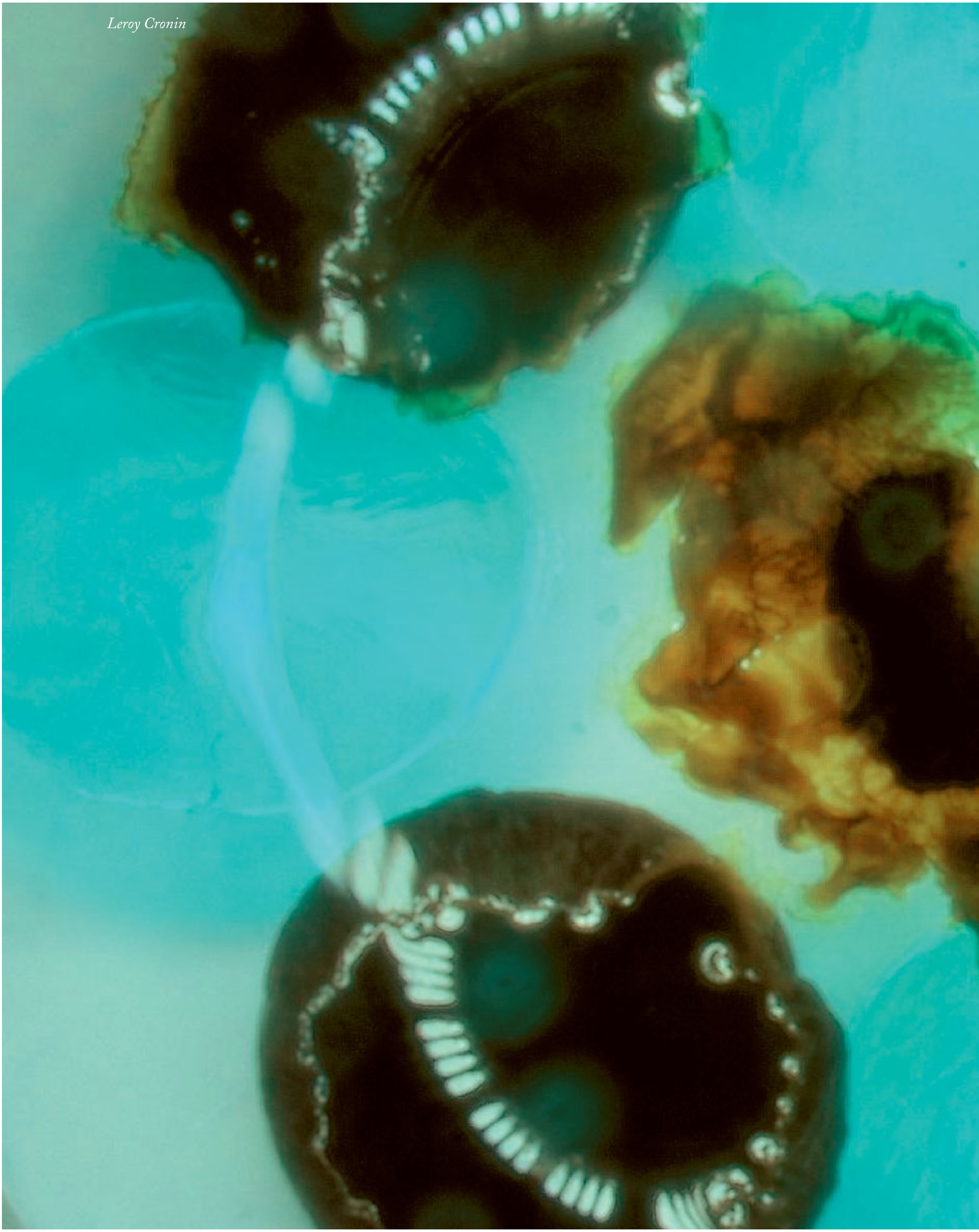
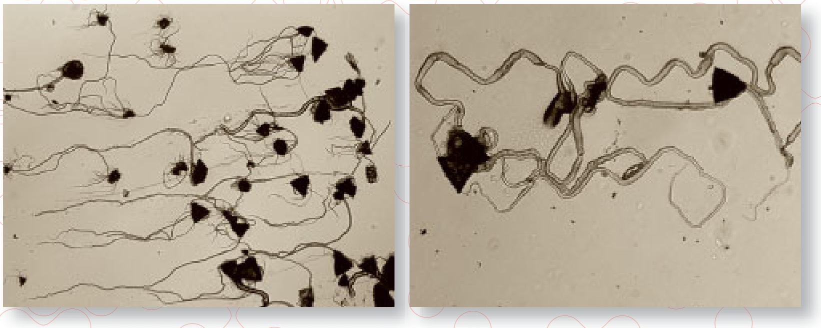


Leroy Cronin, Inorganic Cells, Cronin Group, University of Glasgow, 2010
Grid of iChells arranged so that 'inter-chellular' communication is possible, allowing the exchange of information and chemicals. The iChells here are around 0.05 millimetres in diameter.

