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《Weaving Objects: Spatial Design and Functionality of 3D Woven Textiles》

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编织对象:三维编织织物的空间设计和功能

Weaving Objects: Spatial Design and Functionality of 3D-Woven Textiles

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Abstract

3D weaving is an industrial process for creating volumetric material through organized multiaxis interlacing of yarns. The overall complexity and rarity of 3D weaving have limited its market to aerospace and military applications. Current textile design software does not address the ease of iterating through physical trialing so necessary for designers to access this medium. This paper describes the development of a series of volumetric textile samples culminating in the creation of a fully formed shoe and the collaboration with computer scientists to develop a visualization tool that addresses the consumer accessory design opportunities for this medium.

3D編織是通過有組織的多軸紗線交織產生體積材料的產業過程。 3D編織的整體複雜性和稀有性使其市場僅限於航空航太和軍事應用。當前的紡織設計軟體並沒有解決通過物理測試進行迭代的便利性問題，因此對於設計師來說，需要介入瞭解這個媒介。本文描述了一系列體積紡織樣品的發展過程，並以其創作為一個完全成形的鞋子和與電腦科學家的合作，以開發一個可視化工具，從而利用這個媒介解決為消費者設計配件的機會。

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2016年 NIKE Flyknit 系列

輕量 透氣 彈性 強韌 支撐力 編織紋路

什麼是 Nike Flyknit?

先以強韌又輕盈的紗線精心打造材質，再運用梭織法製成一體成型式鞋面，讓運動員的雙足穩固定位於鞋底之上。

Nike Flyknit 的運作原理

單一 Flyknit 鞋面會運用不同類型的針織紋路，較為緊密的編織區提供雙足更多支撐力，其他區域則展現更好的彈性或通風度。Nike 運用 40 餘年來研究雙足的經驗，為各個區域挑選最合適的紋路設計。

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While the potential for 3D-woven fabric is widely recognized, its deployment has been limited to applications such as ultrastrong, lightweight machine parts and composite forms, which largely derive their three-dimensional forms through the placement of thick woven fabric into molds .
The addition of a third dimension—401 layers of stacked yarns—suggests a far richer sequencing by which layers can connect and molds can be inserted to generate cavities, channels, pockets, flaps and hinges. Breaking open the spatial realm of 3D-woven fabric and making the medium more accessible for functional consumer based product design requires both a setup that is aligned with current textile design methodology and a tool that allows ease of iteration. Our extensive physical trialing of 3D-woven architectures has unveiled a multitude of behavioral tendencies that are used as the functional vocabulary for designing in this realm and by which we can effectively collaborate with computer scientists to develop a new tool for visualizing the complexity of the inner workings of a 3D-woven textile sample. We then used these tendencies, together with this tool, to create a fully formed 3D-woven shoe.

雖然3D編織織物的潛力得到了廣泛認識，但它的應用僅限於諸如超強度、輕量化的機械部件和複合範本等應用，這些應用主要是通過將厚的織物放入鞋模中而獲得三維形態。
這個專案的研究增加了第三個維度—401層堆疊的紗線——意味著更豐富的排序，通過這些紗線，可以連接和插入模具，從而產生空間腔、通道（凹槽）、口袋、袋蓋和鉸鏈（合頁）。打破三維織物的空間領域，使媒體更容易為基於功能消費者的產品。

Toward a Design Methodology for 3D-Woven Textiles

面向3D機織紡織品的設計方法論

Typically, the Jacquard mechanism is utilized to translate graphic files into two-dimensional fabrics with relatively few layers. Our aim is to adapt this process for multilayer volumes by conceptualizing 3D-woven structures as compilations of small architectural blocks. To do this, we utilize a specialized setup for the Jacquard loom, explore existing practices and develop a design methodology to harness this mechanism on all axes of the woven object .

通常，提花機制用於將圖形檔轉換為具有相對較少層的二維結構。
我們的目標是通過將3D編織結構概念化為小型建築塊，使此過程適用於多層體積。
為此，我們利用提花織機的專門裝置，探索現有的實踐，並開發一種設計方法，以便在編織對象的所有軸上利用該機制。

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The Language of Jacquard

The Jacquard loom is an industrial tool that united the hand, the machine and one of the earliest computer systems for translating an image into a simple binary language that encodes interlacings of warp and weft yarn. The technology has greatly evolved since its invention over two centuries ago, becoming faster and more precise through the implementation of different computer-aided design (CAD) systems for translating digital artwork files into binary images. Yet the binary language itself is an archaic way of representing the interaction and behavior of yarns. A standard black-and-white file (the “card image”) can convey which yarns are on the face and which are not, but reveals little about the behavior of yarn movement when extrapolated to compound weaves. This problem is most pronounced in 3D weaving, a form of extreme compound weaving, as yarns move horizontally and vertically, as well as on a third axis throughout the volume of the textile.

提花語言

提花織機是一種集手工、機械和最早的一種工業工具於一體的一種將圖象轉換成簡單的二進位語言的電腦系統，這種語言對經紗和緯紗的交織進行編碼。

自從兩個多世紀前發明以來，這項技術已經有了很大的發展，通過實現不同的電腦輔助設計(CAD)系統來將數字藝術品檔轉換成二進位圖像，該技術變得越來越快，越來越精確。

一個標準的黑白檔(“卡片圖像”)可以顯示出哪些紗線在表面，哪些沒有，但如果外推到複合織物上，則幾乎不能顯示出紗線運動的行為。

這個問題在3D編織中最為突出，這是一種極端複合編織的形式，因為紗線在水準和垂直方向上移動，並且在第三軸上貫穿整個織物。

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3D Weaving Techniques and Practices 3D編織技術和實踐

In traditional 2D weaving, warp ends travel in the vertical direction and are usually assembled under tension on a beam, or large roll, while the weft yarns travel horizontally and are passed above and below the warp ends to create interlacings and woven patterns. 3D weaving utilizes these basic premises but with some significant variations.

First, 3D-weaving techniques enable multiple layers of fabric to be joined together, sometimes linking layer to direct layer and sometimes running individual warp ends in a cascading motion throughout the fabric as "Z-tows" in a process called angle interlock . This movement adds to the vertical warp action and horizontal weft action to create a third axis within the cloth.

Second, the number of layers and the size of the materials significantly impact the duration of weaving.

Third, 3D weaving utilizes a creel for warping, which comprises an array of yarns that are placed individually on a rack behind the loom. The creel allows each warp end to maintain tension, using as much or as little of each warp as necessary throughout the fabric. The variable warp lengths combine with the Jacquard mechanism to allow customizable architectures in the fabric .

在傳統的二維織造中，經紗沿垂直方向運動，通常在經軸或大軋輥的張力作用下組裝，而緯紗水準運動，在經紗兩端上下傳遞，形成交織和編織圖案。3D編織利用了這些基本前提，但也有一些重大的變化。

首先，3D編織技術可以將多層織物連接在一起，有時將一層直接連接到另一層，有時以"Z型拖拽"的形式在織物中以層疊運動的方式運行單個經紗末端，這一過程稱為角度互鎖。這個動作增加了垂直的經紗動作和水準的緯紗動作，在布料中創造了第三個軸。

其次，層數和材料的尺寸對織造的持續的時間有顯著的影響。

第三，3D織造採用了經紗筒子架（經軸架），它包括一組紗線，這些紗線分別放在織布機後面的機架上。筒子架可以使每個經紗端部保持張力，在整個織物中使用盡可能多的每個經紗。 可變的經紗長度與提花機制相結合，可在結構中實現可定制的體系結構。

