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PROGRAMMING MATTER ACROSS DOMAINS AND SCALE

Our quest to explore and re-imagine reality pushes us to question anything that may have been perceived before as impenetrable, layer by layer, from planets and above to atoms and below — and sideways too, across that still elusive quantum panorama. Every slice of a reality becomes ultimately a new design domain to be taken.

Deeply rooted in physics, chemistry, and biology, an increasingly relevant kind of design paradigm is one where by programming local interactions a whole new dynamic design emerges. Precursors span a range of domains and applications from cell automata to design computation in architecture. Yet, this approach does not end with an *in silico* simulation (e.g. the game of life). Nor does it aim to produce programmatically a final design to be later built physically as a static structure (e.g. Today, the envelope of a building may have been generated programmatically but it is not expected to fundamentally change dynamically once built). This design approach is about building parts that continue to change and adapt over time based on fluctuations in the environment; that self-assemble into an emergent shape; that sense and actuate its environment. The local rules of interaction may be similar to those run in a computer simulation but they are embedded physically and played out as in a materialized simulation. In a way, this pattern could be thought as producing an embryonic design output that completes itself upon being built physically and may never stop changing. It's not just about mimicking life. 'It' is alive or in the process of becoming so, by design. Broadly speaking, we can view this design pattern most closely associated with the notion of programmable matter [1], i.e., the computing substrate and the parts composing a design are the same. Today, biology could be seen as the fundamental reference for programming matter, composed of layered computing substrates, being both the source of inspiration and the object of manipulation by matter programmers. Under this broader view of matter programming, specific examples include synthetic biology/virology [2, 3, 4, 5], DNA Origami [6] and in general molecular computing [7], spatial computing [8], amorphous computing [9], 3D bioprinting [10], protocells [11, 12], and more recently 4D printing [13]. Although many of these and other domains have arisen independently of one another, we see them progressively overlap, fuse across scales and continue to co-evolve. Gradually, they are leaking into traditional top-down design approaches until everything, from manufacturing, to architecture, to certainly ourselves, becomes subject to being reprogrammed from the ground up.

A COMMON GRAMMAR

As we look to formally establish the rules for programming matter, we learn how every design choice has consequences that in turn, generate new languages and grammars for every design space they explore. As these different domains fuse and cross-pollinate new unforeseen phenomena and applications may be created. If the grammars across design spaces share some basic language we are more likely to accelerate that cross-pollination and go to the next level, whatever the next level is because we are not anymore alone aiming for a specific exploration or design goal. Our goals are being fused. The local interaction of the parts from which an emergent design applies to ourselves as well - we become a part.

TOOLS TO EMBODY A NEW DESIGN LANGUAGE

New tools are needed to capture our design intent and propagate it to the individual parts in the form of local rules that are run in a massively parallel fashion. At Autodesk Research's Bio/Nano/Programmable Group, and in collaboration with current and past academic researchers [14-33] and industry partners [34, 35, 36, 37], we are gradually co-developing a set of design and exploration tools for matter programming. These tools are often built on Project Cyborg [38], an experimental platform aimed to expose to its users a nascent common design language catalyzing the interconnectedness of domains and scales. A common design language helps grease that recombination of parts. DNA is that common language in biology enabling a Cambrian explosion to occur. Biological systems are the most advanced kinetic trap we know of today. Being able to create a common design language across inorganic and organic matter from nano and below to the human scale and above, will bring a new point of inflection in the sophistication of kinetic traps in our known universe – and take this to a new level where we are able to occupy radically new kinds of spaces that we may never have previously encountered.