DEFINING NEW ARCHITECTURAL DESIGN PRINCIPLES WITH 'LIVING' INORGANIC MATERIALS

At the University of Glasgow, **Leroy Cronin** is leading a group of scientists that are pioneering the engineering of a fundamentally new approach to building materials, which scales up from the nano scale to the micro. Cronin reflects on the possibilities of this new paradigm that gives inorganic cellular materials the potential to be 'programmed' to sense environmental changes, generate power, self-repair, shift properties and even compete with other building materials for resources.



Imagine a space that is able to undergo antonomous structural morphogenesis in response to various stimuli both inside and outside the structure. In the virtual-reality world this scenario is already a reality, but in the 'built' material world the technology is still far from realisation in a practical sense. It is fascinating that the drive for morphogenically adaptable structures, from the millimetre, to the tens of metres, is coming not from what is scientifically and technologically possible, but from the push and evolution in architectural design demanding a fundamentally more responsive, intimate, tactile and intelligent class of materials. This is pushing the limits of what is conceivable in materials science and technology as architects and designers try to create more sophisticated and intelligent spaces that serve a multitude of purposes from the functional to the aesthetic.

Also, the development of metaspaces, which change over time, has been possible thanks to the advent of modern lighting and materials; for example, transmitting to reflective glass which can be switched as a function of the environment or the user. Such approaches, which allow the development of adaptive environments, are extremely interesting for energy-efficient buildings: programmable spaces, for example. In the work being carried out by the Cronin Group at the University of Glasgow, attempts are being made to tame and manipulate spaces from the nanoscale (a billionth of a metre) to the micron-scale (a millimetre is 1,000 microns). However, the focus is not on inanimate materials, but rather on attempting to engineer a fundamentally new materials paradigm. To define this new approach, the group proposes exploiting a new class of nanoscale inorganic molecules that can be reconfigured to allow the fabrication of scalable new building materials and systems that can emulate living systems (based upon inorganic cellular materials).[1] Such materials could be 'programmed' to modulate the environment (temperature, luminosity, humidity), generate power, self-repair, change mechanical properties, and even compete with other building 'organisms' for material, information and resources. The ultimate aim is to reduce the fundamental building block of building materials from the centimetre (real bricks, nails, concrete blocks) to the same dimensions as the building blocks of biology and to produce inorganic cells.

Imagine the outcomes of establishing such a paradigm. Buildings would have a cellular structure[2] with living inorganic components that would allow the entire structure to self-repair, to sense environmental changes, establish a central nervous system, and even use the environment to sequester water, develop solar energy systems, and regulate the atmosphere, internal temperature and humidity using this decentralised approach. Further, by engineering the cellular system with a standard information network the entire architecture could process and distribute vast amounts of information. In fact, such systems would constitute a type of living technology where biology and nanotechnology would be fused together.[3] Biological systems themselves are incredibly complex and the fact that they have been assembled according to a global evolutionary process means that understanding new architectural design principles could inform biologists about how ecosystems develop and vice versa. The most exciting extrapolation could be the development of inherently sustainable built environments whereby the sharing of resources, and the environmental impact of the architecture, was ameliorated by sustainable interactions between the surrounding architectures and the environment. For example, if energy or water was in short supply, then the architecture may develop water- or solar-collection systems; or if the air was polluted, it could develop filtration systems to clean the local atmosphere. The key aspect here is that not only biological principles would be at work; we could also define the desirable positive interactions that support the living architectures. Of course such control is also open to abuse as well as being used for positive environmental outcomes.

