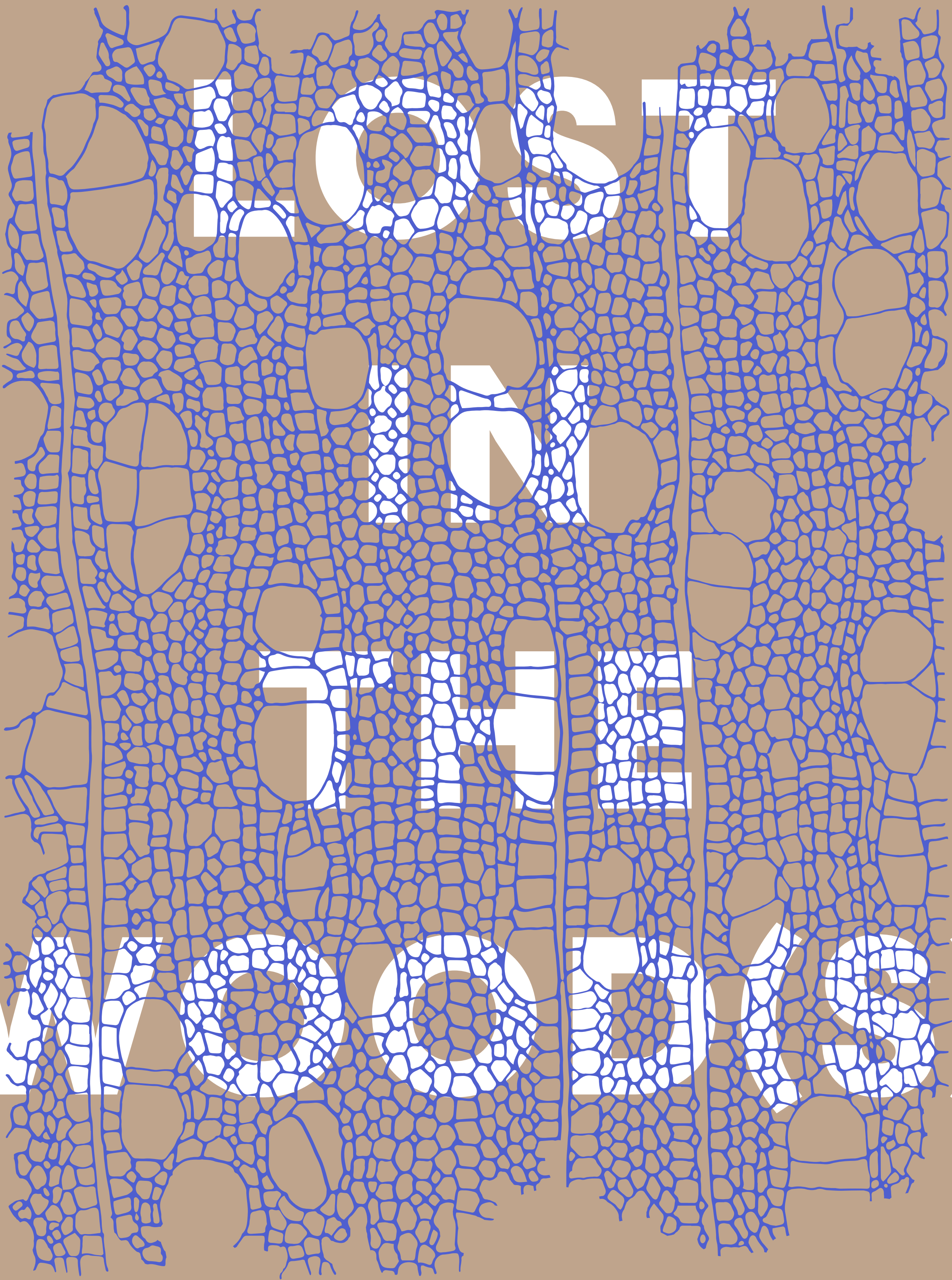
LOST IN THE WOOD(S)



Aalto University

LOST
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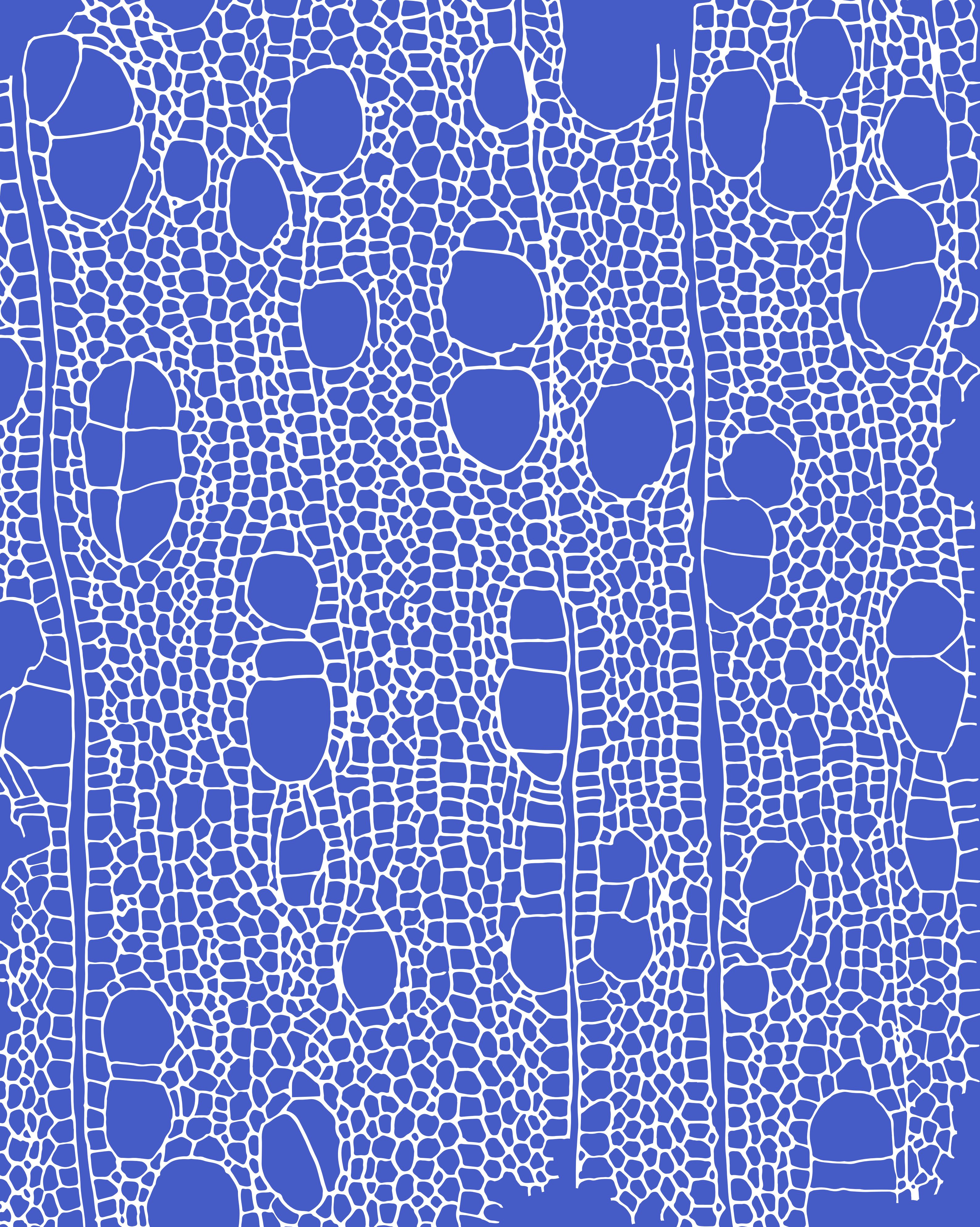
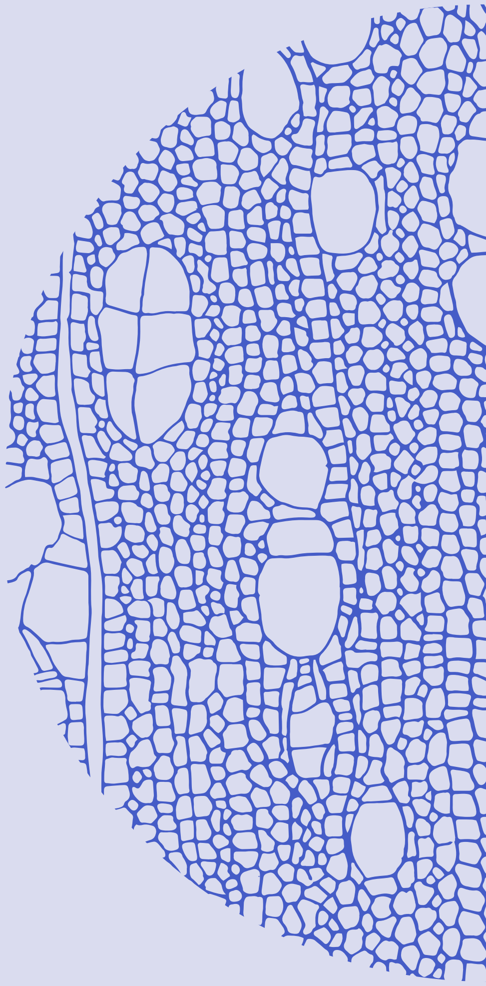
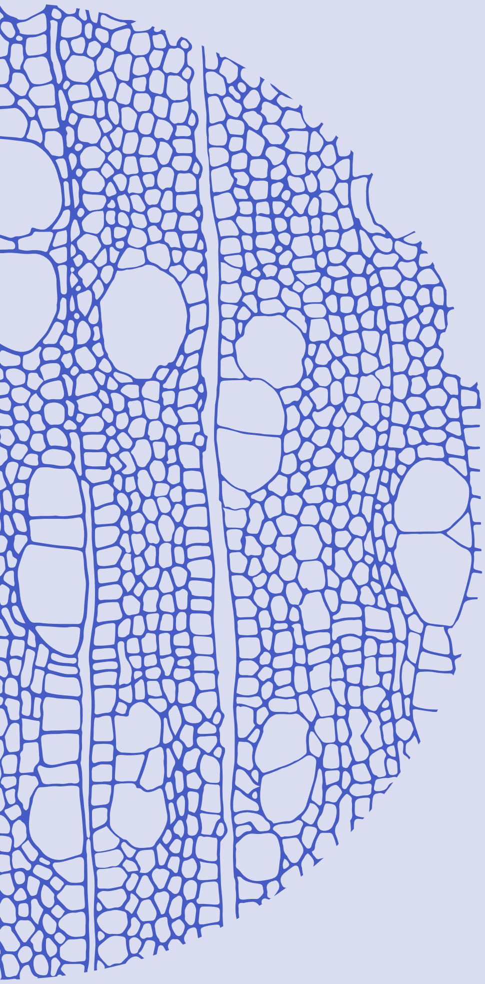


LOST
The New
IN
Biomateriality
THE
in Finland
WOOD(S)

PIRJO KÄÄRIÄINEN & LIISA TERVINEN (EDS.)

Contents





INTO UNKNOWN TERRITORIES

NOTES FROM THE JOURNEY LOG

PIRJO KÄÄRIÄINEN *editor*

is a designer and CHEMARTS facilitator, with roots in the Finnish forest and work experience in textile industry and in higher education.

LIISA TERVINEN *editor*

is a designer and producer, who has worked in a variety of fields of new media, craft, design and biomaterials.

EEVA SUORLAHTI *photographer*

is a designer and photographer who is working among visual research, fine art and communication through pictures and materials.

