The Toolpath Problem: Compressing Representation and the Real

"A grid was laid out on the floor of a large warehouse at full scale, and the curve was then 'plotted.' At full scale it was found to have some kinks and waves, so Tucker [the concrete contractor] laid out a long length of rubber hose between the points, which he and Kreuger [his foreman] than adjusted an inch or two to give an even though irregular curve. Next templates were cut to fit the curves. Formwork was then made by Nova Scotia shipbuilders specially taken on for the job."[1]

GABRIEL FRIES-BRIGGS
University of California, Los Angeles

NICHOLAS PAJERSKI
University of Southern California

BRENDAN SHEA
University of Southern California

In his analysis of the Carpenter Center, Stan Allen quotes at length this passage from Le Corbusier at Work.[2] The recollection of pouring the building's curved slabs illustrates Allen's point that a series of material transformations were required to bridge between the drawn "curves of the studio" and the instructional path for tools (or the complex translation from drawing to building). In the inch or two gap between the hand-drawn curves of the plan and the final full-scale curvature of the slab, lies a methodologically different form of translation. The materiality of a rubber hose provided the construction translation on-site when plotted coordinate scaling failed. A continuous flexing line that responded to adjustments made throughout it's length supplemented the point of the pen on paper that drew the studio curves. Beyond a testament to the ingenuity of Le Corbusier or the people around him, the Carpenter Center's rubber hose calls attention to a problem lurking behind modes of architectural production and reproduction—the toolpath problem. Le Corbusier's divergent toolpaths point to many of the problem's persistent themes: the directionality of translation, the resolution of materiality, and the toolpath's relationship to the body and to tools of architectural production.

TOOLPATH

Despite this background of complex engagements between design, drawing and making, architectural discourse most commonly links the toolpath with computer aided manufacturing, or CAM. CAM, a method of automating mechanical action, arose first in the automotive and aeronautical industries and were only later adopted in architecture. The earliest CAM program UNISURF was developed by Pierre Beziers for Renault in the 1960s and rapidly altered the process of car body design and tooling by increasing the efficiency and accuracy of milling clay models—a practice common to the prototyping and manufacturing stages of the production process.3 CAM protocols sought above all else to address the

frequent problem of inaccuracies encountered during the design and production of surfaces with complex curvature native to car body design. As such, this methodology narrowed discrepancies between drawing and making. This model finds a nearly-direct equivalent in the field of architecture as digital fabrication.

The toolpath as a problem has a deeper history than within the narrow confines of digital fabrication techniques, yet can be newly conceived in our computational moment and at the end of the early digital age in architecture. Fundamentally, the toolpath is a set of instructions operating between making and drawing, material and line, working and designing. As such the toolpath acquires its potency by compressing a form of representation with instructions for fabrication. Through this compression the toolpath provides a specific, bounded, operative area of investigation for the discipline, largely because of its medium-insolubility, or resistance towards simple categorization within one of architecture's more well-established representational protocols (plan, section, axonometric). The toolpath as a medium is ripe for experimentation when appended to this standardized set of architectural representations.

Mapping the toolpath against architects' most basic methods of production: drawing, writing, and making paints an a-chronological portrait of working through the problem across architecture's protocols. If the toolpath has emerged as a more discrete medium for cutting across protocols in the late digital age, it can also be seen as a latent problem that has historically suggested diverse entanglements of these protocols.

