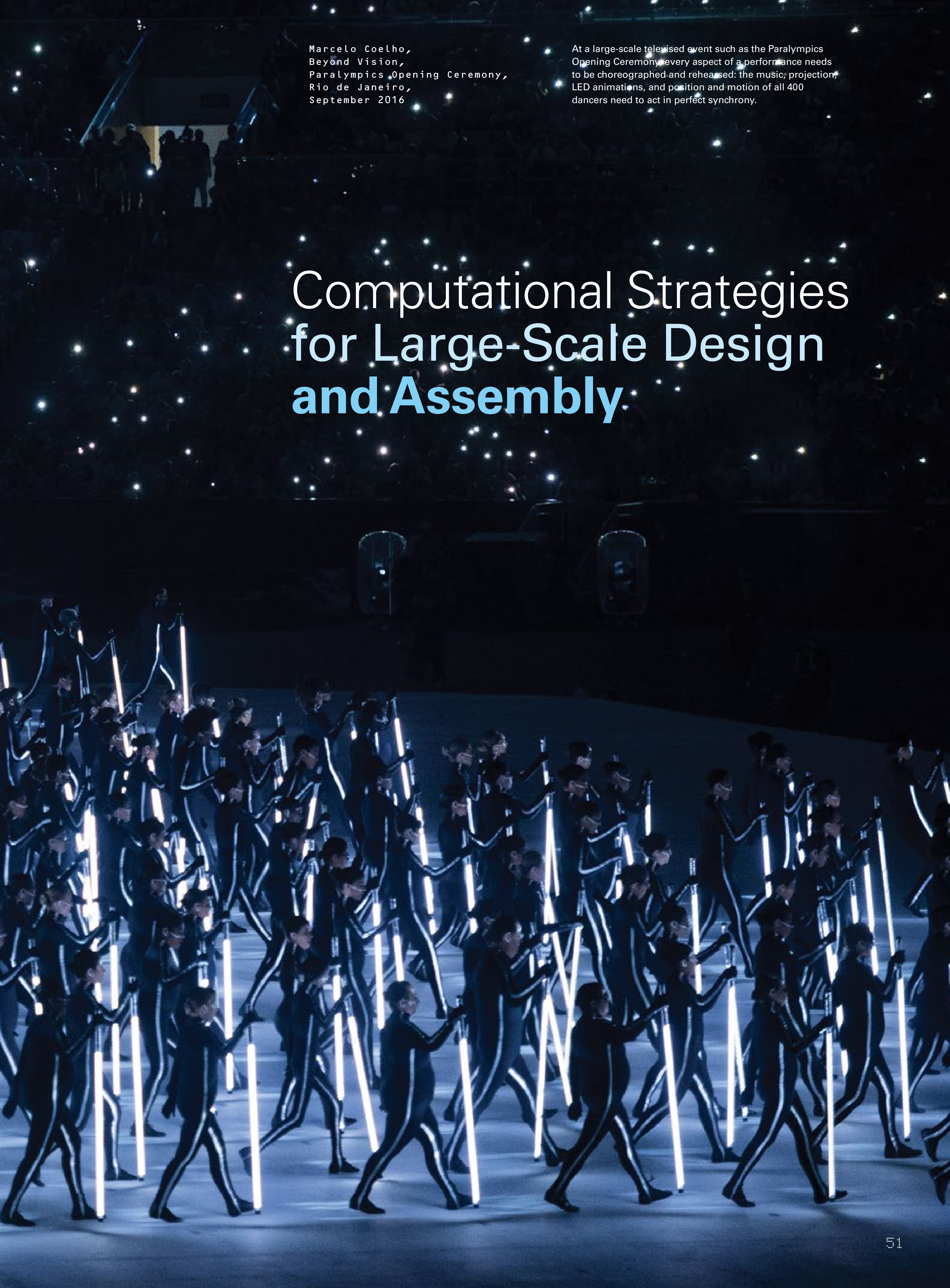
Marcelo Coelho
and
Tovi Grossman

Crowd-Driven Pattern Formation

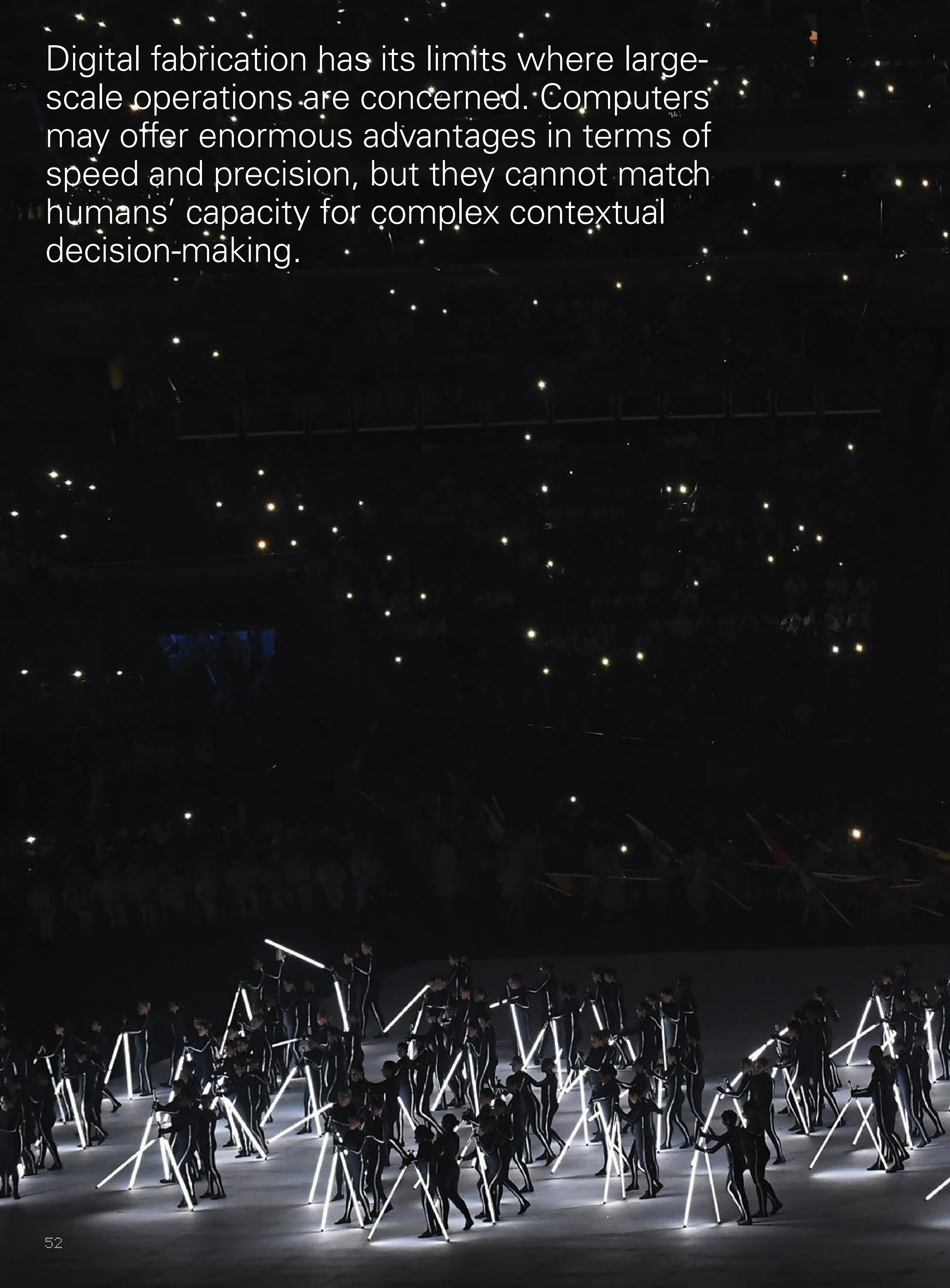
Marcelo Coelho,
Beyond Vision,
Paralympics Opening Ceremony,
Rio de Janeiro,
September 2016

At a large-scale televised event such as the Paralympics Opening Ceremony, every aspect of a performance needs to be choreographed and rehearsed: the music, projection, LED animations, and position and motion of all 400 dancers need to act in perfect synchrony.

