabrication provided a means to reintroduce the circular feedback that was usually attributed to the tactile, intuitive intimacy of pre-digital, artisanal or craft processes.

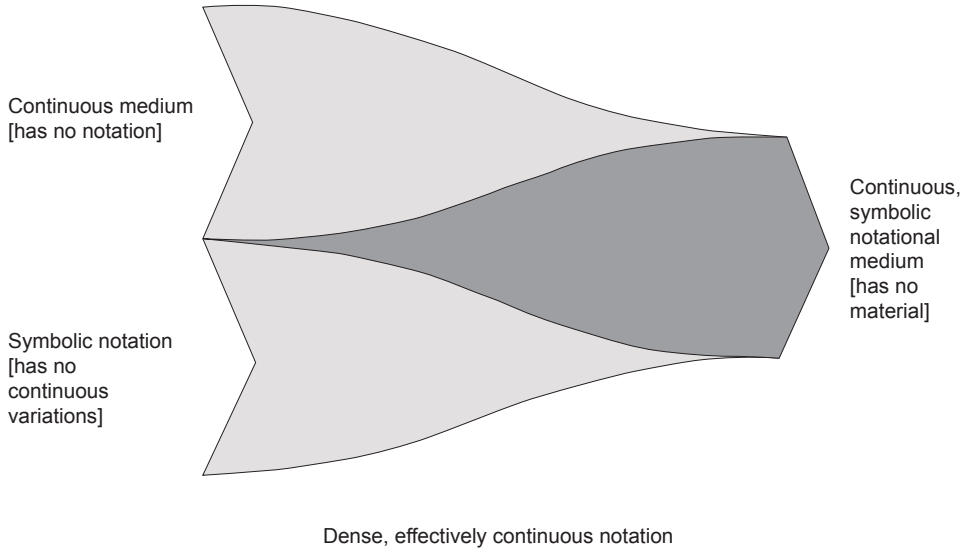


Figure 6. Notational Density Diagram. Redrawn by Author from original in Malcolm McCullough, *Abstracting Craft,* 1998, 215.

Notation and Medium

The possibility of a merger between Allographic and Autographic modes of engagement between digital and material mediums, emerges as a result of *"Notational Density"* (Fig. 6)[16] This is described by McCullough as existing between two extremes: a continuous medium (with no notation), and a continuous, symbolic notational medium (with no material). This new Post-Parametric relation provides a means to re-examine or re-situate architecture's hybrid or mixed status (Nelson), incorporating both craft and notation.[17] This complex relation between material practice and computational design, questions the tenuous reliance on an 'Albertian' or allographic model.[18] From our current perspective, the historical shift from "identicality" (Carpo) towards variation or differentiation of form was based primarily on development of parametric, computational or procedural practices. It can now be seen as a more complex and intertwined relation between *Code* and *Material* or medium, within a Post-Digital or Post-Parametric culture of making.

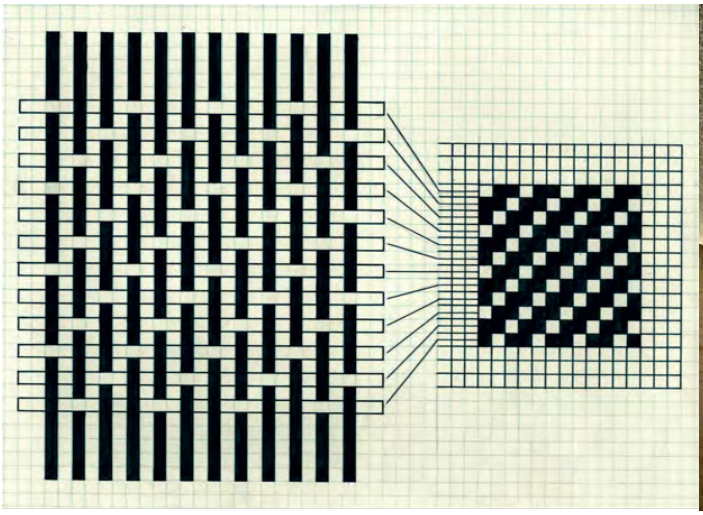


Figure 7. (L) Draft Notation diagram by Annie Albers.

