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9

Explorative Growth for Art and Architecture

**Petra Gruber[1], Angelo Vermeulen[2], Ceren Yönetim[3]
and Barbara Imhof[4]**

[1]Biomimicry Research and Innovation Center BRIC,
The University of Akron, Akron, USA
[2]Systems Engineering and Simulation, Faculty of Technology,
Policy and Management, Delft University of Technology, The Netherlands
[3]Vienna, Austria
[4]LIQUIFER Systems Group and University of Applied Arts,
Vienna, Austria
E-mail: pgruber@uakron.edu; a.c.j.vermeulen@tudelft.nl;
cerenyonetim@gmail.com; barbara.imhof@liquifer.com

9.1 Introduction

This chapter describes how architects and artists develop their work through looking at nature and finding role models for proto-architectural applications. Artistic research methodologies are being used to transfer growth strategies in nature into concepts for a new living architecture. The chapter also describes the example of the artistic research project GrAB – Growing As Building, which was conducted between 2013 and 2016 at the University of Applied Arts in Vienna with an interdisciplinary and international team of architects, artists, engineers and scientists. The project was funded through the Austrian Science Fund, a funding institution for fundamental scientific research in Austria. The programme of developing and enhancing the arts is part of the FWF services and represents a unique opportunity to develop research in an artistic context.

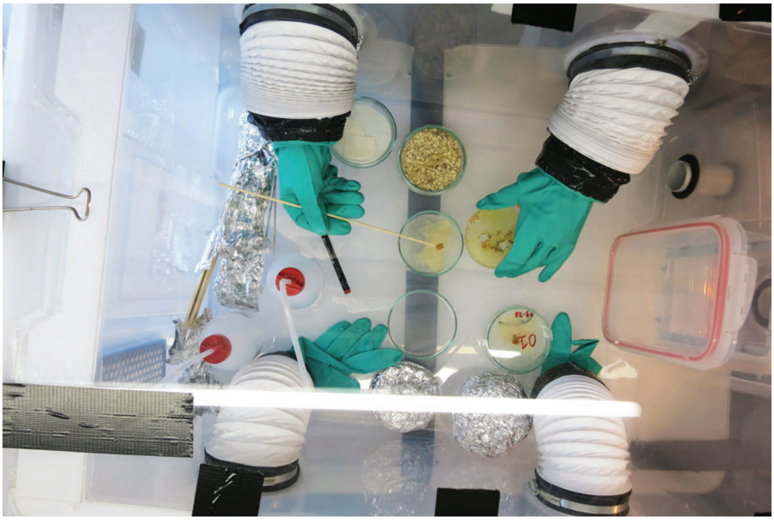

Figure 9.1 Slime mould in a glovebox and Petri dish.

Photo: GrAB team, 2014.

GrAB emerged from another artistic research project funded by the FWF: Biornametics – Architecture Defined by Natural Patterns explored a new methodology to interconnect scientific evidence with creative design in the field of architecture. GrAB took this exploration further and specifically looked at growing structures with focus themes on explorative growth, material systems, technological transfers and closed-loop systems. The investigations were multifaceted and broad at the beginning and were narrowed down to biological role model research which could be conducted in a biolab established at an art school (Figure 9.1).

The slime mould was investigated as part of the theme of explorative structures. Looking at the slime mould through an artistic lens, informed by renowned biologists yielded new insights into the interpretation of its behaviour and proto-applications for architecture and the arts.

9.2 Art, Architecture and Science Template

Artistic research is becoming a research area in its own right applying similar methods to those found in the scientific and humanities' fields of research. This starts with the same operational system of writing proposals, formulating research questions and describing methods of approaching the problem at hand. Artistic research is a discovery-led form of knowledge production, (Von Borries, 2015) similar to exploring the ‘what’, ‘why’ and ‘when’ of our universe, where the actual questions and methods are only gradually revealed. This kind of artistic research transitions into other disciplines and previously unexplored territory, leading to the discovery of new paths and outlooks. Both art and science are driven by a desire for fundamental understanding (or truth) and a desire for new products (Borgdorff, 2009).

This growing interest in the intersection of arts and sciences has led to a number of research programs and opportunities that take a transdisciplinary approach. ‘Artistic research’ and ‘Research by design’ acknowledge the investigation of possible futures as valid scientific approaches, and scientific findings are increasingly taken up and translated by artists and designers (Badura, 2013).

In the project Growing as Building, the multi-disciplinary team looked at growth principles through an artistic and scientific lens using and borrowing methodologies from different disciplines. The project is also understood as an endeavour to reconnect highly specialised fields and the common exploration of yet unknown areas. This unification of different fields is not new but has not been in the focus of our work and production in the last 200 years.