Computational Strategies for Large-Scale Design and Assembly



Digital fabrication has its limits where large-scale operations are concerned. Computers may offer enormous advantages in terms of speed and precision, but they cannot match humans' capacity for complex contextual decision-making.



Massachusetts-based designer **Marcelo Coelho**, and research scientist **Tovi Grossman** of Autodesk Research in Toronto, present three major recent installations that explore how to make the most of both.

Every year the Arirang Mass Games held in Pyongyang, North Korea, organises an impressive spectacle of perfectly choreographed dancing and gymnastics in what might be the most incredible example of human coordination in the world. Every 20 seconds, for a period of two hours, a human mosaic composed of thousands of people switches the panels of coloured flip books to create pixellated images honouring the country's cultural heritage and political regime. In the words of photojournalist Jeremy Hunter, a crowd-driven display of this magnitude 'could only be achieved in a place where you have an unlimited resource of humans who do whatever they are directed to do. Every breath of these people is coordinated.'[1] Despite its tyrannical undertone, such a display encapsulates a stunning example of coordinated human workers collaborating to assemble an emergent large-scale form.

Marcelo Coelho, *Beyond Vision*, Paralympics Opening Ceremony, Rio de Janeiro, September 2016

previous spread: As dancers move to predetermined locations on stage, their exact position is resolved through subtle, real-time and local low-level interactions among them. In contrast, the animations displayed by the LED sticks are determined a priori, controlled by an external radio system, and are perfectly synchronised to both music and projection.

An Assembly Problem

Though design software and digital fabrication tools have had a transformative effect on how we make things, their utility is still severely limited when it comes to the assembly of large-scale forms. Traditionally, information and logic flow unidirectionally and without human intervention from computers to tethered fabrication devices through programmatic instruction sequences such as G-code. For large-scale fabrication and assembly, this introduces a whole host of problems: for example, the size of machines inherently limits the size of the parts they can make; small variations in part geometry or placement can introduce compounding errors during assembly; and machines are incapable of improvising to address changing environmental conditions.

One solution is to introduce human workers back into the fabrication equation, where their observation and cognitive abilities complement the strengths of digital tools for performing repetitive and precision tasks.[2] Automaker Toyota has for years employed people alongside robots to retain human insight in its manufacturing processes,[3] a concept that can be extended to crowd-driven pattern formations in which coordinated human workers collaborate to assemble large-scale, high-level designs through small-scale, low-level and distributed interactions. This novel design space provides a number of unique challenges and opportunities. In all of the large-scale installations described below, which are collectively assembled by humans and computers working in close collaboration, there is a clear distinction between parts (the multistate physical voxels that are arranged in the space), pattern (the image or target design the system seeks to achieve) and instructions (the guidance system that provides assembly information to the human workers).

A custom software tool developed by Marcelo Coelho was used to determine the scale, place and arrangement of the balls in order to create the desired visual effect. Black and white areas are pre-registered with the help of strings and high-powered video projectors. Each soccer ball acts as a multi-state pixel that can be individually rotated to display a different black-and-white gradient.