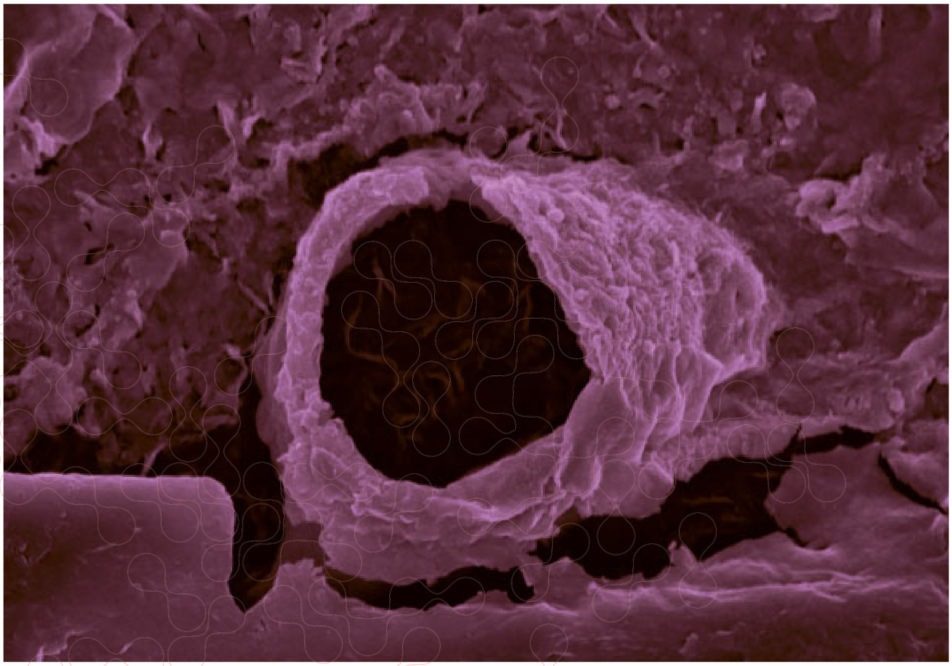
Let us now focus on how the building blocks are being developed. Today, the promise of 'living' inorganic materials is embodied and characterised by self-growing or fabricating entities that are able to seek out and adapt to new environments and stimuli, growing from a 'seed' or 'nucleus' that contains the information or blueprint for the architecture to develop.[4] As this architectural unit develops in time and space, it is able to both explore the surrounding environment and to adapt or learn from its surroundings. This means that the design process is inherently bespoke, whereby the architecture is defined by a range of chemotactic responses and pathways that lay down the hard inorganic material skeleton. In this respect the Cronin Group has been able to develop a micron-scale inorganic

Leroy Cronin, Tubular Architectures, Cronin Group, University of Glasgow, 2009
opposite left: A collection of inorganic crystals undergoing a spontaneous metamorphosis from single ordered crystals into tubular architectures growing in one direction following the flow of liquid. The tube diameter is around 0.001 millimetres and itself is capable of flowing liquids. The transformation is shown here around 3 minutes from initiation, 10 minutes after which the crystals have completely disappeared and the area is densely packed with tubular architectures.

