FABRICATING THE FUTURE

建筑数字化建造

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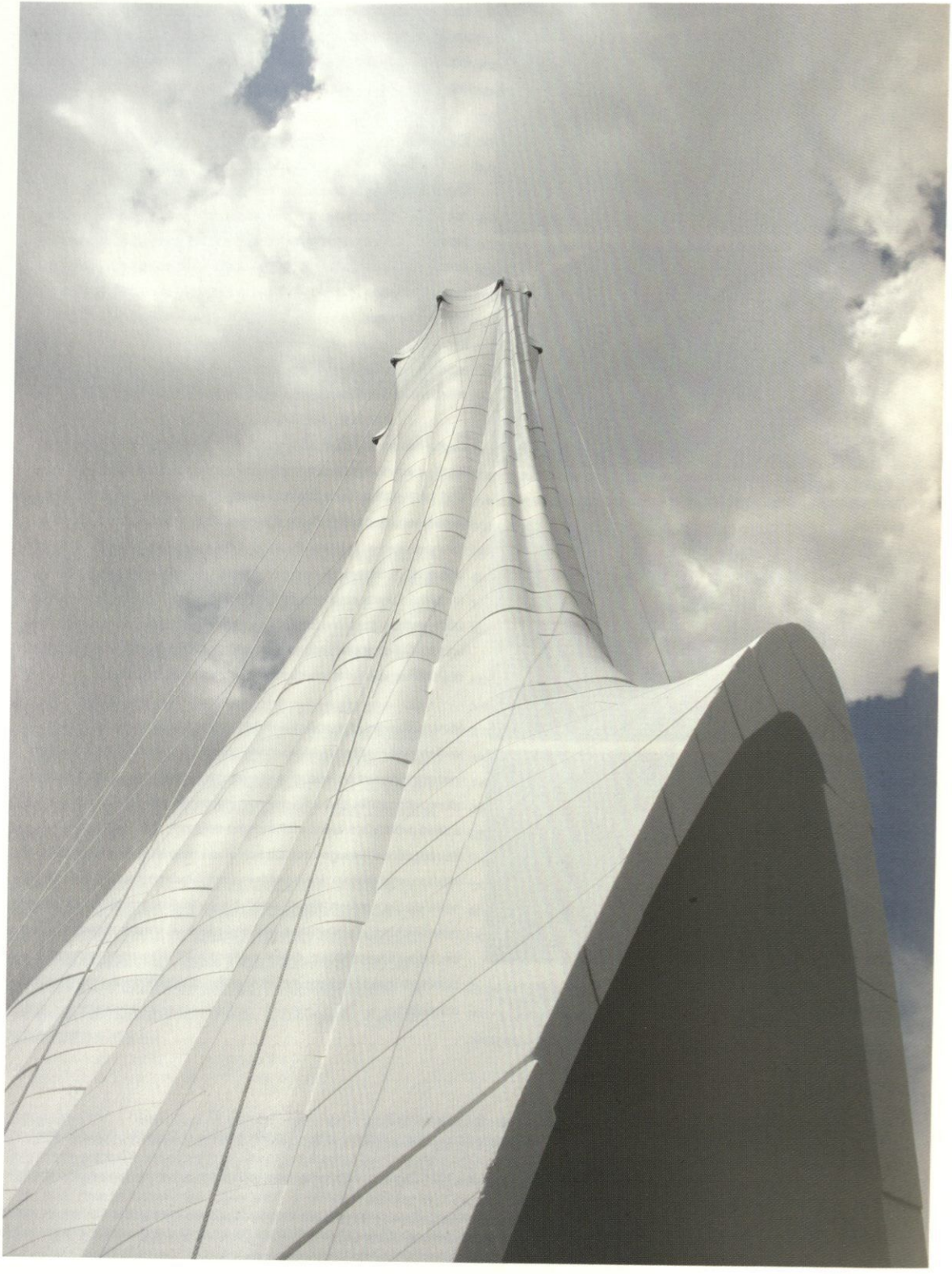

Stereotomic Robotics
机器人切石法

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马克 · 嘉佐姆贝克最近提出这样一个观点，即人们可以通过运用精确雕刻石头的能力可以大大推动其社会发展状况。诸多有关数字设计和建造的讨论都集中在外表皮上。无论是因为我们从工业时代已经继承了薄板材料，还是因为当代所呈现的同构趋势，或是可能因人工石刻效率低下，我们确实失去了处理体积的水平与能力。下述研究的目的并不是回到陈旧的建筑形式，而是挖掘已丢失的关于切石法的知识，从而找到处理体积的当代方法。①