To all the Aalto CHEMARTS *students who have inspired us to have faith in the future with more sustainable ways of being, creating and designing.*

Foreword

Dear Reader,

This book was born out of a passion for Finnish biomaterials, especially wood-based cellulose. It aims to explore from a designer's point of view how these precious resources could be used for renewable and functional high-tech materials. As the role of design in the context of material sciences is mainly unexploited, we want to share some of our experiences from the journey through these unknown territories. We would like to thank warmly Aalto University and all the colleagues who have contributed to this book.

The first section is about planning the journey: it gives a short insight into Finnish forests and future of biomaterials, and explains about the main raw materials derived from wood. The second part talks about collaboration and presents new collaborative teams in Finland that are currently crossing boundaries and aiming to solve some ecological problems in our living environment. The third section explores how to develop cellulose-based materials together towards business concepts and products. In the last part, you'll find some experiences and thoughts about the future.

Our path with this book has been full of fortunate encounters and pleasant surprises. We have been inspired by fascinating material innovation and even more by the amazing people behind those ideas: designers, scientists, engineers, entrepreneurs and business specialists, both students and professionals. Some of their stories are documented in this book – and there are many more to be told.

No matter how digitalised our world will become, we all still live in a material world. Let's make it a better place together!

Pirjo Kääriäinen & Liisa Tervinen

Our Recipe for Successful Collaboration

Pirjo Kääriäinen & Liisa Tervinen

This recipe is based on our personal experiences and on several discussions with colleagues who have been working in creative multidisciplinary teams. The ingredients are well tested and we can warmly recommend them. Feel free to test portions and methods according to your own ideas and preferences.

FOR 2+ PEOPLE

Ingredients

- A mix of open-minded people
  Try to find different species, preferably curious ones
- 1–2 inspiring encounters
- A bowl of support in the form of resources
- At least 10 portions of communication
- A handful of action & doing things together
- A large spoonful of courage
  Detailed maps can't be provided beforehand. To find something unseen, you have to explore and experiment. And fail.
- Lots of mutual respect and goodwill
- A lot of patience
- Add another 10 portions of communication to understand each other's language. *You can't have too much!*

Method

1. Enable inspiring encounters and let people find their shared interests. Stir if needed.
2. When the seeds of collaboration emerge, acknowledge them and let them grow. However, some of them might not survive – don't worry, you can try again. And not all of them will grow into anything at all.
3. Nurture promising seedlings carefully but not too much; they should have enough space and freedom to grow courageous and persistent.
4. Check that the collaboration is beneficial for all parties; it is equal and fair, talk and find a mutual agreement on IPR and acknowledgement.
5. Talk, talk and talk about the collaboration and process with each other. Then share it with others too as an inspiring unique story – your story.
6. Be proud of the journey and what has been achieved.
7. Repeat steps 1–5 until you are happy.
8. At its best, this all will lead into blooming, new, world changing and worth the effort.

PLANNING THE JOURNEY

Happiness and Fortune Reside in the Finnish Forest

FINNISH FOREST CENTRE
A state-funded organisation covering the whole country of Finland. Promotes forestry and related livelihoods, advising landowners on how to care for and benefit from their forests and the ecosystems therein, collecting and sharing data related to Finland's forests and enforcing forestry legislation. Operates under the guidance of the Ministry of Agriculture and Forestry.

WWW.METSAKESKUS.FI

Markku Remes
Senior Forest Management Specialist
The Finnish Forest Centre

Anna Salminen
Communications Specialist
The Finnish Forest Centre

Finland is Europe's most forested country, with forests covering three quarters of the land area. They are also Finland's most important renewable resource. The methods for utilising forests have changed over the years. The importance of forests and how they are used has had, and will continue to have, an impact on the forest types grown in Finland.

The everyman's right in Finland allows anyone to wander freely in the forests, camp temporarily and pick berries and mushrooms regardless of land ownership. These present-day rights are part of a long-standing tradition dating back to the times when the small and scattered population lived self-sufficiently from the forests and rivers alongside occasional long hunting trips through the forests.

Changes in the way of life and formation of settlements transformed Finnish forests to be suitable for the use of agriculture and pasture for animals. Clearing the forest through burning was the first method used for making living space and fertilising the ground for agriculture in Finland.

The change from using forests for domestic needs to more and more efficient forms of use gathered speed in the 17th century. Tar, produced from burning pine trees, was a valued substance for preserving wood, and the demand for this in Europe made Finland the world's leading tar producer for nearly a century.

The combination of slash-and-burn agriculture, forest pasturage, tar burning and the forest industry's growing demand for wood led to rapid depletion of the forests, and in a report from the 1850s it was estimated that in extensive areas around sawmills and log driving routes the forests had been completely destroyed. Forest resources had decreased because insufficient care had given to forest renewal.

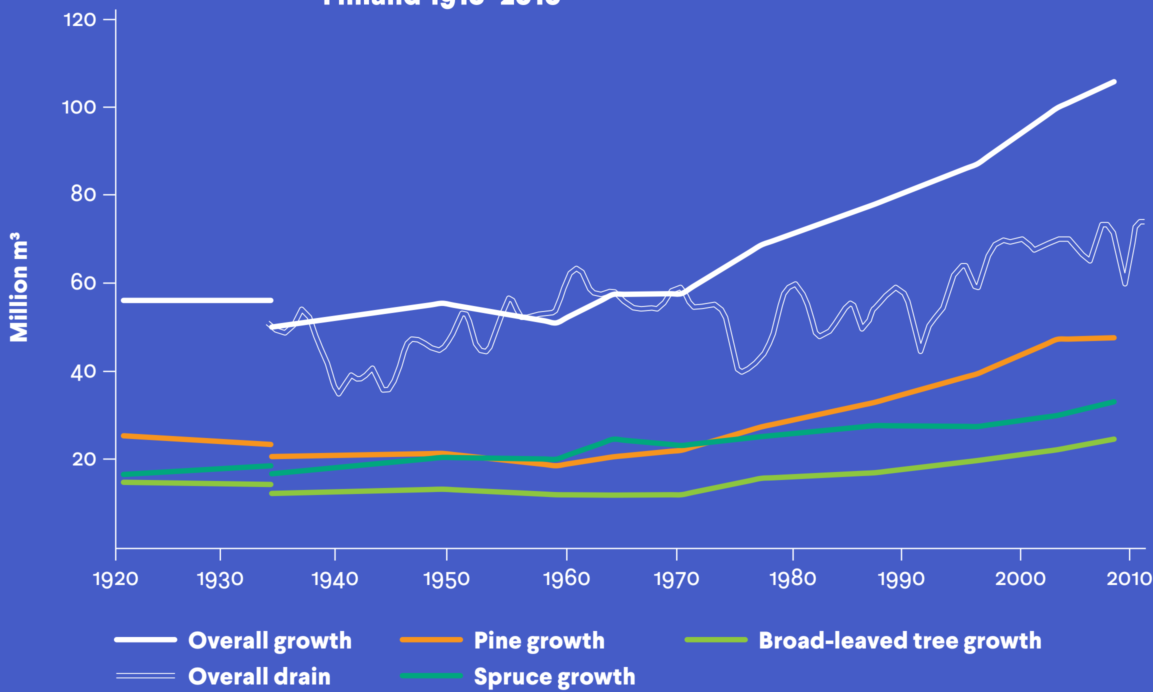
Ensuring Sustainable Forest Management

Concerns about being able to secure the required amounts of wood and under productive forests led in the 20th century to the issuing of the Forest Act, which banned the destruction of forests. In addition, a forest administration was established and charged with the task of promoting forest management and ensuring that the forests are used in a sustainable way with forest renewal in mind.

After the war, forest management guidance and support grew even more, and the quantity of growing timber started to rise rapidly. Large and controversial logging operations were carried out, especially on state-owned land, to pay off Finland's war reparations and to stamp Finland onto the world map with the power of its paper and wood pulp industry.

Alongside the Finnish forests' traditional economic significance, other uses and purposes emerged and increased in importance towards the end of the 20th century. In addition to their economic significance as a natural resource, raw material and source of employment, forests in Finland are also a climate-regulating ecosystem and carbon sink as well as a living environment for a diverse range of species.

Forest growth and drain in Finland 1918–2010



With good care, the Finnish forest can be used and continue to be used and enjoyed in many different ways.

Finland's forests in 1850

- Abundance of forests
- Abundant supply of firewood and smallwood, not enough logs
- Large amounts of firewood and smallwood, scarcity of logs
- Enough firewood and smallwood for household needs, shortage of logs
- Not enough firewood or smallwood, shortage of logs
- Few forested areas

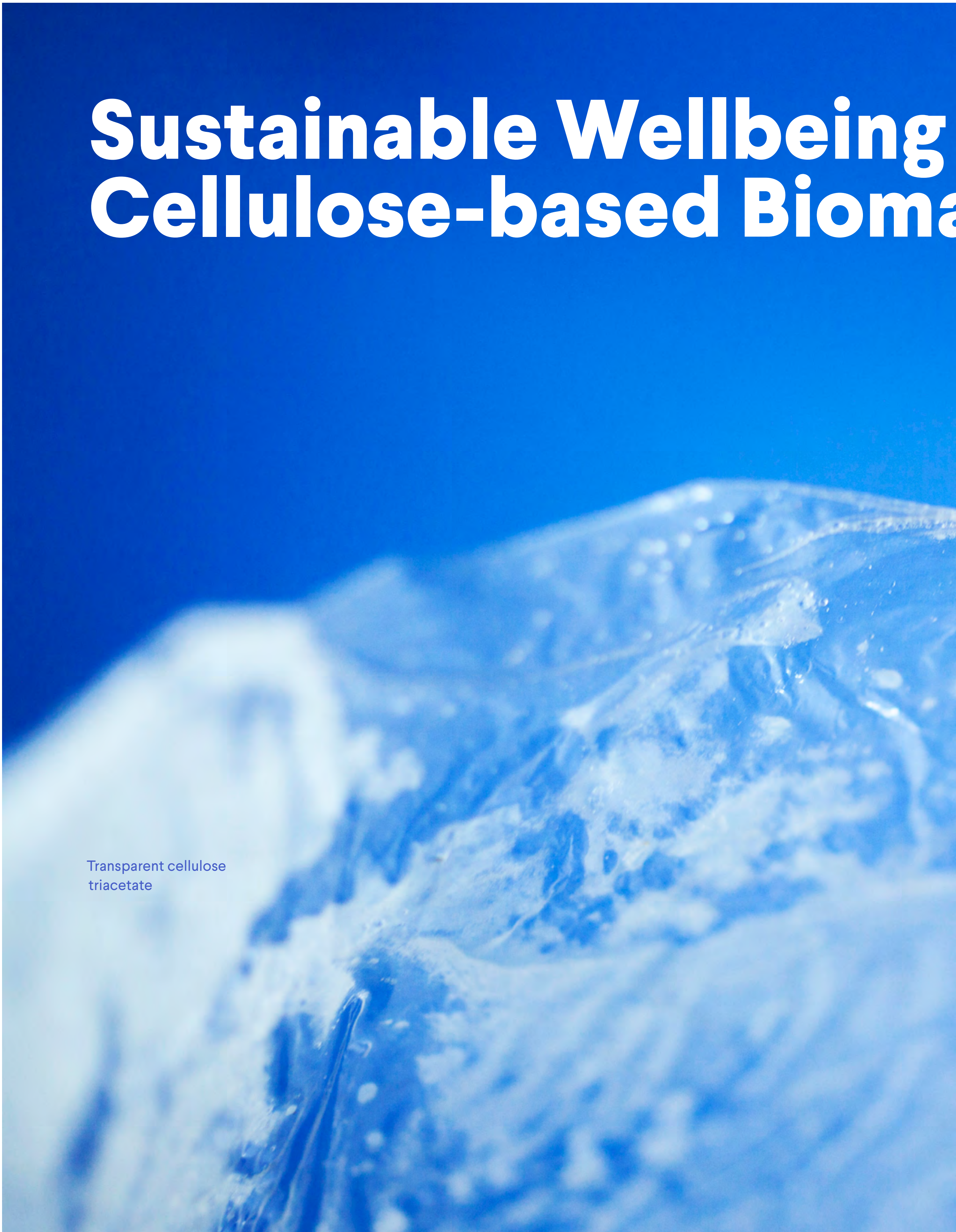
In accordance with the principles of sustainability, forest growth in Finland exceeds forest depletion through logging. More and more attention is paid as to how forest management must take into consideration not only timber production but also other matters such as species diversity and reindeer herding. Changes in the structure of the economy have contributed towards the current situation where forests are to many city dwellers first and foremost an important source of recreation and well-being. The hunting lifestyle has not completely disappeared, however, and there are even people from distant, far off countries making use of everyman's right.