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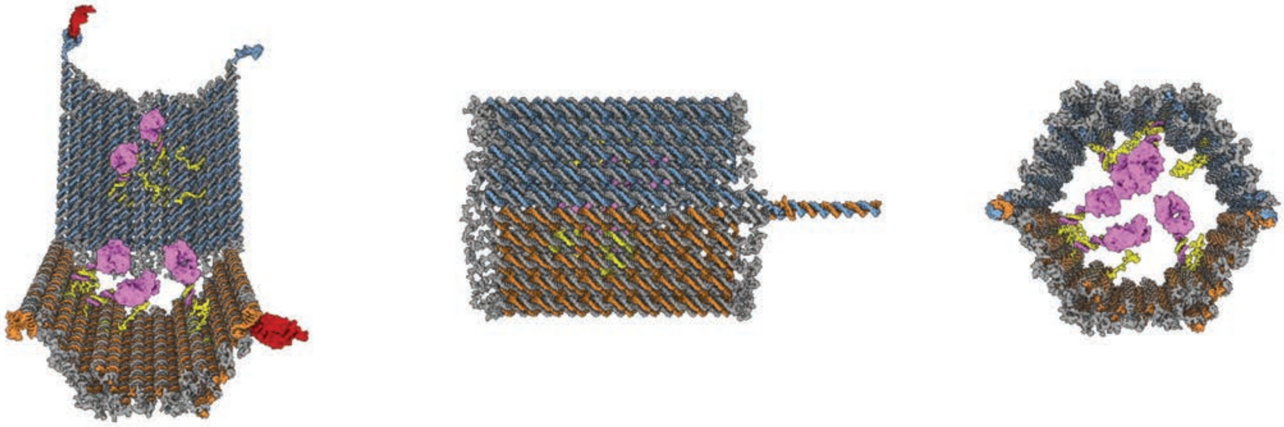


Fig. 1. Closed and open conformation of a self-assembled cell-targeting nanorobot, Douglas, Bachelette, Church [39].
(Image created by Campbell Strong, Shawn Douglas & Gael McGill using Molecular Maya & cadnano, 2011)

Fig. 2. Synthetic Yeast 2.0: Extract of design specification for chromosome 7 right arm.
(Yue Shen. Cai Lab, University of Edinburgh, Unpublished)