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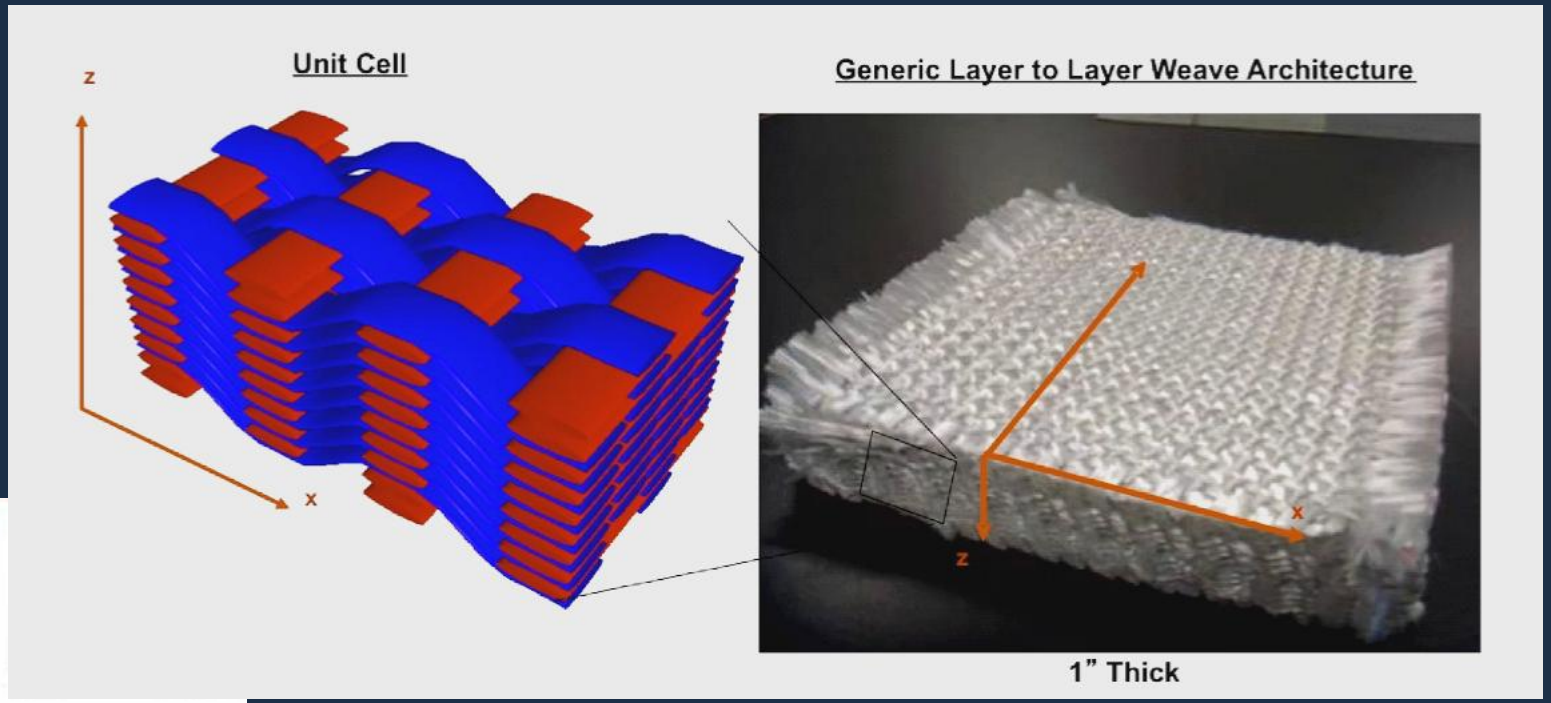
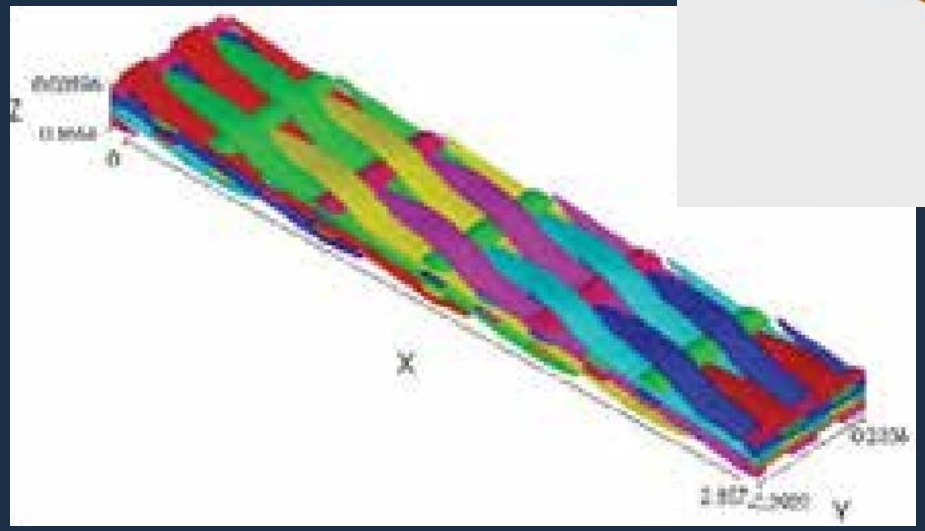


層與層之間的編織構架



三維編織結構:在三維編織織物的每一層中，經紗末端的連鎖動作。

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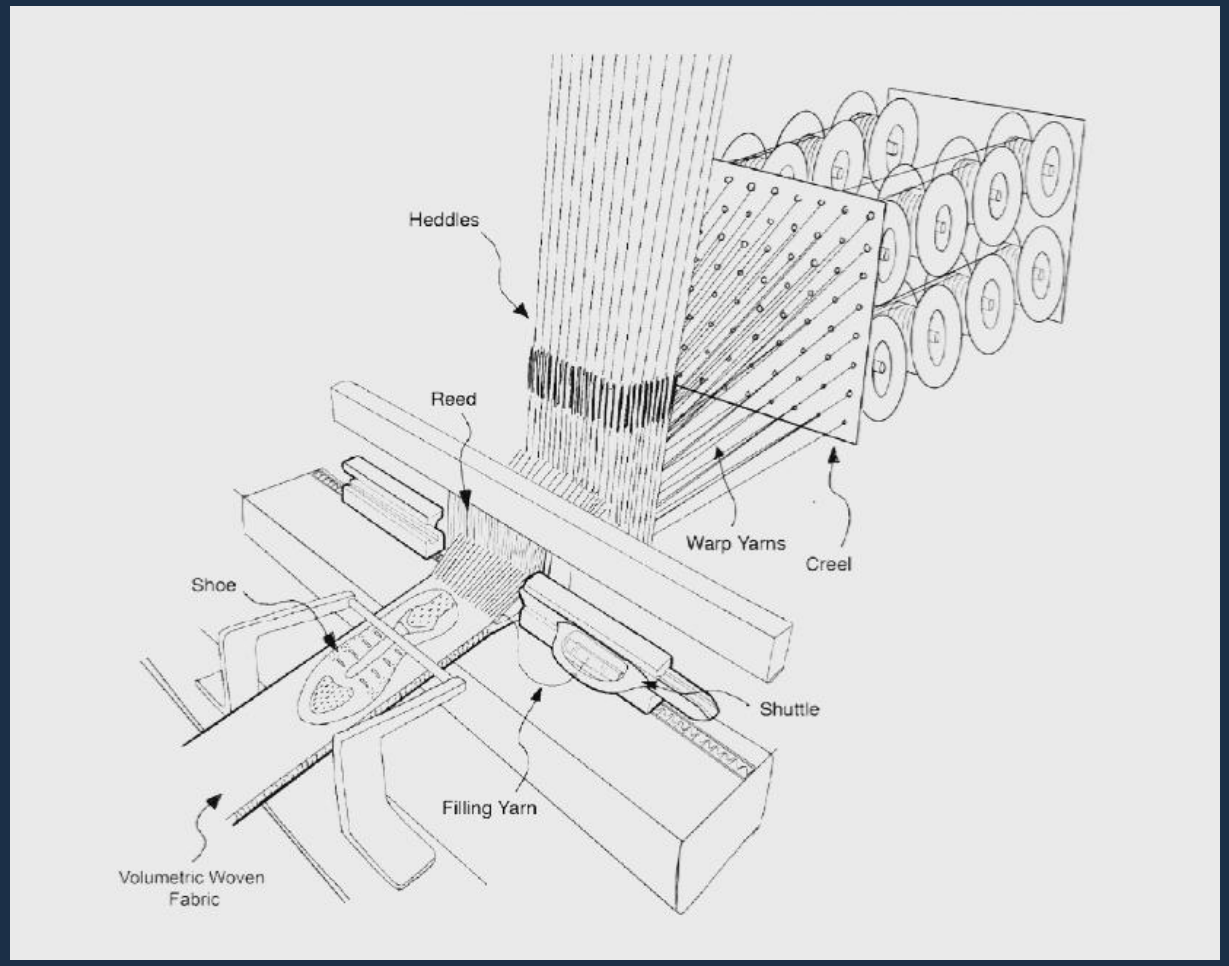