A large proportion of Finnish forests continue to be family owned, and generally are financially beneficial for their owners. The importance to the domestic economy of forestry products such as wood pulp, plywood and sawn timber, cannot be disputed – they account for a fifth of Finnish exports. The wood used can be shown to be almost one hundred percent sourced from sustainably managed boreal forests.

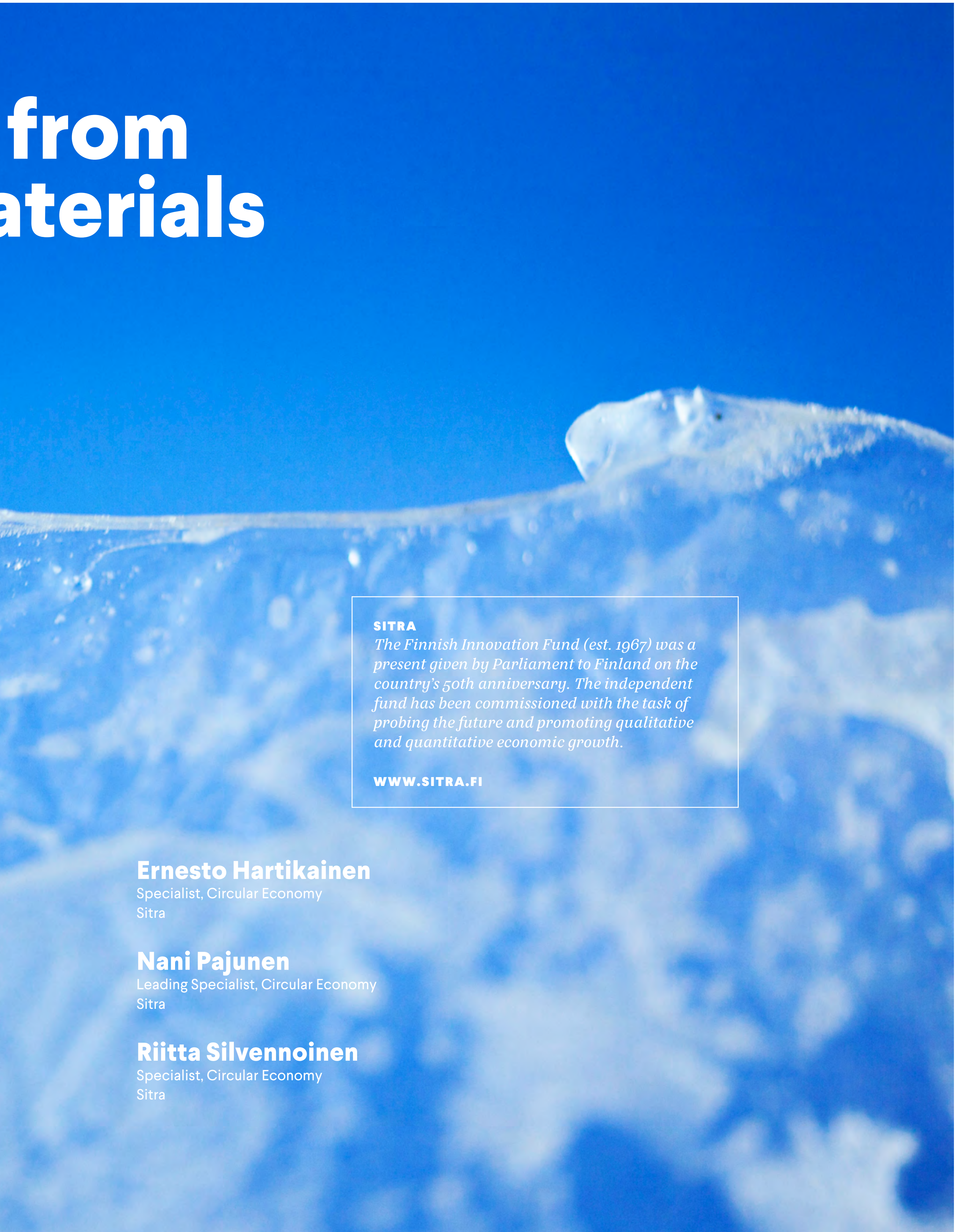
Wood is now more important than ever as a renewable resource that can replace oil and metals. It is also an inspiring material which has many incomparable natural properties – there is plenty in wood fibres and other forest products to serve as the foundation for inventions and product development. In the global operating environment, Finland's challenge is to both convincingly show that it is both possible and worthwhile to sustainably utilise Finnish forestry products as raw materials and also at the same time ensure that the forests grow and serve their function in cooling the atmosphere. With good care, the Finnish forests can be used and continue to be used and enjoyed in many different ways.

Ernesto Hartikainen, Nani Pajunen & Riitta Silvennoinen

Sustainable Wellbeing Cellulose-based Bioma



Transparent cellulose triacetate



from aterials

SITRA
The Finnish Innovation Fund (est. 1967) was a present given by Parliament to Finland on the country's 50th anniversary. The independent fund has been commissioned with the task of probing the future and promoting qualitative and quantitative economic growth.

WWW.SITRA.FI

Ernesto Hartikainen
Specialist, Circular Economy
Sitra

Nani Pajunen
Leading Specialist, Circular Economy
Sitra

Riitta Silvennoinen
Specialist, Circular Economy
Sitra

The world is being shaped by global megatrends such as the rapid development of digital technologies, the growing scarcity of natural resources due to increasing consumption and unpredictable political turbulence caused by the aftermath of globalisation. What role will cellulose-based biomaterials play in the future? We at Sitra, with our vision of Finland as a successful pioneer in sustainable well-being, believe that cellulose-based biomaterials will play a significant role in the future of this planet.

Our traditional thinking around economic growth and increased wellbeing, which in the past century has been built on industrialisation and the extraction and utilisation of finite resources, is being challenged. The circular economy aims to decouple economic development from environmental degradation. Digital platforms and data are used to fully utilise resources and servitisation protects businesses and national economies from volatile natural resource prices.

The Finnish Road Map to a Circular Economy

We see the transition from a linear to a circular economy as not only a necessity, but also a great economic opportunity. Finland is pioneering the path towards a circular economy with the ground breaking and highly actionable Finnish Road Map to a Circular Economy, built together with key public, private and third sector organisations in 2016. The road map sets a goal for Finland to be a global leader in the circular economy by 2025.

With forests being so important for Finland's economy and the wellbeing of its people, it is natural that "forest-based loops" were

defined as one of the five focus areas on the road map. Forest-based loops aim to promote economic growth and create new jobs in Finland by supporting the development of new, higher value-added products and services from forests.

Meaning of Materials Know-how

Fossil oil-based materials such as plastics and resource intensive materials such as cotton or aluminium can be increasingly replaced by cellulose-based materials as technologies develop and markets become more favourable. The renewability, climate-friendliness and biodegradability of cellulose-based biomaterials are not the only properties that make these materials attractive when compared to the finite materials that they are substituting for. The organic nature of biomaterials also involves unique properties and allows for previously unimaginable applications.

As products become increasingly complex through the mixing of multiple materials, we face new challenges – how to extract and separate those materials at the end of the product's life. Often the target

Layered nanocellulose mixed with coal.

of developing these new composite and hybrid materials is to find new lightweight solutions or to substitute fossil oil based materials with biomaterials.

Materials know-how in the material development and product design phase are essential elements of an approach to the circular economy. We cannot stress enough just how important these phases of the life cycle are. Early phase decisions play a significant role in the product life cycle, which enables the transition towards the circular economy.

Nanocellulose, carbon fibres from lignin and bio chemicals from hemicelluloses have a multitude of future applications ranging anywhere from bionic materials to superconductors to growth substrates for synthetic biology. These future applications and specialised high value products will add value to cellulose and current value chains and even create completely new markets. New cellulose-based products will provide Finland with a significant competitive advantage as we have a sustainable source of biomass and the infrastructure to export products all over the world. By developing and utilising new technologies manufacturing industry can once again flourish in Europe.

As our understanding of human wellbeing grows we uncover new advantages for biomaterials such as health benefits. On a rapidly urbanizing planet with people becoming unhealthier in densely packed cities made of concrete and asphalt, a future society built on organic materials is a vision truly worth striving towards.

Bacterial cellulose

Materials know-how in the material development and product design phase are essential elements of an approach to the circular economy.

Paper yarn, bacterial cellulose and birch bark

Heli Kangas

Super Materials from Wood
Cellulose, Hemicellulose and Lignin

VTT
VTT Technical Research Centre of Finland Ltd (Est. 1942) is a research and technology company.

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Heli Kangas
Senior Scientist
VTT Technical Research Centre of Finland Ltd

It is an old saying that Finland lives from its forests. And in these forests lies a golden treasure – trees that consist of nature's own wonder materials – cellulose, hemicellulose and lignin, the major chemical constituents of wood. Cellulose is the most abundant polymer in the world, with lignin coming a close second. In wood-fibre cell walls these polymers are closely interconnected, accompanied by various hemicelluloses. Cellulose is already known to us in many commercial products, such as paper and cardboard, films (cellophane), textiles (viscose, lyocell) and chemicals and additives used in cosmetics, food etc., whereas lignin is mostly used for energy with a small fraction being used in other applications. Scientists around the world are however actively working on increasing the utilization of lignin in added-value products.

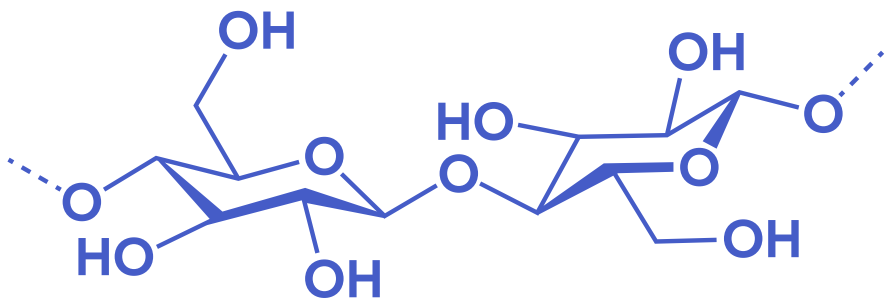

FIGURE 1
Cellulose polymer

Cellulose

Cellulose consists of only one type of a sugar molecule, a 6-carbon glucose, linked together by strong hydrogen (H) bonds between hydroxyl (OH) groups, thus forming a linear cellulose polymer (Figure 1). The degree of polymerisation (DP), i.e. the number of glucose units bonded together to form cellulose in wood is about 10,000 and the length of the cellulose molecule can be around 5 μm. The linear cellulose molecules are further aggregated into cellulose microfibrils primarily due to strong forces existing between adjacent cellulose molecules containing free OH groups. Cellulose microfibrils form either highly ordered, crystalline, or less ordered, amorphous regions in the wood cell wall. Cellulose fibrils make up the wall layers and eventually the structure of the wood cell wall. Free OH groups in cellulose are also responsible for its strong interactions with water, i.e. the hydrophilic (water-loving) nature.