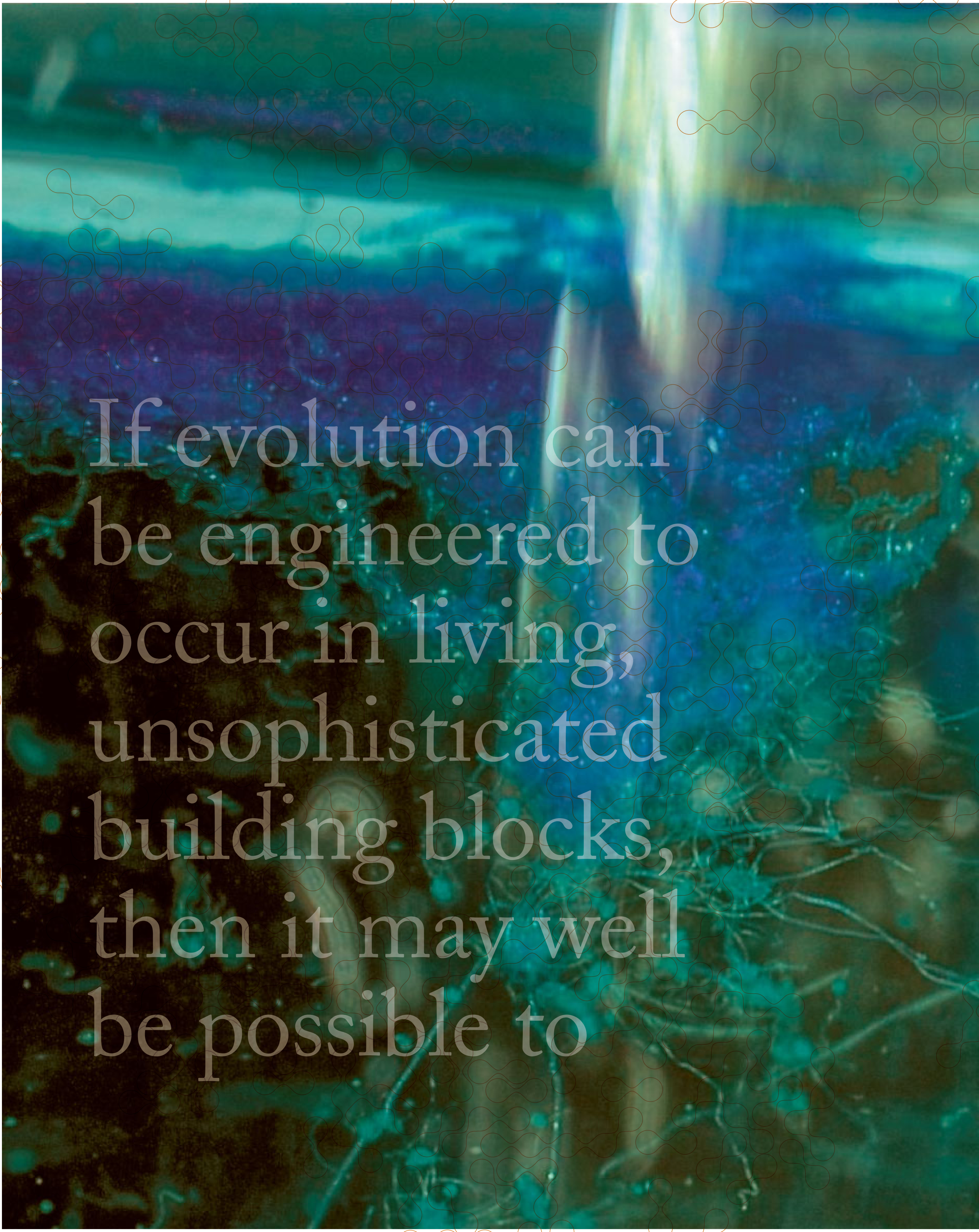
opposite right: Crystals undergoing metamorphosis that have traced a staircase pattern drawn using an external electrode array to direct the precise path of the tubular architectures. The diameter of the tubes is around 0.001 millimetres.

below: View into a sheered tube showing the cross-section, revealing the edge of the tube and the rough exterior as well as the interior. The diameter of the tube is around 0.001 millimetres.