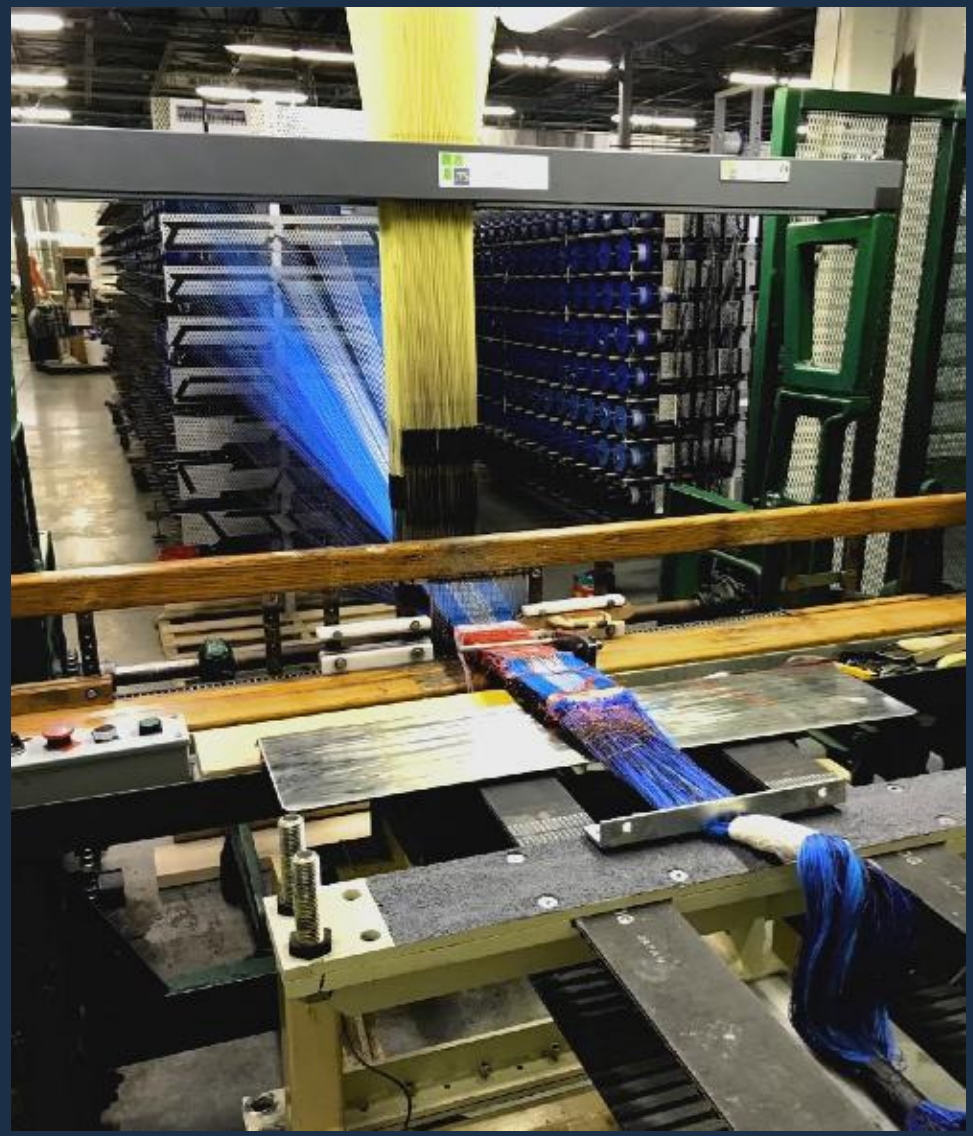

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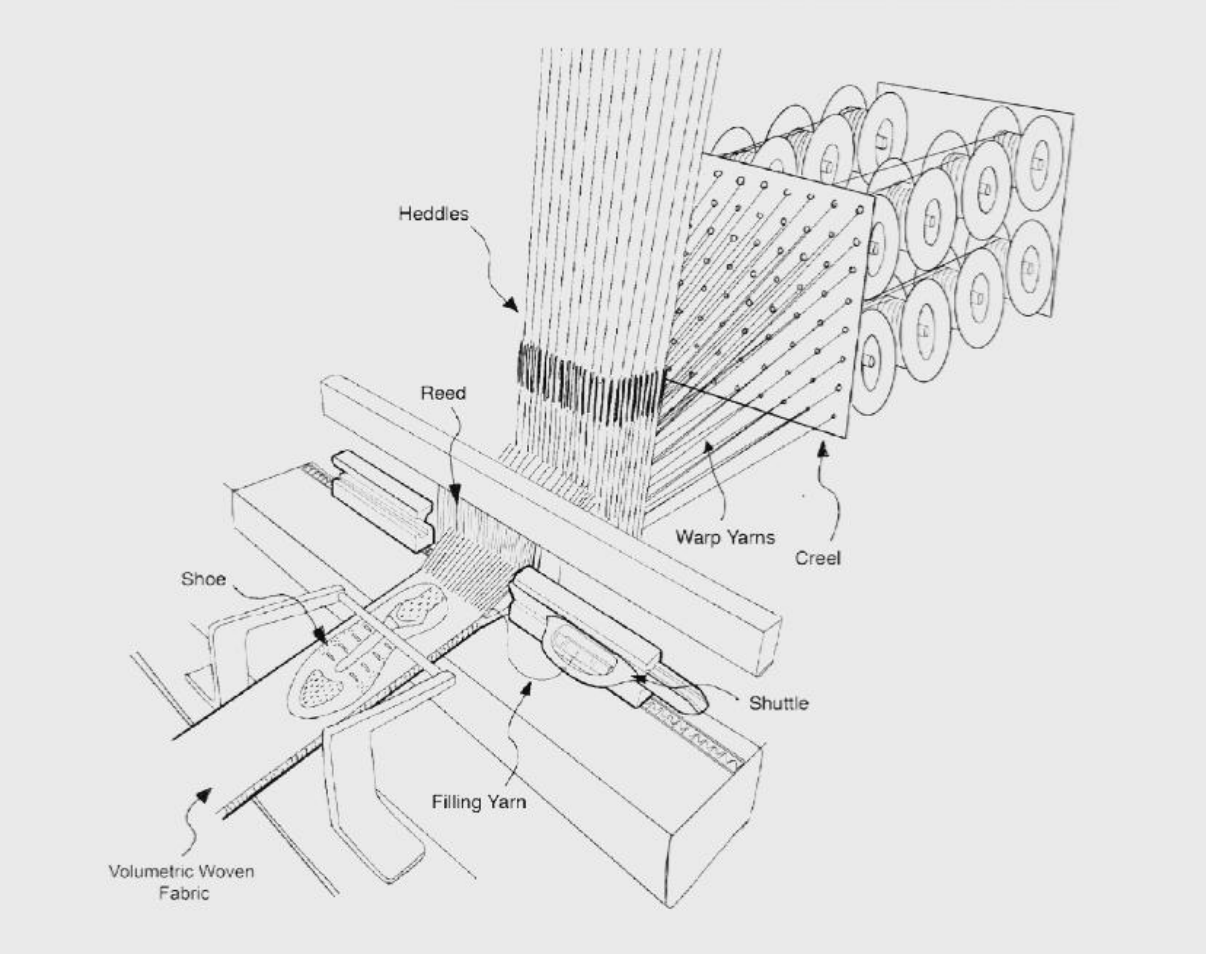
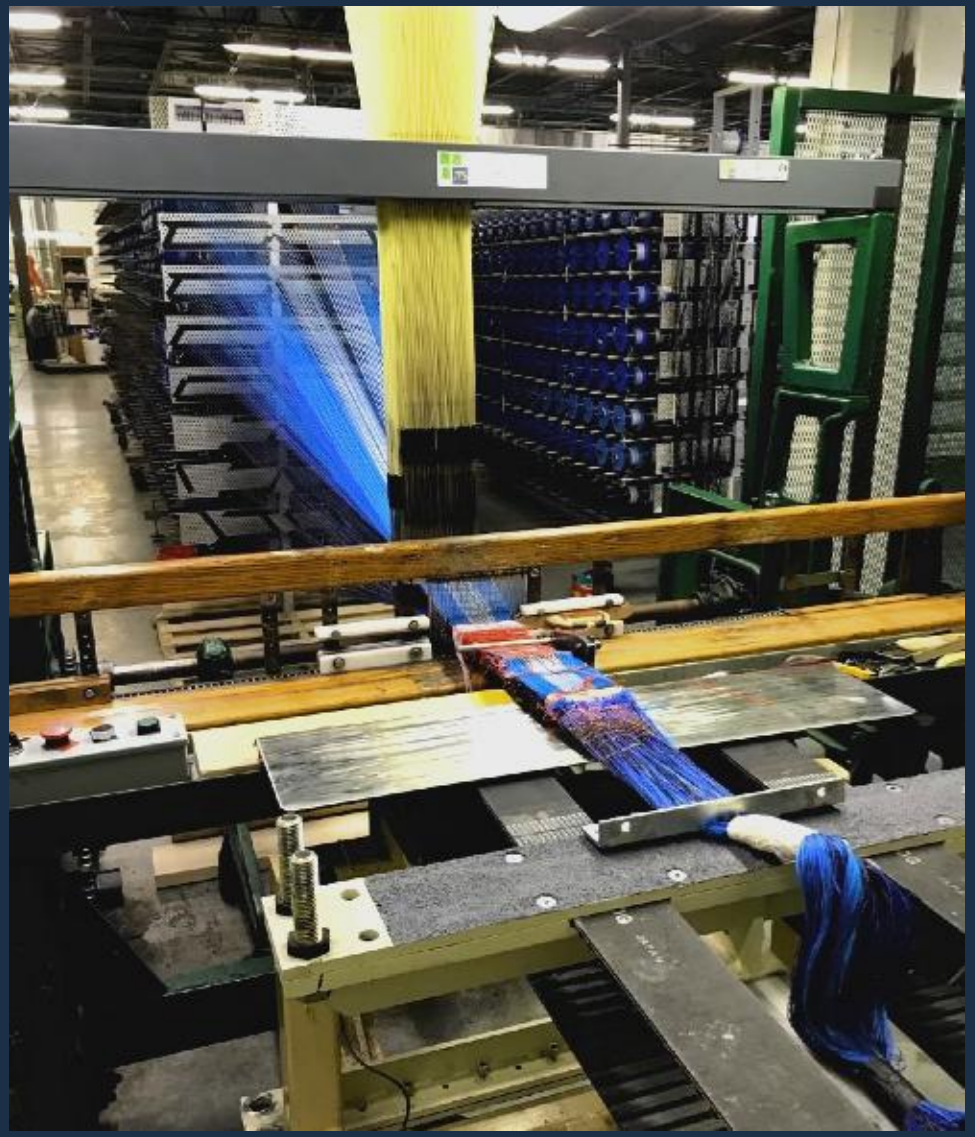
Many Jacquard-woven 3D fabrics are simple and take the form of rectangular billets molded into shape for the composites industry . A 3D-weaving setup requires a castout designed for depth and density rather than width, a key difference from more traditional decorative or greige woven goods. This depth-prioritizing setup is essential for enabling the warp yarns to stack on top of rather than next to one another .
Equally vital is the weft insertion sequence and mapping the shuttle path throughout the fabric. Given that most 