Figure 8. (R) James Birrell, Union College, University of Queensland. Photograph S. R. Pérez 2019.

Notation and Pattern

The comparison between representational, pictorial or compositional modes of production, and procedural or notational abstraction of pattern, is revealed in both artistic practices and architecture in (pre-digital) 20th century examples. The development of pattern-logic or notation was examined at length in the analysis of weaving, by Anni Albers, in her *Draft Notation*[19] diagrams and constructions (Fig. 7). The reduction from a pictorial diagram to a binary "on-off" pattern, reveals the link between the mechanical loom and process of weaving (material), and the precursors to early computational mechanisms and processes. No doubt Albers was aware of the influence of weaving as a process, and the mechanism of the Jacquard loom in particular, controlled by a pattern of holes in a punch-card, in the development of the "Analytical Engine" of Charles Babbage.[20]

In the work of Australian architect James Birrell, we observe both pictorial or compositional influences in tiling patterns (in the Wickham terrace car park, Brisbane, 1961) and brickwork determined by notational patterns recalling textile weaving (Fig. 8). The Agriculture and Entomology building, University of Queensland, completed in 1969, is a study in both notational patterning and fluid geometry, subtly embedded within an otherwise nondescript external brick wall.[21] In addition to the patterned brick, the spatial joint between the wings of the building, reveals an extraordinary cast concrete curved scupper roof detail, belying the architect's interest in dynamic geometries inspired by Arp and Laszlo Moholy-Nagy.[22] While beyond the scope of this essay, Birrell's oscillation between subdued rational modernism, and the exuberance of geometry and pattern, deserves detailed analysis in its own right.

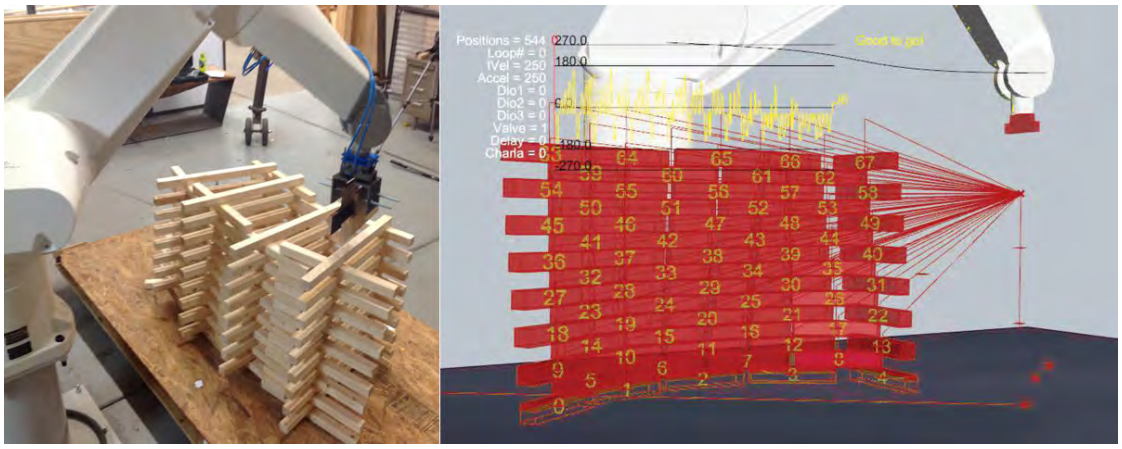


Figure 9. Robotic Module Fabrication + Point Sorting. Fabrication Research by Author, 2015.