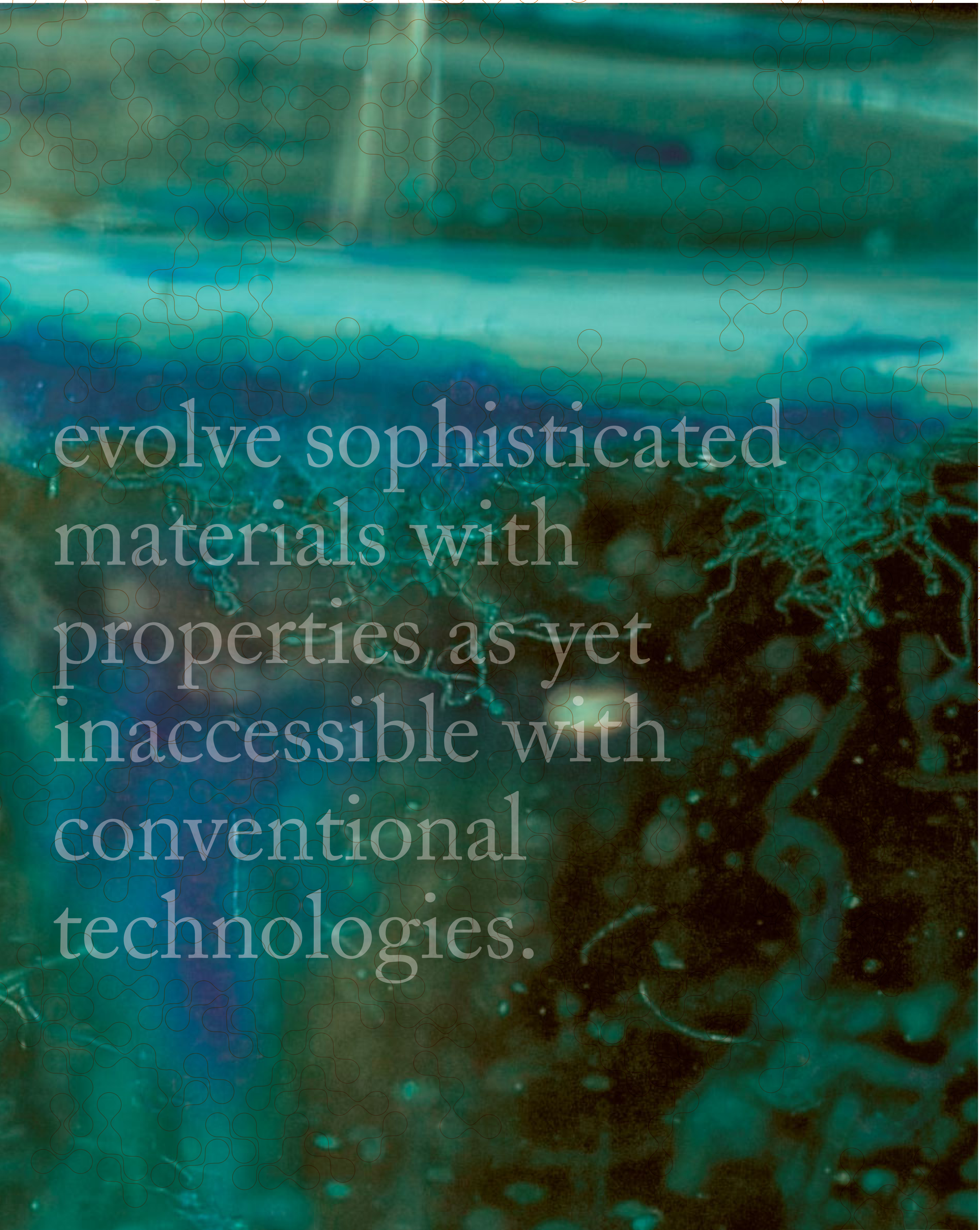
overleaf: Mass of tubular architectures that have formed at the air–water interface in a beaker of chemicals.



Biological systems themselves are incredibly complex and the fact that they have been assembled according to a global evolutionary process means that understanding new architectural design principles could inform biologists about how ecosystems develop and vice versa.