Hemicellulose

Hemicelluloses consist of various 6-carbon sugar molecules, such as glucose, mannose and galactose as well as of 5-carbon sugars, like xylose, arabinose and rhamnose. The main chain of hemicellulose can consist of only one type of unit or two or more. Hemicellulose chains also contain side groups and are branched in some cases (Figure x). The molecular chains of hemicelluloses are much shorter than in cellulose, containing only around 100–200 sugar molecules. Hemicelluloses also lack the crystalline structures observed in cellulose, thus being amorphous materials in nature. Due to their lower DP and crystallinity hemicelluloses generally have lower chemical and thermal stability compared to cellulose. For example, hemicelluloses are soluble in alkalis and some even in water, while it is much more difficult to dissolve cellulose.

Heli Kangas

Lignin

In contrast to cellulose and hemicelluloses, the structural constituents of lignin, called phenylpropane units, are not linked to each other in any systematic order, giving lignin an irregular chemical structure (Figure 1). During biosynthesis, lignin is built up by polymerization from three main precursors, the proportions of which vary with their origin. These structural units are then linked together to form an aromatic, amorphous lignin macromolecule. The degree of polymerization of lignin has been estimated to be around 75–100. In wood, lignin acts both as a binder between the wood cells and a material bringing rigidity to the cell walls. During the development of the wood cells, lignin is the last component, which is incorporated into the frame formed by cellulose and hemicelluloses, interpenetrating the fibrils and providing a strengthening effect.

The chemical composition of wood varies between tree species, parts of the tree etc., but the typical content of cellulose is 40–45% of the dry content of wood, while the content of various hemicelluloses is between 25 and 35%, and that of lignin 20–30%. The content of the chemical constituents also varies across the ultrastructure of

Heli Kangas

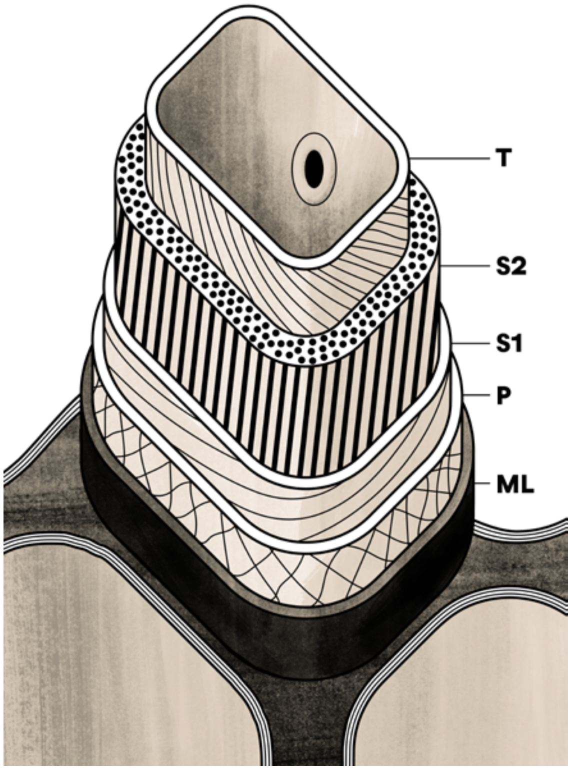

FIGURE 2 – Wood cell wall
T: Inner layer
S2: Middle layer
S1: Outer layer
P: Primary wall
ML: Middle lamella

the wood cell wall (Figure 2). Most of the cellulose and hemicelluloses can be found in the secondary wall (S2), while the primary wall (P) and the middle lamella (ML), the layer bonding the wood cells together, are rich in lignin. However, due to the thickness of the S2 wall compared to the P wall, most of the lignin is in fact also located in the S2 wall. In order to benefit from the unique properties of the wood chemical components, they must be liberated from the wood ultrastructure. Cellulose can be isolated from the wood cell wall by traditional pulping processes, commonly used for the manufacturing of papermaking pulps. The most common method, alkaline kraft pulping, targets the removal of lignin, while hemicelluloses are partly retained with cellulose fibres and partly hydrolysed and dissolved. After the lignin removal, cellulose fibres are liberated.

Nanocellulose

Cellulose microfibrils of 10 to 25 nm in width consist of even smaller units, elementary fibrils of an average 3.5 nm in width (Figure 3). Through the application of mechanical energy or strong chemicals it

Pine bark, needles and growth rings

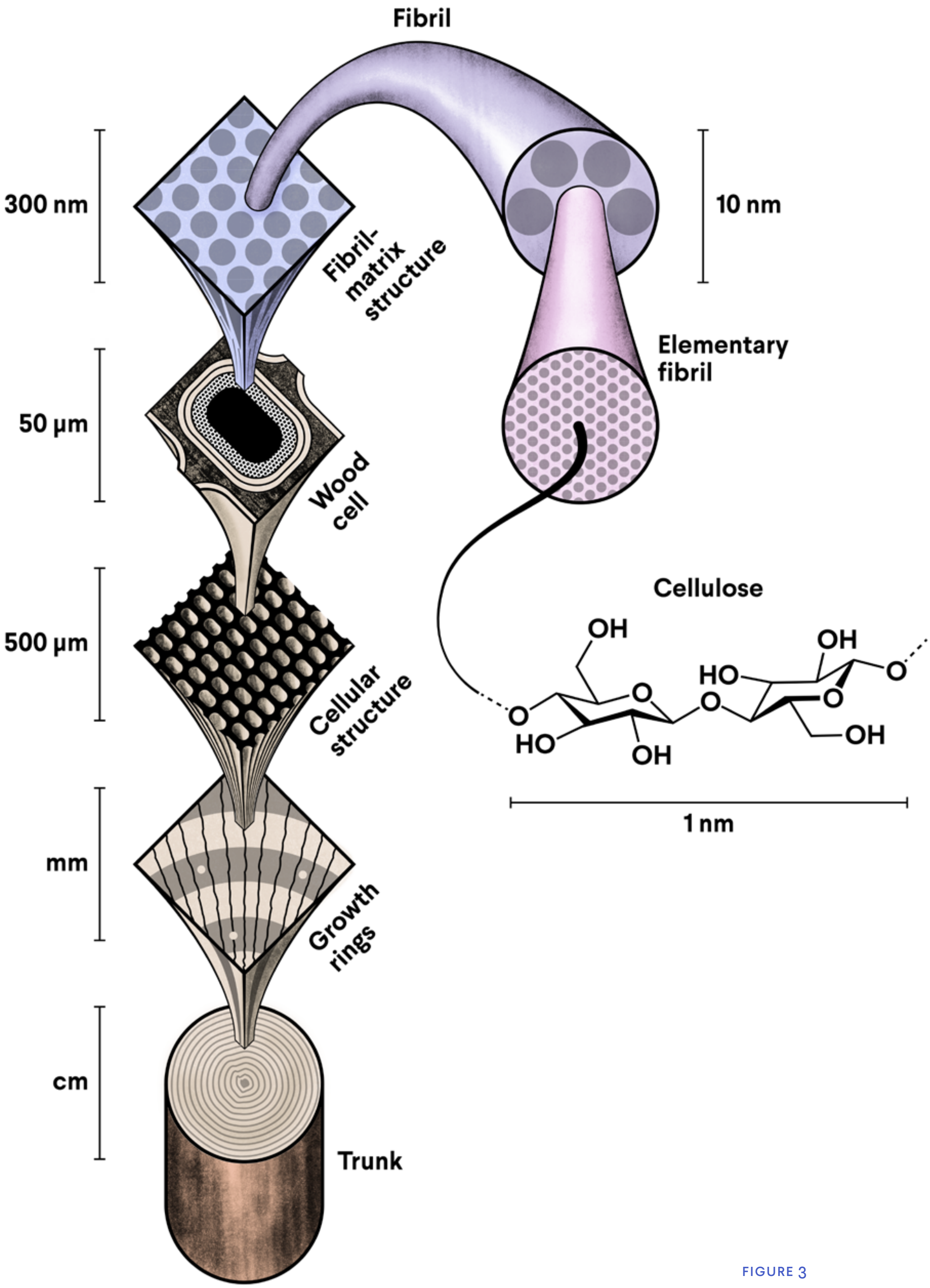
Fibril
300 nm
Fibril-matrix structure
10 nm
Elementary fibril
50 µm
Wood cell
Cellulose
500 µm
Cellular structure
OH
OH
HO
O
O
O
O
O
HO
OH
OH
1 nm
mm
Growth rings
cm
Trunk

FIGURE 3

is possible to separate the individual cellulose fibrils or crystals within the cellulose fibre structure. The produced materials, which have one or more of their external dimensions at a nano-scale, i.e. between 1 to 100 nm, are referred to as cellulose nanomaterials or nanocellulose. Based on their production method, size and other properties, wood-derived cellulose nanomaterials are generally divided into two classes: cellulose nanofibrils (CNF) and cellulose nanocrystals (CNC). Cellulose nanofibrils are manufactured by mechanical treatment, for example grinding, homogenisation or microfluidisation, often combined with enzymatic or chemical pre-treatment, whereas cellulose nanocrystals are produced by acid hydrolysis, breaking the amorphous regions of the cellulose fibrils. Sulphuric acid is the most commonly used acid as it generates a negative charge on the fibril surface, thus leading to more stable suspensions. As a result of the differences in their production method, CNF and CNC differ from each other in most of their material properties, such as dimensions and surface chemical properties. However, some similarities can also be observed.

Cellulose nanofibrils consist of thin, long fibrils, which are in many cases branched, bearing a resemblance to brushes in appearance. The width of the smallest fibrils, manufactured by using chemical pre-treatments in combination with mechanical treatments, is around 2–5 nm. Mechanically manufactured CNF (which in many cases are referred to as cellulose microfibrils, CMF) are more heterogeneous, consisting of fibrils of many different sizes (from nm to µm) and even fibre fragments and unfibrillated fibres. The average width of mechanically manufactured CNF varies, but can be estimated to be around 20 nm and their length can be several micrometres. CNF on the other hand are shorter than CNC, around 50–500 nm, depending on the raw material source, while their width is around 3–5 nm. A good analogy to describe the different appearance of CNF and CNC is to describe cellulose nanofibrils as spaghetti-like and cellulose nanocrystals as rice-like.

Due to their unique, nano-specific properties such as small size, high aspect ratio (length / width ratio), large specific surface area, high strength and stiffness, gelation and shear thinning behaviour, the liquid crystalline behaviour of CNC, reactive surface, inherent film formation tendency etc. cellulose nanomaterials (CN) have many potential application areas. For example, they can provide increased strength in packages and composites, while simultaneously enabling weight reduction. For packaging, this would mean material savings and a reduced carbon footprint. In addition, CN films are known for their excellent oxygen and grease barrier properties, thus providing additional functionality for the package. In transportation, lightweight composites would enable savings in fuel and energy. In addition to their interesting properties, CN originate from an abundant and sustainable raw material, wood cellulose, and are biodegradable and biocompatible.

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JOINING THE TEAM

CHEMARTS student Nina Riutta preparing samples for an exhibition.

