Embodied Fabrication: computer-aided spacemaking

Lisa Iwamoto University of California Berkeley

Abstract
This paper discusses work from two digital fabrication seminars taught at the University of California Berkeley: Fabricating Space and Thick Skinned. The full-scale installations explore relationships among the body, digital design, and making. They combine investigations of perceptual and spatial effects with digital modeling processes and full-scale CNC fabrication, focusing in particular on how new media practices forge alternative methods of representing and constructing corporeal and sensorial experience.

Introduction
Architecture continually informs and is informed by its modes of representation, perhaps never more so than now, when digital media is rapidly expanding what we conceive to be formally, spatially, and materially possible. The increase in the use of the computer has led to the claim that the body is becoming increasingly distant from architectural production. However, as architects engage computerized input and output technologies, opportunities arise for greater confluence and specificity between the embodied material world,
immaterial phenomena, and architectural space. Pedagogically, the immediate tangibility of the body offers valuable and inescapable geometries that both push and draw upon digital methods of generating supple form. Experientially, it affords investigation and critique of something intimate and familiar.

While pursuing such physical and phenomenological conditions, students explore the relationship of digital design to fabrication. They are asked to work with conventional construction sheet material, and to tackle issues of aggregative methods of detail and assembly, delving into relationships between continuous form and constructive articulation. The projects attempt to create new modes of experience elevated by the cumulative effects made possible with CAD/CAM – while still employing an economy of means. Selected works of Eva Hesse serve as conceptual precedents in their exploration of seriality, uniformity, and non-uniformity, and the relationship of manufacturing to hand labor (Rothkoff 2002). Work from the seminars address similar concerns through the lens of digital representation.

Aggregation and accumulation are terms infrequently used in connection with the construction industry, though the actual assembly of buildings relies heavily on these techniques – asphalt shingles, board siding, and the like. Computer fabrication allows architects to heighten and make visible the nature of this accretion through constructed repetition and difference. Like Hesse’s obsession with seriality, the intensity of material articulation that CAD/CAM fosters has the capacity to relate back to the viewing subject on a visceral level. A latent theme underscoring the work is to tap into a direct response, one aroused by the intricacy of manufacture and labor. This investigation is partially revealed in the projects through the conflation or separation of structure and skin. Returning to the body, students consider analogous relationships between body and building: for example, skin and surface, skeleton and structure. These investigations inform the constructive sensibility of the full-scale installations.
The two semesters employ inverted methods of design: one additive, making an object in a space; the other subtractive, making space in an object. This inversion developed out of both physical necessity (in the second semester the projects needed to be freestanding) and the desire to directly engage the body as site.

Fabricating Space

The first class, Fabricating Space, revolved around a semester-long project to design a threshold. Though simple in conception, the project foregrounded making an occupiable installation, one that constructs a dialogue between at least two experiential conditions: above and below, light and dark, in and out.

Students worked in teams to design, fabricate, and install their projects. They began by choosing, surveying, and modeling their site. The site therefore became the first physical and digital artifact for the project, providing resistance to each subsequent design decision. The students gained an intimate dimensional understanding of the site in relation to their bodies through this process. The work of the studio alternated between physical and digital production. The designs began conceptually, much like in any studio project. Both three-dimensional prints and hand-made models were used to study successive iterations. Small, homogeneous models were made using rapid prototyping equipment to study overall form. Simultaneously, students conducted material investigations and made full scale detail mock-ups to investigate constructability. This process later supports translating the digital information into full scale. The projects — Spiral Surface, Ceiling Aura, and Lofted Mesh — are described here.

1. Projects:
   Spiral Surface, Ceiling Aura, Lofted Mesh

Spiral Surface develops the threshold as an extended space that frames the passage of the moving body as it descends the small staircase. Students saw this movement as a spiral progression reflecting the layout of the existing stair. The design is also inspired by an early conceptual image of Duchamp’s Nude Descending a Staircase. Early computer models describe the project as a group of intersecting, arced planes, forming a partial volume that wraps the occupiable space of the stair.

Figure 3. Students using Waterjet Cutter

Figure 4. Digital Models and 3D Prints

Figure 5. Final Digital Model, Waterjet Templates of Joints
One desired quality of this project was to deny structural hierarchy, and elevate the role of surface as a spacemaker, to allow the moving body to be seen as the object rather than the installation. The sculptural arced pieces transformed into a series of interlocking members that systematically join the planes. Students also concentrated on the method of connection at the joints, which were designed to form fluid creases that highlight the continuity of line and surface. The material distinction articulates the legibility of the crease both from above and from within the threshold space.

**Ceiling Aura** explores the notion of the threshold as the ceiling in the other small shortcut stairwell of Wurster Hall. Like **Spiral Surface**, this project attempts to embody movement. In addition, it addresses the transmission of light from a skylight located above the second-floor stair landing. This group worked intimately with the dimensional constraints imposed by the height of standard doors and the human body. The design is a permutated volume derived from what the students termed the *threshold aura* of a person traveling up the stair. They began by modeling a simple volume that filled the space between the standard door height of 6'-8” and the second floor. From this, a warped surface was created by deforming the exterior surfaces along the path of travel.