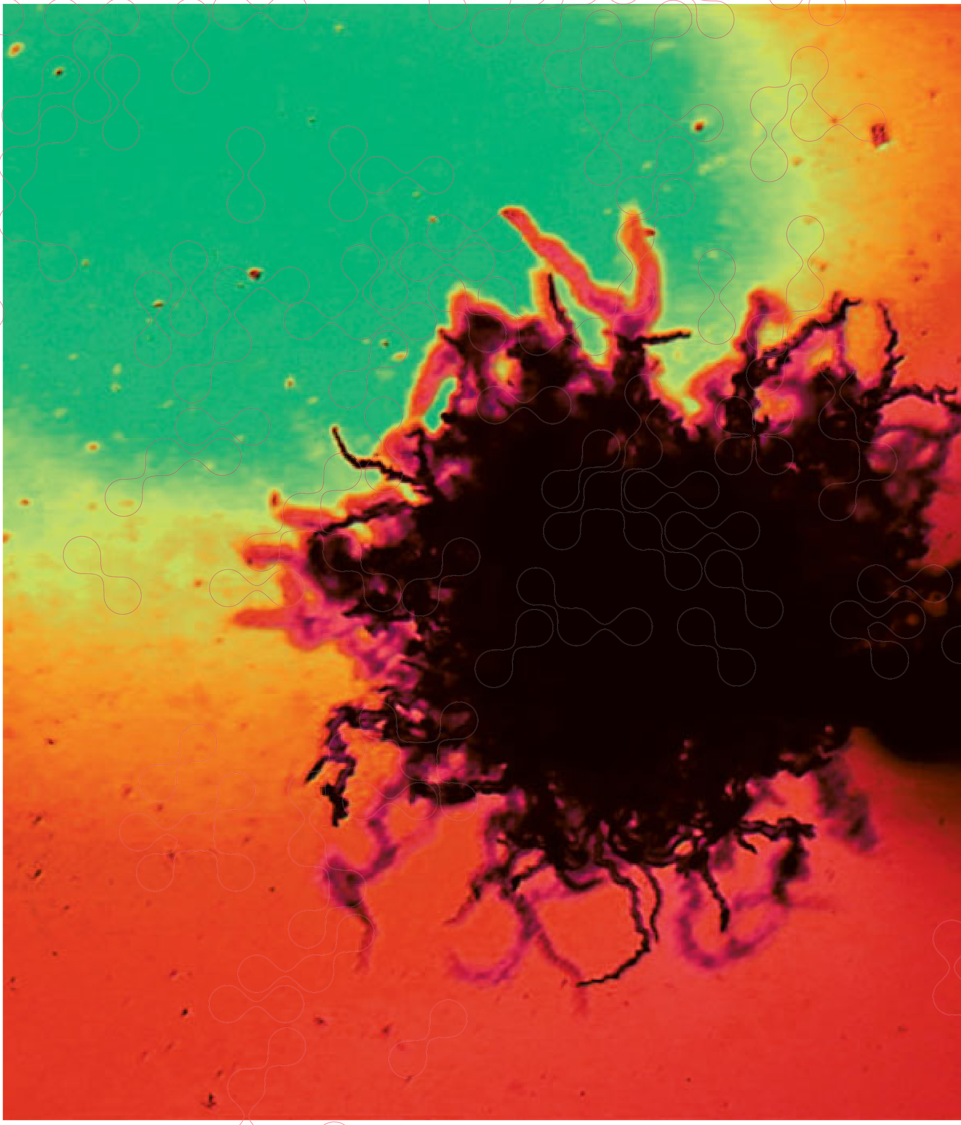


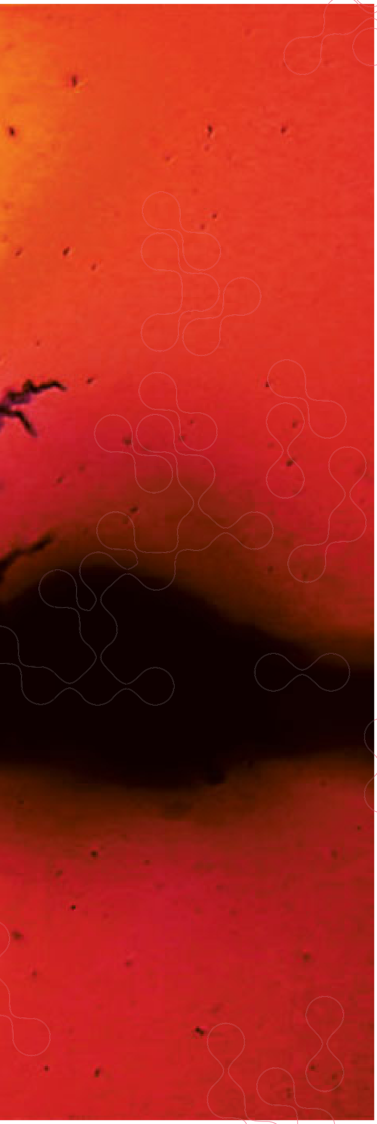
If evolution can be engineered to occur in living, unsophisticated building blocks, then it may well be possible to



evolve sophisticated materials with properties as yet inaccessible with conventional technologies.

The key aspect of any living technology is its potential for autonomous adaptation, and its application to design and architecture could be profound in the extreme.





Leroy Cronin, Combined Tubular and Cellular Architectures, Cronin Group, University of Glasgow, 2010
The inorganic chemical cell can develop and tolerate a range of chemistries and also extrude tubular architectures that could act as sensors, feeding pipes and transport networks to move chemicals around the system.

fabrication system whereby crystals of inorganic mineral are refabricated into tubular architectures many thousands of microns long, with well-defined paths and with tube diameters of only around 10 microns. These self-growing architectures[5] are extremely interesting since they can respond to the physical and chemical environment; they can grow as fibres with vast aspect ratios, and have a well-defined chemical composition.