3D-weaving setups incorporate a single shuttle, the same weft yarn must be programmed to pass entirely or partially across the fabric and to repeat actions in different sections of the fabric to build up necessary depth and material bulk.

許多提花機織的3D織物結構都很簡單，並採用矩形坯料的形式成型，用於複合材料行業。一個三維編織裝置需要一個壓鑄機來設計線編織的深度和密度（而不是寬度），這對於更傳統的裝飾或胚布織物商品來說，是一個關鍵的區別。這種深度優先的設置對於使經紗堆疊在彼此之上而不是彼此相鄰是至關重要的。
同樣重要的是，引緯順序和在整個織物上繪製穿梭路徑。 鑒於大多數3D編織裝置都包含單個梭子，因此必須對同一根緯紗進行編程，以使其全部或部分穿過織物，並在織物的不同部分重複操作，以建立必要的深度和材料體積。

3D织机和压铸机：工业提花织机，用于3D织造，带有线架和线束细节。。





经纱上的每一根经线都要经过一个综丝Heddle，综丝是用来把经线分开以便经纱通过的。典型的综线由绳索或铁丝制成，悬挂在织布机的轴上。每个综框的中央都有一个孔，经纱就是从这里穿过的。

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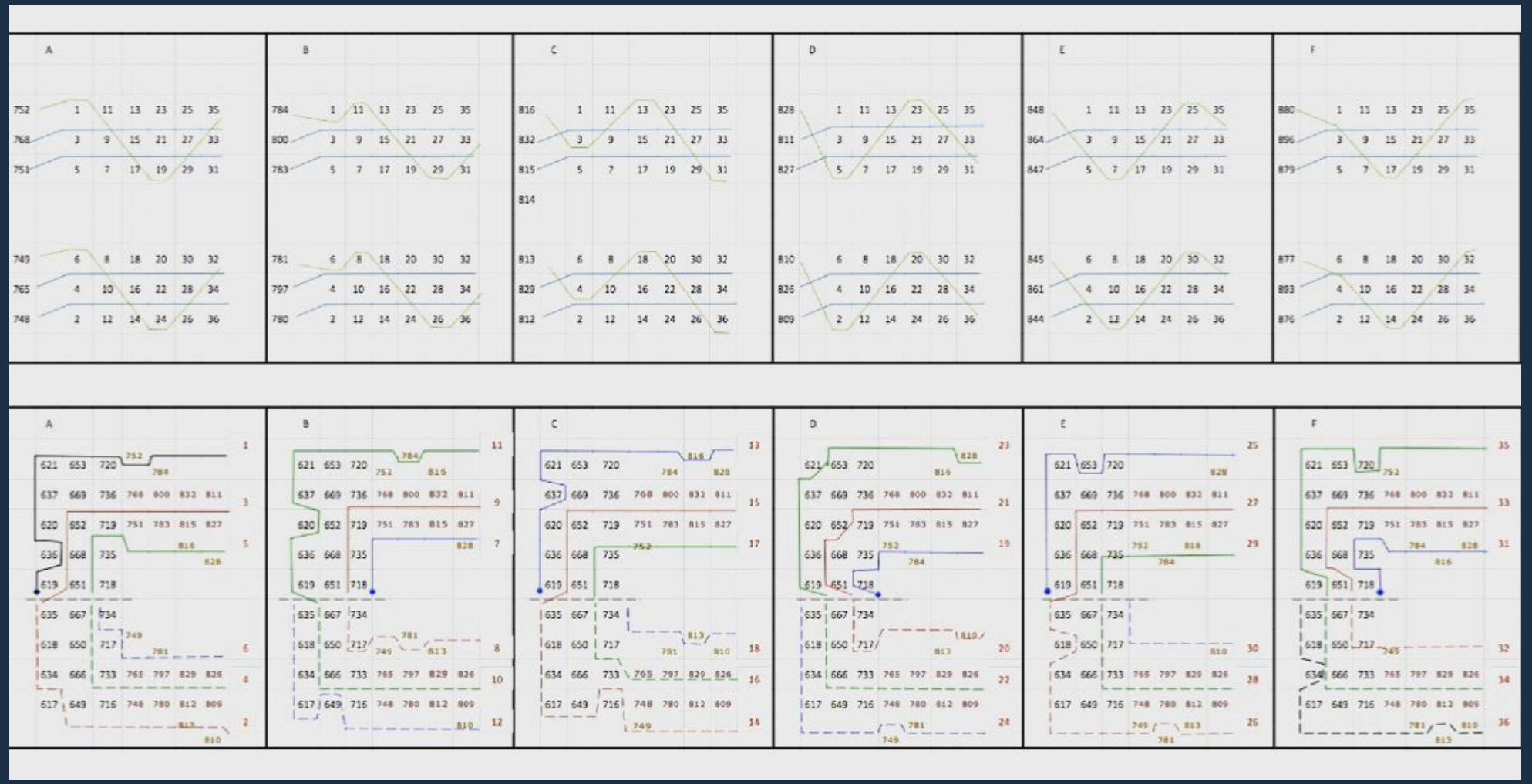