To emphasize the floating quality of the ceiling, the project used an existing railing to cantilever from the second floor and suspend the volume below. The students employed a ribbed waffle framework for this structural purpose, as well as to accommodate the geometric complexity of the volume. The ceiling surface itself is designed as a light transmitting fabric shell. It is sewn together from pieces cut from a template based on the developed surface of the exterior. The project acts as a hovering shroud into which one enters when moving along the stair.

The last project from the Fabricating Space seminar, **Lofted Mesh**, considers the idea of threshold perceptually and visually. It forms a light threshold between the window and the dark space of the stairwell. It also acts as a threshold to a new semi-enclosed space under the existing landing, and introduces perceptual and perspectival depth into this confined corner.
The design is inspired by an interest in projected light rays entering one of the two windows. The students modeled lines indicating sun angles at different times of year and day, inscribing them in the space. The space itself is located at a juncture in the fire stair that joins the two different building geometries. The projected light geometries are extrapolated to extend across this area, and subsequently adjusted to draw upon existing and projected site edges, such as the window edge and that of the stair landing.

Formalizing the idea of light rays, the students developed a system of structure and skin that reiterates the geometry of the projected lines, and creates a mesh-like surface that both screens and reflects the sun. The lofted form is expressed through the converging shingle pattern of waterjet cut aluminum sheets. The project creates an illusion of visual depth when seen from the stairs below and, contrary to the initial emphasis on sun lines and angles, produces a shimmering, indirect light in the stairwell space.

Thick Skinned

Thick Skinned follows a similar course structure as the previous class. However, it pursues conceptual ideas developed in the first semester more aggressively and literally. Where Fabricating Space began with digitally modeling the site, this course began with digitally modeling the body. The class employed new input technologies to closely and directly map the human form. These include using laser scanning and motion-capture devices that have the ability to track and represent highly specific physical data, otherwise extremely difficult to collect. This data was created with the intention that it would provide critical base information from which to draw upon in the designs. We first laser scanned two people in the class that were of different sizes with the intention of animating them. This proved extremely cumbersome, however, and eventually, we found other methods to digitally incorporate the body. However, one group chose to use this technology in a different way, and although we were not able to use it as intended, it still clearly holds potential for digital investigations in the future.
The project was also structured around a subtractive space-making procedure. Students were asked to make ‘body templates’, that is, digitally generated volumes formed by maps of the body that could be used to sculpt (or boolean) out of a simple volume. These negative spaces were intended to form physically and visually occupiable spaces. The initial volumetric envelope was defined as a 3’ deep x 5’ wide x 8’ high rectangle, the outer dimensions reflecting the size of common sheet building materials, as well as to allow sufficient space to create an inhabitable interior. As the projects developed, however, this procedure varied, and students could modify the dimensional and formal constraints, as long as they met programmatic requirements. These asked that the project house the body in at least two ways: one physically, sitting/leaning/lounging/standing/etc.; the other phenomenologically, through sight/movement/temperature/touch etc.

Overlaid on these criteria was the requirement that the two programmatically formed spaces intersect to form a third space, or double negative. This constraint developed around the desire to heighten the perceptible presence and interconnectivity of the subtractive voids. As discussed in Michael Heizer’s double negative piece, the project explores how two absences can make a positive or third space; in this case, absences formed by physical and experiential criteria.

1. Projects:
Embodied Surface, Motion Map, Steel Light
Embodied Surface employs laser scanning to bring together the body and the environment. The project is thought of as a continuous skin that deforms to accommodate the body, and views out toward significant elements surrounding the site. The scanner was used to capture physical data from as far as fifty meters, and generate a point cloud of the physical information. This group used this capability to model near and distant site boundaries. This data was used to develop volumetric cones of vision that sculpt the interior surfaces of the project.
The imperative to develop a *double negative* transformed in this case from one of solid and void, to skin and surface. The intersecting voids are integrated into the formulation of a continuous skin that connects together the housing of the body in a reclining position with the view cones.

Constructionally, the wrapping surface is seen as a structural skin with inner and outer sides. It is made using a structural waffle layered on one side with fiberglass sheet and resin. This allows the complex geometries to become self-structural. The inherent complexity of the multi-directional and cantilevered form demanded that the project be made by cutting a series of uniquely sectioned shells (rather than sectioning the whole form). These sections are eventually attached together with steel edge plates that hold the fiberglass in place along the seams. The seams are dictated primarily by the geometries, but also designed so that they bisect the view cones, integrating them with the construction of the surface. The inner surface of the shell becomes a smooth liner for the body.