Procedural Material: From Geometry to Choreography

The autographic link between author and material practice is questioned with the advent of conceptual art practices, for example in the wall drawings of Sol Lewitt, who dictated specific procedures for painting as an "original" code, script or score, to be executed remotely, as the most valuable aspect of the work. Beyond the issues of "Authenticity and Identicality," topics beyond the scope of this paper, we may consider the emergence of a ***non-standard series*** as an emblematic aspect of contemporary material culture. Defined *"not by its relation to the visual form of any constituent item, but by variances, or differentials, between all sequential items in the series."* [23]

The 'collision' between compositional and geometric strategies in architecture, versus the notational encoding of material in space, has been a subject of research in built work directed by the author. The procedural stacking of unit elements, to create precisely patterned structural components or modules, necessitates a rethinking of Form, from a Geometric to a Choreographic

field of operations (see Fig. 9). This project has been well documented in previously published research, as an example of the "gap" between Procedure and Material Instantiation[24]

The direct-engagement with drawing and material, is now mediated and distanced by codified procedures and parametric models, while at the same time creating an instantaneous feedback loop of material-processes, informing the (indirect) control of form by shifting from a Geometric ideal to Choreographic control of movement. [25]

Thinking with Material: From Noun to Verb

Moving beyond earlier conceptions of craft or workmanship (Pye)[26] and Tectonics (Frampton)[27], the rise of digital materiality combines the (20th century.) modernist legacy of efficiency and reduction, with the (19th century.) engagement with detail and ornament. Contemporary material practices combine performative and aesthetic systems towards a confluence of economy and expression or 'Material Effects.'[28] This immediacy proposes to collapse the distinction between thinking and making, shifting from the slowness and distance of 'construction' to the speed and intimacy of fabrication practices. In a very real sense, material is now a progenitor of form. [29]

To understand the role of digitally mediated material practices in architecture, in relation to both the distancing and immediacy of the (body), we may compare current modes of making with conceptual art practices altering our relation with material, from noun to *verb*. In his early work, the sculptor Richard Serra used a "verb List" composed of 84 verbs, such as: "*to roll, to crease, to fold, to cut, etc."* to initiate specific material processes involving the body, combining an abstract system of operations with the physicality of production.[30] These autographic, embodied practices are also evident in the Action Paintings of Jackson Pollock, and the large scale blade-scraping processes of abstract expressionist painter Gerhard Richter. In comparison with these examples, *I Digitally Mediated Body* extends our ability to engage materiality, via prosthetic tools and processes moving beyond the direct engagement of the Hand as an instrument.[31]

Serra's early work utilised the *Gesture of Making*, a term used in the writings of philosopher Vilém Flusser. Whereas Alberti insisted on the separation of design (Allography) from production, Flusser reminds us of the prejudice against making in Western culture that he identifies as beginning with Plato's rejection of *techne*.[32] Within this context, Flusser dissects the various encounters between raw material and the hands, in terms of contemplation, research, production, fabrication, etc. Ultimately the hands encounter *'resistance.'* Examined from the historical perspective of "craft," this obstacle to the forming of material is proposed to give value to making, allowing creativity to flourish. However, this is a much contested position stemming from 19th and 20th century modes of practice, from Ruskin, Semper and Loos, in comparison with today's proponents of "Digital Crafting."[33] Hands, considered by Pallasma[34] as supporting creativity through direct contact with a medium, have now been replaced by an extended view of Embodied Material Practices. Emerging design practices move past the binary body- machine dichotomy, combining earlier technical and intuitive practices towards *Material Computation.*[35]

To escape the simplistic view of representation versus materiality, a continuous relation between model and material must be maintained. The *Persistent Model* provides a bridge connecting representation and material, in a continuous (non-linear) feedback loop.[36] By "Co-evolving Geometry and Material," we "move beyond the precise description of explicit geometry to deploy, in some way, the behaviour of matter within processes of formation.[37] The co-evolution of model and material may be situated within a larger historical framework, for example the hanging chain model of Gaudi, the cable networks of Frei Otto, or the concrete shell models of Isler. Persistent Modelling moves the concept of "Form-Finding" from analogue practices to digital material logics. The shift from material resistance to *material persistence,* is based on a "negotiatory process of transformation, feedback and iteration. [38] The primary value of this concept is to move away from the deterministic notion of a model as an explicit representation, towards "limits that emerge implicitly."[39]

