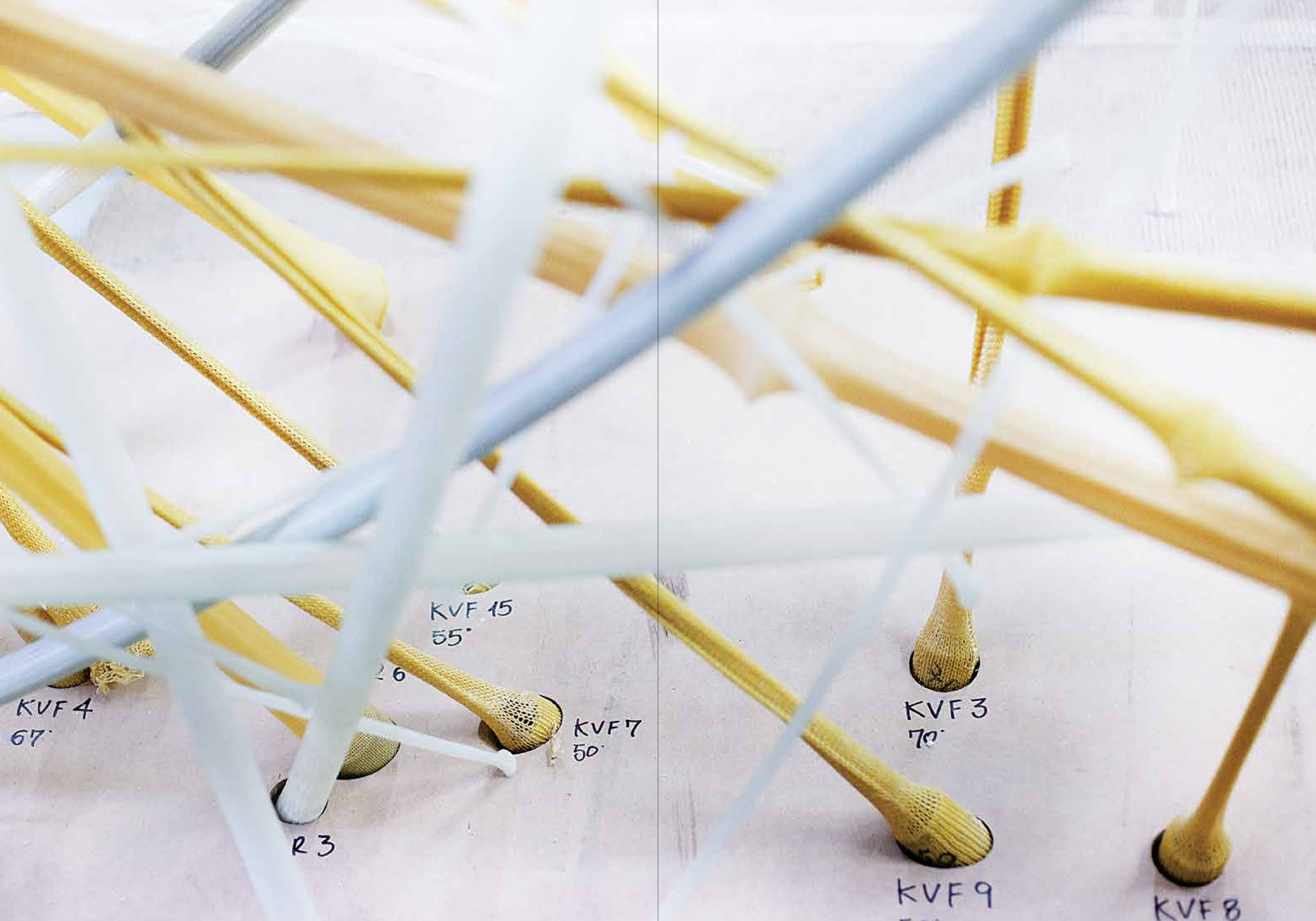
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ADAPTABILITY
APOPTOSIS
AUTOIMMUNE DISEASE
BIOMINERALIZATION
BUDDING
COMMENSALISM
COMPOSITE MATERIALS
CONTROL
DEATH
DIFFERENTIATION
ECOSYSTEM
EMERGENCE
FEEDBACK
GENOTYPE-PHENOTYPE
FIBERS
FOLD
GANGRENOUS NECROSIS
HIERARCHY
HYBRIDITY
HYPERTROPHY
IMMUNE SYSTEM
INTELLIGENCE
ISOMERS
LIQUID CRYSTALS
MEMBRANE
MEMORY
METABOLISM
MITOCHONDRIA
MOVEMENT
PARASITE
REFLEX
RESILIENCE
RESUSCITATION
RHIZOME
SCAR
SKELETON
SELF-ORGANIZATION
SYMBIOSIS
SYNTHESIS
TRANSPORTATION SYSTEMS
TUMOR
VARIATIONS

′FRP TWIGS′: EMBEDDING FABRIC MATERIALITY

ARIELLE BLONDER

‹ Branch-like components formed by self organisation out of knit fabrics of para-aramid fibers in different grades.

LifeObject is an architectural interpretation of a natural structure where engineered, industrial materials stand in for nature′s readymade resources. In the bird′s nest twigs are arranged carefully to form a resilient, lightweight and robust structure. Through humanly engineered fibre composites, which are embedded with design approaches and performative capabilities derived from nature, we have created a lightweight, resilient structure. Relying on the composite′s *fabric materiality*, we transpose the variety, lightness, and functionality of the nest′s twigs into the world of design.

WHAT ARE FIBRE COMPOSITES?