Already Rene Descartes introduced the concept of the unity of sciences (Descartes, 1905, Descartes, 2015) and thus marked a revolution in the search for the truth. Today, at the convergence of fields such as biology and technology (biotechnology), or mechanical engineering and electronics (mechatronics), this perspective has become the state of the art.

> The problems challenging us today, the ones really worth working on, are complex, require sophisticated equipment and intellectual tools, and just don’t yield to a narrow approach (Brown, 2018).

We have to solve complex problems; therefore, more people with different kinds of skills and expertise need to collaborate since no single person has all the traits required to tackle the world’s big environmental issues, migration streams and population growth.

The arts have played a side role in our industrialised society. The arts are viewed as inspiration, an add-on to our lives producing joyful contemplation, sometimes the arts were used as propaganda tool, e.g. during the cold war but hardly in their true capacity: a potential to create a critical perspective on the “things” happening around us. Art allows for broad investigation and interpretation and this is why the funding bodies support artistic research.

9.3 Problem Statement

9.3.1 Philosophy

The now obvious impact of human activity on the planet has changed the worldview and this era has been defined as the Anthropocene. However, moving forward and preserving the human live on our planet, some changes are inevitable: firstly, environmental protection is not to protect our surrounding and biodiversity for the sake of other creatures but because it is a key to our human survival on our planet. Humans cannot adapt within a few generations to completely new environments and are living systems, which can only exist in a small spectrum of temperature, atmospheric composition and surrounding pressure. Some animals or plants can adapt fast and can live in a greater variety of conditional range, such as amphibians or cockroaches, which can hibernate and are hardy animals being able to withstand higher dosages of radiation.

Despite the fragility of humans and our absolute dependence on the right climate, we have, secondly, developed a false dichotomy of human and nature. This developed from our history of having to shelter from the wild when it was still a dangerous place. However, always have “humans been part of nature, and not apart from nature.” Indian physicist Vandana Shiva has described this “apartheid” because like us she is confronted with an unprecedented speed of change. “In the last six decades, anthropogenic forcings have driven exceptionally rapid rates of change in the Earth System” (Gaffney and Steffen, 2017). Scientists researching the rate of change in climate, atmosphere and biodiversity talk about the “Great Acceleration”, hinting to a “fundamental shift in the state and functioning of the Earth System” (Steffen et al., 2015).

The built environment holds a large share in the exploitation of the planet.

> Because of their size, economic strength, and profound societal importance, construction activities and processes are among the largest consumers of materials and energy and significant polluters on the global scale” (Horvath, 2004).

An estimated 33% of materials consumption globally is attributed only to construction materials (Steinberger, K. 2009).

Approaching a world population of 8 billion humans soon, we need to address these issues in the way we build and live our cities and dwellings. Concepts for sustainability, renewable energy, alternative building techniques and refined materials including the use of technology will support us in creating architectural designs that are resilient, adaptive, reactive, sensing and attributed with life-like characteristics so we can actually survive on this planet. Therefore, we need to develop the self-growing house with all these above-described characteristics because in the future, most people will live in cities. Cities will also be where most of the world's pollution is produced. We are already faced with metropolitan sizes of nearly 40 million inhabitants and the consequences of problematic decrease in elementary resources such as clean air and water, and the challenges of massive waste production (Bushan, 2009).

9.3.2 Why GrAB

Being confronted with these challenges, the project GrAB, Growing as Building, addresses these challenges with the aim of creating a new living architecture, focusing on dynamically growing architecture which can adapt to the environment and the needs of users in a process of constant evolution. The GrAB interdisciplinary team looked at a broad spectrum of growth principles and focused on the following four key research areas:

- the slime mould, self-organising and with 'explorative' growth nature as a co-designer of complex architectural structures (Figure 9.2),
- mushroom mycelium as a lightweight, naturally grown material system,
- algae that produce oxygen and biomass within a bioreactor,
- the development of novel, mobile 3D printers capable of mimicking biological structures and processes, optimising material and energy use.

The artistic research project incorporating four different biologists (botany, ecology, microbiology and biomimetics) aimed at transferring qualities present in biological growth; for example, adaptiveness, exploration or local resource harvesting into technical design and production processes (Bushan, 2009).

In implementing principles of growth into the built environment, the team searched for proto-architectural applications that could potentially transform the way we construct our buildings and cities today. The aim of project GrAB was to develop ways for a more integrated and sustainable setting, a new living architecture (Bushan, 2009).