對同一根緯紗進行編程

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Computational Tools 計算工具

Current CAD tools for 3D weaving provide little information about yarn behavior within fabric. 3D fabric designers commonly work from sketched diagrams to transpose complex card images manually. We begin the process using Pointcarre, an industry standard textile CAD platform that maps weave structures to color pools in a graphic image. Pointcarre allows for dexterity in traditional fabric design, but is insufficient for 3D-weave design, failing to fully engage the complexity of layers within a 3D setup. Without spatial organization of 3D-weave structures, it is common for fabrics designed in Pointcarre to contain unnoticed errors. For more precise work, we require a binary tool in the form of a Microsoft Excel sheet containing an array of hooks for distributing the design pattern and shuttle path. As the graphic file usually originates in Photoshop, current practice requires the use of a combination of Photoshop, Pointcarre and Excel to attain a working 3D-weaving file .

當前用於3D編織的CAD工具提供的有關織物內紗線行為的資訊很少。 3D織物設計師通常從草繪的圖表中進行工作，以手動轉置複雜的卡片圖像。 我們使用行業標準的紡織品CAD平臺Pointcarre開始該過程，該平臺將織造結構映射到圖形圖像中的色池。

Pointcarre允許傳統織物設計中具有靈活性，但不足以進行3D編織設計，無法充分利用3D設置中各層的複雜層。

由於沒有三維組織結構的空間組織，在Pointcarre中設計的織物通常會包含未被注意到的錯誤。為了更精確的工作，我們需要一個二進位工具，它是Microsoft Excel表格的形式，包含一個鉤子數組，用於分配設計模式和穿梭路徑。由於圖形檔通常是在Photoshop中生成的，因此當前的實踐需要結合使用Photoshop、Pointcarré和Excel來獲得一個工作的3d編織檔。

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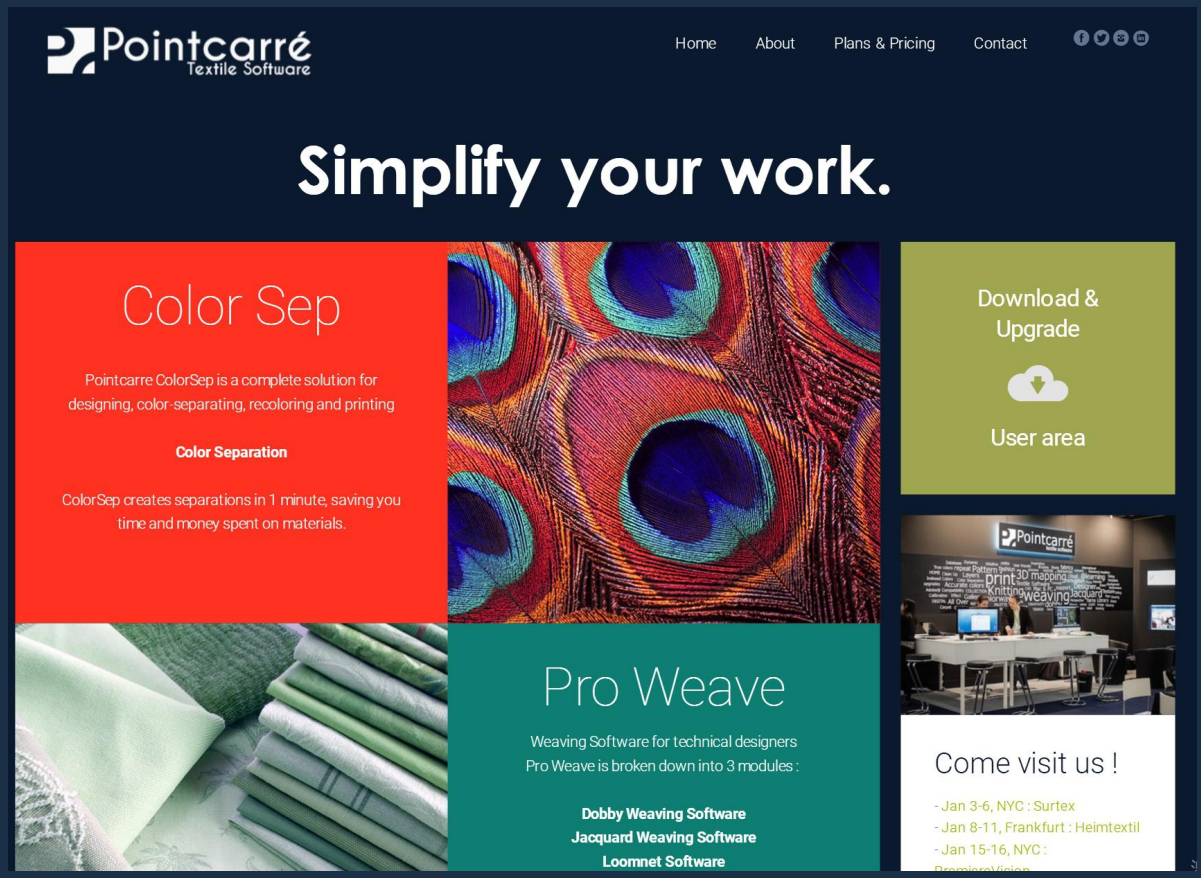

POINTCARRÉ設計軟體具備針織設計、織物設計、提花組織設計、軟體可與外部機器連接等功能，其強項是花型設計與修改，能夠方便地從一個原始圖像變化改造出豐富的系列設計方案。

A New Approach 一種新方法

Partnering with textile manufacturer T.E.A.M., Inc., we have accessed industrial weaving equipment to develop a range of samples exploring material and behavioral properties of 3D-woven textiles. Through ongoing collaboration with computer scientists at Cornell and Stanford Universities, we have aided in the development of a software platform that allows for the design of weave “blocks”that aggregate to complex 3D fabrics. The samples, together with the card images and the experiences gained from the production process, have lent critical insight to the platform development. Each iteration of the platform in turn has further streamlined an otherwise cumbersome workflow and enabled more trialing.