Fibre based composite materials have been used since antiquity, when man coupled wood and straw with mud to produce the brick. The merging of distinct functional elements that retain their physical and chemical identities results in a novel, more useful whole, with a set of properties exceeding the properties of its components.[1] Today, advanced fibres such as glass, carbon and aramid are combined with polymers to make extremely strong and lightweight materials commonly referred to as Composites, or FRP (fibre reinforced polymers). Since their initial development for aviation during The Second World War, the use

1. The mere concept of a composite material, being the merge of distinct functional elements that results in a novel more useful whole, has its origins in the nascent biological sciences of the 17th century. John Fernandez, *Material Architecture: Emergent Materials for Innovative Buildings and Ecological Construction* (Boston: Routledge, 2005).

2. In the architectural field, FRPs were first introduced with great enthusiasm in the late 1960s, experiencing a decade of flourishing experimentation and global "plastic optimism." Seminal architectural projects of medium scale, like the Monsanto house of the future by MIT at Disneyland Anehaim (1956), the Futuro house by Matti Suuronen (1957), and the Fly's-eye dome by Buckminster fuller (1965), demonstrate the experimental approach towards this new material, introducing a new formal language, promising lightness, brightness and a new way of living. After several years of experimental applications, followed two decades of relative abandonment of the material.

3. Branko Kolarevic, *Architecture in the Digital Age: Design and Manufacturing* (Abingdon: Taylor & Francis, 2005).

4. Architects of the early years of digital architecture were strongly influenced by the writings of Gilles Deleuze and Felix Guattari, such as "The Smooth and the Striated," in Gilles Deleuze and Felix Guattari, *A Thousand Plateaus: Capitalism and Schizophrenia*, Translated by Brian Massumi (Minneapolis: University of Minnesota Press, 1987).

5. Sylvia Lavin, "Neither: Plastic as Concept, Plastic as Material," in Michael Bell and Craig Buckley, eds., *Permanent Change: Plastics in Architecture and Engineering* (New York: Princeton University Press, 2014), 15-22.

6. Greg Lynn and Mark Gage, *Composites, Surfaces, and Software: High Performance Architecture* (New Haven, Conn.; New York: Yale School of Architecture, 2010).

of composite polymers has spread extensively to almost every industrial field; the ever-increasing quest for high performance materials across disciplines has driven the development of FRPs' various applications, from aerospace projects to automotive parts, infrastructure, and product design.

In the architectural field[2] FRPs have been the subject of renewed interest since the late 1990's, influenced by the introduction of computation in architecture.[3] Diverting architecture towards the creation of smooth spaces, continuous variation and curvature, the theoretical discourse around the fold has found a natural echo in this malleable material. FRPs present unique mechanical properties marked by extreme strength, high durability, and low density, coupled with plastic and tectonic surface qualities that can be infinitely varied to adopt almost any aesthetic nature. The material ideally embodies contemporary concepts about smooth space and continuous curved forms, with its amorphous plasticity, that is unlimited in both form and scale.[5] It opens up new theoretical approaches towards materiality and tectonics, and introduces new design paradigms of differentiated matter.[6]

NATURALLY ENGINEERED TEXTILE COMPOSITES

The extraordinary characteristics of FRPs enhance novel applications and introduce new performance standards; but the groundbreaking new design paradigms they introduces are rooted in their fibre-matrix structure.[7] Structured similarly to all living matter, from the cellulose fibre-based plants to the collagen fibres that constitute the majority of our human tissues, FRPs introduce biologically inspired paradigms into the world of design. As is the case in nature, an extremely wide range of performative capabilities can be achieved by the mere design of the two components (fibre-matrix), varying spatial and hierarchical organisation. The same two materials make up the composition of our stiff bones and flexible tendons.[8] The structural capacity of these relatively low-density biological materials is achieved by their geometrical and hierarchical fibre architecture. Composites allow for the careful customisation of functional properties, through the variation and combination of multiple parameters affecting the final material. FRPs suggest the possibility of engineering continuous variation within material fabrication, enabling the localized deposition of material in accordance with structure and performance, as opposed to the conventional approach of uniform, mechanically engineered quality.

TEXTILE QUALITIES

Similarly to FRPs, but on a different hierarchical level, fibres are engineered by man to form textiles, a structured arrangement of fibres in space created through mechanical interlocking. As with biology, the fabric's behaviour and properties are defined by the architecture of its fibres. Variations in fibre type,

1



2

Figure 1
Knit fabric of para-aramid fibres.

Figure 2
Sample of knit fabric hardened by resin impregnation.

7. Jan Knippers and Thomas Speck, "Design and Construction Principles in Nature and Architecture," *Bioinspiration & Biomimetics 7*, no. 1 (2012): 015002.

8. Michael Hensel, Achim Menges, and Michael Weinstock. 2010. *Emergent Technologies and Design: Towards a Biological Paradigm for Architecture*. Oxon, U.K. ; New York, NY: Routledge.

9. spatial configurations formed by fiber constructions, such as weaving , knitting or braiding, have been a source of interest for architects under various forms. See for example: Semper, Gottfried. *The Four Elements of Architecture and Other Writings*. 2011. Reissue edition. Cambridge; New York: Cambridge University Press. Lars Spuybroek. 2009. *The Architecture of Variation*. London: Thames & Hudson.

10. On fabric materialtiy in FRP, see Arielle Blonder and Yasha Jacob Grobman, "Design and Fabrication with Fibre-Reinforced Polymers in Architecture: A Case for Complex Geometry," *Architectural Science Review*. (April 2015).

11. Linking biomimetics with experimental fabrication of FRP architectural structures is researched by Prof. Achim

density, and spatial configuration[9] alter the material's performance. Textile is a material system with a capacity for self-organization in three-dimensional space, which reacts to extrinsic forces such as gravity, and to the induction of low-stress forces on the material through its manipulation. The pliability of the material, its resilient character and its internal fibre-based structure, enable the generation of complex forms by simple means. Garment-making has developed, through millennia, the art of creating 3D complex surfaces and volumes, by simple manipulations, through pattern-making and needlework. Stitching, gathering, pleating, furrowing, and draping, amongst many other techniques, have transformed flat fabrics into complex three-dimensional structures in space.