Collaborative Material Research

Designers and Scientists Working with Materials Development

Carlos Peralta
Postdoctoral researcher
Aalto University, School of Arts, Design and Architecture

AALTO UNIVERSITY
A Finnish university, bringing together various fields from business to engineering and design.

WWW.AALTO.FI

People experience materials through their interaction with objects and spaces. Such experience depends not only on the technical and functional features of the material but also on its perceptual characteristics, as different materials offer different aesthetic and symbolic experiences. For example, the technical and functional characteristics of the plastic of a mobile phone carcass might be useful to protect the mobile's internal components, to help heat dissipation and to provide electrical insulation. But its aesthetic characteristics are the ones which determine the feeling users may have when they hold it, while its symbolic treats underpin users' perceptions of its value and desirability. People may reject mobiles that feel too "plasticky" and choose those made from materials that "feel" metallic as they reflect higher quality, durability, and status.

The development of new materials entails an integrated approach that pays attention to their technical, functional and perceptual characteristics. It should pursue useful, meaningful and pleasurable experiences, but also respond to the current context of complex interrelations between new technologies, environmental challenges and sociocultural realities. For instance, as the concern for global warming becomes a societal issue, the development of materials and processes that are sustainable and communicate the values of sustainability becomes paramount.

Engineers and scientists who pay special attention to the technical characteristics and sometimes to their functional traits are usually in charge of the development of new materials. However, these developments are rarely focused on with the perceptual features. It is only in the later stages of the product development process, that designers "select" (instead of "develop") materials to meet product requirements. Furthermore, the choices of materials are often limited, and the process of choosing can be hindered by an absence of "designerly" classification systems. Designers regularly face situations in which technically sound materials do not fit perceptual requirements. This circumstance normally leads to additional research and

Teams need to develop mutual trust to operate efficiently.

developmental work, and even though this is not necessarily a problem, sometimes it can be a costly and time-consuming exercise.

In materials development it's useful to focus on both the technical and perceptual characteristics of materials right from the beginning. On the one hand this can expand the range of materials available, making the process of material selection and product development shorter and cheaper. On the other hand, it might help to develop a stronger material functionality that facilitates the development of cheaper and more useful products.

Also, while disciplinary approaches to new materials development tend to be centred either on the technical, functional or the perceptual characteristics, an integrated multidisciplinary approach that focuses simultaneously on all three types of characteristics is desirable, especially as materials need to respond to complex and interrelated design requirements. For example, while the design of a coffee machine requires the use of strong and safe materials that protect the device components and its user, it also requires the use of materials that visually correspond to the places in which they are going to be employed and to the values of their users. It is reasonable to expect that multidisciplinary teams of designers and scientists have the

Timo Kaljunen and Vesa Kunnari from VTT setting up the DWoC exhibition 2016.

potential to enable this integrated approach, to bring together and interweave disciplinary expertise, and to address all requirements at the same time.

Multidisciplinary work offers multiple advantages. It deals better with complexity, fosters creativity, and its results have greater impact and cater to larger audiences. However, it offers challenges too. Interdisciplinary groups need to develop a common language to overcome the limitations of disciplinary jargon. Also, they need to have a clear and explicit common purpose, as work driven only by a disciplinary interest can be detrimental to the work results. Teams need to develop mutual trust to operate efficiently. The development of this trust links to how aware team members are of their peers' capabilities and limitations, and of their expert knowledge. Interdisciplinary collaborators need to develop mechanisms to integrate their disciplinary methods and approaches. That will not happen by itself, it takes time and effort.

A good example of such collaboration is the DWoC project at Aalto University, where designers and scientists are working together to develop new cellulose-based materials using a design-driven approach. Employing an iterative prototyping process, team members are developing materials with unique technical and perceptual characteristics. Developments to enhance cellulose composites' technical characteristics such as physical strength and structural stability are undertaken paired with an intensive exploration of some of their perceptual characteristics such as form, colour, and texture.

Building the 'New Biomateriality Lab' installation at the Design Museum, Helsinki, 2017.

The Story of CHEMARTS
Sharing a Passion for Wood-based Biomaterials

Pirjo Kääriäinen
Designer in Residence
Aalto University, School of Arts, Design and Architecture
and School of Chemical Engineering

Tapani Vuorinen
Professor in Wood Chemistry
Aalto University, School of Chemical Engineering

CHEMARTS is the name for a long-term collaboration between two Aalto University schools, The School of Chemical Engineering (CHEM) and The School of Arts, Design and Architecture (ARTS).

The main idea is to inspire design and material science students and professionals to learn from each other, and to together create innovative applications for wood-based biomaterials. The CHEMARTS team is also active outside the University: it has organised events, coordinated the New Biomateriality Lab concept for exhibitions and created CelluloseFromFinland.fi

Aalto University was formed from the merger of three universities in 2010, and there was a demand for new form of collaboration between art, design, business and technology. CHEMARTS as a story began in December 2011 when Aalto ARTS was having visitors from Parsons New School (NY). The Dean of Aalto ARTS, Helena Hyvönen, decided to organise a 'Fashionable Technology' seminar to discuss the future of textiles and fashion. Dr Sabine Seymour from New School presented her work, and professors from the design and forest products technology schools in Aalto explained their programmes and research projects. The atmosphere became very excited when participants recognised a shared interest: to combine design with technology and to design biomaterials for the future. The lucky encounter had taken place.

CHEMARTS founders Pirjo Kääriäinen and Tapani Vuorinen (front) in the lab with students Laura Niemelä (behind left) and Andreas Lindberg (right). Photo: Aki-Pekka Sinikoski.


Primo Star
Primo Star
ZEISS

In nature tiny seeds grow into plants, and in favourable conditions the plants flourish and create a durable ecosystem. That has been happening within CHEMARTS. The Dean of Aalto CHEM, Outi Krause, enabled the next step by allocating special funding to hire six students for the summer of 2012. The students explored multidisciplinary collaboration in practice: they familiarised themselves with each other's working methods, experimented with cellulose-based materials, generated fresh ideas and as a result, named their project 'CHEMARTS'. They also created concepts like 'World of Cellulose' and 'Luxury Cellulose Finland', which were soon then further developed by the professors and scientists from VTT and Aalto University. As a result, a new design driven research programme focusing on cellulose was initiated. In 2013 'Design Driven Value Chains in the World of Cellulose' (DWoC) project received a positive funding decision from Tekes, the Finnish Funding Agency for Innovation. Other research projects combining design and materials research have followed, e.g. Trash-2-Cash in 2015.

Chemartsing in Aalto University

After three successful summer projects (2012–2014), it was time to establish the CHEMARTS Summer School and CHEMARTS minor programme. A short introduction course 'Design Meets Biomaterials' has been organised since 2014. The courses are open to all Aalto University students. The pedagogical approach is student-centred, and working methods are experimental and practice based. Students work in multidisciplinary teams, and they define together the topics they want to focus on, or the problems they want to solve during the course. No strict guidelines are given. The role of the supervisors is to provide some background information on wood-based materials, on-going research projects and design methods, and to tutor the workflow. Students are encouraged to get out of their comfort zone: designers can become engineers, or chemists can be designers. Safety issues still have to be continuously considered meaning that experienced researchers always supervise the laboratory work. As a conclusion to the course, the process and results are presented publicly through visual presentations and then in an exhibition.

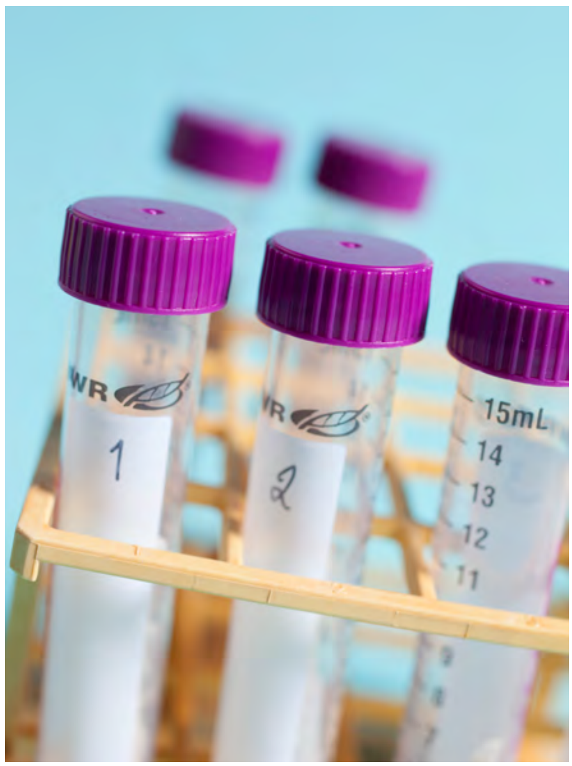
The most important outcome from the CHEMARTS courses is the learning experience. Students get familiar with different kinds of approaches and working methods, which hopefully helps them to collaborate with other professionals in the future. They are confronted

Material explorations by Katja Utriainen, CHEMARTS Summer School 2016

Material research takes time, and prototyping with experimental materials is demanding. There will certainly be failures and those failures have to be accepted.

with uncertainty, as they have to define their goals and design their working process by themselves. Material research takes time, and prototyping with experimental materials is demanding. There will certainly be failures and those failures have to be accepted. A creative mind-set, a persistent way of working and respectful collaboration are the keys for a successful CHEMARTS project. As summer school student Tino Koponen concluded in his learning diary 2016: 'It is all about chemartsing'.

CHEMARTS student Monika Faidi in the Summer School 2016



Experiments with paper yarn, nanocellulose, lignin and birch bark by Katja Utriainen, CHEMARTS Summer School 2016

Wood based materials can also be transparent. Experimental lampshade produced from triacetate by Nina Riutta, CHEMARTS Summer School 2016.

Lampshade produced from nanocellulose and coal by Nathalia Mussi-Weidlich, CHEMARTS Summer School 2015.

Eatable dish from bacterial cellulose and *pettu* (pine bark flour) produced by Maija Järviniemi and Outi Mustonen, CHEMARTS Summer School 2015


OF CELLULOSE-
BASED MATERIALS
BACKGROUND
CHARACTERISTICS
POTENTIAL APPLICATIONS
CELLULOSIC
STRUCTURES BY
3D-PRINTING
3D NON-WOVEN
STRUCTURES FROM
PULP FILAMENTS
NANOCELLULOSE
FILAMENTS FOR
COMPOSITE
REINFORCEMENT

Cases: Working Together

"Designing Cellulose for the Future II", DWoC seminar and exhibition 2016.

DWoC – Designing Cellulose for the Future

Kirsi Kataja
Project Manager
VTT Technical Research Centre of Finland Ltd

Design Driven Value Chains in the World of Cellulose (DWoC) is a multidisciplinary research project (2013–2018) focused on finding new and innovative applications for cellulosic materials. The goal is to make Finland the source of value-added cellulosic products and business concepts, and to accelerate the transformation of the current large-scale forest industry into a dynamic ecosystem for the bioeconomy containing both large and small-scale businesses. The project is funded by Tekes, the Finnish Funding Agency for Innovation.

DWoC is looking for highly refined applications and sustainable production processes for cellulose-based materials. Design thinking and design-driven prototyping is combined with a strong competence in technology development. DWoC organises 'Designing Cellulose for the Future' seminars and exhibitions (2014, 2016, 2017) and participates in various design, science and business conferences and events in Finland and internationally. The project has also established a portal www.CelluloseFromFinland.fi to build awareness and to help create a cellulose-based business network – a new Cellulose Community in Finland.