Through new technologies, such as 3D printing or contemporary computing, and robotics, GrAB investigated in merging program and tool and process and result. Growth, as one of the important characteristics of living organisms, was used as a frame for research into systems and principles that

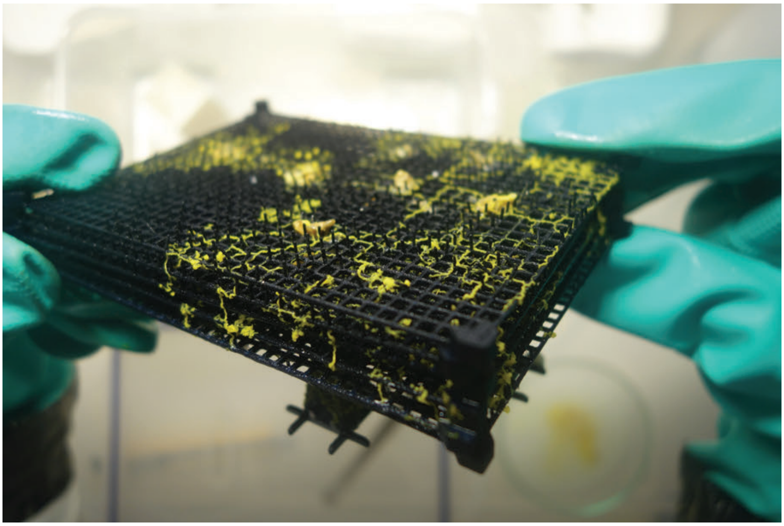

Figure 9.2 Slime mould growth in a 3D printed model.

Photo: GrAB team, 2014.

the team believed to deliver innovative and sustainable solutions in architecture and the arts. Biomimetics as a methodology was used to create and guide information transfer from the life sciences to innovative proto-architectural solutions and for the vision of a self-growing house.

For the future, the team wish for houses that behave more like living things which include buildings that

- grow through biological and technological processes;
- end its own site through self-organisation;
- can adapt to the climate and its environment;
- keep growing whenever sufficient space and material resources are given;
- produce no waste and dissolve itself when its lifetime has expired.

9.4 Life as a Paradigm

Life has a lot to offer to architecture and design. Life is in constant flux, in an ongoing process of seeking equilibrium. And it is open ended, in permanent exchange with its surrounding environment. These dynamic aspects of life have a lot of potential to transform inert structures into more responsive and resilient environments.

Biological research and role models from nature increasingly inform technological solutions, and architects and engineers also look to nature for inspiration. The investigation of the overlaps between the fields of biology and technology, biomimetics, has gained ground in research and development (Bushan, 2009; Bar-Cohen, 2012; Goel et al., 2014). Signs of life, as defined by the life sciences, are introduced into former static and unresponsive buildings so that sensing, reactivity, adaptation and also evolutionary development are found in contemporary architectural design (Gruber, 2011; Schumacher, 2016; Gruber et al., 2017).

Biomimetics as a methodology allows for the purposeful search for solutions in biology that can help achieve innovate human technology to meet the current global challenges. Some of the most striking aspects that are found in biological systems and we wish for ideal buildings are defined in the following:

Adaptation

Survival of an organism depends on its ability to adjust to, or resist, external events. This requires appropriate behaviour, internal chemistry, morphology and control systems. If an organism can adjust these variables such that it survives, it is said to be well adapted.

Resilience

The term describes the capability of a system (plant, fungus, animal, building, machine, etc.) to cope with internal or external changing influences or interferences.

Self-organisation

Self-organised systems are capable of spontaneously developing and maintaining order with no control from outside, and stability and change of self-organised systems depends on feedback mechanisms.

Aspects such as adaptability and resilience that biological systems exhibit are highly sought after in the built environment. Complex feedback systems are a prerequisite for adaptive capacities in natural systems. Biological systems that increase resilience and withstand unforeseen environmental developments, especially vulnerability during the processes of transformation, can serve as valuable role models for architectural applications. The biomimetic approach of deriving technological processes from research into biological growth principles provides insights that might improve or completely change contemporary traditions and technologies of building (Imhof et al., 2015).

9.4.1 Design with Nature/Organisms

Designing with nature is defined here as relinquishing part of the design process to living biology, with the goal of generating co-created solutions that exhibit some of the characteristics of the natural world.

Landscape architecture is probably one of the oldest examples of 'designing with organisms'. The landscape architect defines structures, boundaries and constraints in which nature operates. The resulting emergent landscape is a constant dialogue between man's interventions and nature's internal dynamics.