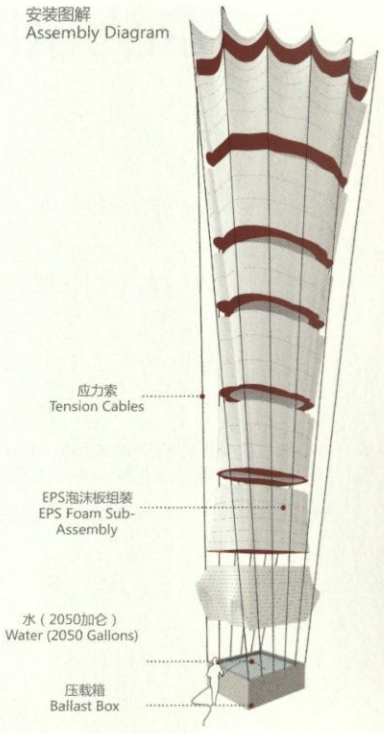
很多有体积的材料都有可能实现此研究：AAC（高压加气混凝土）、再生石、EPS（膨胀聚苯乙烯）泡沫。我们选择EPS泡沫作为最初的案例分析材料，这种材料有一定体积，具有经济性，并且可以100%回收利用。EPS泡沫的材料特性与先进的建构方法相结合，为建立带有立体建筑逻辑的数字化建造搭建了坚实的平台。

数控机床（CNC）铣削出传统的轮廓不再是个创新的提议，然而从一块建筑材料上打磨出一个立体形状的费用成本过高，而铸造可以生产不同的体积部件。为了妥善地解决体积建造的问题，要求人们在将体积作为常用做法时对使用方法进行研究。我们已经将开发成形的表皮技巧转换为数字过程，重新使用几乎已不被采纳的切

Marc Jarzombek suggested recently that one could determine the well being of a society by its ability to carve stone precisely. So much of the discussion around digital design and fabrication has focused on the surface. Whether it is because we have inherited thin sheet materials from the industrial era, or because of contemporary isomorphic tendencies, or because of the assumed inefficiency of manual labor to carve stone, we have certainly lost the ability and knowledge to work with volume. The purpose of the following research is not intended to revert to an antiquated mode of construction, but to mine the lost knowledge of stereotomy as a way to inform contemporary methods of making with the dimension of volume. ①

A number of volumetric materials have the potential to fulfill this research agenda: AAC (Autoclaved Aerated Concrete), Reconstituted Stone, EPS (expanded polystyrene) foam. We selected EPS foam as an initial volumetric and inexpensive case study material, that is 100% recyclable. The material properties of EPS foam in conjunction with advanced fabrication methods provide a solid platform to inform digital fabrication with stereotomic construction logic.

① 切石法是将实体切割成特定形状和尺寸的技术。
Stereotomy is the technique of cutting solids to specific forms and dimensions.



石法。可展表面（具有讽刺意味的是，其也适合于众所周知的在轻薄表面材料中占据着重要地位的 “可展开曲面”）是通过最小限度地扫掠线条定制石刻的方法，这些线可被拉平，否则便从三维几何变为二维制图，这是众所周知的显著特征之一②，[1]。通过提炼这些原则，我们可以将这些假设的线条想象为物理的和CNC的设备——密歇根大学陶布曼建筑与城市规划学院的一个定制的七轴机械自动控制的热钢丝切割器。传统技术与当代材料和建造方法的结合形成了下述两个项目中所展现的制图和建造的相互关系。

潜望镜：泡沫塔

潜望镜成功闯入“10 Up!”全美建筑大赛入围奖。比赛要求参赛作品可以在5 000美元的预算内由两个人建设完成。团队有一个月时间在一个10英尺见方的地块内设计一个装置，并且必须在24小时内搭建完成。潜望镜的搭建仅用了6小时，它不仅是亚特兰大竞赛的标志，同时也是当代数字建造文化的产物，其建造方法和手段与设计（也就是定制机器人建造工具）同步进行。比赛并没有高度限制，但绝大多数参赛作品都采用了10英尺的立方体，而高达50英尺的潜望镜则显得更加雄心勃勃。

在远处的观察者直接看到的是它的尺度。塔楼犹如拉紧的织物，在垂直方向上由极细的拉索拉伸。高耸的形象吸引了观察者走近，可以仔细辨认切割建构逻辑。水平面的两个舷窗吸引观众凝视着“裙子般的