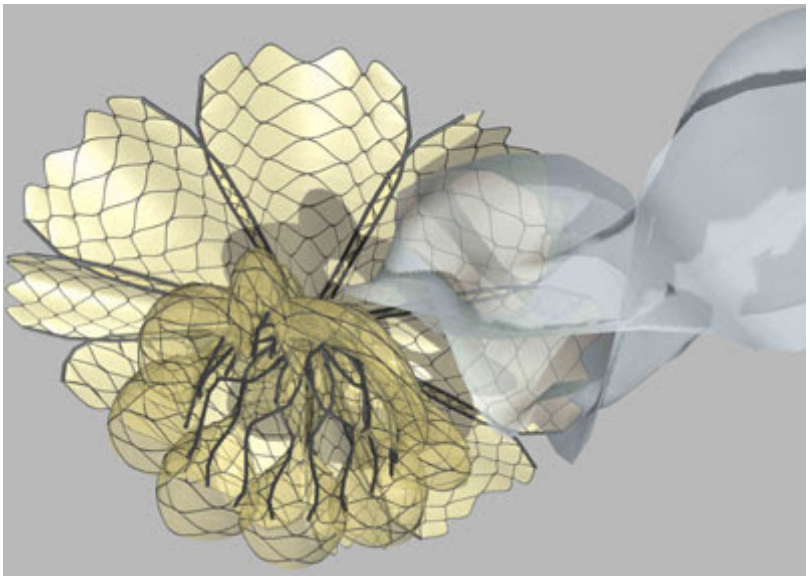
DRAWING (PROJECTION)

A well established discourse draws the disciplinary boundary between architecture and other forms of artistic production along the problem of projection. Defining architecture as the translation from drawing to building, Robin Evans's definition of the architectural discipline casts architecture as a series of lines that mediate between the act of intellection and the act of materialization. Stan Allen recapitulates Evans on the problem of projection by stating that projection,

> "[E]xists between these two seemingly opposed worlds: the fluidity of geometry's graphic means and the concrete, material reality of the building. We are reminded that architecture is a complex intellectual labor, carried out with highly specific tools, and yet at the same time, it is never reducible to the catalog of those tools or techniques. 'Projection,' Evans writes, 'breaches the boundary between the world and self.'"[5]

Evan's characterization of architecture along the problem of projection points to the latent promise of lines; to be constructed as part of a system of abstraction instructing materialization. From their inception, Evans's lines are aware of their own limits and liberties according to the concrete processes of material translation to which the contours describe. The unidirectional flow between drawing and building is opened up as a primary mode for disciplinary investigation.

Architectural advances occur through incremental changes in the translation of the effects of drawing to the effects of building. Evan's definition of architecture as the problem of projection does not explicitly encode toolpaths—instructions concerning the working of implements and the handling of matter for architectural fabrication. However, the act of drawing does provides a meaningful set of working abstractions that refer to the act of building, primarily through constraints imposed by the latter. Puzzlingly, the new tools, techniques, and



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episteme corresponding with the introduction of the computer into the design studio, have heralded in changes to architecture's working protocols and core values (including composition, structure, and ornament), but left the translation from drawing to building relatively unscathed.

An examination of Building Information Modeling illustrates a difference between the toolpath and a distinct counterpart, the digital model. BIM extends the architectural representation beyond conventional two dimensional drawings (plan, section, axonometric) and three dimensional models in order to manage the entirety of the dimensions informing a design, including: time, cost, construction, and tooling. BIM positions the toolpath as merely one among a host of derivatives able to be extracted from a comprehensive model. Deriving the toolpath directly from the three dimensional model has become the most common approach in the studio for both pedagogy and practice. Toolpaths for rapid prototyping are extracted from the geometry of a digital design surface model—producing geometric abstractions to specifically match the syntax and file type of the intended machinic output.

The digitization of the toolpath reformed architecture's disciplinary identity and catalyzed an aesthetic project through the toolpath's capacity for customization, variation, and intricacy. New digital tools capable of producing variation necessarily engaged disciplinary protocols of both representation and fabrication, albeit unevenly—with representation governing fabrication. The alignment of the two through digital tools gave birth to endless compositional play. Virtual tools for digital animation set the stage for the "digital-to-physical" practice, as the paradigm of *Intricacy*.[6] Difference and variation became the focus of technical experimentation, pointing toward a deeper tendency of architecture to chase after effects arising first in representation.