9.4.2 Design with Biotechnology

Through biotechnology such staged relationships between the living and non-living have taken entirely new dimensions. In tissue engineering, for example, porous scaffolding material is used as a template to guide the growth of new tissue. In a way, tissue engineering can be regarded as an extension of the same logic found back in landscape architecture: man-made structures and interventions guiding the growth of living biology (Dodington, 2009). Art projects such as *Victimless Leather* (2004) by the Tissue Culture and Art Project, and the *Semi-Human Vase* (2015) by Hongjie Yang explore the ethical consequences of such cell-based design methodologies. In designing with nature, the level of autonomy of the biological agents can be varied, and either a top-down or bottom-up perspective can be applied. Are organisms or cells merely allowed to grow along to a predefined path, within for example a specifically shaped mould? Or is their agency used as an asset to allow for a more emergent design?

9.4.3 Organisms as Co-workers

In biofabrication, organisms 'naturally' produce materials for manufacturing and construction. This can happen in bulk in semi-open systems, guided along scaffolding, or inside closed moulds. Biofabrication is essentially a top-down approach in which organisms such as fungi, bacteria and insects are coerced into the role of co-workers (Collet, 2018). Fungal tissue or mycelium can be dried, and the resulting product is both strong and lightweight. Because of these properties, it has been used as a structural material in a range of architectural research projects, such as GrAB (Growing as Building) in Vienna (2012–2013) (Imhof et al., 2015) and the Hy-Fi tower by David Benjamin in NYC (2014). In both these projects, mycelium was grown inside moulds resulting in bricks and simple structural elements that could be stacked to create larger architectures. Bricks can also be created with entirely different organisms and materials as demonstrated in the Biobrick project of Ginger Krieg Dossier. Here bacteria cement together sand grains using urea and calcium, thus producing bricks without the need for fire and baking (Dosier, 2010). Soft materials can also be useful in architectural construction. In the Silk Pavilion of MIT, silkworms weave along a predefined architectural structure, and consequently reinforce and close it (Oxman et al., 2014). And in the BioCouture project of Suzanne Lee bacteria and yeast cells create bacterial cellulose with the properties of a 'vegetative leather'. The resulting material can be used to make clothing and shoes (Cecchini, 2017). In all these examples, the organisms produce the physical material to be subsequently used by the architect or designer. In another role of co-worker, organisms can also replace the function of processing plants. Through such bioprocessing, waste materials can be transformed into useful chemical compounds as exemplified in the LIAR (Living Architecture) Horizon 2020 project (http://livingarchitecture-h2020.eu as viewed 31.8.2018). Organisms can also be passively embedded inside materials only to become active when damage occurs. Through their particular metabolism, the damage is then repaired again. Bio Concrete developed by Henk Jonkers at TU Delft is a good example of this (Jonkers, 2011). The common thread in all these examples is organisms taking over labour from humans and machines in the production of more natural materials.

9.4.4 Organisms as Co-designers Integrated Organisms in the Design Process

When we include organisms in the actual design process, and welcome their creative agency and intelligence, we open up an entirely new set of possibilities. Through such a bottom-up approach, we relinquish part of the control of the design process to the organism itself, enabling the emergence of novel designs with unique visual qualities or increased efficiencies. Some designers use growth patterns or organism behaviours to help in generating visual patterns. In the Bio Lace speculative design project of Carole Collet, for example, roots of bioengineered plants generate textiles with particular geometric qualities. In the ironic Miserable Machines: Soot-o-Mat art project of Špela Petric, mussel contractions create visual patterns on small glass lamp shades. But from a design perspective, living biology can do more than generate visual patterns. Organisms are in constant interaction with an environment in flux, and compute optimal solutions for ever-changing challenges. Nature is characterised by adaptability and efficiency, and it is precisely these qualities that can be harnessed in the design process. There is a multitude of experiments that have, for example, shown that slime mould can realistically optimise traffic networks (Adamatzky et al., 2013, Adamatzky et al., 2013). In MIT's Silk Pavilion, the formation of fibre structures by the silkworms with varying spatial and environmental microconditions was used as a computational schema for shape and material optimisation of fibre-based surface structures (Oxman et al., 2013).

9.4.5 Integration of Living Biology

All of the above are essentially examples of 'organism aided design'. The organism itself is absent in the naturally produced artefact. In contrast with this, bio-design is defined as design in which living organisms are an integral part of the final product (Myers, 2012). Through this radical integration of living biology, these products exhibit characteristics of the natural world such as adaptability and explorative capacity. In Growth Pattern by Allison Kudla, tobacco plant leaves are cut into decorative patterns, after which local hormone delivery stimulates the plant cells to grow. The cells move beyond the original boundaries, and as a result change the entire living pattern. In so-called botanical architecture, plants actively co-construct architectures. The Fab Tree Hab (2005) of Mitchell Joachim is a speculative design project in which an entire dwelling is gradually created by growing trees. Project Footbridge (2005) and Project Tower (2009) of Baubotanik are real examples of architectural structures created with living, growing trees. In fact, the idea of using growing plants to create architecture goes back centuries. The living root bridges in Meghalaya in India are an excellent example of this (Myers, 2012).