While FRP is mostly a fabric-based material, its standard fabrication processes do not rely on its inherent textile attributes. Fabrics impregnated with resin are pressed onto rigid moulds, with mechanical pressure overruling the fabric's resilient character and its capacity for self-organization. The resulting morphology reflects only the form of the rigid mould, eradicating any of the textile's typical forms.

The total reliance on moulds in standard fabrication processes of FRPs presents a significant barrier for architectural applications. The large scale and uniqueness of the architectural object restrict potential applications; contemporary architectural practices, such as complexity of form, surface articulation, and differentiation, act as barriers for the wider implementation of FRP in architecture.

FABRIC MATERIALITY - AN ALTERNATIVE APPROACH TO FRP

LifeObject is an experiment with alternative design and fabrication processes in FRP. Fabric materiality is embedded in the process,[10] enhancing the textile's attributes and incorporating biologically inspired design methods into the process.[11] Integrating textile-related techniques of form-making and

3 

 4

 5

Figure 3
Forming process relying of fabric materiality.

Figure 4
Knitting variants.

Figure 5
Knitting variants, formed and cured.

Menges of ICD Stuttgart in collaboration with Prof. Jan Knippers. Achim Menges and Jan Knippers, "Fibrous Tectonics," *Architectural Design* 85, no. 5 (2015): 40–47.

12. Form finding, or self-forming, refers to a design/fabrication process in which form is not defined by the designer, but rather generated by the definition of boundary conditions. These notions have developed into architectural design methods, which today are embedded in digital tools for design and simulation.

*Specific tensile strength is relative to the material's weight, obtained by dividing strength (tenacity) by density.

**Pilling is the appearance of short fibers and the formation of small balls over the surface of the fabric. When hardened with resin, the surface becomes 'spiky' and requires additional surface treatment to remove the thorns.

material construction from the world of garment making, as well as from the architectural form finding discipline,[12] it illustrates a novel approach to FRP and architecture. Relying on fibres, as opposed to the more standard practice of relying on moulds, allows for sustainable variation and local differentiation. Fabric manipulation, self organisation and resilience, as core assets of textiles, are reflected in the *LifeObject*, by virtue of its embedded fabric materiality [Fig. 3].

FABRIC MANIPULATION

The fibres chosen for The LifeObject are glass and aramid (E-glass, Technora and Twaron, in different grades). Similar to the cellulose fibres of the twigs, they both present excellent mechanical properties under forces of tension, with a specific tensile strength* that exceeds steel and carbon fibre. While glass fibres allow for translucency, the great tensile modulus and unique suppleness of aramid fibres enable their knitting while keeping a neat pilling-free** surface. Glass fibres are braided and aramid fibres are knit as sleeves, to form tube-like elements. Different fibre grades and knitting types are used with varying parameters such as the number of needles, the level of tension, and the integration of additional fibres and patterns. These result in diverse textile types with a wide range of performance and behaviours, allowing for the increased differentiation of the material. The required overall flexibility is obtained using epoxy resins with special elastic properties. It is enhanced or restricted by changes in patterns and knitting tension that introduce variations in the tube's overall degree of flexibility.

Fibre composites present a logic of integrating different functional parts into one single element[13], thanks to the differentiation of material properties it contains.

Figure 6
A "catalog" of components.
Photo: Amit Ofek

Figure 7
Forming process by fabric manipulation introduces qualities of craft into the industrial setup of composite manufacturing.

13. Rayner M. Mayer, *Design with Reinforced Plastics: A Guide for Engineers and Designers* (London: Design Council, 1993).

14. Lynn, Greg, and Mark Gage. 2010. Composites, Surfaces, and Software: *High Performance Architecture*. New Haven, Conn.; New York: Yale School of Architecture .

Standing in contrast to joinery techniques and assemblies of multiple discreet parts, as in the classical mechanical world, this principle is dubbed by Greg Lynn as '100% surface. It calls for the integration of a maximal number of components within the surface, while simultaneously exploiting their primary use and structure[14]. Similarly, the nest's twigs have embedded 'stoppers' and joints within the element, in the form of spikes over the branch; there are no additional elements or materials in the structure to serve as glue or joints. The local articulation of the knit and braided elements, formed by the manual manipulation of the fabric, make the details, stoppers, and end parts, while also providing local reinforcement.

SELF-ORGANIZATION

Due to the differing spatial organization of the fibres in the braided and knit surfaces, they self-organise differently and result in distinct forms. 'The knitted material' is formed under tension by hanging; its loose internal structure benefits from the additional tension, forming an airy and strong surface. Form-found by gravity, it is naturally optimised and resembles natural elements such as bones or wooden branches. The interlaced fibres of the braided material tighten and get "locked," when tension is applied; the braided sleeves are therefore formed by a local compression of the material over a simple tube that serves as a rough guide. The forming process, relying on tension or compression, requires a minimal amount of moulding elements, such as standard polyethylene pipes and plastic rings. The fabrication process of the elements is optimised and oriented towards minimizing manual labour surface finish. We rely on the textile's capacity for self-organization to generate variations and integrated details.

RESILIENCE

Embedding fabric materiality into the forming process of the tubular elements enables the fabrication of similar yet different forms. This diversity of similarly structured components is a key factor in the nest's resilience, being composed solely with twigs of several kinds, all random and slightly differing from one and other. The fabric's resilience, its ability to deform and spring back to its original shape, orients the structure towards a formal and structural language of flexibility, adaptivity and redundancy, rather then a mechanical robustness of stiffness and strength. The resilient character of the *LifeObject* is rooted in its fabric materiality. It relies on the multiplicity of weak elements to form its structural coherence, reaching stability and strength through redundancy and high connectivity between elements.

A NEW ROLE FOR FIBRES?

Though architecture and textiles have multiple points of convergence, the world of fibres presents a design paradigm that strongly differs from the mechanical-based architectural one. Fabric materiality suggests a biologically inspired design approach to composites, redefining the fibres' role in the making of the forms. Replacing the restrictive moulds with fibres enables local differentiation, inherent optimization, ornamentation and sustainable variation. Through their flexible strength, fibres suggest a future integration across scales of the man-made and the natural.