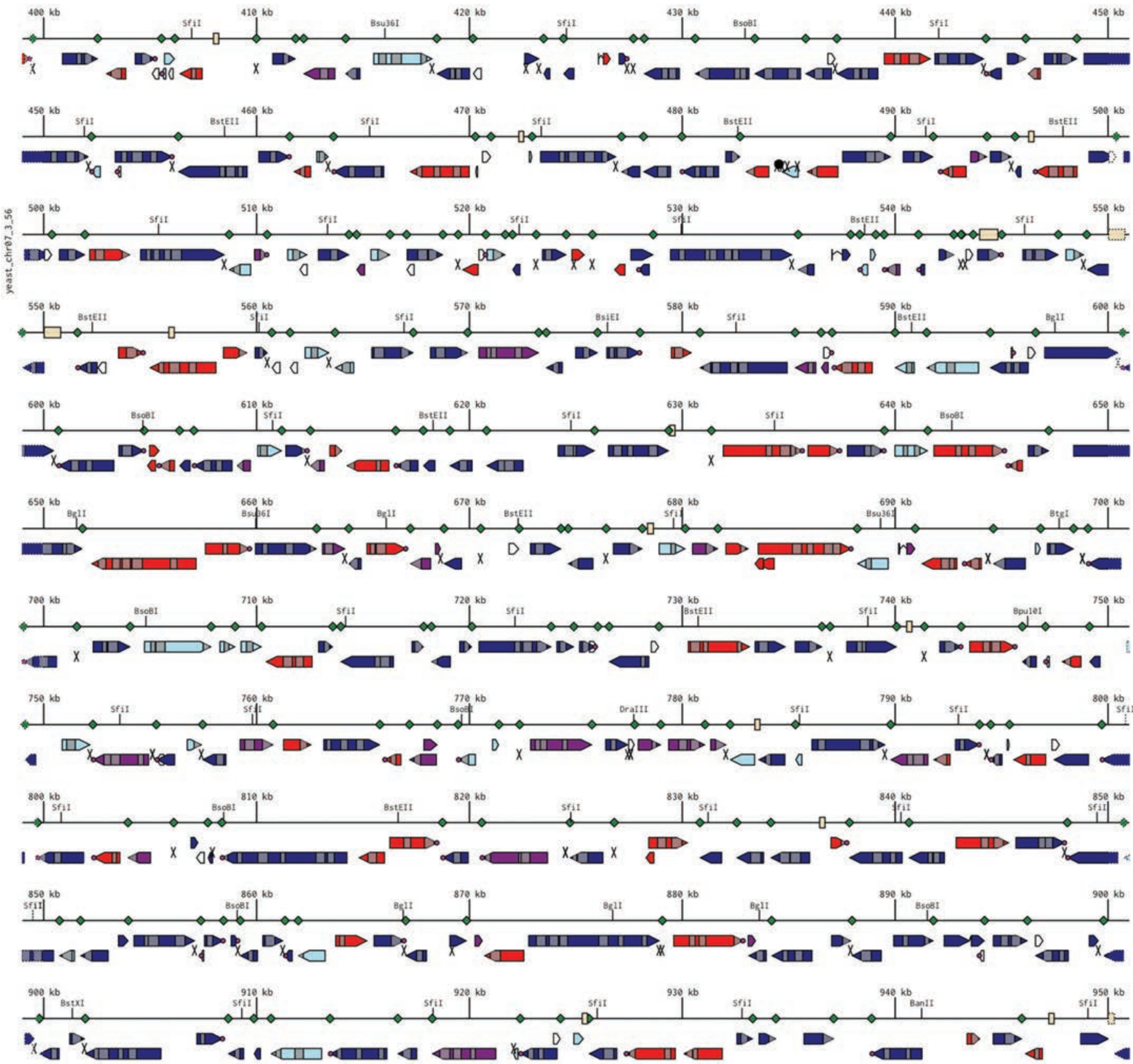


Fig. 3 3D Bioprinting done by Organovo 2012.