With *Intricacy*, Greg Lynn championed the introduction of drafting techniques native to ship construction, into architectural design. Spline curvature became an available drawing principle after relationships abstracted from the material behavior of wood bending during hull construction were instrumentalized. Representation based on splines produces effects of smoothness, continuity, and variation. The project of *Intricacy* took this a step further into the articulation

Figure 1: Greg Lynn. *Lamp*. Intricacy Show. 2003.

2

of digitally smooth (spline modelled) surfaces highlighting variation, customization, and quantity—further synthesizing the ideal relationship between the digital model and physical form.[7] The alignment of form and production framed the toolpath within an increasing interest in the fidelity of digital modeling.

Nat Chard has produced a set of drawing tools that encapsulate the instructional precision of the toolpath into operative devices, or Instruments. Each device establishes a protocol for setting ink into ballistic motion as a means of drawing.7 In contrast to the tight-fit between drawing and building proscribed by orthographic projection, these instruments opt for processes of translation that are fundamentally more indeterminate (throwing, flinging, dropping, etc.). Pursuing the potentials of the loose-fit, these investigations provide a structured, procedural, yet experimental, approach towards making marks on surfaces, volumes, and bodies. As a form of architectural production, these procedures imply a change in the order of operations for the discipline; the the toolpath initiates an act of materialization that produces a drawing. As such, the changing role of the drawing implies prediction, anticipation, and interpretation of the particularities of the toolpath as primary tools for authorship when encountered at the intersection of designer and machine. The device-toolpath relationship provides a means to systematically leverage the toolpath towards the indeterminacy of projectile motion as a compositional strategy for drawing.

Suggesting a new relationship between drawing and making at the nexus of the toolpath opens up a the potential to re-engage the body during architectural production. Chard reexamines the drawing office in Ford's airplane factory where 1:1 scale orthographics were too large to be produced as portraits and necessitated a shift to horizontal drawing boards and direct bodily contact with the drawing surface. These very large drawings provide an example of the compression between representation and fabrication through the the point-for-point correspondence between the drawn line and it's instructions for materialization in the built artefact. In this instance, the path of the draftsman approximates the work of the toolpath. Moreover, this full-scale representation necessitates physical engagement calibrated by dimensional and ergonomic specificities of the body of the draftsmen as enter the "interior" of the drawing surface.

> "The physical engagement of the draftsman with the surface make the drawing important as a thing as well as an image...They suggest that the drawing

Figure 2: Nat Chard. Cover Image for Pamphlet Architecture 34, Fathoming the Unfathomable.

has the capacity to be occupied as well as represented. They illustrate ways in which the drawing can bridge between material and pictorial space."[8]

The reference and impact of the body in Chard's work is an example of the impact strategies of projection can have when materialized or removed from their normative coordinate systems. Displacing drawing information through multiple dimensions is analogous to the reverberation of the toolpath when projected into the space of production and its necessary social impact. Machines are overseen, material is prepared, and bodies are conducted according to the instructions of the tool, and vice versa. Existing in a multidirectional state and projected between responsibilities, both visual and nonvisual, the toolpath is not a drawing, nor a score, nor g-code—but a compression of these mediums.

Although the toolpath as a mode of representation has gained new agency in recent decades, working through the problem of the toolpath as a matter of representation can be traced to the Renaissance. Descriptive drawings for the construction of stone architecture were necessarily concerned with the path of tools in addition to or in conjunction with the overall form of stone blocks. This was particularly the case when stone was left exposed, without a layer of plaster or other finish, as the cuts to make the block were the same that shaped the ornamentation. In his expansion of stereotomy, Philibert de l'Orme's created meticulous panneaux or development boards that demonstrated the precise means for cutting stone blocks in vaults.[9] The representation of the stone mason's toolpath through *panneaux* served as more than a constructional translation. De l'Orme worked through the *panneaux*, a direct engagement with the medium of the toolpath, as a means of arriving at the holistic form of vaults and their ornamentation. Here the compression of aesthetic and tectonic takes place in the path of the tool.