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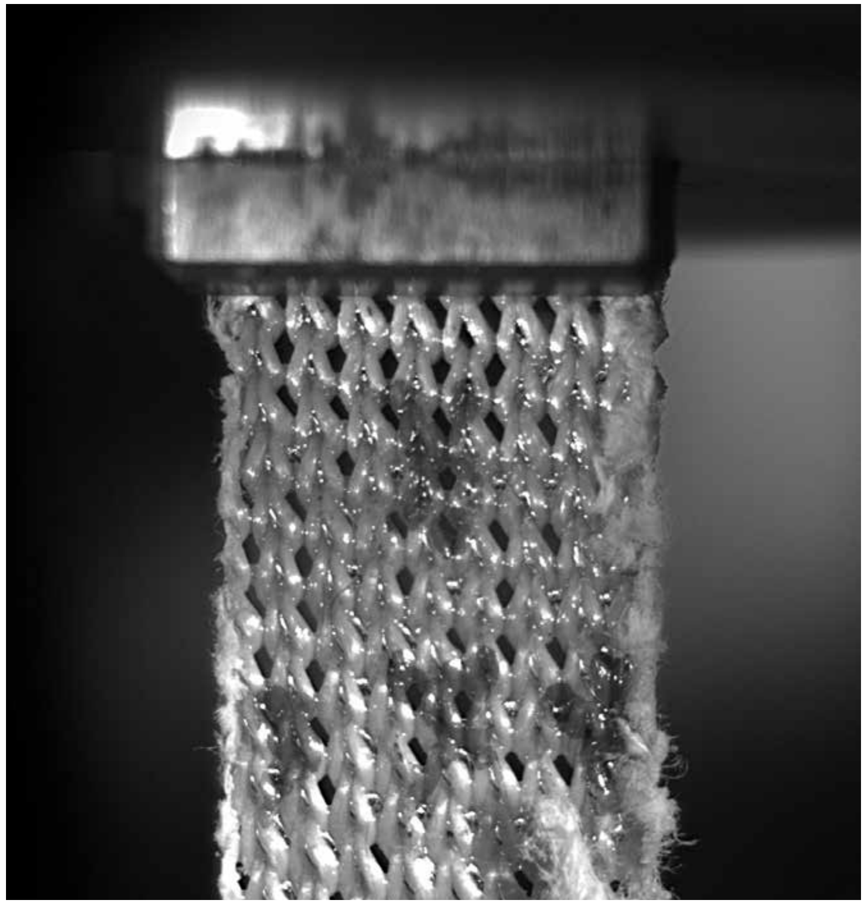
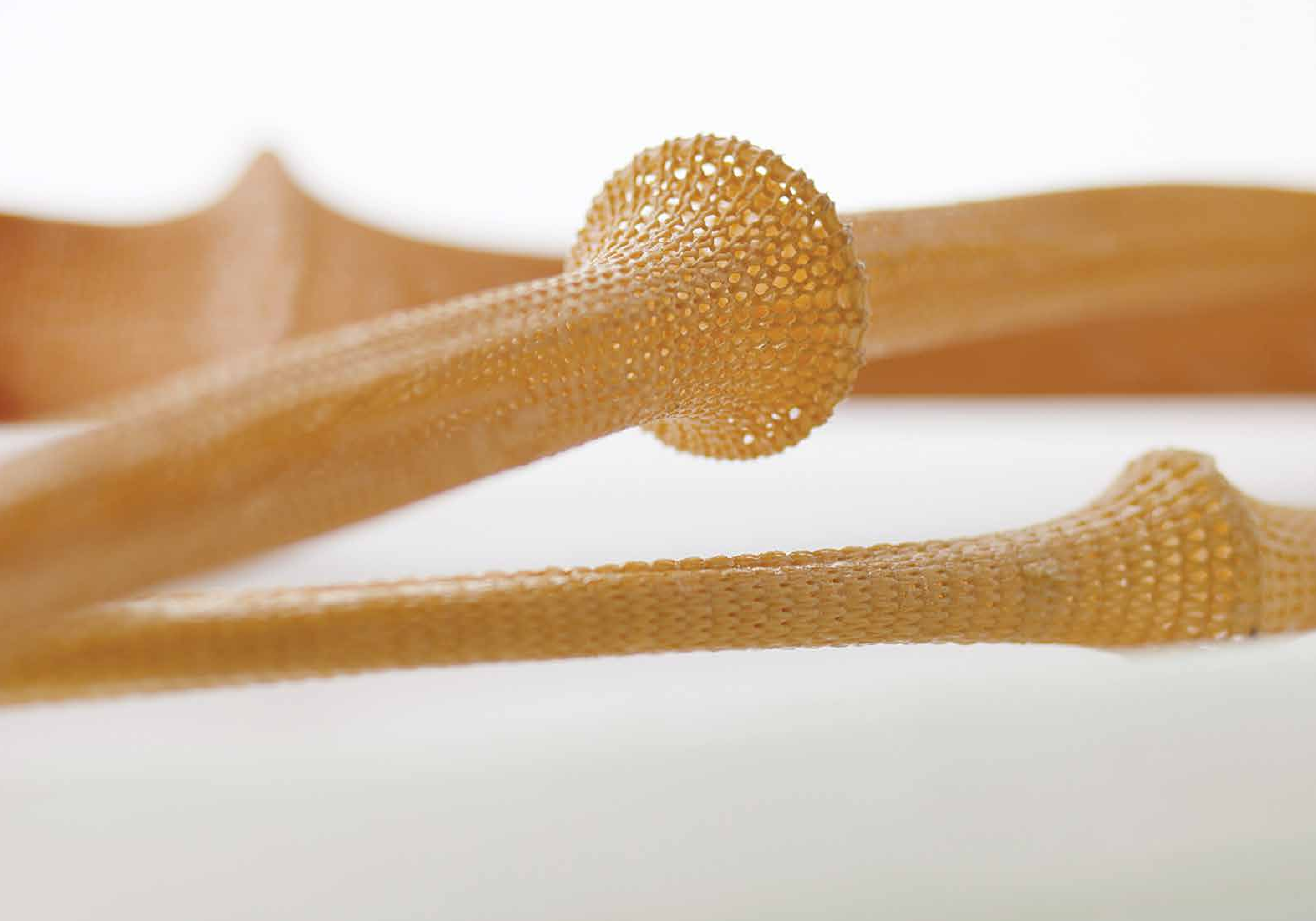
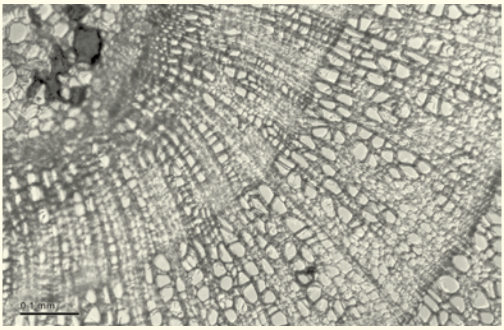