The partners in the DWoC project are Aalto University, VTT Technical Research Centre of Finland, Tampere University of Technology and the University of Vaasa.

WWW.CELLULOSEFROMFINLAND.FI

Wood can be transformed into diverse materials.

Innovative Packaging by Pack-Age

Markus Joutsela
Lecturer
Aalto University, School of Arts, Design and Architecture

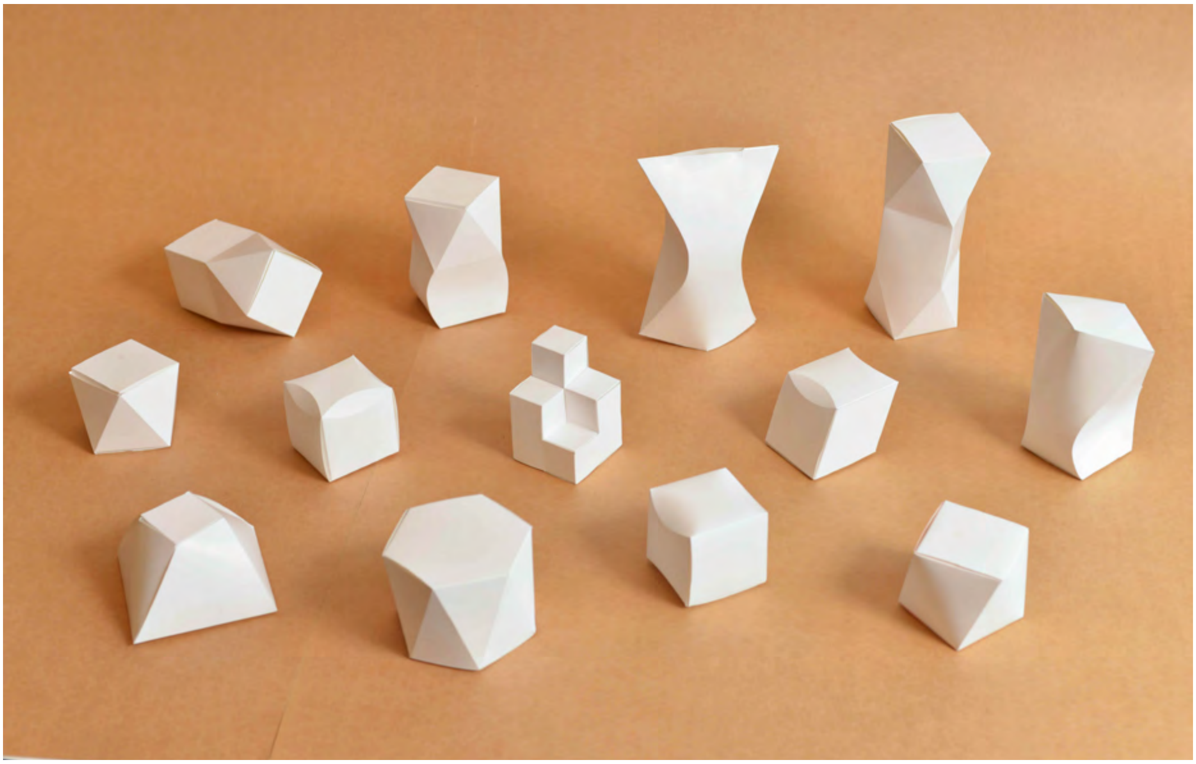
Pack-Age is an innovative packaging design course and minor programme intended for students who are interested in learning packaging design in a fun way. Pack-Age combines design thinking, business and engineering for sustainability and project-based learning. Students work in interdisciplinary teams with real projects from industry. The key concept is creative problem solving. The idea is to use each student's background and prior knowledge as a resource for creative group work. The project work is supported by excursions and a wide range of theme lectures from various international specialists, designers and researchers from the industry.

Teachers from Aalto ARTS, Aalto BIZ, Aalto CHEM, Lahti University of Applied Sciences and Helsinki University team up to provide insightful course content and workshops for our students. By collaborating with different schools we are able to offer a more complete understanding and a more innovative approach to packaging design. Our teaching themes include: Visual Communication Design & Branding, User-Centred Design & User Experience, Packaging Materials and Engineering, Sustainable Product Design, Marketing & Consumer Research, Packaging Development and Model Making.

Participating students learn how to design, communicate, evaluate, test and justify their solutions. They learn how to understand packaging on a systemic level from many different perspectives, adopt good project work practices and learn how to collaborate with various stakeholders.

These carton mock-ups were created by students without any tape or glue as part of their learning about folding techniques for packaging.

Future food packaging prototype with hemicellulose aerogel. It controls the maturing process of avocados with the help of aerogel and active gas. The solution provides a longer shelf life for the fruit and therefore helps to prevent food loss. Photos: Markus Joutsela




LONGER
Mellow
Avocados
5pcs

Carbon Sink – Hiilinielu Design Studio

Ulla Häggblom
Head of Bio Product and Process Technology Degree Program
Tampere University of Applied Sciences

In the Hiilinielu Design Studio (Carbon Sink Design Studio) project, design students from the Lahti University of Applied Sciences and engineering students from Tampere University of Applied Sciences were brought together to share future visions, design methods and bioproduct knowledge. The common dream was to make the world a better place by using fewer non-sustainable materials and to see the Finnish forests as a source for raw material that can be turned into high-quality innovations, not just paper and paperboard.

Three different multidisciplinary workshops were organised in order to develop sustainable packaging prototypes for companies. At the beginning of the workshops, the students were given small team building tasks to ensure they had time to get to know each other. After this, the product and service development started and was brought close to the customer interface, where ideas were made concrete then tested and assessed through quick prototyping. One example of an assignment given by a collaborating company was the design of cardboard food delivery packaging to suit the ageing population and increased urbanisation. The prototype model was a compact, openable and quality packaging solution that resembled a toolbox, with food portions, drinks and cutlery located neatly in different compartments. Another interesting assignment was to combine the barley and oat husk waste resulting from food production with wood pulp and then use this paper as, for example, packaging for bread.

During the workshops, there were a lot of good moments, genuine interaction and a growing respect towards different disciplines. One engineering student summed it up, “Now I know I will include a designer in the team right from the beginning”. In the Hiilinielu Design Studio, we think this kind of mindset has been worth working towards. Based on our experiences, we encourage everyone to look forward to new openings in the field of bio-based products.

Hiilinielu Design Studio students explored and prototyped packaging ideas for liquids 2016.

HIILINIELU DESIGN STUDIO (CARBON SINK DESIGN STUDIO)
A multidisciplinary joint education project (2015–2017) of the Universities of Applied Sciences in Tampere (TAMK), Lahti (LAMK) and Design Forum Finland to develop cooperation between bioprocessing and creative industries.

WWW.HIILINIELUDESIGN.FI

New Tree Tells What a Tree Can Do!

Eveliina Pokela
Project Manager
Uusi Puu

NEW TREE (UUSI PUU)
A community of operators in the Finnish forestry sector to increase awareness of the wood-based bioeconomy – of products and solutions already available, their impact on society and the growth potential of the sector.

WWW.UUSIPUU.FI

The New Tree (Uusi Puu) project aims to increase the awareness of the existing wood-based bioeconomy. It is currently a community of more than 20 organisations in Finland.

Megatrends are affecting consumption behaviour and posing ecological and economic challenges – but at the same time they create new opportunities for a more sustainable future. Current megatrends, such as scarcity of resources, aging population, urbanisation, digitalisation and the increasing awareness around conscious consumption, have an effect on the goods and services we will utilise in the near future. The forest industry now already has responses to many of these challenges: safe, sustainable and recyclable products made out of a renewable, constantly growing and sustainably managed raw material - wood.

New Tree offers insights into tangible wood-based products and solutions and their societal impacts through communication and a variety of activities, such as exhibitions, events and competitions. The project is open to all operators in the field, and the participants represent an extensive range of Finnish forestry sector players, from forest owners to organisations, small and large companies, educational institutions, employees and users of wood-based products. They all share a strong desire to develop, market and make use of Finnish wood-based bio-product expertise.


recipe
ted White-Top Kraftliner
Powerflute (B-flute)
owerflute
werflute (C-flute)
White-Top Kraftliner

INTO UNKNOWN TERRITORIES

Foam formed, moulded tetrahedron is produced from pine pulp by Tiina Härkäsalmi and VTT material researchers.

Cellulose-led Design Research
Knowledge Production Through Material Exploration and Experimentation

Tiina Härkäsalmi
Postdoctoral researcher
Aalto University, School of Arts, Design and Architecture

Tiina Härkäsalmi

The key aim of design in DWoC project is the humanisation of technology and to use design research as a tool for enabling new application areas, product concepts and business development from the technological development in cellulosic materials. However, the integration of the design approach into the materials research and development differs from the conventional product design process, where the design requirements commonly outline the materials selection from existing materials.

In the development of novel cellulosic materials, the design process is less structured and focuses more on the unknown functional and perceptual qualities of the new materials and on original potential solutions where the cellulosic materials can bring added value[1].

The wood-based cellulosic materials afford a broad palette of different soft, hard and porous material, for example, pulp from soft or hard wood, and crystallised or fibrillated nanocellulose, that all have unique behaviours depending on the origin of the raw material and the production method. One of the major challenges of productisation is the low technology readiness level for processing novel types of cellulose-based materials and objects on an industrial scale.

Materials exploration, experiments and early phase prototyping are the key elements of the design approach in order to get new insights and understanding on material properties, performance and behaviour. Together with the technological properties of the materials the perceptual qualities, such as visual performance, touch and smell have an incremental role for the usability of the materials in novel applications[2 3 4]. Material samples are made entailing different colours, forms, structures and compounds in order to investigate the material properties and processability. At the fuzzy beginning, the materials themselves, in this case pulp and fibrillated nanocellulose, have been a start point for exploration based on a more opportunistic and intuitive approach without strictly predefined methods and systems. In this way, preconceived ideas are not limiting the creative process, which is nonlinear and iterative by nature. For example, hemispherical forms were chosen to test the formability and mouldability of 100% fibrillated nanocellulose into 3D structures. More systematic experiments were then followed to test specific properties, such as shrinking and adhesion between compounds of nanocellulose and pulp, cellulose filaments or foam formed nonwovens. Applied methods of textile dyeing with reactive dyes were then used to test the dyeability of pulp and nanocellulose.

The tangible material samples, in the design context, provide new visions not only for the material's intrinsic functional properties, but also for a more holistic understanding of the potential limits and benefits of cellulosic materials and for identifying their unique characteristics as regards perceptual and associative qualities[1]. They can have a great effect on the usability, desirability, feasibility and viability of the utilisation of cellulosic materials in novel application areas. Material samples also give insights into potential end-uses and into prerequisites for product design and productisation. The different types of cellulosic materials and technologies offer wide-ranging opportunities for further development, especially in the products that need to be recyclable and biodegradable. The combination of fibres, filaments, films, and foams enables the production of high strength lightweight all-cellulose sandwich structures and composites for different fields, such as construction, landscaping, health and wellbeing and especially for the emerging circular bio-based economy.

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LUMIR

is a Finnish company producing sprayable, bio-based sound absorbers for indoor acoustics. Open spaces that have large, hard, sound reflecting surface areas are increasingly used in architecture around the world. These acoustically challenging spaces offer a growing market for easily installable, sustainably produced and safe acoustic solutions. Lumir products decrease the reverberation time, or, in other words, remove echo caused by sound reflection from hard surfaces. They can be installed seamlessly and they can be customised in colour and surface texture according to customer needs.