Rewriting the toolpath as a representational strategy in contemporary architecture discourse opens up new means of addressing the problem. As an expanding system of graphic notation, toolpaths now circulate more freely in the space between drawing and fabrication techniques. While continually underwriting architectural production, the toolpath has also remained on the margins of architects' graphic production. As such, it remains less tethered to the mark of the author. It is neither the product of the genius architect nor the anonymous craftsman. When robotic fabrication was introduced into the production of stone pieces for the Sagrada Familia in the 1990s, the architects dedicated themselves to replicating the mason's mark on finished surfaces.[10] The 5.5mm grooves cut by CNC saw mimicked the traces of hand tools. The continuity from the mason's mark to the robotic grooves reveals an effort to extend the anonymous index of craft through distinct methods of engaging materialization in architecture. The toolpath across history both connects and obfuscates the link between authorship and object.

WRITING (CODE)

Similarly destabilizing and disseminating authorial identity, the mechanical reproduction of texts minimized variation through the protocols of duplication. Mario Carpo contrasts the recent capacity for customization in file-to-factory production with the standardization of texts following the introduction of the printing press.[11] Mechanical standardization took hold in both architectural design and building production as well, limiting variation in favor of identicality. While the predominance of identical and master copies is far from gone in contemporary

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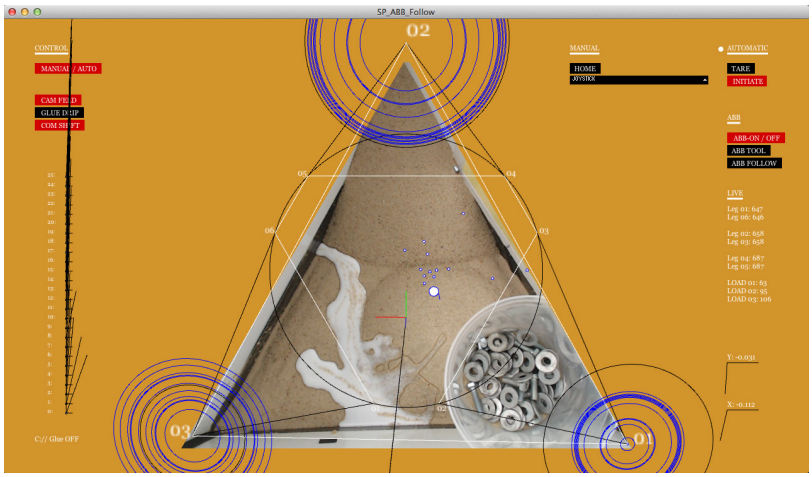
practice, digital technologies and more recently the rise of computation has reinvigorated non-standard methods of reproduction.

The pervasiveness of writing instructions for variable looseness has been a growing concern of practitioners for the last half century. This has been the case in both architecture and related fields, particularly art. Drawing and building have been guided by rapidly proliferating forms of graphic notation and text, much of it in service of blurring the boundaries between designer, author, user, and builder. Bruce Nauman's text-based directives, Robert Smithson's pours, and Sol Lewitt's instructed drawings described various efforts to free up the toolpath in relation to the author, producer, and work. In Robert Smithson's *Glue Pour*, a bucket of glue is overturned at the top of a dirt incline. Photographs capture the state of the earthwork as the glue runs over the dirt, down the hill. Reading this piece within the framework of the toolpath suggests two routes for exploration. In the first, the toolpath is the transportation of the bucket, it's placement, and subsequent tipping. The artist is present in the toolpath only inasmuch as she fixes the buckets location and selects the direction in which to knock it over. In the second route, another toolpath is created by the edge of the glue as it works its way across the landscape; in Smithson's vision, an investigation of entropic processes. The industrial material of the glue generates a form as it comes into contact with geologic surfaces. More recently in architecture, the pursuit of chance, stochasticity, and emergence have been used to describe an engagement with the physical world and materiality via exploration of toolpaths across diverse media. This work has expanded the discipline's use of toolpaths to pursue divergent aesthetic, political, and perceptual notions of the real.

Of the many new forms of architectural texts, perhaps none have become so pervasive as architects writing code. More often mediated through software

Figure 3: Robert Smithson, Glue Pour. Vancouver, Canada. 1969.