我們與紡織製造商T.E.A.M.Inc.合作，使用了工業編織設備來開發一系列樣品，以探索3D編織紡織品的材料和行為特性。通過與康奈爾大學和斯坦福大學的電腦科學家的持續合作，我們已經協助開發了一個軟體平臺，該平臺允許將編織的“塊”設計成複雜的3D織物。
這些樣本，連同卡片圖像和從生產過程中獲得的經驗，為平臺開發提供了關鍵的洞察力。
平臺的每一次迭代都進一步簡化了原本繁瑣的工作流程，並支持更多的測試。

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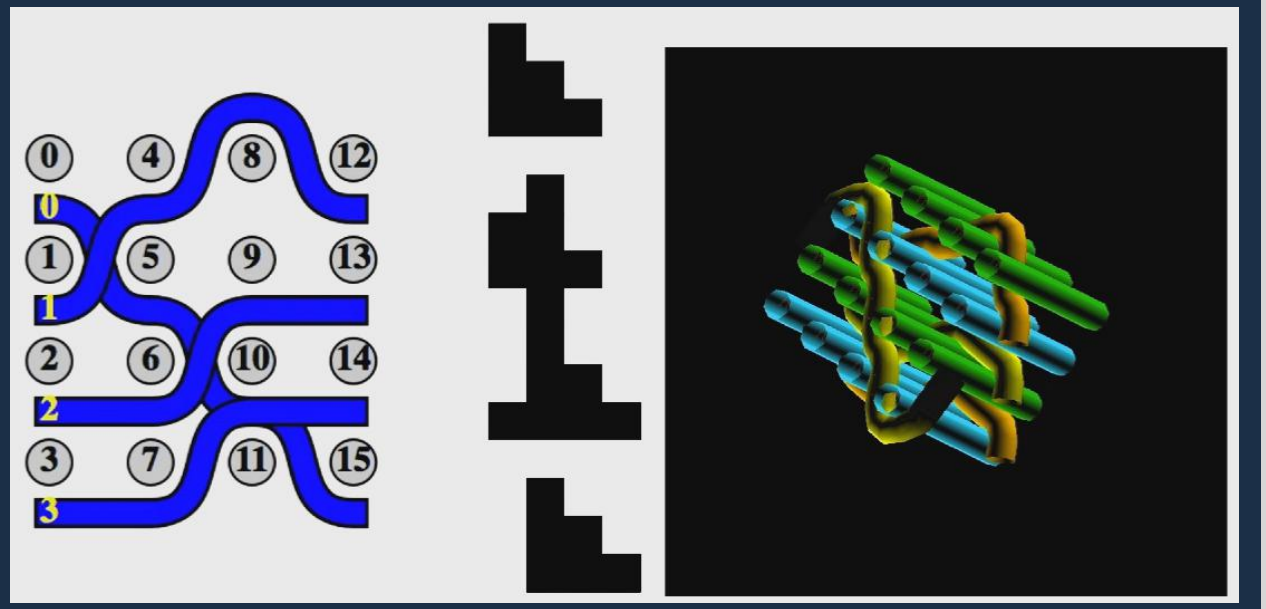

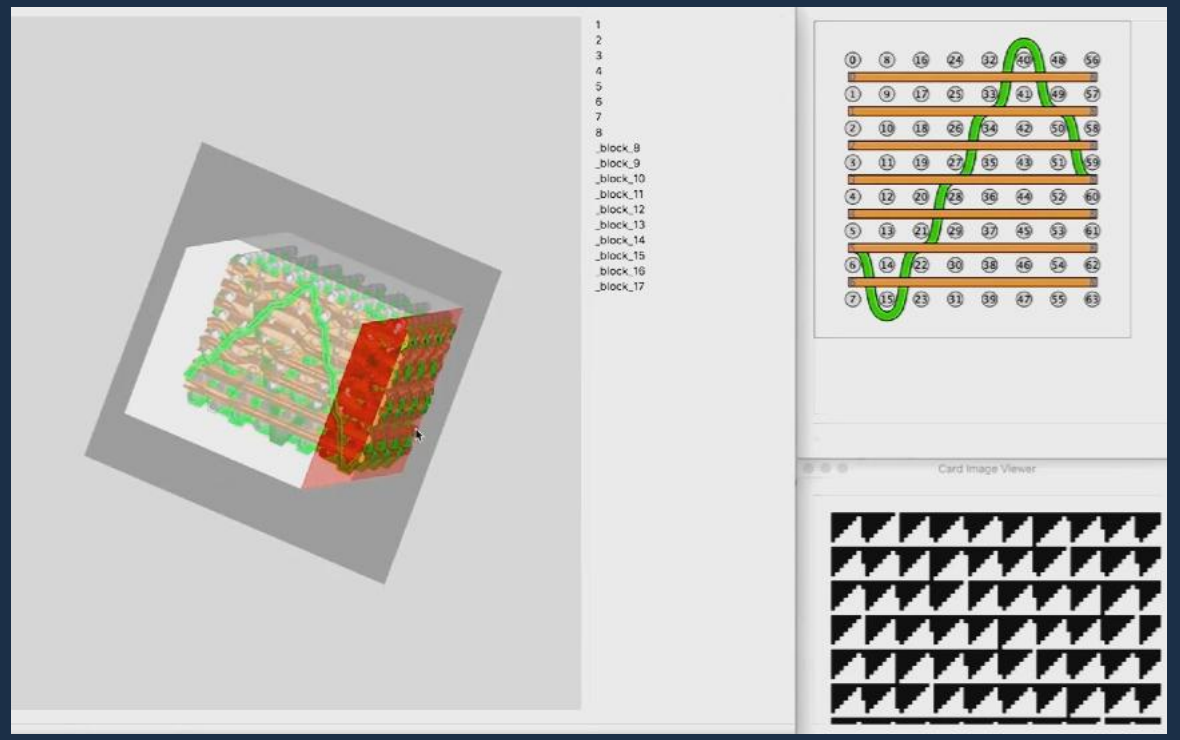

這種工具可以輕鬆地對織物橫截面進行編程，這些橫截面可以連接在一起並在空間上進行查看。編織布塊的定制將允許設計師在整個織物中進行連接和通道的穿梭。設計完成後，將自動生成準確的卡片圖像來驅動織布機。新出現的工具Weavecraft為設計師提供了一種將編織結構可視化、收集和設計為空間架構的方法，並為創建複雜的3d編織對象提供了路徑 。

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The Project: A 3D-Woven Shoe

Given the specialized nature of 3D weaving as a way of creating volumes with woven fabric and its underutilized potential for complex object formation, we seek to demonstrate the capacity of the medium by creating a technically sophisticated shape in the form of a 3D-woven shoe.
We chose to create a shoe as a grand challenge to test our ability to understand the medium and to engage the dominant design object in this domain, the Nike Flyknit sneaker, which hasprofoundly changed the market since release in 2012.
We ask: Can an entire complex volume be produced through weaving rather than knitting or even 3D printing? A shoe is a functional object and an ideal vehicle for addressing many of the design issues emerging from 3D weaving, such as varying density, layer linkages and shaping of distinct functional zones.

鑒於3D編織作為一種通過編織物創造體積的方式的特殊性及其在複雜物體形成中未被充分利用的潛力，我們力求通過以3D編織鞋的形式創造技術複雜的形狀來展示介質的能力。
我們選擇創造一款鞋子是一項艱巨的挑戰，以測試我們對媒介的理解和參與這一領域主要設計對象的能力——Nike Flyknit運動鞋，該鞋自2012年發佈以來已徹底改變了市場。
我們的問題是:是否可以通過編織而不是編織甚至3D列印來製作整個複雜的體積?
鞋是一個功能對象和一個理想的載體，以解決許多設計問題，從三維編織，如變化的密度，層連接和塑造不同的功能區。

