Using Formal & Behavioral Patterns in Nature to Evaluate the Design of Bio-inspired Structural Shapes
The case of a Canopy for a South-east Asian Masterplan

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Born out of a Design Project at Foster+Partners, a number of three-dimensional shapes is examined vis-à-vis the recently emerging attempt of applying principles of evolutionary biology to engineering and design.
1 Introduction

Notwithstanding its artistic and scientific associations, Architecture has always dealt with man’s primitive need for shelter; in the beginning, this was merely an issue of creating an enclosure, which in turn maintained a structural integrity. The tectonic hierarchy used was logically influenced by nature’s own structural hierarchies; for example, a tree consisting of the trunk (base) from which branches are deployed to form the canopy (root).

Natural forms at this stage existed only as abstract references—not viewed as ‘nature per se’ by the designer, but as a mere tool—something which changed over time, when architects became more consciously concerned with patterns and designs occurring in nature and used these as building ornament. Ornament in architecture has of course, been applied in very diverse ways.

Archaic Classical ornament referred to sacrificial ritual, and was even inherently embedded within columnar design alluding to biological references, such as the ‘echinus’ of the Doric capitals; during the Baroque, ornament acquired a more three-dimensional presence that endeavoured to impress, while in the 19th century, there’s a nostalgic attitude towards natural patterns: Louis Sullivan’s buildings attempt to integrate ornament within structure, albeit in a kind of literal way (i.e. the Guarantee Building in Buffalo, where all surfaces ‘seem to leaf and to flower’). In a more holistic context, the capitals of the pillars within the Oxford University Museum are carved after plant specimens from the surrounding Botanic Gardens. The ornament in this case, transcends the scale of an object and becomes symbolic, whereby a whole building may be read as a work of natural reference.

In tandem with the development of ornament, the evolution of engineering allowed for a different perception of form thanks to the ever expanding boundaries of construction. Architecture has witnessed a varying (in)dependence between structure and ornament that is lately shifting towards a technologically oriented paradigm.

We are hopefully moving away from the Promethean attitude that classical engineering has towards technology in the sense of studying natural laws, albeit in a rigid way that focuses on counter-fighting gravity instead of embracing all other flexible natural processes from which we can learn without any severe ecological impact.

In particular, designers are looking towards buildings and objects that are efficient in terms of economy and performance (both structural and environmental). Structure is no longer an issue in terms of function but of performance. The distinction between the two lies in the threshold separating the expected efficient behaviour of a structure and its ability to perform beyond these obvious pre-defined boundaries.

At this point one can foresee the possible benefits that may result from the study of evolutionary biology within the context of engineering research (Weinstock 2004). As Michael Weinstock explains, these lie in the fundamental difference between human-engineered structures and natural-born organisms: engineering tries to achieve efficiency through economy and optimization, while nature exhibits redundancy and differentiation, thanks to which it has developed adaptability. This strategy can prove very useful within design, relative to producing systems that allow for certain degrees of variety.

This concept is herewith discussed in relation to a project done while working at
Foster+Partners, for a number of canopies used to integrate various elements within one larger masterplan in south-east Asia.

2 Canopy objective within the project and morphogenetic strategies

This paper began as a design exercise for a canopy within a tropical environment masterplan. The master-plan houses a number of—aesthetically and programmatically—dissimilar buildings, and so the repetition of canopy elements through-out is used for the integration of all enclosed spaces under a kind of uniform ‘skin’.

In particular, the canopies act as filters for the natural elements; sometimes they are more solid to block excessive heat or vary their transparency to create natural ventilation. Additionally, they offer shelter from the heavy monsoon rain and block the light to create areas of shade. They range from small, where they relate to the human condition and define pedestrian routes, up to large-scale where they respond to whole buildings.

In search of an optimum shape, we looked into natural elements such as the leaf and the mushroom. As natural organisms, they both demonstrate variation within their systems, which enables them to perform in various ways under different conditions; this is what Weinstock calls the stochastic model in design—as opposed to the conventional deterministic model that is present in classical engineering. A stochastic system exhibits a number of ‘small random mutations over a large number of iterations’ in a component, which makes the component flexible. A deterministic system on the other hand ‘produces the same output for every given starting condition’.

3 Formal generators: Palm leaf

The Monstera Deliciosa, an indigenous palm to South-East Asia, whose leaves can grow up to 1m long and 1m wide (figures 2, 3), has been used as a starting point, initially aiming to create shapes which are wide and slightly indented (the leaf does not seem like one big surface but smaller ones stitched together). Furthermore, the surface is perforated at places, letting light through (hence the English name of this palm: ‘Swiss cheese plant’). During the process, leaves are modelled using a number of ways, such as lofting between individual surfaces or separately combining a number of three-dimensional shapes. The arc and spiral are used as paths along which the surfaces occur.

In the resulting shape, we have considered a ‘half-leaf’ instead of the whole. This allows for a more open shape, avoiding a totally enclosed space, but most importantly gives the canopy structural integrity. In reality, the leaf’s canopy is suspended from its stem on both sides; in reality, nevertheless, the spine of the leaf needs to touch the ground, so one half is used, from which ‘sprout’ the surfaces forming the canopy (Fig.8).