9.5 Methodology

The methods used are an important part of interdisciplinary research projects and artistic research. Methods of science and art were merged and introduced into architectural and artistic context. The tools of the QFD (Quality Function Deployment) were taken from product development: QFD is used in commercial research and design for combining ideas with outcomes, and for quantifying qualitative relationships. The introduction of a Biolab, a hands-on laboratory space constructed from simple off-the-shelf components was the second important approach in the GrAB outset. The rhythm and flow of the project work was characteristic of interdisciplinary collaborations – time needed to familiarise with the other discipline was allocated in intensive workshops. In those workshops team members exchanged knowledge but also collaborated on navigating the project within the frame of the roughly predefined goals.

9.6 Slime Mould

Analogy

The slime mould experiments use the explorative capacity of the organism in the frame of a human design task. The ability to find efficient pathways to and between food sources is applied to similar and scaled setups for traffic networks, whose computational optimisation is complex and was solved mathematically only a decade ago. Letting slime mould to the task seems to be a reasonably simple method that elevates the role of the organism to that of a co-designer, a relevant participant in the process. In this way, the slime mould projects are bio-utilisation rather than biomimetic, as they make use of the organism itself, instead of finding an abstracted translation into technology.

> Cellular slime mould cells move around as individual amoebas throughout their substrate. However, they can change their behaviour and start aggregating to become a single multi-cellular body as a reaction to a changing environment. Cellular slime moulds are thus of great interest to developmental biologists, because they provide a comparatively simple system for understanding how cells interact to generate a multicellular organism (Imhof et al., 2015).
>
> The goal of the slime mould experiments within the GrAB Project was first to cultivate the model organism Physarum, to be able to grow it in different environments, and then to observe and analyse the slime mould's behaviour. There are two main areas of research that could greatly expand current knowledge in slime mould behaviour and use. First, three-dimensional growth of slime moulds which in turn concentrates on vertical growth and on growth in three-dimensional grids (Figures 9.2 and 9.3). Second, the growth

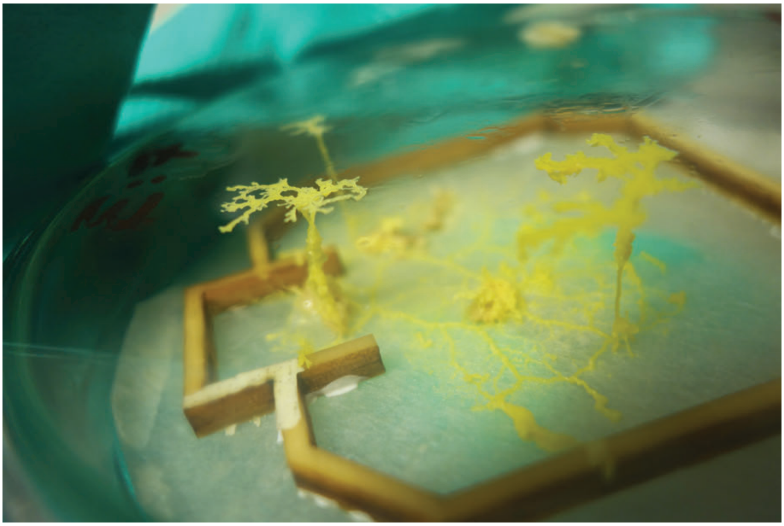

Figure 9.3 Slime mould growth in 3D, first experiments.

Photo: GrAB team, 2014.

patterns of the organism were studied in order to use slime mould as a co-designer. For the GrAB research the slime mould was solely used as a tool to generate optimised patterns, which can then be translated into architectural structures (Imhof et al., 2015).

9.7 Explorative Growth

The capacity to explore is one of the most striking features of biological growth. Exploration is carried out to reach a suitable environment, and this phenomenon is especially interesting in the plant kingdom. Although plants cannot usually move freely around, because they are bound to a specific location, they have developed strategies to explore space by growth. In higher plants, the capacity to explore is limited to sensing and adaptive growth. Explorative behaviour in growth is also observed in the kingdom of protists (unicellular organisms including slime moulds). Slime moulds exhibit a collective intelligence to discover food sources and grow optimised networks. Slime moulds explore their environment by growth, being capable of "knowing" about their surroundings, able

> to find their paths efficiently and to find a suitable environment for producing fruiting bodies. It is not fully understood how those processes function in this simple organism. Some aspects, such as the sensing of past presence by chemical tracers, have been described and could be mimicked in technical systems (Imhof et al., 2015).