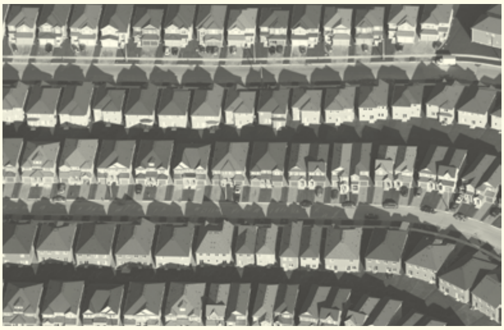
Mechanical tensile testing for the definition of material properties of the new composite material of knit para-aramid fibres.
Tests and photos: Rami Elias, TA University, School of Mechanical Engineering



HIERARCHICAL MATERIAL



Plant stem, cross section of Tilia. Photo: Dr. Josef Reischig, CSc.



Markham suburbs, Ontario. Photo: IDuke

The hierarchical structure of biological materials is an integral part of their design, making no distinction between material and structure. Since raw biological material is in itself weak, brittle and soft, its strength and stiffness are achieved through its layered internal architecture. Examples of structures studied for their hierarchical material structure include all types of organic building blocks, of both simple and composite materials, ranging from the cellulose-based tree trunk, to the chitin based crab-shell and collagen-based tendons and bones. Moving upwards in spatial scale of the material, its strength decreases and toughness increases, a fact demonstrated in the material's ability to resist the proliferation of cracks in its consistency.[1]

The spatial arrangement of elements, from the nano to the micro level, determines the structure's behavior. The "Bouligand structure," a twisted plywood-like arrangement of elements, strengthens the crab's shell to resist predatorial attacks; the same structure makes the Arapaima fish scales resistant to penetration, by enabling the dynamic reorientation of its composing collagen lamellae in response to the loading environment under attack.[2]

Housing units are the basic building blocks of the urban tissue. Their massive aggregation into the modernist housing blocks of the 1950's, stretching across the globe from Europe to Africa and Israel, demonstrates the non-hierarchical approach of architectural modernism towards urban matter. Units are piled up, composing the macro-scale whole of the building block, with no intermediate levels of hierarchy; the meso-level of semi-public spaces and qualitative transition spaces are often absent. Likewise, the organization of the building blocks in space, which together form the macro-scale of urban space, is often ordered by the principle of simple repetition, creating a fabric with no organizational hierarchy of a differential order. In a similar fashion, the suburban fabric is composed out of the unit of the private house, in infinite repetition, with no hierarchies or intermediate levels of order. The resulting urban tissue is a vulnerable one, easily fragmented and with no capacity for resilience. The number of levels and their interconnections, in the hierarchy of a structure - be it social or spatial - affects its ability to withstand external pressure and regain a stable point of vitality.

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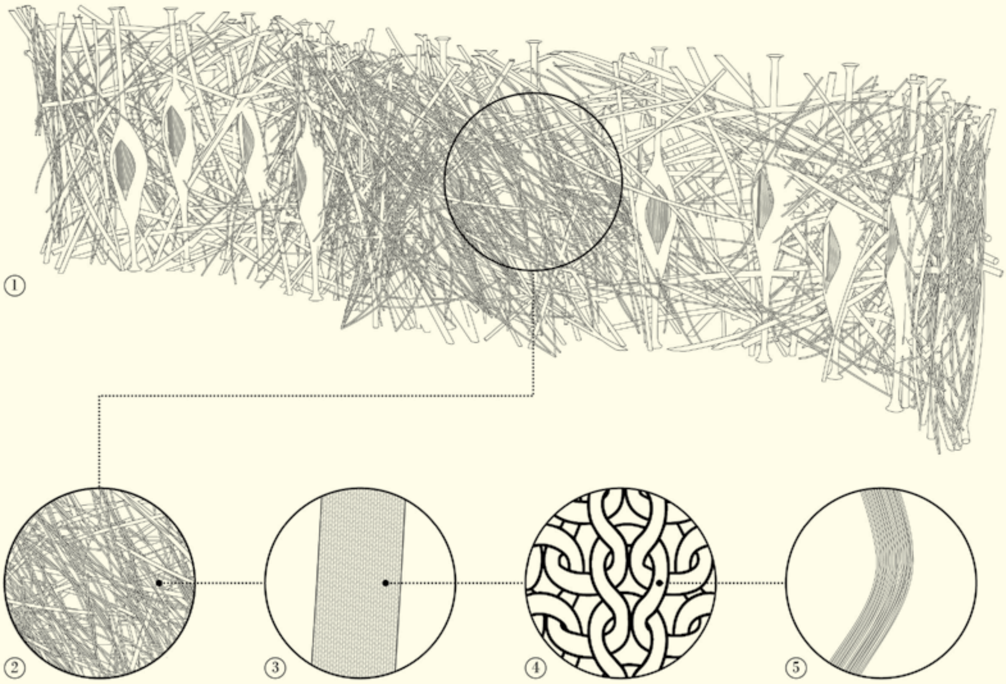
1. John W.C. Dunlop and Peter Fratzl, "Biological Composites," *Annual Review of Materials Research* 40, no. 1 (2010): 1-24.