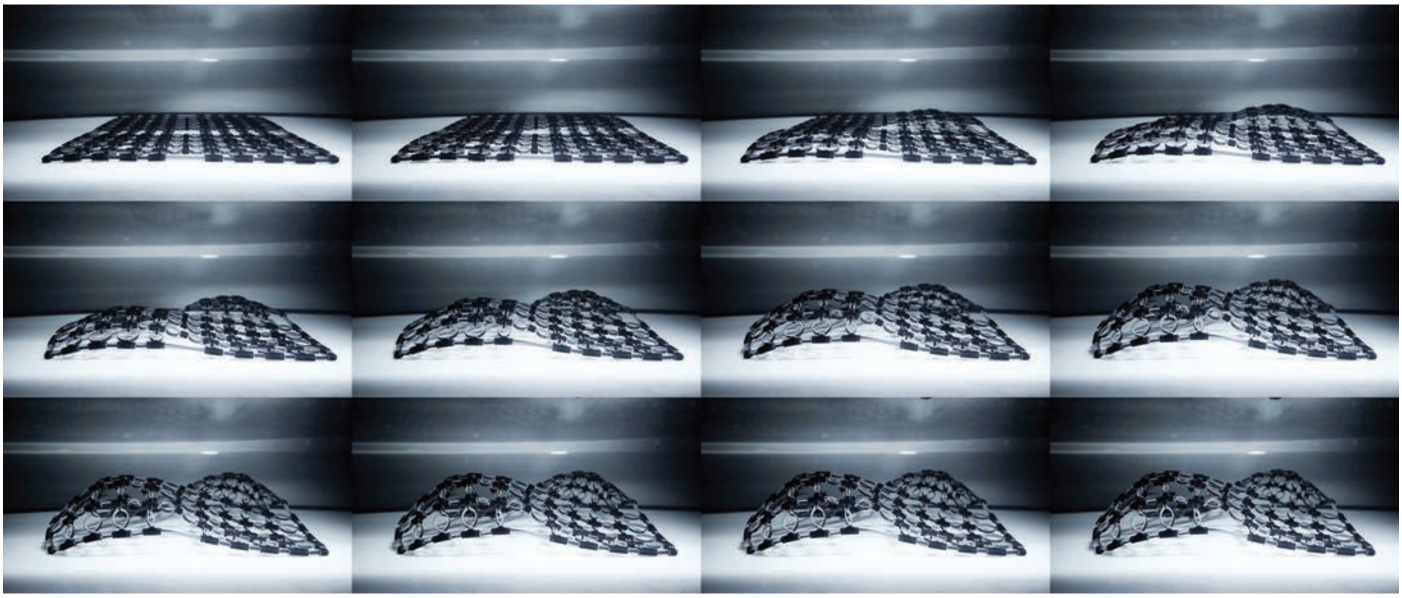
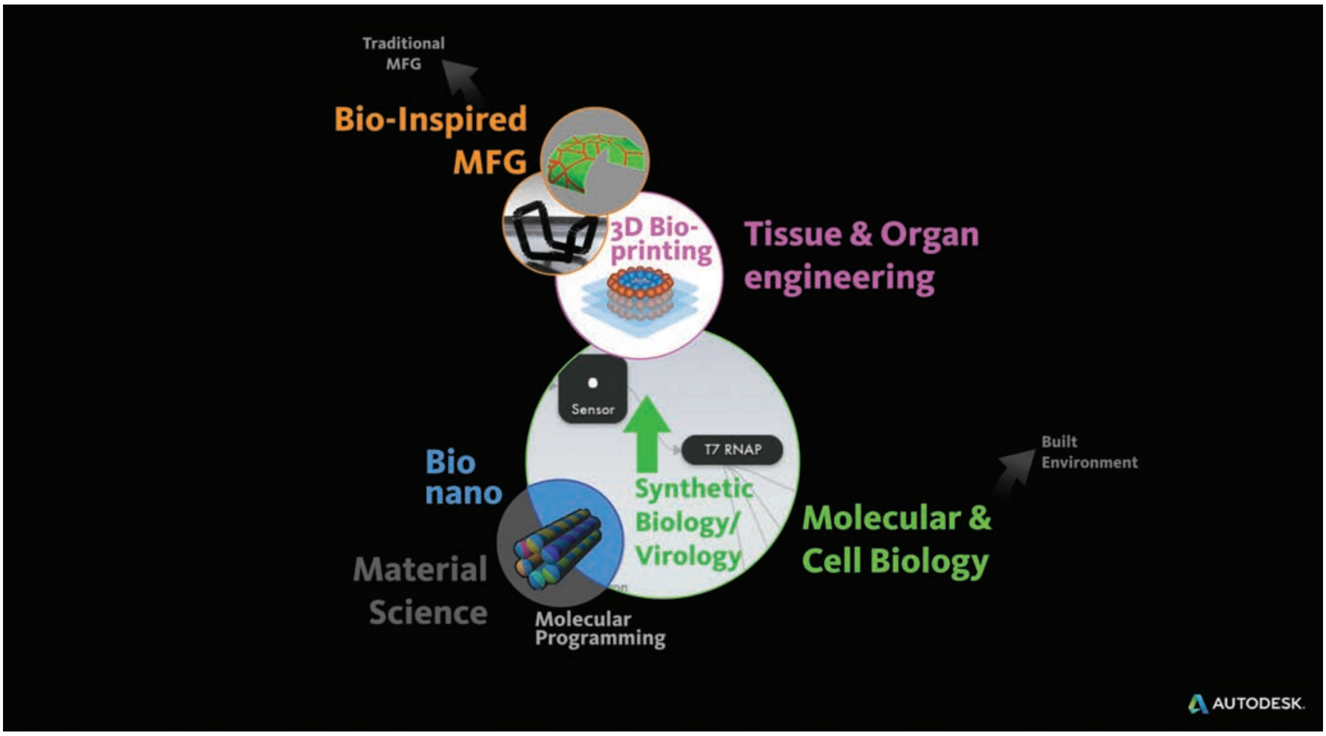


Fig. 4 4D Printing. Self-Assembly Lab at MIT, Stratasys Education, Autodesk Research. 2014. Work also featured in [40].

Fig. 5 Design Spaces for Matter Programming at Autodesk as of 2014.