Exploration means moving through space and assessing certain aspects that are critical for a reason. We can look for a water source in the Sahel zone, or specific details of Indonesian temple architecture. Both would be called exploration, and both are critical for our survival as a species.

How can we use another organism to explore? What is the benefit?

- Exploiting the intelligence of the slime mould in finding efficient pathways.
- The organisms search for a living environment entails a set of aspects that it evaluates and also processes into a generic answer.
- We do not need to lead the process, the process happens by itself due to the activity of the organism. All we need to do is record it.
- We may not be fully aware of the single aspects that contribute to a decision.
- By using the decision-making process of another organism, we might even integrate new aspects into the design process, that were not considered before, or that were not sensed by the technology we commonly use. In this way, by relying on the organism's intelligence, besides improving the design, we might also be able to learn new aspects about preconditions for life.

9.7.1 Background Environment and Context

Architecture and urban design is about creating a built environment, a space to live, work and thrive for people and societies.

Environment and context describe a location and area that is not clearly defined. It can be a few square metres, or may square kilometres, depending on the organism and the aspect that is investigated. For example, whales swim thousands of kilometres crossing oceans, fleas live on small animals and inhabit specific small regions of their bodies, and microbes are capable of moving over distances like a few millimetres. Roaming neighbourhood for good options means to look for food, shelter, warmth, mates or anything else that is needed for survival. So, environment has the notion of an immediate surrounding area with all that it entails, whereas context has the notion of all that has a connection with or is influential for whatever is the focus of the observation.

For humans, cultural environments evolved as very specific systems, providing those resources for large numbers of people within a small area. Flows of matter, energy and information constitute infrastructure and functional space for living, working, moving, driving, storing, changing, etc.

9.7.2 Information in Biology and Technology

In biology, information on the environment is gathered by sensing, and the connection between the sensing organism and the aspect is usually strong, but some animals have developed amazing strategies. For example, insects can sense certain chemical compounds at extremely diluted rates, so that the distance to a food source or a potential mate can be kilometres.

In technology, we have created an amazing collection of data about our environment, which is representing a virtual world, where we can move and search and find without actually moving around. Still, our data and simulations only capture a small fraction of what we think of as reality. Also, we cannot capture the dynamics of everyday changes, and we do not care to assess aspects that do not translate into an immediate need. The capacity of biological sensing on the one side, and our narrow framework in human technology on the other side make it even more interesting to move towards a hybridisation.

9.8 Results

The slime mould experiments in GrAB extended the explorative capacity of the organism into the three-dimensional space.

> Until now, Physarum polycephalum has been used to solve shortest path problems, creating complicated networks between nutrient sources optimising for efficiency, fault tolerance and cost. However, these experiments were limited to topological surfaces. The research GrAB focused on was the three-dimensional growth of slime mould in order to prove similar growth methodology and resource management results as in planar environments (Imhof et al., 2015).

After proving the possibility of vertical growth in preliminary experiments, the second stage of the investigation was conducted.

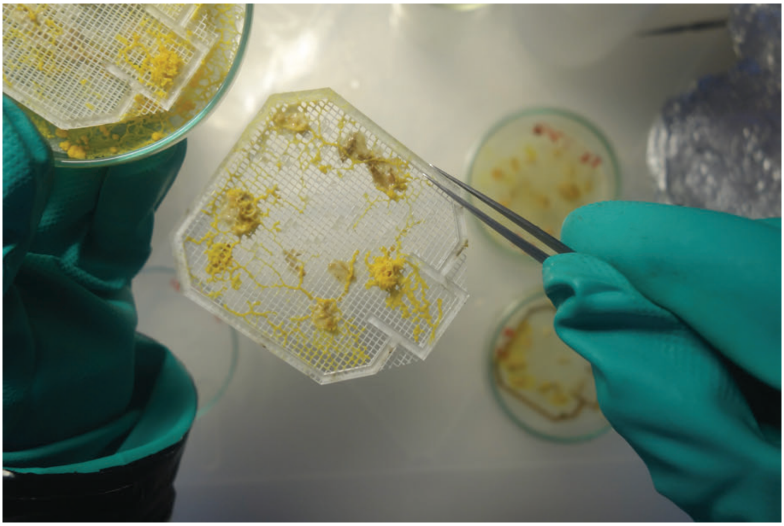

Figure 9.4 Slime mould growth in a layered 3D printed model.