2. Elizabeth A. Zimmerman et al., "Mechanical Adaptability of the Bouligand-type Structure in Natural Dermal Armour," *Nature Communications* 4 (October 2013): 2634.

LifeObject's HIERARCHICAL MATERIAL



1. Element 2. Structure 3. Component 4. Knitted Fabric 5. Fiber

The design of the *Life Object* is considered on six levels of hierarchy, ranging from the fiber to the overall system. Although its design takes place on different magnitude than that of biological materials, it can be described from the structural 'macro' level, through the meso level of 'components' to the nano level of fiber itself. These different layers are interconnected, with design parameters on each level that determine its performance, inform adjacent levels of hierarchy, and affect the structure's overall characteristics. Starting from the lowest level, the fiber is in itself a spatial organization of filaments, which are either flat or twisted in a variety of grades. The fibers are knit (for aramid fibers) or braided (for fiberglass fibers) in different patterns to form the fabric of the micro level. Moving upwards, the fabric is combined with resin to construct a composite material for the tubular components of the meso-level. These are interlaced in space in relative compression, making a structural volume. The macro level of the structure is designed by a parametric algorithm that populates required global volumes with components of the meso-level, in an interactive process; it is informed by the algorithmic analysis the nest's CT scan with numeric values such as material density and orientation of twigs. The resulting macro level is a free-form porous volume of airy components.

The integration of the 'breathing cells' into the structure, can be seen as its system level, where the structural and the functional are integrated into one organism; the vital cells that perform the dynamic function of the metabolism are nested within the structural tissue. The biological materials displayed in the capsules suggest possible future integrations, which could transform the overall structure into a biological composite, where the structural mineral-based material surrounds and supports the non-structural organic.

SELF-ORGANIZATION

A flock of birds. Photographer: D. Dibenski

Antonio Gaudi's inverted structural model of hanging chains.

Self-organisation in nature describes complex biological or ecological systems that behave in a non centralized manner and create complex organic patterns and arrangements.

Biological structures are assembled from the bottom-up, a necessary factor within all growth processes, since no overriding scaffold or external direction (apart from environmental stress) bears upon the process. Self-organization encompasses notions of spontaneous and dynamically produced adaptive organization within the natural world. These processes are attributed today to complex systems in various fields, such as transportation, communication and computer science.

The phenomenon of a global pattern that emerges out of multiple undirected interactions within a system's lower hierarchal levels characterizes systems in chemistry, biology and physics; many systems in nature spontaneously organize themselves into a variety of different macroscopic forms, such as stripes, droplets, bubbles, etc. In biology this pattern can be seen at various levels, starting from protein folding and the creation of cell membranes, trough the creation of germ colonies, and up to complex social behavior within a species, or different species in the eco-system, such as the behavior of flocks of birds and schools of fish, bee swarms and termite colonies.

The capacity for self-assembly of the living organism includes management of self-configuration, faculty for self-optimization in changing environmental conditions, and the ability to self-repair/heal.

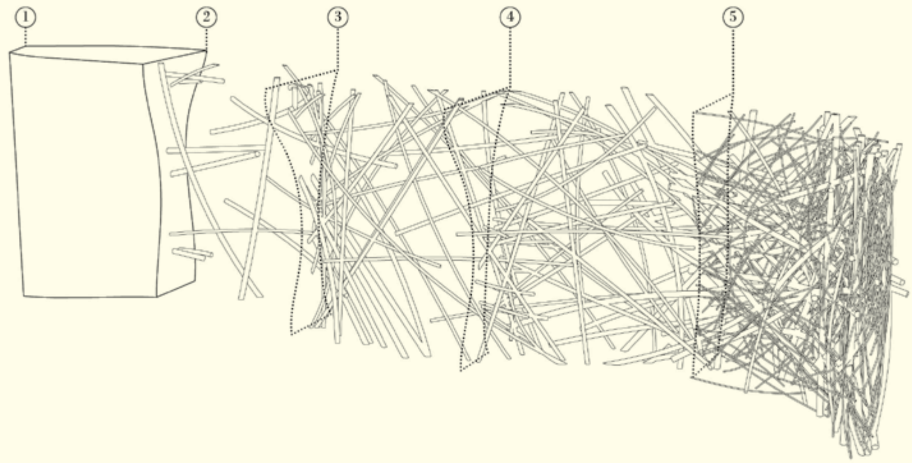
In architecture, one can observe complex systems that are created by self-organization at an environmental and urban scale down to the scale of materials and nano-materials.

The concept of self-organization is one of the central characteristics of complex open systems. In such systems, clear organizational patterns can be identified within chaotic, non-linear, unstable and non-casual states. This can be observed in complex systems such as cities, where many agents operate locally and independently in a bottom-up process of self-organization, regardless of top-down planning efforts. The modernist approach of controlling urban space by architectural top-down processes is integrated today with mechanisms of self-organization based on the interactions between the various factors constituting the city.

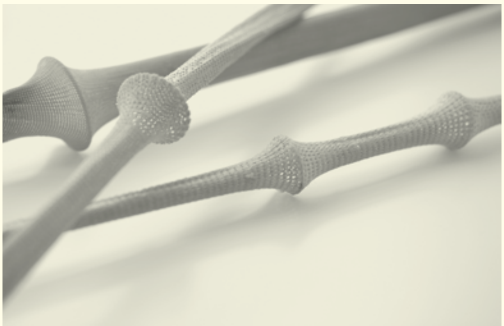
The use of mechanisms of self-organization has been taken by architects and engineers to material contexts as well. It is a founding principle for structural form finding, where a material or components of a material system achieve structural stability as a result of the material's properties, in reaction to the forces applied to it and its boundary conditions. Relying on the material's inherent capacities, this leads to optimized performance by spatial organization. It has been serving as a structural model, morphogenetic process and as a construction methods.