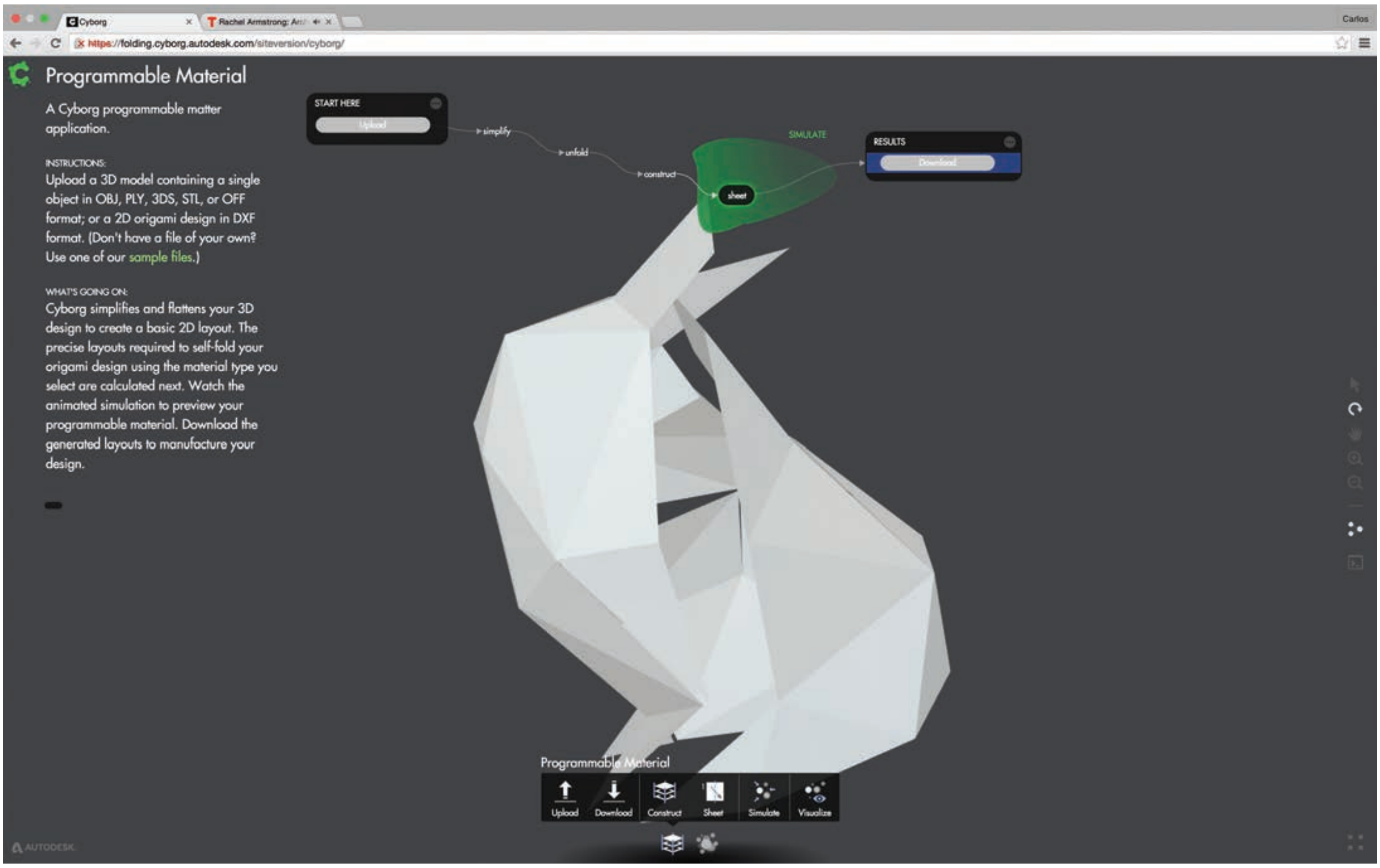


Fig. 6 Programmable material application built on Autodesk Project Cyborg (2015). Collaboration between Bio/Nano/Programmable Matter Group at Autodesk Research and Self-Assembly Lab at MIT [41].

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