CNC milling a custom profile is no longer an innovative proposal, and yet milling a solid figure out of a block at an architectural scale is cost (and time) prohibitive, and casting produces volumetric, but regular components. In order to appropriately address the issue of volumetric fabrication, one is required to research methods practiced when working with volume was common practice. We have translated the developed surface technique into a digitized process as a way of embracing the almost forgotten practice of stereotomy. The developed surface (while ironically re-appropriated to the more widely known ‘developable surface’ that holds its roots in surface thin materials) was a method for customizing stone carving through the minimal means of a sweeping line that can be flattened or from a three-dimensional geometry into a two-dimensional drawing otherwise known as a trait [1]. By extracting this principle, it is possible to conceive of this hypothetical line as a physical and CNC (computer numerically controlled) device — a custom built, seven-axis robot-controlled hotwire cutter at the University of Michigan’s Taubman College of Architecture and Urban Planning. This converging of past techniques with contemporary materials and methods informed the reciprocity between drawing and making in the following two projects.

Periscope: Foam Tower

Periscope is the winning entry in the 10Up! National Architecture

② 对于石材砌筑来说，这些线不是一个物理的对象，而是一个用二维性状来描述三维形式的几何原理。
For the stone mason, this line was not a physical object, but rather a geometric principle allowing 2d traits to describe a 3d form.

外围”和塔身。这个孤立的角度产生了天空的景象，显现出一个全新的与外表面并不一致的内部轮廓。其实，这是由两个圆锥角度交叉创建出来的轮廓，也是固体布尔逻辑运算偏移的结果。 第一次看潜望镜的外形，不会有一种表面是膜的感觉。视觉接触到的这种拉伸结构是一种坚实的压缩泡沫。拉索事实上是可拉伸的电缆。

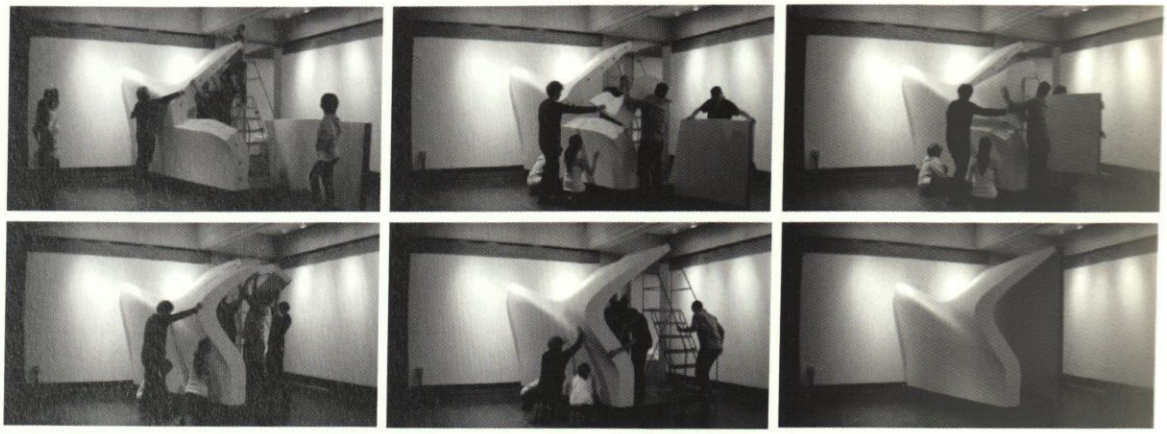
这种带修辞色彩的倒置既是对表皮操作（与体积相对立）的当代实践，也是将观众拉入到亚特兰大竞赛中来。约500多个定制泡沫单元从EPS 泡沫块中切割出来。然后用粘合剂将这些泡沫块堆积在一起，组成3英尺高的分组合件。在每个分组合件的顶部和底部是一块夹板平面，既起到海运保护的作用，同时也是更重要的设想，可以保证通过手工集合的单元组成预期的几何图形不会慢慢散开。单元的堆积是一个手工过程。试图将不规则单元排成一列可能会导致每一项的细微变化。除了因为手工没有对准之外，另外还需要能够允许承受长热丝切割，因为没有绷紧可能会导致移动的误差。

每个分子组构件都设计得足够轻，使两个人就可以直接搬运。当堆到三个那么高时，每个组件都在半拖挂车内能够贴合得很好。14个分组合件堆到一起，建设成50英尺高的建筑，通过拉紧的电缆将建筑固定到基础。这些固定基础重约为16 500磅，从而可以抵抗设计风值范围的翻转力量。柱体的内外表面在塔身中央至少有4英寸的搭接，但是可以互相分离或扩展，从而满足用泡沫袋解决的各自功能。此技术和材料性质质疑了这样一个观点：当代建筑的表现与实践必须像纸一样薄的表面。