Photo: GrAB team, 2014.

> The goal was to research whether three-dimensional growth of slime moulds would follow the same patterns as in the commonly seen planar growth of slime moulds. The hypothesis was that, given ideal conditions, the slime mould would spread through the three-dimensional space equally in all directions. Possible deformations of the circular spreading could be based on gravity or irregularities in the workspace. After finding food it would choose the shortest path in the three dimensions” (Imhof et al., 2015).

3D printed grids in form of white cubes were used as scaffolds for the slims mould growth (Figure 9.4). It could be demonstrated that slime mould could make use of the scaffolds and grow in all directions. The boxes that were used were just a few centimetres large, and the cultivation under those conditions was challenging. In a follow up experiment, black material was used for the prints, and the growth proved to be more successful under the same atmospheric conditions (Imhof et al., 2015).

> Because slime mould exhibits multidirectional growth, it can create complex three-dimensional networks and structures. This specific capacity offers interesting perspectives for architectural design. The organism always tries to optimise its own physical configuration

> in terms of efficiently accessing food and circulating nutrients to different parts of its body. As mentioned before, this characteristic has been harnessed to optimise traffic networks. In the same vein, slime mould can also help optimise spatial design challenges within a three-dimensional lab environment. In this way slime mould becomes a co-designer that can provide optimised circulation patterns or spatial/programmatic arrangements (Imhof et al., 2015).

The Maunsel Sea Fort of the Thames Estuary was chosen as an exemplary location to redevelop and renovate, aided by the intelligence of the slime mould, and representing the approach to use existing architecture for further development.

The Maunsell Forts are a remnant of the Second World War and were originally built as defence structures against the German air raids in the Thames river mouth. Seven interconnected platforms were erected, joined with metal grate bridging connections, and operated by the army and navy forces. Today, only the tower structures are left, and the bridges have mostly decayed. More recently, through artists and journalists, the Maunsell Forts have come into the light of the public again, as a memorial but also as a picturesque decayed assembly in the sea. Therefore, this building was an interesting structural pattern to rebuild in a scale that a slime mould could access inside the glovebox. Apart from redesigning the overall structure of the fort, slime mould could also help in rethinking the interior circulation patterns of the individual units.

> This design experiment was carried out by letting slime mould grow within a three-dimensional scale model of the historic site of the Maunsel Fort. Two experiments were carried out using a 3D printed 3D grid through which the slime mould could potentially navigate and grow in all directions. Oats were strategically placed throughout the grid to indicate key locations that needed to be connected (Imhof et al., 2015).

The first experiment used a 3D printed scaled model that was an interpretation of the floor levels within one tower of the Maunsell Fort structure. The slime mould successfully accessed the model in the vertical, horizontal and diagonal axes.

> The organism could bridge the 2 mm distance between the grid layers. Growth conditions were optimised by using a humidifier

> that led to a healthy growth time of 20 days. After the culture was well developed, a simple photogrammetric process was used to extract a digital point cloud. The slime mould data was then used to help design structural inlays for the fort (Imhof et al. 2015).

The second experiment composed of a 3D printed abstracted model of all Maunsell Fort towers and the GrAB team was interested to see how the slime mould would three-dimensionally connect these towers recreating the lost bridges again.

> The slime mould was used as a tool to find optimised patterns in three-dimensional space representing the connections between different floors of different buildings (Imhof et al., 2015).

The final growth stage of the slime mould was recorded with photogrammetry and CT imaging technology, and the 3D information processed in architectural software (Imhof et al., 2015) (Figures 9.5 and 9.6).

Naturally, this design methodology in making living organisms into co-designers requires quite some effort and thus might not be considered in everyday design developments. However, the question of how to create a

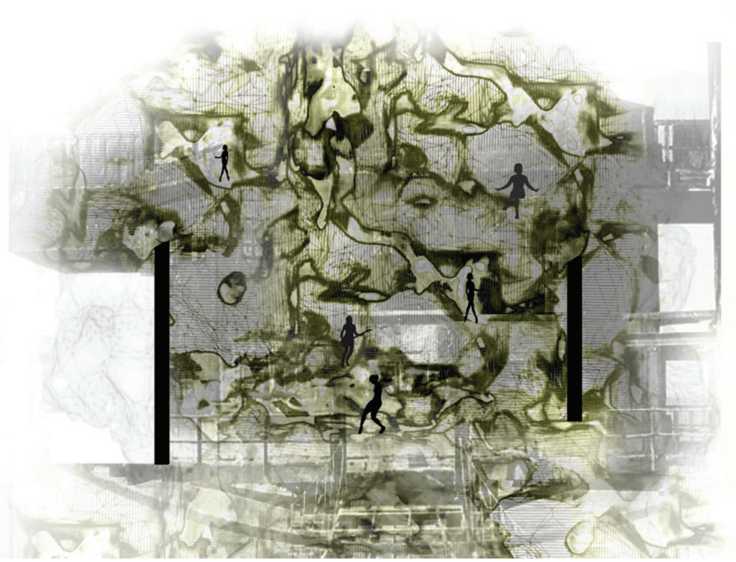

Figure 9.5 Architectural proposal based on slime mould growth.