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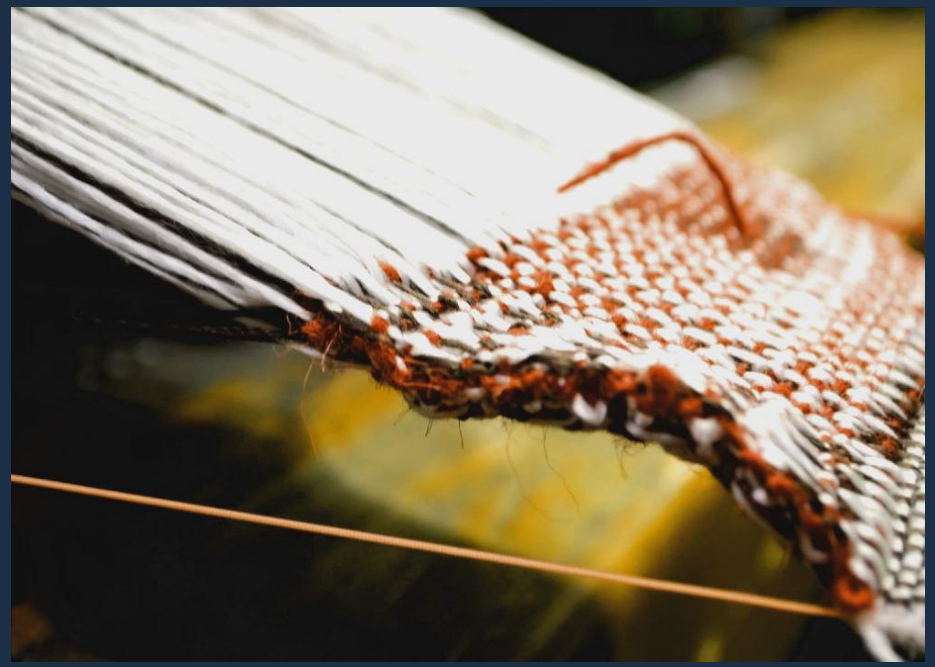

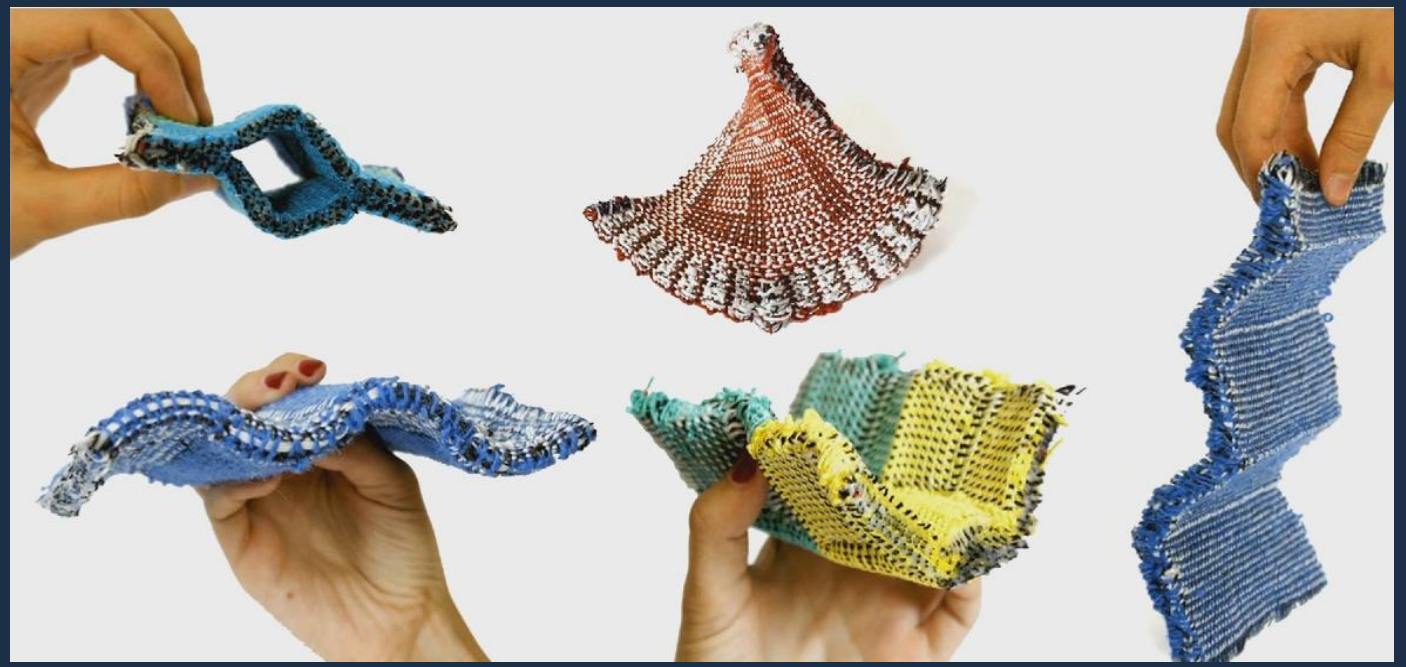

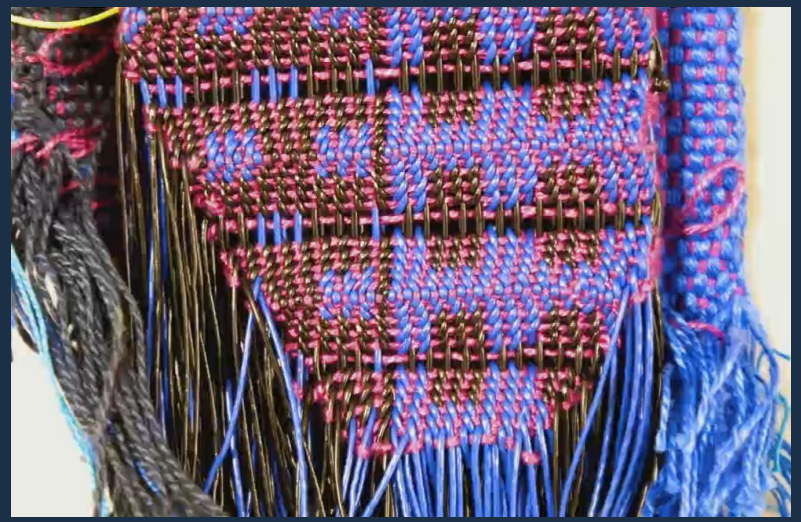

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The Shoe Our 3D-woven composite shoe derives its form, materiality and structural integrity from the textile itself. By approaching the design of a shoe as a fully formed woven object, it is possible to streamline many of the secondary processes usually associated with shoe fabrication. Seaming, gluing and molding can be translated into woven manipulations, creating a shoe preform that requires only trimming and molding off-loom to create a finished, stable product.

我們的3D編織複合鞋的形式、材料和結構的完整性來自於紡織品本身。
通過將鞋子設計成一個完全成形的編織物體，可以簡化許多通常與鞋子製造相關的次要過程。縫，粘和成型可以轉化為編織操作，創造一個鞋坯，只需要修剪和鞋預成型件，就可以完成一個牢固的產品。