Competition, whose brief called for entries that could be constructed by a two-person team, working within a $5,000 budget. The team would be given a month to design an installation for a ten foot square plot, which could be installed in less than twenty-four hours. Mounted in only six hours, Periscope is not only a beacon for the Modern Atlanta Event, but is also a product of contemporary digital fabrication culture in that the means and methods of fabrication were developed in parallel to the design, namely custom robotic fabrication tools. The regulations did not stipulate a height restriction and most entries assumed the ten-foot cube volume. Periscope, at fifty feet tall, was more ambitious.

From a distance, the observer confronts the sheer magnitude of the figure. The tower appears as tensile fabric stretched vertically by impossibly thin compression rods. This initial confusion is productive: it pulls the observer in for closer inspection to reveal Periscope's logic of rough stereotomic construction. Two portholes at ground level invite the spectator to peer up the "skirt" and through the body of the tower. This isolated view crops a view of the sky and reveals a new internal figure that is not coincident with the exterior surface. Rather, it is a figure created by the intersection of two conical views, a result of a solid Boolean offset. Persicope resists an initial reading of its form as a surface membrane. Where the eye once read tensile fabric there is now solid compressive foam. The compressive rods are actually tensile cables.

This rhetorical inversion is both a commentary on the contemporary practice of surface operation (as opposed to volume) as well as a vehicle to pull spectators in to the Modern Atlanta Event. Over 500 custom foam units are carved from stock blocks of EPS (expanded polystyrene) foam. These blocks are then stacked in a running bond and assembled into three-foot tall sub-assemblies. At the top



临时居

临时居是一种原型安装，是对迅速配置和定制化住所方案的检验。这一方案排斥持久性的概念，是一种应对物业价格波动变化的建造方法，响应解决城市所面临的衰落和居住者的财务困境等问题。这一建造方法是之前所进行的研究的延伸。

该项目的工具轨迹几何学的基础是通过水平切片将预先确定的几何切割开，然后提取每个路线的顶部和底部曲线，在两个曲线中间重建放样操作，电热丝按曲线的空间和方向矢量进行移动。此过程将复合的几何体分解为一系列的构造几何构件单元。通过排成一行的顶部和底部曲线，导致大量不连续光滑面。为了解决这个问题，临时租住项目的安装几何直接从表面的切割路线中提取出来。这意味着预想中的表面决定了电热丝路线的斜度和角度。无穷多种表面可以通过在两个曲线放样决定表皮形态。但这种方法只能加工特定的连续曲面。

此类研究的悖论

切石法的建造方式在历史上仅是一种砌筑的方式，其材料是曾经具有代表性的石头——沉重、持久性很强的材料。然而，有些人认为，砌筑状态的石头结构不再是有效、实用的建造方式，而我们的观点是，这些结构比其他的拉伸结构更持久，更具有持续性。这显然是我们希望此研究能得出的结论之一，然而，为了与其他价格便宜的板式材料相竞争使用，充气材料也可以减少体积材料的成本。但成本的降低使材料重量过轻，因而无法用于砌筑这种建造方式中。

具有讽刺意义的是，这些推动施行切石法的社会动力与快速建造产生矛盾。在设计这些项目时，通过压力是必须的，因而，研究并不仅限于轻质材料。泡沫在这里只是作为石头的模拟物来使用。如今很多结构研究都侧重于源自形式生成的轻薄外壳。当想到使用这些先进技术将坚实的材料切割成不同的变化尺寸时，可以想象，砌筑结构并不会对结构上已确定的形态作出贡献。通过使用体积材料来改变这种局部深度时，与“找形”相对立的“找深度”的方法可能就会出现。

and bottom of each of these sub-assemblies is a plywood profile performing as both shipping protection and more importantly a jig to ensure the manual aggregation of units would not drift away from its intended geometry. The stacking of units is a manual process. Attempting to align irregular units results in subtle variations between each course. In addition to these manual misalignments, a small error tolerance is needed with such a long hot-wire cutter as the slack of the length can cause drifting.

Each sub-assembly was designed to be light enough for two people to carry. When stacked three high, each would fit snugly inside a semi-trailer. Fourteen sub-assemblies stack to construct the fifty-foot tall figure held down with tension cables to the ballast base. This ballast weighs approximately 16,500 lbs to resist the overturning forces of the design wind. The interior and exterior surface of the volume touch at a minimum of four inches in the center of the tower, but are free to expand and depart from each other to serve their individual purposes resolved with a poché of foam. This technique as well as material properties questions the notion that contemporary architecture must perform in the realm of paper-thin surface.