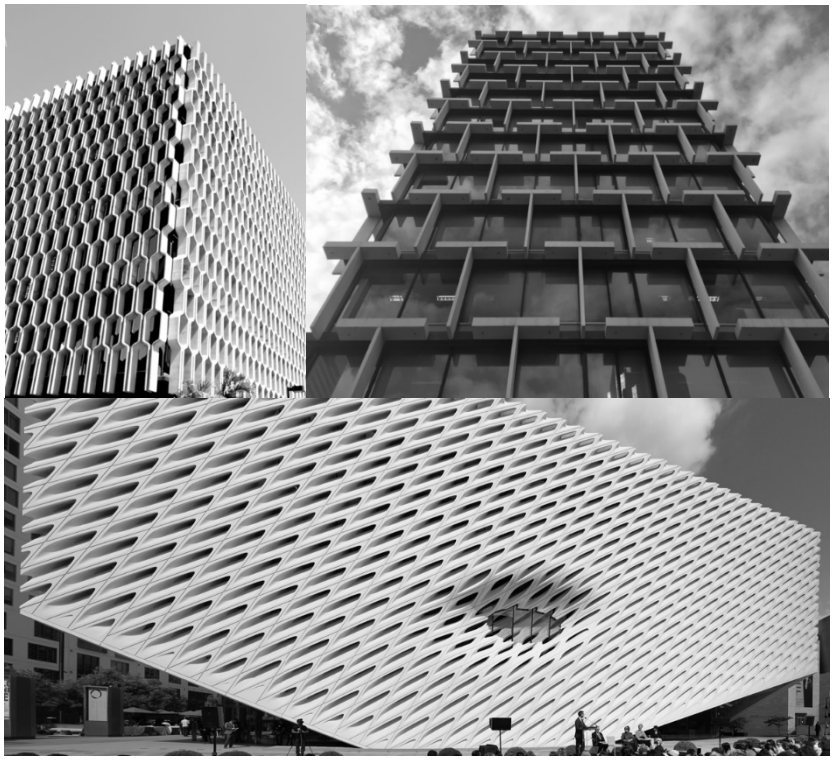


Figure 10. (Above, L) IBM Building, Oahu, Vladimir Ossipoff 1962 (Photograph S. R. Pérez 2009).
Figure 11. (Above, R) Council House, Perth, Howlett and Bailey, 1962-63 (Photograph S. R. Pérez 2018).
Figure 12. (Below) Broad Museum, Los Angeles, Diller Scofidio + Renfro, 2015. Source: https://commons.wikimedia.org/wiki/File:The_Broad_Museum_Preview_(21658765245)_cropped.jpg.

Beyond Material: From Intensive Differentiation to Discrete Assemblies

In contemporary design two simultaneous trends may be observed, in relation to material-practices. On the one hand, an extreme differentiation of material towards mass-customized variations, and on the other, the radical rethinking of repetition and sameness of material, reduced to an abstract pixel, voxel, or "discrete assembly."

Material systems may be considered, from a historical perspective, to be the result of a techno-poetic merger of aesthetic, economic, technological and physical constraints. 'Material Cultures' emerge when these multiple influences align, creating new design opportunities. The IBM building in Oahu by Ossipoff, and the Perth Council House by Howlett & Bailey, completed in the early 1960s, exhibit a pre-digital materiality constrained by material economy. The mirroring of precast concrete shade elements in the IBM building provide a means to extend the compositional limits of repetition, while utilizing identical forms for the production of the precast facade. Similarly, the Council House in Perth exhibits the compositional limitations of repetition, in this case extended by the discontinuous placement of T-Shaped tiled concrete elements. The limitations of a material system based on identicality, is most evident in the difficulty of transitioning material at the corners of the buildings.