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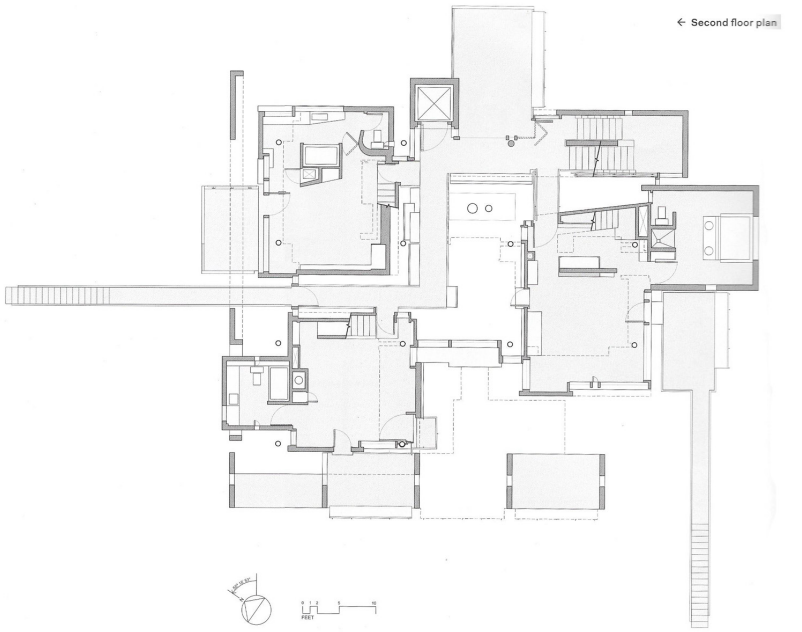
than directly written, code has become a pivotal tool to engage computation toward simulation and emergent processes. Although these computational categories have had severe effects on architectural form, they fall roughly within the standard directionality of abstracting material processes into drawing to be subsequently constructed or physically output. In effect, architects writing code has not upended utilization of the toolpath toward pre-determined geometric inscription. An engagement with the toolpath's specificities, on the other hand, its portability, abstraction, and translational effects, has reopened investigations into matter's indeterminacy, contingency, and entropic realities. In engaging these properties of matter, architectural models of authorship are necessarily less concrete and more social.

It is, in part, a loosening up of methods of writing toolpaths, that explains the three-author structure of this paper. Our own work to define a bidirectional toolpath produced a collective framework for design and materialization. An instantiation of this framework inscribed in a series of instruments and their choreography with us as designers through writing code, illustrates the inevitably social nature of this work. In *Performing on Prepared Instruments*, a series of scores structured the designing and making of architectural models with one parallel robotic platform, one robotic arm, three designers, three cameras, two screens, and multiple materials. A written script, composed in pre-production, choreographed the relationship of responsive instruments with protocols of fabrication and material objectives. A long series of procedures was initiated one by one. Material deposition of aggregates by hand was sensed as mass by the parallel robotic platform which adjusted its position according to the script and fed values to the interface. The interface managed the live score, legible by the designers, and initiated the next series of material depositions. The robotic arm followed the path of the parallel robotic platform and provided another image of the procedure. This sequence of actions was iteratively performed until the physical model was complete.

Performing on Prepared Instruments authored a provisional vocabulary of design. It improvised by mixing rapid material processing, choreographing responsive machinery, and amplifying feedbacks of collaborative making. The toolpath reframed the array of manual procedures, stochastic material processes, and actions of drawing and making. A collective toolpath of variable control and interaction provided resistance against the discipline's computational and robotic tools being reductively instrumentalized, purely objective, or merely present.

Figure 4: Reimaging Fabrication, Screencapture, *Performing on Prepared Instruments*, 2014.