Natural systems demonstrate recurring geometrical patterns like triangles, pentagons and spirals, within different organisations and across divergent scales (Weinstock 2004). The leaf canopy uses a three-dimensional spiral in pairs to generate a surface-component and an octagonal base along which to place this (Fig. 5, 6, 7). According to the stochastic model, each component is structurally identical but slightly different in scale and orientation. This variety, although originally introduced to make the canopies more discreet and self-contained, probably creates a more resistant structure to varying loads.

In biological self-organisation, ‘simple components are assembled into three-dimen-
sional patterns to form larger organisms that, in turn, self-assemble into more complex structures that have emergent properties and behaviour\(^6\). The design of the leaf canopy as different parts which join to form a system is in accordance to this logic. However, we have overlooked some of the sub-systems within the leaf’s generic structure, such as the branching system of veins that in nature would move fluids within the leaf. Going back and re-considering what’s under the surface of the leaf, we have to go down in scale and therefore look at the smaller sub-components of each component (the space between the components, which acts as a joint). These sub-components can be formed from a series of layers, of varying textures, which, once superimposed one upon the other, create various degrees of transparency and therefore allow control of light and air-flow. This extra number of layering is an example of redundancy in natural models (Weinstock 2004\(^7\)).

### 4 Formal generators: Mushrooms

Mushroom systems have been considered as an alternative formal model, looking at the mushroom’s optimized shape, which is a sort of umbrella, and also the clustered nature of its population\(^8\). The new canopies are composed of two parts, the surface (canopy) and the base (structure). Their size exceeds human scale but remains small enough to create a dialogue with pedestrians. This type of canopy is investigated as a suitable shelter over walkways, paths, balconies and small size structures like one or two storey buildings within the overall master-plan.

The canopy (figure 10) is broken down into the base, which consists of a kind of forked column that creates a threshold (pedestrians can cross under) and the covering surface. The surface, in harmony with the logic of redundancy discussed earlier, is non-symmetrical (this is also a result of the Golden Section used as a footprint to define the canopy boundary in plan) and has various thicknesses and lengths: the canopy comes closer to the ground on one side, thus creating more shadow. Furthermore, it is thicker on this same side, consisting of more layers of material (weaved bamboo was considered at the time) to filter light and stop water penetrating. The varying curvature of the canopy surface—from convex around the edges, it becomes concave towards the centre—allows for the collection and channeling of rainwater, which can be used for irrigation, or just drained away (figure 13). What is more, this canopy as a collector of some sort is suitable from a symbolic point of view, because fungi (of which mushrooms are a part) are by default nature’s ‘cleaners’, breaking down organic materials and recycling the component molecules back into the environment...\(^9\). The type of mushroom examined has a characteristic cap that turns upwards, and is called *Cantharellus tubiformis*.

### 5 Dependence of canopy’s formal characteristics on a pre-conditioned environment, and Sheldrake’s theory of Morphic Resonance.

How much is the design of the canopies predisposed by the programme and how much a priori influenced by a collective cultural subconscious? In other words, do the natural forms of the leaf and mushroom exist in our mind within frameworks of history and empirical/cultural knowledge or are they born *ex-nihilo*, to fit this specific need\(^10\)? In fact, one is most likely to have visited a forest during childhood, and be familiar with trees and vegetation; furthermore, having almost certainly used an umbrella for rain or sun protection. There are evidently preconceived notions of these shapes from which one establishes strict associa-
tions with their performance. As a result, it seems perfectly logical that designers turn to nature as a source for formal inquiry, because there-in lie a lot of widely acknowledged and admittedly successful models of performance.

An interesting view is that of biochemist Rupert Sheldrake, which supports the existence of 'morphic units' (units of form, organisation or arrangement) which are surrounded by a field that dictates their formation and development over time, based on existing and recurring attributes. In other words, there is an inherent memory in every form that helps it refer back to its characteristics and maintain its appearance; in the event of a new form, the already existing forms are used as guide for imitation. This process is called 'Morphic Resonance' (Sheldrake 1988).

Sheldrake’s morphic fields can be further sub-classified as ‘morphogenetic fields’, and have been often used to explain the evolution of organisms. An example he uses is that of formal traits passed on within the species of giraffes, through morphic fields. These fields have evolved in time and are inherited from previous giraffes; these fields ‘contain a kind of collective memory on which each member of the species draws, and to which it contributes’. There is a possible association here between the evolutionary character of morphic fields and the existence of robustness and differentiation in living organisms as mentioned earlier on (see Weinstock 2004).

There may be a possibility to create structural and formal systems that show adaptive qualities through the use of embedded memories that accumulate over time. This can be introduced for instance, in the case of the mushroom canopy system.