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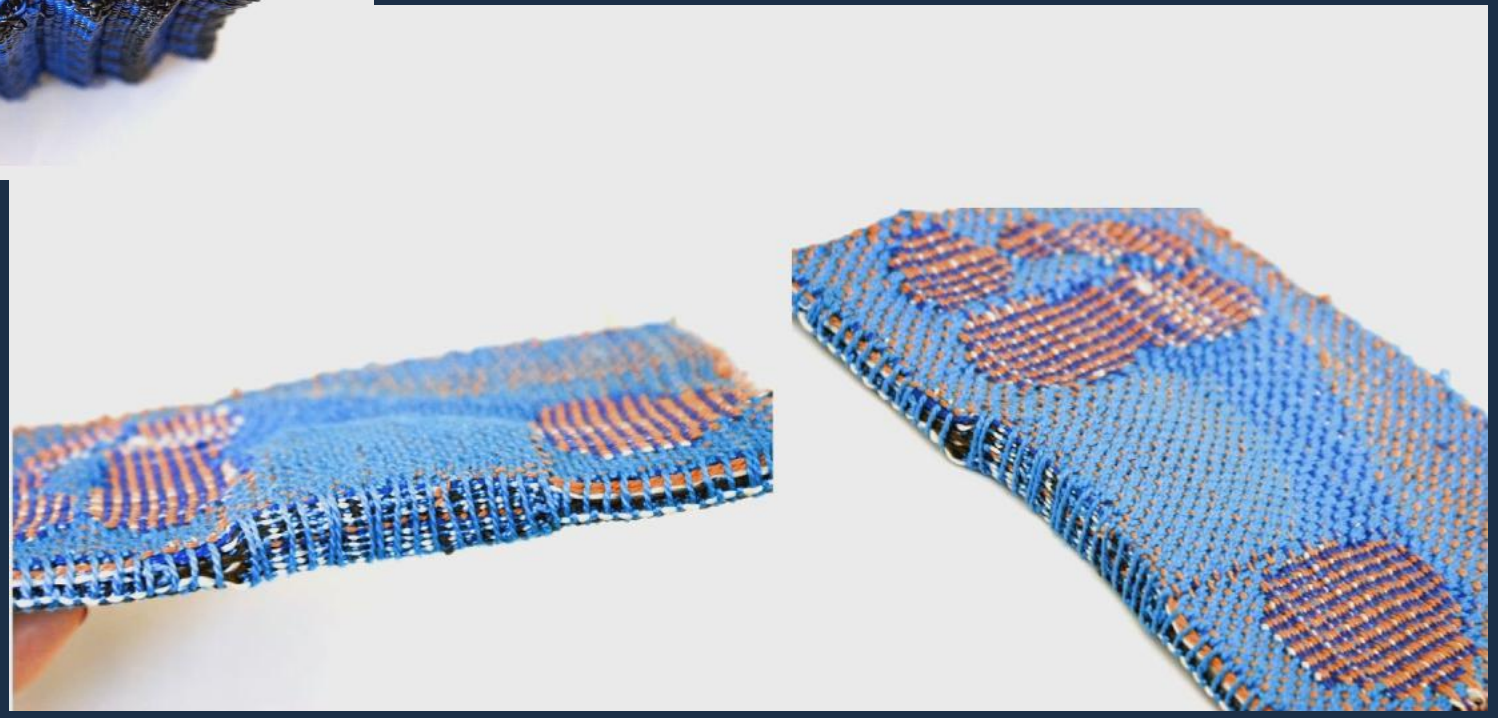
In organizing the warp, we divided the shoe into three zones: the sole, the insole and the upper. These zones draw from our library of tendencies and were executed in specific materials to enhance their physical behavior. In the shoe sole, we executed a variation of TL007 in a PVC-coated polyester yarn to create a flexible tread. The insole, executed in 5/2 cotton, provided areas of cushion and support. The fine cotton upper provided the means to create a deflected weft graphic fabric. These three major zones, defined by their material properties, can be edited separately using Weavecraft.

在组织经纱，我们把鞋分为三个区域：
鞋底，鞋垫和鞋面。
这些区域从我们的趋势库中提取，并在特定的材料中执行，以增强他们的物理行为。
• 在鞋底，我们在pvc涂层聚酯纱线中执行TL007的变体，以创建一个柔韧的胎面。
• 鞋垫由5/2棉制成，提供了区域缓冲和支撑。
•细棉线鞋面提供了制作偏斜的纬纱图形织物的方法。
由其材料属性定义的这三个主要区域可以使用Weavecraft进行单独编辑。



Conclusion

Accessing 3D weaving as a medium for designers necessitates new methodologies and tools. To produce complex 3D wovens requires an upgrade in the Jacquard process that goes beyond laborious binary encoding to an integrated computational environment in which the designer can effectively sculpt soft woven forms. The parallels to other 3D fabrication technologies are obvious, and design in this medium is relevant to numerous industries such as soft goods, accessories, fashion, technology and medical accessories.
For our design research team, the grand challenge of developing a 3D-woven shoe enabled us to explore a range of factors including materiality, functionality, weave architecture, postproduction finishing and adaptation of existing manufacturing platforms and processes. Our collaboration with computer scientists resulted in the creation of a new tool for accessing the medium. This tool helps us approach woven textile design in a new way, with the expectation that better modeling can provide more information about the behavior of complex fabrics and aid in the composition of multidimensional forms, a shoe being but one example.

使用3D编织作为设计者的媒介需要新的方法和工具。为了生产复杂的三维织物，需要对提花工艺进行升级，使其从繁琐的二进制编码转换为集成的计算环境，使设计者能够有效地塑造柔软的织物形态。
与其他3D制造技术的相似之处是显而易见的，在这种媒介中进行设计与许多行业相关，如软商品、配件、时尚、技术和医疗配件。
对于我们的设计研究团队而言，开发3D编织鞋的艰巨挑战使我们能够探索一系列因素，包括材料，功能，编织架构，生产后整理以及现有制造平台和工艺的适应性。
我们与计算机科学家的合作的结果是创建了一种通过媒体使用的新工具。该工具帮助我们以一种新的方式处理编织纺织品的设计，期望更好的建模可以提供有关复杂织物行为的更多信息，并有助于多维形式的构成，而鞋只是一个例子。

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随着样品的开发和编织，我们能够切割，缝制和更改现有形状，从而构想出新的可编织设计特征，可以将其纳入下一个编织原型的结构中。通过在提花图案上进行比例更改，可以编织出新的尺寸。

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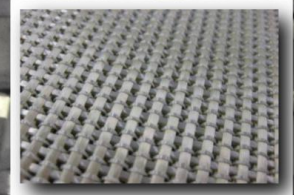
Engineered Textiles for the Composites Industry



3D Woven Fabrics and Billets

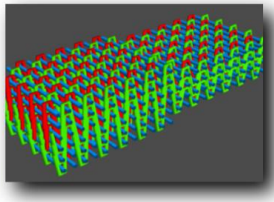
Near net shape 3D woven preforms for aerospace and industrial applications

2D Woven Roll Goods

Narrow tapes, full width rolls, hybrid weaves, standard and custom widths, weights and architectures

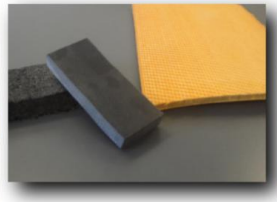
3D Woven Preforms

Near net shape 3D woven preforms for aerospace and industrial applications



Design Tools and Methods

Braided Sleeves and Preforms



Complimentary Processes

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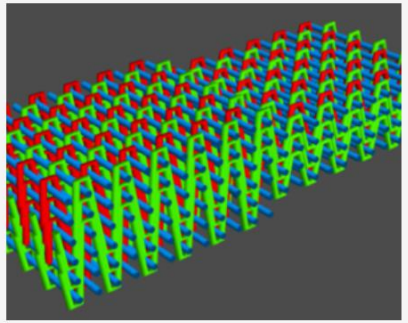
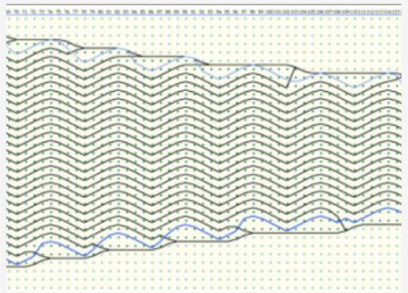
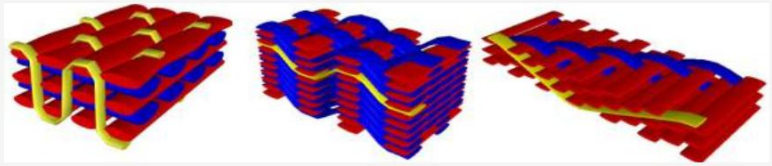




Design tools and methods

TEAM employs a suite of software based design tools including commercial packages (Auto-Cad and Solidworks), open source codes (TexGen, KSU DfMa), and several proprietary tools developed both in-house and with university and industry partners. For complex mechanical and thermal analyses and testing outside our core area of exptertise, TEAM routinely partners with the industy's most respected and well known composite design and test houses.

E_x (Msi)	E_y (Msi)	E_z (Msi)	ν_{xy}	ν_{xz}	ν_{yz}	G_{xy} (Msi)	G_{xz} (Msi)	G_{yz} (Msi)
xx	xx	xx	xx	xx	xx	xx	xx	xx



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personal opinion

01 服飾品多种織造方法形式的衍生

02 便於新產品的延展和再升級

03 是未來的一種發展趨勢

04 綠色環保


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