**Motion Map** begins to define more precisely and literally what several of the Fabricating Space projects articulate from the previous semester. That is, how can form frame and capture movement of the body. Early experiments in animation by Eadweard Muybridge and his contemporaries suggestively translate the body in motion using serial imagery, and flip book techniques. This project expands upon this work through digital means.

The project is generated from the intersection of several paths sculpted by the transitory positions of the body in motion. The phenomenological and experiential dimension of the assignment is interpreted here as movement over time. The design process charts the positions of a person traveling along several paths created around the site. An existing collection of benches and planters serve as props on which to sit, lean, climb, and lay, and characterize the different natures of the paths.

In order to accurately map the many body positions, this group worked with MOCAP, a motion capture technology used in the animation and gaming industries. They simulated the physical attributes of the
site and recreated the paths of travel while wearing a suit that locates LED’s at key points of the body: feet, knees, hips, arms, shoulders, and head. The motion capture software tracks the LED’s and translates them into a digital point cloud.

The students used this data to derive volumetric outlines of the body in motion. Following, lofted volumes were created around splines that connect the key body points from one position to the next. This not only afforded a precise map of the body, but directly engaged the technology through representation. The 3D Print describes the literal intersection of these volumetric paths. The lofted computer model suggested a technique that could take advantage of the CNC technologies at hand, namely, two-dimensional cutting.

This group initially developed a system for an inflatable fabric structure whose seams would be along the loft lines. They sought a solution that would allow both the specificity of the internal geometries derived from the motion map, and create a loose enclosure that could be occupied by different users. Due to some technical difficulties, they opted to make the project through cross sectioning, taking sections along the different paths at primary points. There was also the idea that like the flip book, movement could be articulated through serial progression. Similar to the material give of the inflatable iteration, they developed a foam structure whose softness allowed for a tactile and malleable experience for different users.

The last project, **Steel Light**, was conceived as an experiential extension of the tree under which it sits. Although the geometries of the body are not explicitly present in the design, the students sought a body sized enclosure within which a person could experience light – the light from the sun, and the dappled light under the tree – in an isolated and focused manner.
The form of the project ultimately worked itself away from the initial rectilinear envelope because of these considerations, and because it began with the design of a single unit. The constraints of the unit suggested a self-supporting form such as this dome-like configuration. The blocks are folded out of uniquely waterjet cut steel plates—steel being used as a material that will dissolve into its surroundings over time. Though the blocks are geometrically different from the leaves above, the effect once inside is one that articulates the dappled light and hovering canopy of the tree.

Conclusion
In conclusion, the two seminars invite speculation on Frederick Kielser’s vision for an architecture ripe with reference to a perceiving humanist subject, and explore methods to capture, represent, and construct such a space (Lynn 2002). Though Kiesler has become a poster child of sorts for proto-topological architecture, what the class culled from his work is less about form than about Kiesler’s aim for a sentient architecture responsive to its occupants’ mercurial perceptions, as we find in his project for Peggy Guggenheim’s Surrealist Gallery, where the picture frames suspend from the walls to interact with different viewers.

Throughout both seminar processes, the digital and technological particulars provided constraints that geared the evolution of the designs, and the manner in which they enabled or limited body-space manufacture. The addition of new input technologies, in Thick Skinned in particular, fostered ways of mapping the dynamic interplay of the body with space and laid the groundwork for future investigations. The built projects in Fabricating Space suggest how these investigations can be strengthened architecturally by mediating shifts in representation, scale and material throughout the design process. By cross-pollinating CAD/CAM practices with something both as multifaceted and mundane as the body, students were able to engage new media as an extension of their everyday experience. In this way, the digital medium encouraged a fresh conception of architectural space and form.
Figure 19. Model, Unfolded Block Template Chart

Figure 20. Final Steel Light Installation
Spiral Surface
Jenny Li
Laura Mezoff
Matt Snoap

Ceiling Aura
Rebecca Laubach
Hector Martell
Matthew Stromberg

Lofted Mesh
Aaron Brumo
Alejandro Delgado
Nic Hamilton

Embodied Surface
Mike Eggers
Danny Lee
Pitchayada Treetipbut
Enrique Sanchez

Motion Map
Luke Wendler
Nash Hurley
Beau Tricina
Rick Johnson
Josh Zabel

Steel Light
Susie Douglas
Ted Steinemann
Bill Glauch
Graham Hill
Dong Jin Seo

Z-Corp 3D Printer
Integrated Manufacturing Laboratory
UC Berkeley Dept. of Mechanical Engineering

Waterjet Cutter
Lawrence Berkeley National Laboratory
Design and Engineering Shop
References


Lisa Iwamoto is principal of Iwamoto Scott Architecture, and Assistant Professor at UC Berkeley. Her design research work focuses on amplifying the perceptual performance of architecture through surface, material, and fabrication technique. Recent projects include an installation at SFMoMA using motion capture technologies and IN-OUT screen, an operable surface made using CAD/CAM.