This is Not a Ball

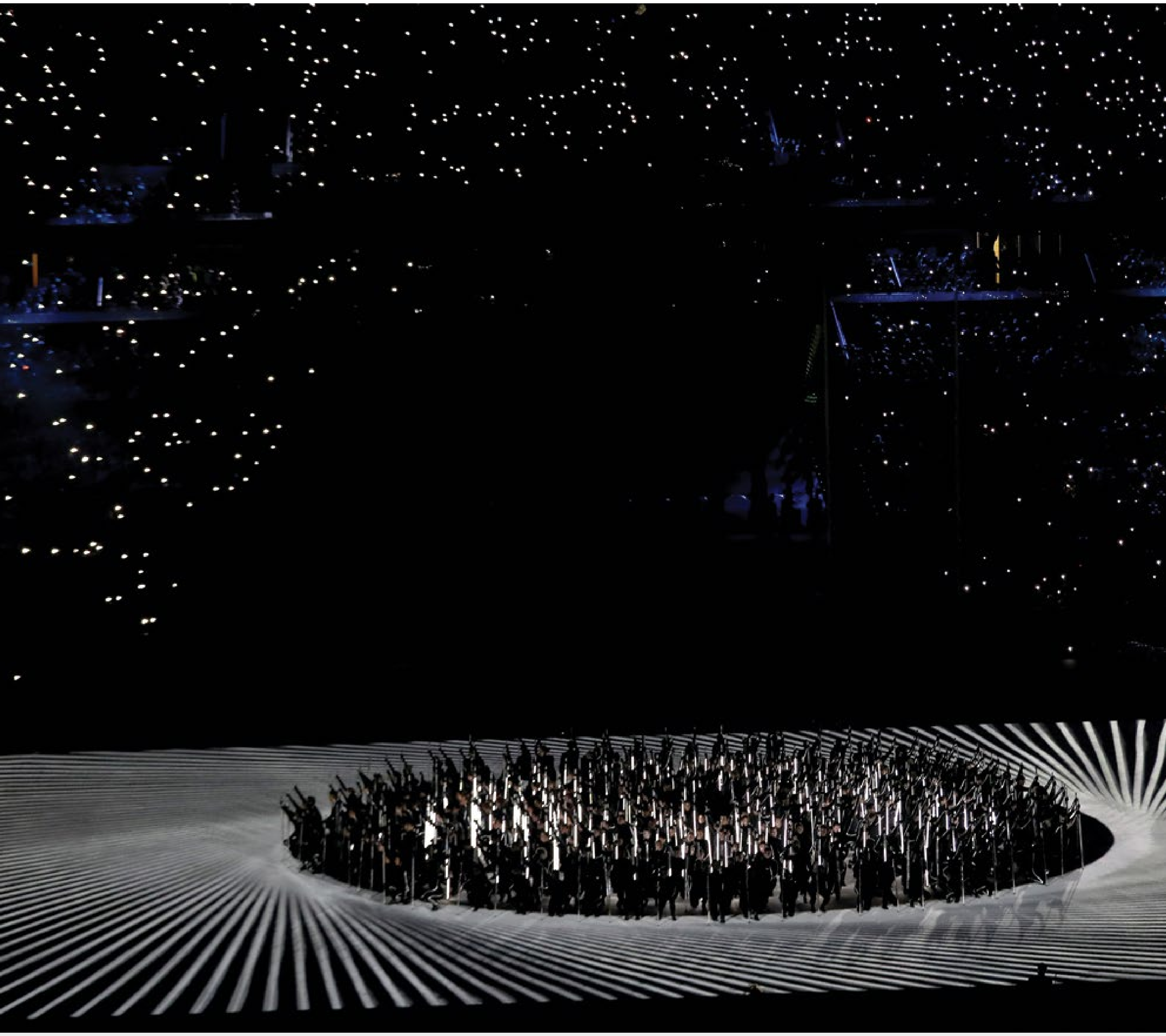
Created in anticipation of the 2014 FIFA World Cup, *This is Not a Ball* is a documentary directed by Brazilian artist Vik Muniz and Juan Rendón that follows the design and fabrication process of a stadium-scale drawing.[4] The film culminates with a formation of 10,000 soccer balls, recreating Leonardo da Vinci's illustration of a truncated icosahedron for Luca Pacioli's 1509 book *The Divine Proportion*.

Vik Muniz,
This is Not a Ball,
Rio de Janeiro,
April 2014

A re-creation from 10,000 soccer balls of Leonardo da Vinci's drawing of a truncated icosahedron for Luca Pacioli's 1509 book The Divine Proportion. Only when seen from the same angle from which Da Vinci drew the original image does Muniz's work appear to be three-dimensional.