On the nanometric scale, internal forces and high levels of proximity between particles generate processes of self-assembly, in turn composing materials of high performance. Materials such as Nano Cellulose (NCC) and Carbon Nano-tubes (CNT) are developed on the nano scale to offer unique qualities, such as extreme strength, high adaptability, tensile modulus, electrical and thermal conductivity, and optical qualities, relying on materials' internal processes of self-assembly.

LifeObject: MADE BY SELF-ORGANIZATION



Phases of construction:
1. The element: global volume to fill
2. Guides
3. Components of predetermined location
4. Components of predetermined measures, bottom up placing
5. Free placing of short components



Self ogranization of knit fabric, forming the components. Photo: Amit Ofek

The negotiation between top-down decisions and bottom-up evolution of the structure is reflected on various levels of hierarchy, namely in the design, fabrication and construction processes of the *LifeObject*. The design code combines random elements with preset values, such the data inherited from the nest's analysis, the material characteristics of the elements and the global volumes to be populated. Each run of the code will generate a different phenotype expression of the common genotype, reflecting its characteristics of self-organization. The bottom-up assembly of The *LifeObject* resembles the bird's construction procedure, rather than a typical architectural one; the structure is stable at all points during the construction process, not relying on scaffolds or temporary supports of any kind. External control is minimized, with a minimal configuration of components that is defined in space, following the global volumes planned. Respecting the numeric values of the code, components are then gradually placed in space, freely, contracting each other by tension, building up stability and affecting the overall configuration of the structure.

The fabrication process of the components of *LifeObject* relies on the self-organization capacity of its material; as a fiber composite, its main constituent is fabric. The relative movement between the fibers that constitute the fabric, allows it to self-organize into complex forms in reaction to external forces. As opposed to traditional forming processes of composites, no rigid mold is involved in the forming of the elements. Rather, enhancing its fabric materiality,[1] the textile sleeve is suspended, formed by tension and gravity. Thanks to the stretching qualities of the knit fabric structure, allowing self-organization, and the formation by tension, the resulting components are all similar but varied. Visually resembling a branch, or a bone, the *LifeObject* components self-organize under stress, their morphology resulting from the loading by tension and material properties, adapting to forces according to boundary conditions.

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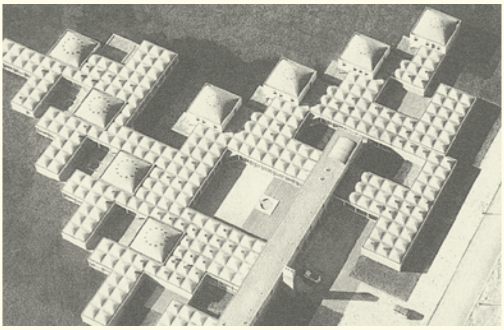
1. Fabric materiality is a term coined in relation to alternative design and fabrication processes suggested by the author for architectural FRP elements. Arielle Blonder and Yasha Grobman, "Design and Fabrication with Fibre-reinforced Polymers in Architecture: a Case for Complex Geometry," *Architectural Science Review* 0, no. 0 (2015): 1-12. see for example

ADAPTABILITY

Tree trunk branching



Dutch structuralism. Orphanage in Amsterdam, Aldo Van Eyck, 1960.

Biological systems adapt to their environment, and develop under load, or conditions of stress. During growth, biological systems actively respond to external stimuli, forming architectures and microstructures with improved functionality. The microstructure of wood cells, for example, strongly depends on its loading conditions, varying from square shaped to circular shaped cells on upper and lower parts of the branch, depending as to whether it's been under processes of compression or tension.[1] Flexure, the action of bending or curving, is the common way of loading in biological systems, sustained by the organic components of the material that have a variety of structures and present anisotropic multi-axial properties.

On the broader time-scale of evolution, adaptability to environmental pressures and instability are the keys for the complexity and diversity of living systems. A fully-optimized species adapted to a specific environment will not resist instability and change; as an organism with excessive capacities or redundancies, it will persist and adapt, by gradual stochastic variations. Conforming to a logic that opposes mechanical concepts of efficiency and standards, the robustness of biological system relies on redundancy and differentiation.

Buildings are complex systems for living, and as such they are also objects of transience, exhibiting morphological changes throughout their life, and responding to ever evolving contexts.[2] Users, functions, technologies, ownerships, market and state policies, change over time, and it is the building's ability to respond and persist which determines its life cycle, involving aspects relating to space, structure and services. As with nature, a "tight-fit" design that is highly determinate and responds optimally to a specific condition will not have the necessary resources to accommodate change. It is rather by an excess of capacities that a system can adapt and enable alternative modes of operation. Moveable structures, convertible spaces, modular systems and scalable platforms are some of the architectural responses to the challenge of change, all requiring a certain redundancy. Generic spaces, anisotropic configurations and ubiquitous service distribution enable flexibility and a longer lifecycle, but lack the advantages and qualities of the unique, the specific and custom-made. Instead, alternative approaches focus on 'design for deconstruction and disassembly' as strategies for sustainable change, keeping the valuable specificity of the components while focusing on the interface between them, as a critical design decision to ease future changes.[3] Based on a layered model of the building, adaptability is understood through the dependencies between its components in terms of space and flow.[4]

1. Michael Weinstock, "Self-Organisation and the Structural Dynamics of Plants." Architectural Design 76, no. 2 (March 1, 2006): 26–33. doi:10.1002/ad.237.