WWW.LUMIR.FI

Acoustic icosahedrons coated with Lumir Spray produced by Tiina Härkäsalmi and Ville Arkonkoski from Aalto ARTS and Ott Pulst and Jari Grundström from Lumir Ltd.

This acoustic panel prototype is produced by foam forming. The moulding technique has been developed through the collaboration of Tiina Härkäsalmi and VTT material researchers.

Dried nanocellulose is hard, light and durable and might one day replace plastics. Colour and material explorations by Tiina Härkäsalmi.

Colour map for reactive-dyed cellulosic foams produced by Tiina Härkäsalmi and VTT material researchers.

Joint Adventures in Foam Forming

Jukka Ketoja
Principal Scientist
VTT Technical Research Centre of Finland Ltd

Foam forming is a new technology that enables the effective production of a vast range of fibre-based materials. The bubble structure of wet foam gives a handle to control the spatial distribution and orientation of fibres inside the foam. By feeding the fibre foam onto a porous fabric and then sucking out the wet foam, one is left with a fibre network that forms the skeleton for a lightweight material.

The first trials in the 1970s focused on papermaking applications. In this current decade, VTT, the Technical Research Centre of Finland, and several other companies and research institutes have recognised a greater potential in the technology. Unforeseen product opportunities are hidden in novel fibre-network structures and material combinations such as new types of nonwoven fabrics and tailored 3D materials.

In the last few years, interdisciplinary research collaborations between scientists and designers have explored the full range of possibilities. A working production process generally requires contributions from engineers, chemists and physicists. The role of designers is to provide the keys to locked mental doors behind which creative development then takes place. One such key is 'Iterative Prototyping', often leading to unexpected results. This approach was applied e.g. in the development of interior sound insulation in DWoC. This led to the discovery of multi-scale structural features affecting both the technical and perceptual qualities of the material. The simultaneous tailoring of macroscopic 3D form, controlled surface texture and micro-porous structure would be difficult using conventional forming methods.

The challenge in such an interdisciplinary effort is to move together to unexplored territories even though initially there is little common language and without knowing exactly the final destination. Success comes through doing things closely together, trusting in each other's competence and opening the mind to the joint adventure.

Thick and soft cellulose foams from softwood pulp produced by VTT material researchers.

Designing for the Circular Economy

TRASH-2-CASH (T2C)
EU-funded research project (2015–2018) utilising zero-value waste textiles and fibres with design-driven technologies to create high-quality products. Pioneering a whole new way of developing materials.

WWW.TRASH2CASHPROJECT.EU

Kirsi Niinimäki
Professor in Fashion Research
Aalto University, School of Arts, Design and Architecture

Marjaana Tanttu
Doctoral Candidate
Aalto University, School of Arts, Design and Architecture

Eugenia Smirnova
Fashion student
Aalto University, School of Arts, Design and Architecture

Dyed cotton recycled with the Ioncell-F process and transformed into new fibres by Eugenia Smirnova and Aalto CHEM Ioncell team.

Design is moving towards a new more systemic understanding and knowledge in the circular economy is emerging. A circular economy approach aims to close material loops and therefore all products should be designed to have multiple life cycles. After the first use phase, the product will continue in technical or biological cycles, meaning redesigning and remanufacturing or composting. While garments and textiles include many harmful chemicals, and further composting causes methane, which contributes to greater greenhouse gas emissions and global warming[1], priority in closing the loop should be in a technical cycle with textile and fashion products.

In a circular economy all materials flow in the system and even waste is seen as a valuable material source, but for this to happen this needs new knowledge in material recovering processes. We have to challenge current design principles and use new natural or recycled elements as a basis for product design in the future. This text presents some new ideas on how to design in a circular economy context. The presented design examples come from research projects Trash-2-Cash (T2C) and DWoC. The T2C project's (2015–2018) aim is to transform waste materials (cotton, cellulose, polyester and blends) into high quality textile fibres. Paper waste or cardboard waste can also be used to produce high quality textile material. This can be done with the novel Ioncell-F method. Using cardboard and paper is a smart choice, not only because we are utilising waste, but also because in their production fewer chemicals and less energy are used than in making pure, virgin birch cellulose[2].

The following design examples show that we need new understanding and design strategies on how to design in a circular economy context and how to use all materials and even use colours in a new way in the recycling and material recovering processes.

Eugenia Smirnova,
Kirsi Niinimäki,
Marjaana Tanttu

In a circular economy all materials flow in the system and even waste is seen as a valuable material source.

Natural Lignin as a design element

Cellulose has been used in making fibres for over a hundred years, but other compounds of wood may also enter the field of fashion in future. The recently developed Ioncell-F process enables the production of textile fibres from a mix of cellulose and Lignin, and this seems to be a promising method for the chemical recycling of textiles. Using lignin for fibres not only increases the value of this abundant natural resource, but also opens interesting opportunities for design in a circular economy context. Lignin enables the bringing of colour to textiles without any additional dyes. Due to the brown colour of lignin, using varying amounts on fibres creates a range of natural brown hues[3]. By combining these hues, e.g. through knitting or weaving, it is possible to make patterned garments that originate entirely from wood. This could be a benefit in recycling, since fibre recyclers will know exactly what is in the material, instead of having to guess from amongst the estimated 27,000 commercial dyes currently on the market[4]. Using lignin instead of petrochemical dyes would also be one way towards having completely biodegradable textile materials.

Textile waste is a valuable raw material. Illustration by Eugenia Smirnova.

Lignin can find its way into textiles via several routes. Either it is added prior to fibre spinning, or it comes as part of the raw material, such as in recycled cardboard. From the design point of view lignin gives the possibility of communicating the origin of man-made cellulose fibres in a visual and intuitive way [3]. Brown from the birch, or khaki from cardboard could be used as aesthetical eco-statements in design.

Recycled colour as a design element

Knitted trials showing the potential of lignin in textiles. The dark brown knit has 15% lignin; the light brown is made of recycled cardboard. The patterned knit has no added dyes, just cellulose and lignin.

The increase in the amount of textile waste makes it worthwhile to use this waste stream as a source for new fibre production. But what happens with the chemicals inside the textile material as part of the recycling process? In a circular economy system these other compounds should also be suitable for recycling and this suitability also concerns colours. Normally, in the textile industry, the start point is always with bleached and white fibre or yarn, which is then dyed according to certain recipes to end up with a precise colour.

In the Ioncell-F process it is possible to recycle the textile materials and the textile colours. We have tested this with different textile dyes and the first results show that some colours are more reliable and stable in this process than others [5]. Both post-consumer textiles and pre-consumer textile waste could be used in this process. If pre-consumer waste is used (waste material collected from textile factories) the dye type is known while if the post-consumer waste (old, used textiles) is used, the dye type can vary and the end result is uncertain.

Different design paths could be developed if colours are to be recycled in the future. Firstly we could limit the used colour types in the original textile material. We would only use those colours, which are stable in colour and shade within the recycling process. A global system would be constructed where all dyed material could be easily tracked and managed and the where the colour result after remanufacturing could be predicted. The other approach accepts a change in colour in the remanufacturing process. Here all textile waste could be used without knowing the original dye type in the material. Textile waste could be mixed to end up with an approximate shade and further processed as a fibre. The design process could start e.g. after

Textile source materials (rectangle pieces), optic pulp sheets of average colour (round pieces), remanufactured fibres in the upper part of the picture.

old textile material has been manufactured as a new fibre, which then has a certain colour. Fibres with a colour could be further mixed with each other while making a yarn, which ends up with a melange effect. They could also be dyed later so as to end up with new shades. In this kind of system, end colours might not be so accurate and therefore more tolerance for different colour shades would be needed from both industrial manufacturers and consumers[5].

New approaches are needed on many levels

These examples show that in the future technical and system level innovation will not be enough to create the circular economy. New design approaches and design strategies need to be created which will use all waste materials, chemicals and colours in a more appreciative and creative way. Design within an industrial system will need to be more flexible to be able to use all waste sources in the manufacturing process even if the design outcome has more variation than it would today. Currently, even small changes in the colour shade are understood as poor quality and this kind of product is easily discarded in quality control, while in the future, the circular economy context may demand new norms for colour shade variability in industrial design and production.

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IONCELL-F

is a new spinning technology developed in Finland based on research performed at Aalto University and University of Helsinki. The process belongs to the so called Lyocell-type spinning category and allows for the production of cellulosic fibers with excellent mechanical properties. The heart of the process is a novel solvent that allows to spin cellulose and other biopolymers into filaments to be used for textile and mechanical applications (e.g. composite materials). It is a closed-loop process which avoids the use of toxic chemicals and generates no waste and is thus fully in line with an envisioned concept of circular and sustainable economy.

WWW.IONCELL.FI

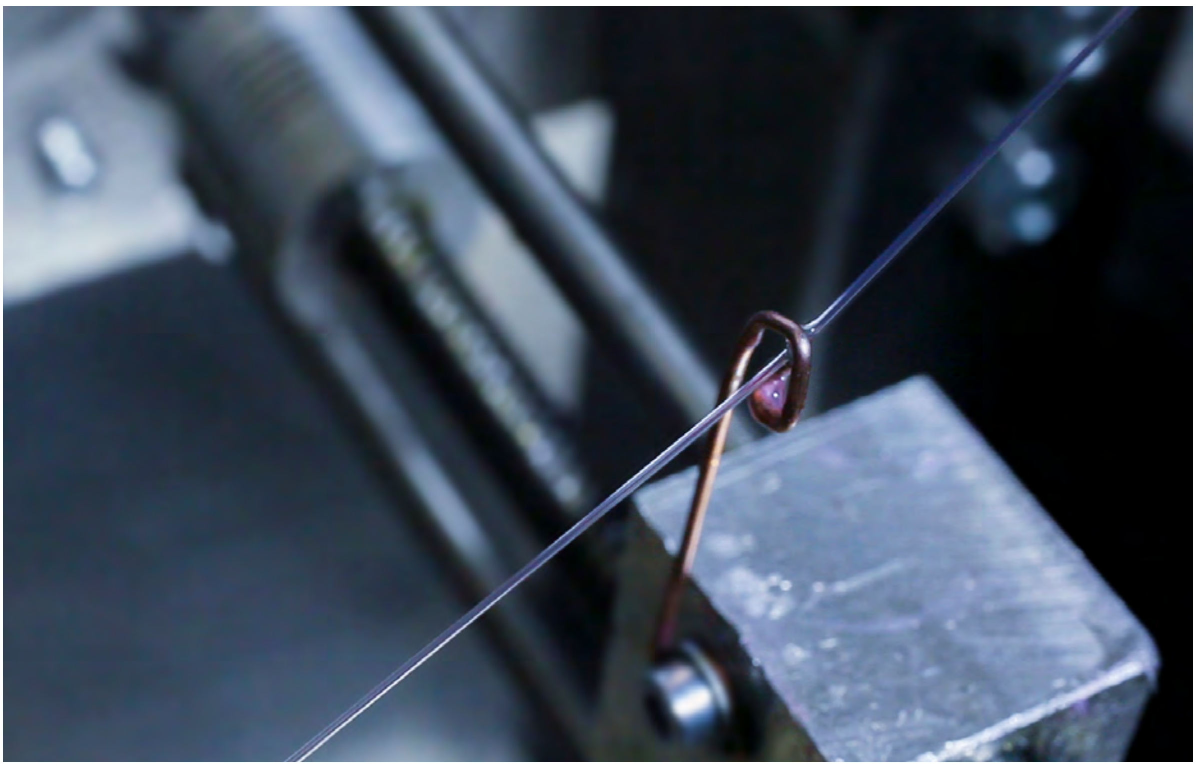
Woven Ioncell-F fabric
produced from birch and
printed by Marimekko 2016.