The film culminates with a formation of 10,000 soccer balls, recreating Leonardo da Vinci's illustration of a truncated icosahedron

The distribution and pattern of all 400 dancers at any point in time was charted on a Cartesian grid and given to each dancer as a series of coordinates to be memorised.



Unique to the work is a custom-designed soccer ball, printed with a black-and-white gradient that acts as a multi-state pixel. A custom software tool transcoded Da Vinci's drawing into a grid of hexagonal black-and-white spheres, taking into account fundamental constraints such as field and ball size, and number of available balls. Since no industrial robots are as big as a soccer stadium, a team of volunteers acted as a large-scale human printer, rotating and placing the balls within areas delineated by a video projector.

Humans are not deterministic fabrication machines, but are good at improvising, making complex contextual decisions and real-time error correction. Prior to receiving detailed assembly instructions, the volunteers tried to parallelise their work by breaking away from the grid and following the projection outline. This deviation in the raster sequence broke the hexagonal relationship between parts and made proper tiling impossible. On the other hand, however, these low-level human decisions made it possible to easily accommodate variations in ball size and pressure changes throughout the day that would otherwise have made the task completely unachievable.

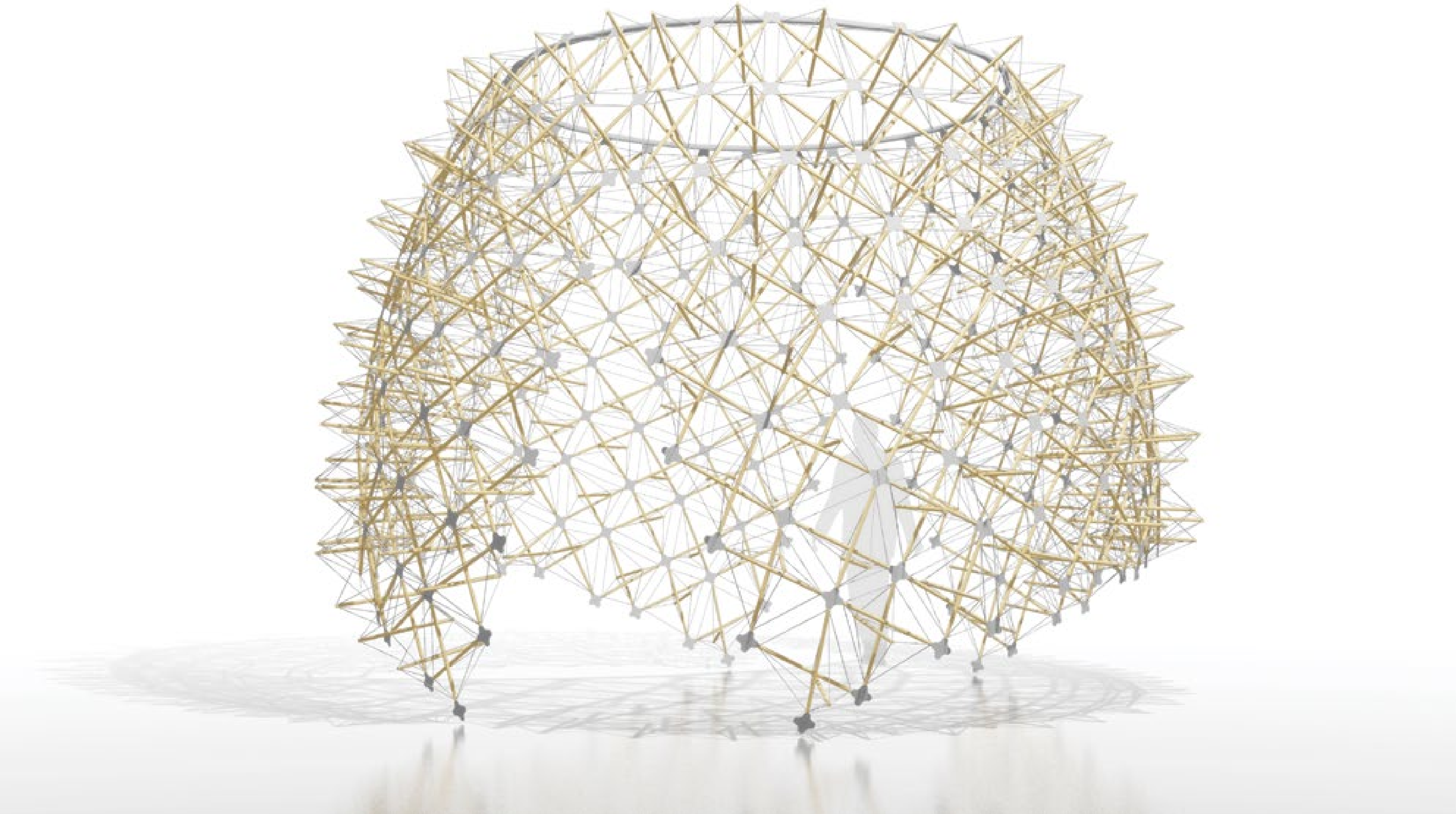
Beyond Vision

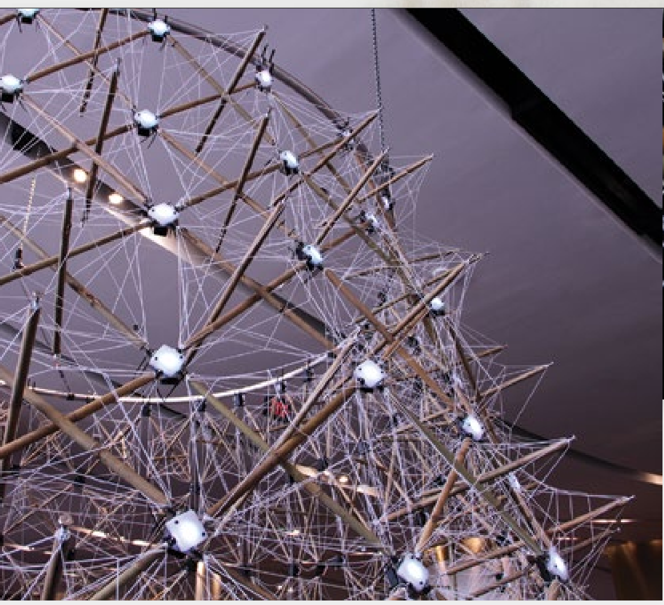
Crowd-scale pattern formation can also be used to create dynamic digital forms. In the *Beyond Vision* audiovisual performance created for the Rio 2016 Paralympics Opening Ceremony, 400 dancers were equipped with illuminated walking sticks to form a large-scale 2.5-dimensional display. As a poetic representation of the sense of sight, each stick was outfitted with a row of 128 programmable, high-intensity LEDs, which were triggered by a radio transmitter to play a series of pre-programmed animations. The distribution and pattern of all 400 dancers at any point in time was charted on a Cartesian grid and given to each dancer as a series of coordinates to be memorised.

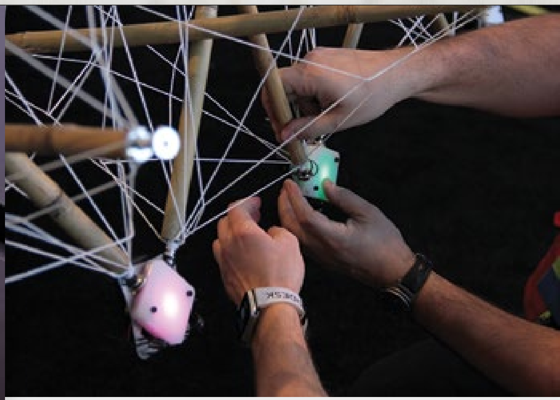
In a live televised event such as this, every aspect of a performance needs to be choreographed and rehearsed. However, even with rehearsal, it was crucial to balance the properties of a high-level animation control system with the ability of the dancers to resolve their exact location in real time through local low-level interactions. Once at a new location, dancers needed to adjust their exact position through their relative distance to others nearby. Balancing the high fidelity and precision of radio control with the improvisational skills of situated humans allowed an incredibly complex performance to be achieved in record time and to great effect.