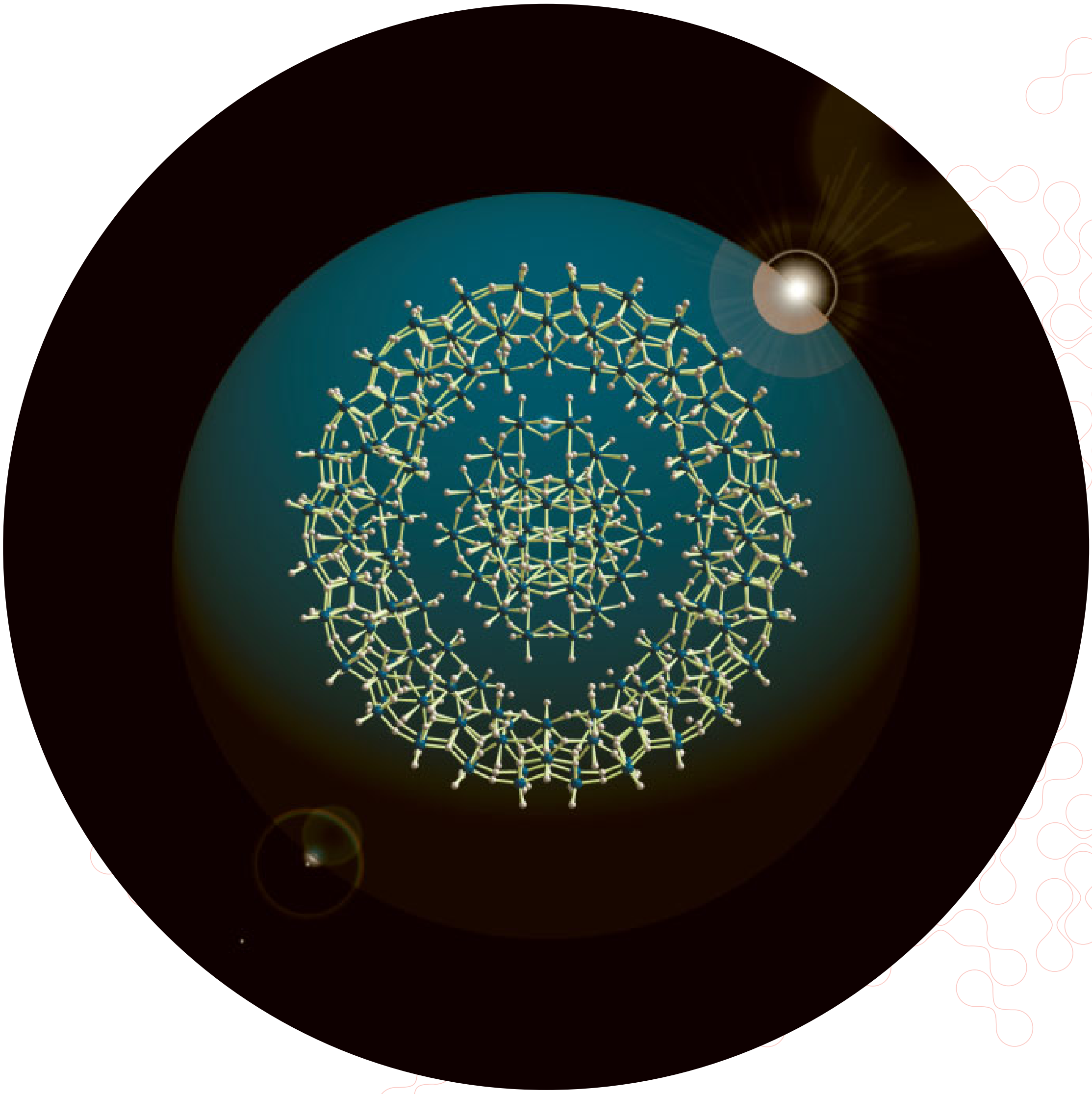
To be useful, to create systems with this degree of sophistication requires a robust chemical library of structures with embedded chemistries that are adaptive, resilient, environmentally compatible and realisable on a global scale. The global deployment of such a fundamentally new building platform, though, should probably not be permitted until we are able to get to grips with the concepts of artificial inorganic 'living technology'. Although the benefits are clear, there are also dangers that the technology will be misunderstood, abused or have a negative environmental impact (the most significant danger is poor representation in the media, rather than any real danger). Current research is informing us how the realisation of such systems will allow us to get to grips with the definition of life, to allow us to understand how easy or hard it is for living systems to spontaneously emerge in the universe, and this will also have a multitude of other implications for humankind.