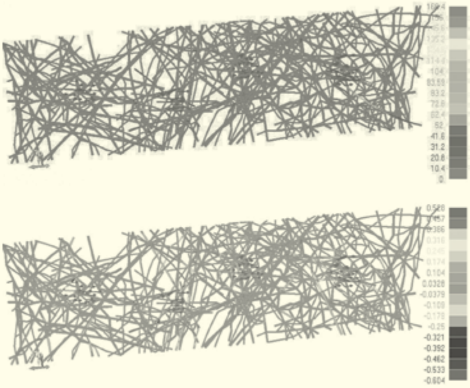
2. Douglas, James. Building adaptation. Routledge, 2006.

3. http://adaptablefutures.com/our-work/toolkit/

4. Robert Schmidt, Jason Deamer, and Simon Austin. "Understanding adaptability through layer dependencies." In DS 68-10: Proceedings of the 18th International Conference on Engineering Design (ICED 11), Impacting Society through Engineering Design.

The *LifeObject*: MADE BY ADAPTABILITY

The bird's nest: complex curved shape achieved by bending forces.



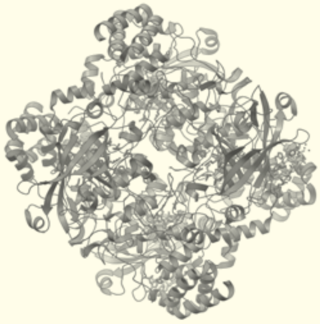
Structural analysis of element, Stresses [Kgf/mm2] under self weight and horizontal 50 Kgf at three locations.

Bending test for fiberglass component.

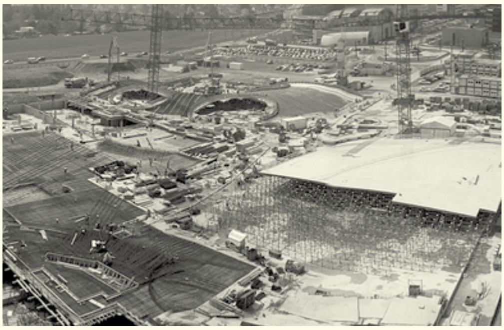
The complex form of the bird's nest is achieved by its adaptation to forces; the twigs are pressed in compression, forming curving shapes that together form the overall structure, almost entirely without additional adhesive materials. The overall free-form porous volumes of The *LifeObject* are achieved by the adaptation of its component to bending forces; pressed in between ceiling and floor, or interlaced, components deform into curve-like forms, applying mutual forces that form and maintain an overall stable structure. The structure relies on the capacity of the elements to withstand deformation without reaching failure. Material parameters, such as mixing ratios of standard and flexible resin, are controlled in combination with geometrical parameters such as proportions and distribution of details along the element, to achieve the required flexibility and strength.

Adaptation to forces appears as a forming principle on all levels: on the lower level, it defines the component's shape as it is formed freely by the fabric's self-organization under tension. On the global level, it guides the construction process as it grows from the bottom-up with partial determination, reacting to the local development of stress by the overall interactions between components.

LOW ENERGY SYNTHESIS



Rendering of Catalase protein structure. Source: Vossman



Concrete formwork for the EPFL Learning Center by SANAA. Source: http://blogs.epfl.ch/learningcenternews

Biological materials form through low-energy processes. Standing in contrast to fabrication processes of engineered materials, living matter is mostly synthesized in ambient temperatures and under low atmospheric pressure, in an aqueous environment. The building blocks of biological materials, such as proteins, lipids and carbohydrates, are formed through a process of biosynthesis, also known as anabolism. Complex molecules are formed out of relatively simple compounds in metabolic pathways, a chain process of chemical reactions catalyzed by enzymes. These macromolecules are thereafter responsible for the life-sustaining reactions in living organisms, such as maintaining constant temperature, growing, and reproducing. The synthesis of macromolecules is thermodynamically unfavorable under cellular conditions, and in order for such reactions to proceed, an additional energy source is required. There are numerous control mechanisms that regulate the production of specific amounts of compounds within the cell. Balancing the anabolic processes of growth that require energy with the catabolic breakdown processes that release energy, with respect to needed mechanical properties, is the key to the survival of biological structures.

Engineered fabrication processes mostly require a high investment of energy, high temperatures, and pressure. The reduction of energy invested in architectural construction processes plays an important role in the overall evaluation of a building's sustainability level. Concrete, the main material currently used for construction in Israel, is formed by casting, which requires the fabrication of molds. Complex forms, large overall size and single use, render these molds costly and inefficient, making the overall construction process unsustainable. Alternative molding techniques, such as dynamic reconfigurable molds operating on pneumatic systems or fabric-based molds for membrane casting, are being developed to reduce cost, machining time, and material waste.

Alongside strategies that tackle the forming process, other developments focus on the material itself, favoring lightweight construction materials. Low-density materials and cellular internal structures like polymers, cellular ceramics, and fiber-reinforced composites, together with traditional wood, are developed for use in the building industry. Lightweight materials are easy to store, transport and manipulate, reducing time, cost, waste and effort throughout the construction process. Structures comprised of a multitude of small components, rather than several larger elements, require less handling resources and favor overall sustainability. This is as true for the brick and concrete blocks of yesteryear as it is for today's experimental systems and composite materials.

LifeObject's LOW ENERGY FABRICATION

Manual forming process of components withou molds

The bird's nest is constructed out of weak and simple elements, the twigs, and achieves its mechanical properties through structure and redundancy. Similarly, the *LifeObject* is made of extremely light components, and their forming requires relatively low energy. Material density of the element is extremely low, with cured material that weighs approximately 150 grams per linear meter, which makes it particularly easy to manipulate. While composite materials are normally formed with the use of costly molds, in high-temperature ovens or under pressure of vacuum of autoclave, these elements are manufactured manually, in low temperature curing, without molds. Fabric sleeves are impregnated manually with resin and then formed hanging over a frame. Curing is done in ambient temperature, supported by a short passage in an improvised outdoor oven of 40°C. The manual fabrication of the elements requires minimal resources and introduces qualities of craft into the final product.