In order to ensure the potential for adaptation within the new system, it should not be optimised, but rather show redundancy and differentiation; an example that may be used is that of trees: for example, within a dense cluster of pine trees (figure 14), the tree trunks (base) have quite some space around them, while there is much more density at the top, where the tree canopies almost touch each other. It is clear that the canopies interlock, which means their shapes have resulted from their co-existence, growing more where they have space and staying smaller where they are limited by already existing adjacent canopies. This is indicative of the distinction between behaviour of a single component and of a group of components that affect each other.

The goal of the leaf and mushroom canopies explored herewith is not that of a single entity but of a unit that belongs to a larger organism, and therefore affects the overall behaviour through change of its own characteristics.

What is more, the example of the tree is relevant in so far as it exhibits differentiation within the same unit: the bottom of the tree being solid, firmly fixed in the ground, while the top is more slender, delicate and able to withstand the wind through controlled movement of the branches.

As a result, within the same component (leaf or mushroom) there may be variety in terms of rigidity and behaviour. The palm leaf canopy in its current state may be strongly joined at its base while having slightly movable joints at the upper ends of the surface (figure 15).

The mushroom canopies due to their shape can co-exist in a synergetic relationship, where they combine to form one large canopy, by joining the top parts (the ‘caps’) so that a continuous surface occurs (figure 17). The resulting shape depends on the placement of the canopies relative to each other (every one allows the rest to expand or shrink accordingly).
The robustness of the system can occur by allowing some sort of flexibility of the tertiary structure; the skin of the canopies may therefore consist of elements that are linked together and have some latitude for movement. Such a skin may rely on the initial arrangement of linear elements—for example, bamboo members—on a grid, where these elements are clamped together at various points. This pushing and pulling opens the skin up at some points while making it denser at others (figures 18, 19).

Once a structure of this type has been set up (differentiation), a step further involves allowing the system to acquire a ‘memory’ of its own (robustness). The process that Sheldrake called Morphic Resonance can be achieved by installing some types of transistors at the points where the movement originates. These devices will then record the location (by using a coordinate system) and time frequency at which the skin moves. The original movement can even be man-made, according to the pattern one wishes to establish as an archetype. From then onwards, the system will re-play and in this way, remember the pre-programmed behavior of its components.

6 Conclusion

We have discussed some possible formal strategies with respect to a specific design task, and their successful adherence (or not) to the flexible models dictated by biological systems. It is now important to ensure that design advances according to the stochastic model, because this allows for an open-ended process in the future.

Is it possible to look forward in the design process so this can be optimized? (How far?)

The existence of non-standard components results in a cost increase; it is therefore essential to predict early on an array of possible evolutionary outcomes for a system, and design (the system) to be able to reform itself to accommodate those outcomes. The adaptability of a system depends by and large on the desirable cost margin (like, for instance, a chess software that is pre-programmed to anticipate $x$ number of move variations versus one that has $n$—infinite—number of possible variations)

It is becoming clear that computational processes are increasingly useful in achieving the variation which is inherent in biological systems; parametric software can be used to populate a surface with a component, introducing very slight mutations regarding its scale, orientation, transparency, etc\textsuperscript{11}. The surface to be populated ultimately becomes disposable, serving only as a guideline for the population of the components, because it is a single entity. The components however, organise a system that can then operate as a single entity, but which is susceptible to the performance of many sub-constituents, thus allowing flexible behaviour.

The initial premise in this project was to simulate the qualities of an organic artefact as a leaf, primarily from a formal, and therefore aesthetic, point of view (client), and eventu-
ally from a performative perspective (designer). The relatively early abandonment of the project prevented the design from reaching its full potential (despite the enthusiasm on behalf of the design and structural consultants to push this to the limit), but interestingly brought up some issues regarding the interrelated dynamic processes present in nature. So, this analysis is an attempt to show what these canopies can be rather than what they are, maintaining above all the use of nature as ‘model’ and not as ‘metaphor’.

7 References

8 Endnotes
1. A visual depiction of this generic sort of structural condition translated in a more intellectual manner is Marc Antoine Laugier’s representation of the ‘Primitive Hut’ (1753), where austere Classical tectonics is paralleled with natural forms, the tree trunks and branches forming columns, entablatures (beams) and pediments (roofs).

The octagon has been used over other polygons due to cultural references of the particular region.


Ibid.

After discussion with the structural consultants, we decided to go up in scale and look at the ‘tree’ as a model instead of the ‘leaf’. The mushroom is in a tectonic sense similar to a tree—formed by the trunk and canopy—so they were chosen as an equally suitable case-study.


Science accepts the existence of certain pieces of information that are genetically encoded within human beings, therefore existing without ever actually having been taught as such.

To ensure a successful outcome, it is important to be selective of the parameters that define the mutations. While some may not impact the overall harmony of the system others may not be suitable for change. In a way, one should manipulate attributes as they are designed to be by default; figure 20 shows this sort of mis-interpretation of ornament, whereby the leaf patterns have become sections of an arched molding, thus contradicting the essence of the leaf which is de facto planar, a surface and not an extrusion. Once extruded, the leaf is no longer the same thing but a distortion of this.