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MAKING (MATERIAL)

In addition to its agency as a mode of projection and writing, the problem of the toolpath also provides a lens for reconceptualizing the making of architecture. The problem of the toolpath should be seen as a critical link between architectural representation and the physical, material real—a connective tissue between architecture and the world. The predominant discourse surrounding the toolpath is comprised largely of technical jargon and technocratic efficiency, and thus a sorely missed opportunity to investigate disciplinary history through even the most basic elements of architecture's technical realm. For example, construction drawings, the set of detailed drawings and specifications for the construction of architecture, is by necessity concerned with the path of tools and the materialization of form. The CD set provides a template to guide contractors through the process of making. And while the conventional phasing of a construction project moves linearly across the independent phases of design development, construction documents, and construction, Jose Oubrerie's Miller House in Lexington proves that this need not always be the case, to surprising effect.

> "The Miller House was built in pieces… we started working in fragments, designing each element only when it was needed. We had some models which showed more or less what we wanted to do, but most of the elements were not elaborated or detailed until it was time to build them. Roger [the contractor] would say, 'Okay, in ten days I need a plan for the west wall.' At that moment, we would give it to him."[12]

Producing the construction documents only upon request, Oubrerie used the tactics of the piece to favor the part rather than a whole. Instead of designing everything all at once in the space of the drawing, his approach selectively designed parts in succession. This methodology promoted a thorough commingling of drawing and making, precisely at the juncture of templates and tools.

> "Of course, though we could not have imagined the final result, we made a lot of drawings of the Miller House—many of them look quite close to what

Figure 5: José Oubrerie, *2nd Floor Plan*. Miller House.

was built. But in the end the space took shape as much from the construction as from the drawings."[13]

As a set of instructions more than simply a record of drawn forms, the construction documents give structure to a continually unfolding collaboration between architect and contractor in the field of design.

Thinking through the toolpath problem more broadly proposes a method to conceive of an architecture sensitive to being transformed as much by construction as by the drawings. In addition to its methodological creativity, the Miller House operates with the toolpath problem in order to pursue an entirely different set of formal, material, and spatial architectural effects than it's more conventionally constructed canonical contemporaries. For example, the bidirectionality between drawing and making that led to a proliferation of parts engineered a tectonic system of independent, freestanding concrete walls. Each was constructed independently and according to a different design logic. Formally, this produces radically different readings of the concrete of each of its four elevations—one a thick expanse of solid poche, one a porous but gridded brise-soleil, one a flexibly fragmented scrim, and one a figural, object-like pavilion. "We put up four completely independent pieces. After that, we continued with the rest."[14] These readings become all the more complicated by the introduction of a secondary tectonic system that defines three timber-framed, clapboard clad volumes which constitute the primary rooms of the house and uneasily nestle into the concrete system. Each facade maintains a different relationship to this secondary system—concealing, hinting, exposing and projecting, respectively. The primary character of the public void spaces is interconnected and three dimensionally continuous, yet erratically punctuated by the distributed intensifications of discontinuity of the rooms. The piling of volumes inside volumes colors the reading of the entire composite assemblage as unresolved, wildly oscillating between precisely composed and partial/incomplete; a multiplication of parts never easily squared into a stable whole.

CONCLUSION

The toolpath problem is of renewed interest particularly in light of it's versatility; it cuts sideways across new tools for digital modelling, new machines for fabrication, new techniques of visualization, and new conceptual approaches to computational design. Thus a new pedagogical approach to the problem, one that engages the rich history of representation located at the core of architecture's encounter with material, is required to wrest the toolpath away from discussions of solutions (optimization, efficiency, and CNC-axes), toward a broad reframing of the most basic modalities of architectural production: projection, writing, and making. Spanning the space between the history of architectural drawing and the ever evolving collection of fabrication tools, as well as the space between representation and the real, the toolpath is positioned to cut across discussions of medium, form, and technique, toward a re-engaged contingent material practice. Beyond discussions of generic translational protocols, re-examining the disciplinary boundary drawn by the toolpath positions architecture to engage excesses of the real, as irreducible to either procedural or linguistic description.

ENDNOTES

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WAY BEYOND BIGNESS