In contrast to these examples, the Broad Museum in LA by DSR, exhibits an extreme differentiation of individual elements, while propagating self-similar elements in a non-standard series. This is made possible by the confluence of computational design, the material economy based on robotic milling of GFRC formwork, and the optimization of shading or views through the application of parametric design strategies. These factors, taken together, engender a new material regime or culture, combining the aesthetic, procedural and material possibilities inherent in Post-Digital materiality. Understood in this manner, material is *encoded* with the marks of its conceptualization, systems of production and material properties (Fig. 13).

Figure 13. Robotic Clay Printing 2020 (prototyping research by Author's students). Photograph S.R. Pérez 2020.

In his short essay titled "After *After Geometry,"* the architect and provocateur Michael Meredith attempts to unpack contemporary modes of engagement with digital and material processes, through the lens of pre-digital and current post-digital practices. He begins by comparing the pre-digital diagrammatic or "stop-motion" tendencies of Peter Eisenman, with the fluidity and continuity of form made possible by animation software and digitally mediated practices, most notably via the writing of Greg Lynn, who inaugurated (or at least curated) the early dissemination of shifts away from (static) geometric models towards more dynamic modes of production. Meredith continues unpacking this trajectory, through the lens of "Deconstructivist" architecture of the early 1990s, and ultimately begins to re-situate the relation between architectural form and materiality as a *"Particle,"* where:

> The specific relationship of part to whole is different, because there is no compositional or pictorial whole.[40]

If we consider this trend in the context of repetition and variation, or more generally as a renewed engagement with *Process* over Form, *'Material'* begins to lose its primacy as an encounter with physical properties, or resistance, and instead becomes an elemental unit, particle, pixel, or atomized presence, encoded with specific geometric, spatial and physical parameters. These parameters are embedded in the digital-physical stream of information that flows from conceptualisation, to procedural encoding, to material-process.

Conclusion

This essay attempts to map possible trajectories of making in contemporary design, influenced by a range of material-practices questioning the relation between representation, procedure logics and control. The intent of this research is to establish a critical perspective on the contemporary culture of making, both as a pedagogical foundation, and as a resource for continued applied research. The author is currently developing robotic fabrication workflows and procedures, questioning the relation between the "embodied materiality" and advanced fabrication technologies. 'Encoding Material' re-situates 'Making' as a foundational aspect of (architectural) design, and the Body as an active agent in the continued evolution of Craft.

Endnotes

[1] For a brief look at the term Post-Digital, refer to Yael Reisner, *Beauty Matters: Human Judgement and the Pursuit of New Beauties in Post-Digital Architecture,* Architectural Design Journal (John Wiley & Sons, 2019), 10-21.

[2] For an excellent examination of Detail and its relation to parametric design, see Peggy Deamer, "Detail Deliberations," in *Building (in) the Future: Recasting Labor in Architecture,* edited by Peggy Deamer and Phillip G. Bernstein, 80-88. New York: Princeton Architectural Press, 2010.

[3] Alberto Pérez-Gómez, "The historical context of contemporary architectural representation, in *Persistent Modelling: Extending the role of architectural representation,* edited by Phil Ayres, 13-25. New York: Taylor & Francis, 2012.

[4] Ibid, 14.

[5] Consider the reversal of the Albertian Paradigm, in Mario Carpo, *The Alphabet and the Algorithm* (Cambridge: MIT Press, 2011), 44–48.

[6] Robin Evans, *The Projective Cast: Architecture and Its Three Geometries* (Cambridge: MIT Press 1995), 272-320.

[7] Ibid.

[8] William Mitchell, *The Logic of Architecture* (Cambridge: MIT Press 1990).

[9] See the introduction to "Versioning: Evolutionary Techniques in Architecture", in AD Journal, Vol. 72, No. 5 (London, Wiley-Academy, 2002), 7-9.