Photo: GrAB team, 2014.

Figure 9.6 Architectural proposal based on slime mould growth.

Photo: GrAB team, 2014.

network and a sensible composition between two structures remains. Computer simulations of slime mould behaviour can aid here without having to deal with an organism. The GrAB team regards the slime mould as analogy of agent-based design, creating optimised connections which can be then interpreted and developed into an actual architectural structure. Furthermore, with this particular experiment, the team has proven that the slime mould can also grow in a 3D-grid mesh structure and not only on topological surfaces.

9.9 Conclusions

When working with a multitude of interacting organisms, the advantages of decentralisation and self-organisation can be harnessed within bio design. The interaction between the multiple agents and with the environment creates a solution-rich space and also enhances some of the advantages already mentioned (such as responsiveness, adaptability and emergence). In the aforementioned examples of botanical architecture, only a limited number of semi-static plants are co-creating the desired structure. But with larger swarms of interacting individuals, design becomes more emergent, potentially leading to more surprising outcomes and innovative design solutions.

To assess a complex urban environment, it would be interesting to go further with abstracting the idea of exploration to other organisms, whose survival and presence would act as a sensing device for aspects like temperature, chemical gradients, air quality and so on. Those bioindicators are already commonly used, but not strategically applied to urban space. A combination of those living sensors would allow for a close monitoring and discovery of quality sets in the environment that again could relate to a specific function that could be implanted into that space. The application of organisms in a strategic way into public space would also involve an assessment of potential hazards to humans and existing ecosystems.

9.9.1 Further Abstraction and Translation into a Technological Context

Inviting nature as a co-designer in the creative design process has a wide range of advantages. As explained before, organisms exhibit a computational potential for maximised efficiency which can be used to create optimised solutions. But it is in the bio design approach with its embedding of living organisms that the advantages of working with nature become most apparent.

A full technical abstraction would be a swarm of sensing devices, exploring the environment and recording data throughout the dynamics of the day and the seasons. In urban environment qualities like surface temperatures, humidity, pollution levels, noise levels, sunlight exposure, vibration, wind, etc. as standard data could be recorded, mapped and used to locate situations that fit to architectural or programmatic implementations.

9.9.2 True Integration of Living Organisms into Buildings – Hybrids

First of all, structures can be created that grow themselves. This brings architectural concepts of on-site production and self-deployment together into an efficient and self-organising system. Additionally, self-repair can be achieved, and structures can be created that are responsive, adaptive and evolvable. Moreover, through the internal presence of living organisms, structures can exhibit properties of movement and even exploration through their surrounding environments.

9.9.3 Further Exploration – Adaptation to Environment

Next steps in the process would be the adoption of new and yet unknown environments as a design space. The current expansion of human environment into more extreme terrestrial, but also the ambition to expand into extra-terrestrial space creates new contexts that need to be explored. The integration of living organisms into this venture allows for a radically different, hybrid approach that could lead to a yet unimaginable future. The resulting blurring between architecture and natural environment coming out of the practice of co-designing with nature could be an answer to the problematic opposition between the built and natural environment. Co-designing the world with organisms could potentially engender a different relationship with nature, one that is less anthropocentric, and leaves more room for the agency of nature itself. However, we still have a long way to go before nature can reclaim an equal position within the design process. In most of the examples above, nature is harnessed to perform functions for the betterment of mankind. One can ask where the benefits for the organisms lie. Aren't we simply forcing nature to unilaterally solve our problems? Also, organisms are not deliberately designing for the sake of design. This is an externally applied concept; the organism only tries to survive (Adamatzky et al., 2013). This makes the ethical considerations of all forms of life within the practice of co-design even more complicated. Nevertheless, we do believe that creating a world in which the agency of life and the principles of nature are tangibly present is a first step in the direction of a more balanced future.

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Editor

Andrew Adamatzky
University of the West of England
Bristol, UK

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The cover design uses a photograph of slime mould *Pysarum Polycephalum* growing in template imitating Bristol city centre made by Elliott Ballam.