Marcelo Coelho,
Beyond Vision,
Paralympics Opening Ceremony,
Rio de Janeiro,
September 2016

Formation of 400 dancers collectively acting as a 2.5D crowd display. While humans determine the Cartesian location of a pixel, the LED sticks animate to create large-scale visual effects.







Hive is an architectural-scale pavilion made from 224 tensegrity parts built by humans and robots working in close collaboration.

Autodesk,
Hive,
Autodesk University,
Las Vegas,
November 2015

opposite top: Illustration of the final pavilion structure, where tensegrity units are assembled together by humans and robots in close collaboration. Each layer provides both structural and informational guidance for the following layer of assembly.

opposite bottom left: As each layer of the pavilion is assembled, the structure is hoisted to make space for another layer. Once completed, large-scale animations can be played on the pavilion surface through its array of embedded LED nodes.

opposite bottom right: Two workers collaborate to attach a tensegrity unit to the larger pavilion structure. Radio-controlled LED lights and wearable devices provide guidance on where and how parts should be attached.

Hive

Extending these prior examples into the realm of 3D construction, *Hive* is an architectural-scale pavilion made from 224 tensegrity parts built by humans and robots working in close collaboration. Assembled at Autodesk University in Las Vegas over the course of three days in 2015, unskilled volunteer workers were guided through a sequence of construction steps while directly collaborating with a group of UR-10 robotic arms.[5] Instructions were generated by a central software engine and distributed in real time to the workers using a custom smart-watch application.

The unique global design of the pavilion required that each of the pavilion's parts had a unique pre-defined geometry and that they be added to the structure in a particular location and orientation. To accommodate these complex variations, each tensegrity unit was composed of three bamboo rods held together with a string wound by a robotic arm so that part geometry could be computationally specified and remain oblivious to human workers. Once a part was ready for placement, LEDs embedded in connector nodes pulsed to direct the workers to the exact location it should be attached. As every layer of the structure was assembled, an animation was played across the pavilion surface so that they could verify the accuracy of their work and correct any errors.

This division of labour affords a variety of new opportunities: digitally fabricated structures can be infinitely large; higher-level design patterns can be adapted in real time to accommodate for errors; and human dexterity can address some of the challenges of special-case assembly.

What is Next?

As the boundaries between materials and computers become blurred, new avenues will surface for digital fabrication and pattern formation to be become an interactive, distributed and highly collaborative activity in which humans play a significant role. The question still remains, however, as to where information and logic should reside and how it should flow through a dynamic system of computational materials, robots and humans. The human workers in the examples above had varying degrees of prior skills and training, ranging from rehearsed professionals to unskilled volunteers. Ultimately, by recognising and taking advantage of the skills perfected and evolved in humans for thousands of years, we can unleash completely new paradigms for design and production. ⅅ

Notes

1. 'North Korea's Amazingly Choreographed Human Mosaics', 30 April 2013: www.odditycentral.com/events/north-koreas-amazingly-choreographed-human-mosaics.html.
2. Austin Weber, 'ASSEMBLY Planbook: Man vs Machine', *ASSEMBLY*, 28 February 2008: www.assemblymag.com/articles/85269-assembly-planbook-man-vs-machine.
3. 'The Human vs Machine Race in Manufacturing', 23 April 2014: www.sikich.com/blog/post/The-Human-vs-Machine-Race-in-Manufacturing#.WCCyveErJE5.
4. *This Is Not a Ball*, directed by Vik Muniz and Juan Rendón, Netflix, 2014.
5. Benjamin Lafreniere et al, 'Crowdsourced Fabrication', in *Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16)*, ACM (New York), 2016, pp 15–28.