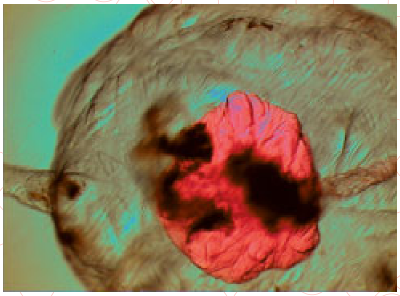
Just as important, and possibly even more relevant from a technology point of view, is the impact of living technology on the architectural world. In this respect, if one subscribes to the ability of living systems to adapt using evolutionary approaches, then the impact on design and architecture could be profound. If the design criteria or specification for the building could be encoded into a robustness of the building material, then using a living technology system to evolve towards the product need will profoundly change our world. In this respect, the only viable route to a physical living materials technology will be to demonstrate artificial materials that have built-in compatibility and mutual dependence with the natural world (both living and non-living).

The key aspect of any living technology is its potential for autonomous adaptation, and its application to design and architecture could be profound in the extreme. This is because coupling this property with present-day engineering paradigms opens up a vast world of material processes and new building materials, since it combines the approaches of

Leroy Cronin, Outerspace and Innerspace at the Nanoscale, Cronin Group, University of Glasgow, 2010
below: Actual image of a nanoscale wheel cluster that has captured, or been found with, a perfect templating molecule.

Leroy Cronin, Inorganic Cells, Cronin Group, University of Glasgow, 2010
opposite: View of a nested set of inorganic cells, or iChells, showing that it is possible to encapsulate a range of inorganic architectures within the cell. The cells are robust and self-repairing as well as able to encapsulate and tolerate a range of chemical environments. The diameter of the iChells is configurable and can range from 0.01 to 10 millimetres.





design and evolution with the idea of autonomous and 'adaptive matter'. This implies that the entire process of evolution of the matter occurs in the chemosphere (chemical world). Similar to biology, such material approaches could benefit from using cellular components as the minimal units of the living inorganic material. Like biological cells, these inorganic chemical cells, or iChells, can be 'programmed' to interact with each other. It would be fascinating to link the tubular and cellular systems; the combination of tube structures with cells would provide a route to networking the inorganic cellular blocks and would even allow the formation of structures based on such systems via the formation of tubular architectures, which may lead to the assembly of electronically programmable units that are already present in the building material.

If evolution can be engineered to occur in living, unsophisticated building blocks, then it may well be possible to evolve sophisticated materials with properties as yet inaccessible with conventional technologies. Indeed, improving the use of evolutionary synthetic techniques could allow the evolution of environmentally perfect materials. This would mean that the specification for the materials and the design brief would be presented as the evolutionary 'fitness parameter' that would be sought during the growth adaptation process. In this concept, the material used in the building design would initially be suited, but not perfect, and only over time would it adapt, evolve, improve and dynamically address the fitness parameter. This could mean the continual evolution of the material and the architecture as the result of changing environmental conditions: pollution, heating or cooling, humidity, available energy and so on. Thus the potential to embed scalable computing elements within the materials so that they could become 'intelligent' could also be an interesting concept, especially the idea of producing cellular materials that could signal between cells, and could compute and adapt.

The functional implications for such materials are profound, and the function–aesthetic aspect is equally intriguing. Self-healing buildings with peer-to-peer information storage, distributed processing as well as energy harvesting could also be embedded. Although the idea of inorganic living materials is coming closer, the use of the robust nature of inorganic materials in combination with the adaptive nature of living systems is extremely important. In some respects the concepts and ideas embodied by living inorganic cells goes way beyond biology, but this potential has not yet been made into a 'hardware' reality.

In terms of new materials design, if living or adaptive materials are to be realised and employed in real architectures, then the requirement of the minimum chemical infrastructure to establish a complex system using molecular building blocks is absolutely key, and it is vital to consider the design at the molecular, nanoscale level. At such scales, the design and assembly of protein-sized (around a billionth of a metre in diameter) inorganic metal-oxide clusters gives a good example of complex inorganic nanoscale architectures that surely can scale up to the macro-world with dramatic effect.[6] But perhaps the most profound metaphysical aspect of the development of living materials would be the position of the designer or architect. No longer would the architect be creating a space that is as inflexible as before, but instead an adaptive, living, morphologically transient space that could develop over time in a profoundly more flexible way. No longer would the imagination of the architect be static; it would evolve in such a way that the encoding of the structure would shift his or her role from architect to creator. Δ

Notes

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