[10] Refer to Nader Tehrani, "Digital Synthesis" in Thomas Schröpfer, Material Design, (Basel, Birkhauser, 2011), 34-47.

[11] Benjamin Aranda and Chris Lasch, *Tooling: Pamphlet Architecture 27* (New York: Princeton Architectural Press, 2006), 8.

[12] For an example of the shift from traditional craft to Digital Crafting, refer to Matthew Schulte, et al., Digital Steam Bending: Re-Casting Historical Craft Through Digital Techniques, in ARCC Journal, 2011.

[13] "Exhibition: Drawing Codes," CCA Architecture, accessed December 10, 2020, http://digitalcraft.cca.edu/research/drawing-codes.

[14] For example, refer to Branko Kolarevic, "The (Risky) Craft of Digital Making" in *There: Journal of Design* (Minneapolis: University of Minnesota, 2010), 24–33.

[15] Philipp Dohmen, et al., "*Digital Chains in Modern Architecture,"* eCAADe 25 *Proceedings,* Session 17: Digital Fabrication and Construction (2007): 801-804.

[16] Malcolm McCullough, *Abstracting Craft,* ((Cambridge: MIT Press 1996), 214.

[17] Nelson Goodman, Languages of Art (Indianapolis/Cambridge: Hackett Publishing, 1976), 281-221.

[18] Mario Carpo, *The Alphabet and the Algorithm* (Cambridge: MIT Press, 2011), 44–48.

[19] Anni Albers, On Weaving (New York: Princeton University Press, revised edition, 2017), 20-33.

[20] Ellen Harlizius-Klück, "Weaving as Binary Art and the Algebra of Patterns," *TEXTILE*, (2017) 15:2, 176-197, DOI: 10.1080/14759756.2017.1298239

[21] Andrew Wilson and John Macarthur, eds., *BIRRELL: Work from the Office of James Birrell* (Melbourne: NMBW Publications, 1997), 50-85.

[22] Wilson and Macarthur, 33.

[23] Carpo, p. 99.

[24] Santiago Perez, "Loss of Control: Error, Glitch and Imperfection in Architecture," in *Lineament: Material Geometry and the Physical Figure in Architectural Production, edited by Gail Borden and Michael Meredith,* 156-173 New York: *Routledge, 2017.*

[25] Ibid.

[26] David Pye, The Nature and Art of Workmanship Cambridge University Press, 1968), 30-37.

[27] Kenneth Frampton, *Studies in Tectonic Culture* (Cambridge: MIT Press, 1995), 335-376.

[28] Refer to Gramazio and Kohler's essay, Towards a Digital Materiality, in B. Kolarevic and K. Klinger, eds. Manufacturing Material Effects (New York: Routledge, 2008), 103-118.

[29] Refer to Materiality Into Architecture, S. Kieran and J. Timberlake, in Refabricating Architecture (New York: McGraw-Hill, 2004), 118-121.

[30] Richard Serra, Verblist, (collection of the Museum of Modern Art, 1967-68).

[31] Dickey, Rachel, Cultural Prosthetics: Mediating Bodies, Technology and Space (CAAD Futures 19), 506-520.

[32] Vilém Flusser, Gestures (Minneapolis: University of Minnesota Press, 2014), 32-47.

[33] Deamer, 81-86.

[34] Pallasmaa, J 2009, The Thinking Hand: Existential and Embodied Wisdom in Architecture (New York: Wiley 2009)

[35] Refer to the issue of Architectural Design devoted to the topic of Material Computation; Menges, Achim, ed., Architectural Design (New York: Wiley, March / April 2012), 34-59.

[36] Paul Nicholas, "Persisting with Material," in *Persistent Modelling: extending the Role of Architectural Representation,* edited by Phil Ayres, 132-140. New York: Taylor and Francis, 2012.

[37] Ibid, 133.

[38] Ibid, 135.

[39] Ibid.

[40] Michael Meredith, "After After Geometry," *Architectural Design Journal* 83, no. 5 (September / October 2013): 103.