Temporal Tenanacy

Temporal Tenancy is a prototypical installation testing a proposal for rapidly deployable and customizable dwellings. This proposal responds to the problems surrounding shrinking cities and foreclosure rates by rejecting the notion of permanence in favor of a method of making that operates in direct correspondence with the ebb and flow of property fluctuations. This method of making is an extension of the research conducted in the previous project.

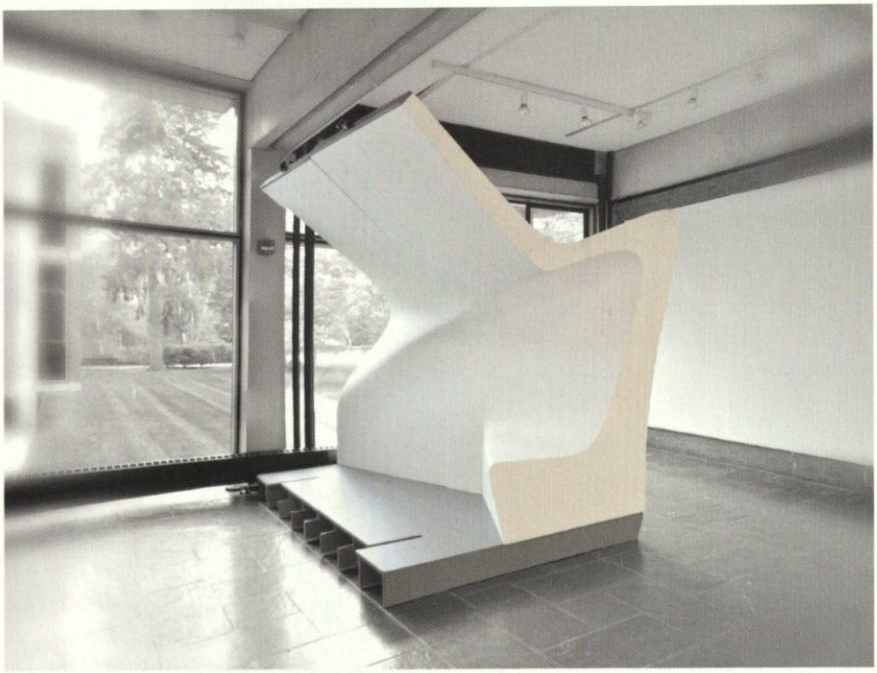
The tool-path geometry for the tower project was based on breaking a pre-determined geometry with horizontal slices, then extracting the top and bottom curve of each coarse and re-creating a loft operation between the two curves with a placement and direction vector for the

wire to move along. This process breaks a compound geometry into a series of constructible geometries. Though the top and bottom curves align, this results in a number of slipped surface discontinuities. In an attempt to resolve this issue, the Temporal Tenancy installation toolpath geometries were extracted directly from the ruling lines of the surfaces. This meant the desired surface determined the ramp and slope of the wire's path. An infinite number of surfaces could be constructed by lofting a ruling surface between two curves. This technique simply ensured we were selecting the specific surface required to complete the continuous surface.

The Irony of Such Research

Stereotomic construction has historically been a compression-only system, as its material has been typically stone — a very heavy and permanent material. While some argue compression-only stone structures are no longer an efficient or valid system of construction, we argue that these structures outlast any partial-tension structure, making them inherently sustainable. This is certainly one of the potential results we intend this research to foster; however, in order to compete with the relatively inexpensive sheet materials, aerated materials reduce the cost for volumetric materials. This reduction in cost unfortunately produces a material with less weight and therefore incapable of performing in a compression-only system.

Ironically the impetus to engage the process of stereotomy conflicts with the prompt for a temporary installation. In designing these projects, tension is required, but the research agenda is not limited to lightweight materials. Foam operates here as an analog for stone. Today much structural research focuses on thin shells derived by form-finding techniques. When considering advanced techniques of custom carving solid blocks of material to variable-depth dimensions, one can envision compression-only structures that are not dedicated to structurally determined forms. By varying the sectional depth with volumetric materials, a method of 'depth-finding' as opposed to "form-finding" could emerge.



参考文献 / References：

[1] On this see Robin Evans, *The Projective Cast: Architecture and Its Three Geometries*. Cambridge, MA: MIT, 1995