New Materials, New Machinery

3D printer for the printing
of cellulosic materials.

Ville Klar
Doctoral Candidate
Aalto University, School of Engineering


A!



Materials development can be approached from various angles. Typically, new raw materials and their combinations are explored with standard laboratory equipment and testing procedures. While traditional laboratory practices are indispensable, through concurrent development early on with production machinery prototypes, materials development can be accelerated and made more efficient both in terms of time and money.

In order to adequately characterise new materials, hundreds of samples need to be meticulously analysed. Material scientists may find themselves spending hours in fume hoods and laboratories to produce the necessary sample sizes and then the exploring of the impact of different parameters in the production process may also be too time consuming, which limits then the understanding of the how the materials would behave in an industrial context.

Through the clever use of machines and automation, time-efficiency can be increased. Samples can be produced at higher rates and value ranges in different process parameters can automatically be swept through to find the optimal values. Prototype machinery reveals the bottlenecks in the process and helps to form the requirements for the material in terms of processability. Early detection of these critical factors is valuable information in the development of the material. In many instances processability can be improved through additives or modifiers, which do not adversely affect later material performance in the intended application.

As these new materials are developed and shown to be promising, upscaling and commercialisation becomes topical. If small prototype production lines have already been tested and functional and

Ville Klar

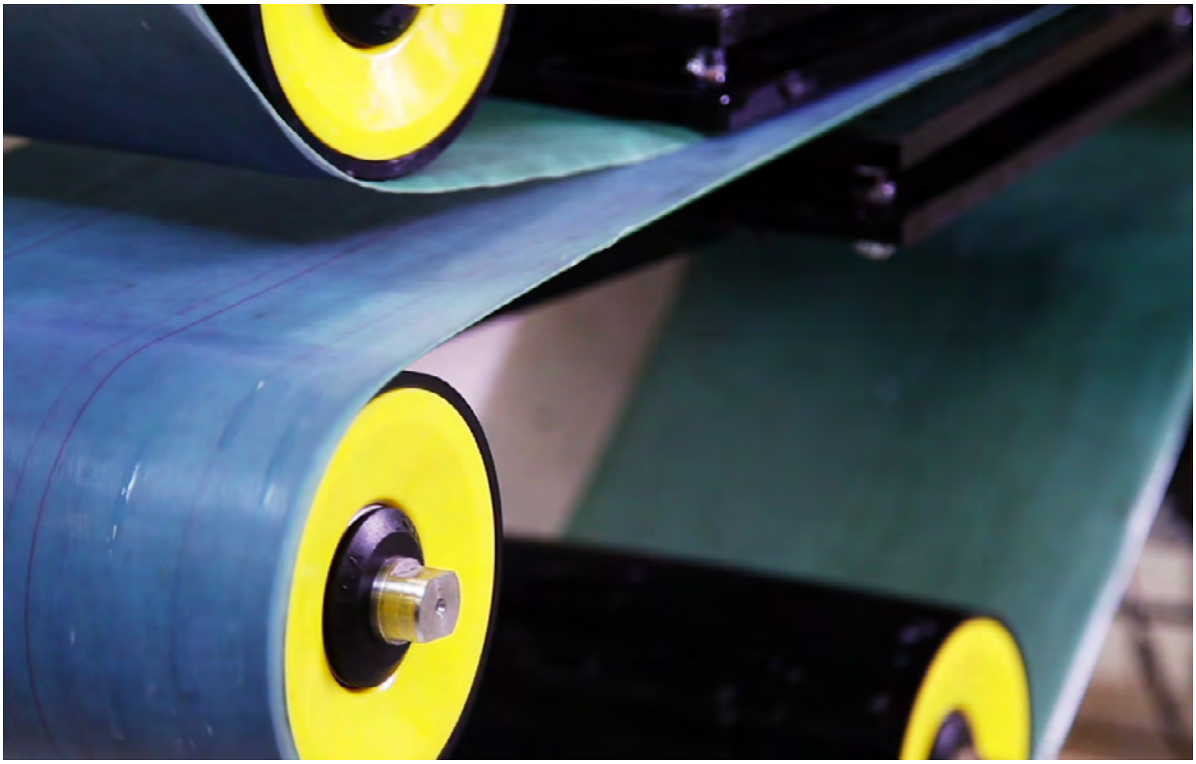
Continuous production of nanocellulose filaments.

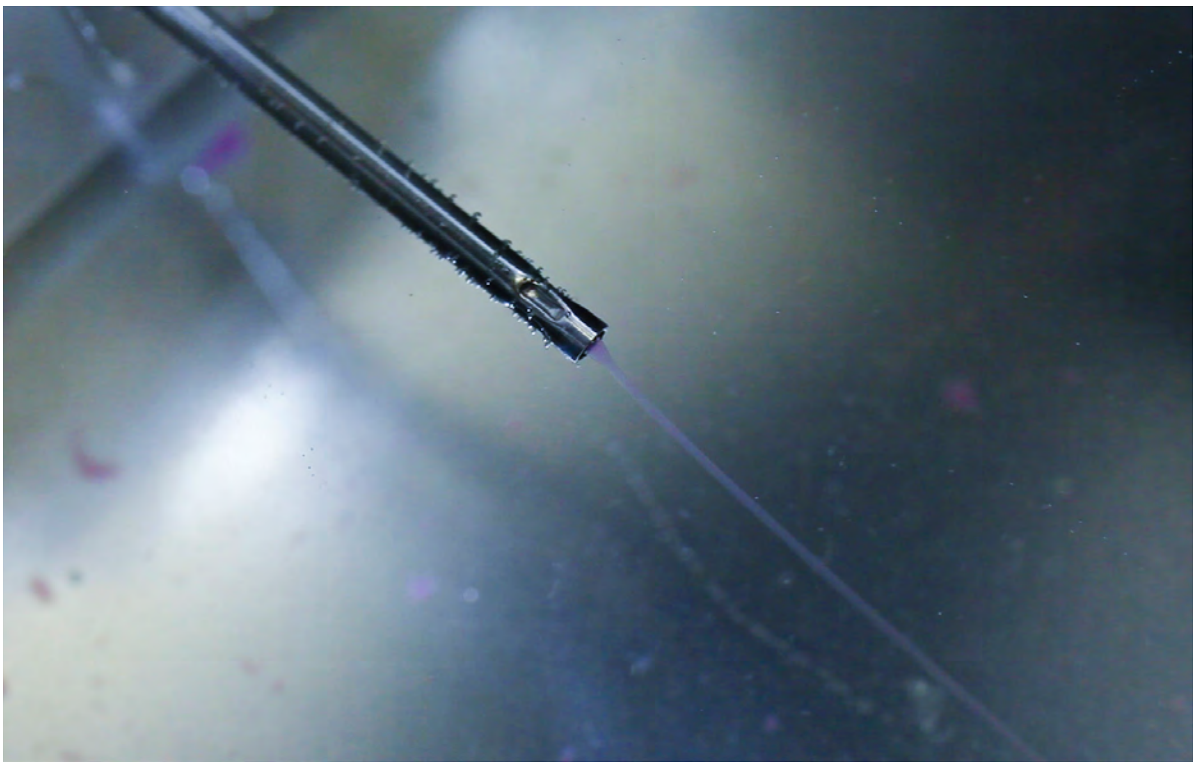
nonfunctional techniques identified, the transition from fume hood to pilot line is considerably smoother. More time can be allocated to important or challenging sections in the process and there are fewer uncertainties that prove costly when outsourcing machine design. The requirements for larger scale machinery do not rely solely on assumptions. Design choices can be made based on quantitative results acquired from early prototypes.

Machine Development in DWoC project

Projects such as the Design Driven Value Chains in the World of Cellulose (DWoC) enable close multidisciplinary collaboration which is essential for innovation and to identify applications where the material properties are fully utilised. New materials can be developed to suit specific user needs and studied efficiently in specific contexts. With the help of new machinery and automation, material scientists can focus on innovation and creative applications instead of sample preparation and laboratory work.

A great example of multidisciplinary collaboration in the DWoC project is the development of spinning lines for producing filament or yarn from native cellulose fibres. Different sections of the spinning lines are developed together through ideation and prototyping. Several approaches and parameters for e.g. coagulation, drying and fibril alignment have been tested, iterated and improved with the help of machinery prototypes. The findings and experimental data acquired from the early machinery prototypes can be used to upscale production and improve yarn/filament properties. Higher quality and increased production capabilities are necessary to test the filaments and yarns in larger structures such as composites, nonwovens and textiles.





When wood-dust is mixed with nanocellulose, the new material can be called 'Casted Wood'. In the future similar material could be used in 3D printing. Various samples have been produced by Heidi Turunen.

Future Vision: 3D Printing Cellulose for Architecture

Heidi Turunen
Architect, Doctoral Candidate
Aalto University, School of Arts, Design and Architecture

Additive manufacturing has been known of since the 1980s and nowadays the technology is well known among designers and industry. This particular manufacturing method, which is also called 3D printing, enables us to transform digitally designed objects into real, tangible items. The product applications of 3D printing could be for example uniquely designed pieces; customised objects or complicated products for small scale mass production. The scale of the printing varies from nanoscale to large-scale pieces produced by gantry based printing units. Business activities in the 3D printing industry are currently mainly related to the manufacturing of components and parts of products, and often focused to serve subcontracting networks for example in the automotive, aviation or medical industries. However, the architecture and construction industries have been awakened to explore the future possibilities of this relatively new production method.

There are several existing 3D printing technologies and each technology has limits concerning source material and size, shape and end-use of the printed object. In addition to commonly known plastics, stone dust, metals and clay, food and tissues are used for bio-printing applications. Some material research projects focus on developing new environmentally friendly materials or in the use of recycled materials. Renewable, recyclable and user-safe materials like cellulose; combined with this emerging production method, have great potential to fulfil the need as a future 3D printing source material for the building sector.

Most architectural 3D printing projects are still at an early stage, though some products; elements and even buildings have been printed successfully. However, with the help of additive manufacturing, new openings and focus points might be possible also in the field of architecture. As there is already a tendency to use digital design and information in construction projects, additive manufacturing offers a prototyping and production method, which adapts easily to the needs of designers. Using this flexible manufacturing method, architects and designers will have new tools to implement novel aesthetics and carefully designed or optimised elements. Totally new product

properties, functional applications or even concepts which are currently completely unknown, might be possible by applying 3D printing directly to end-products. However, here the role of the selected printing material is crucial.

Materials research connected to novel product applications has a great potential to target a more sustainable built environment. The concerns of climate change and resource-wise consumption support a manufacturing method that does not create waste. Wood building is becoming more popular and cellulose-based materials are already used for example in insulation and wallpapers. In the future, these materials could be delivered in a more delicate and refined form through 3D printing. The combination of recently emerged manufacturing methods and the intensive research in cellulose-based materials will enhance future sustainable solutions in the architecture and construction industry.

Wood-dust and nanocellulose balls coloured with mineral pigments are produced by Heidi Turunen.

3D printing of cellulosic materials is still challenging as cellulose usually shrinks when drying. These small experiments are printed out of coloured nanocellulose by multidisciplinary team Anastasia Ivanova, Ville Klar and Pyry Kärki in Aalto University.

Case NoMa
Printable Bio-based Hydrogels

Panu Lahtinen
Senior Scientist
VTT Technical Research Centre of Finland Ltd

Katariina Torvinen
Research Manager
VTT Technical Research Centre of Finland Ltd

NOMA
A research and education project (2015–2017) that applies the existing knowledge of lignocellulosic fibres and their processing to create novel structural fibre foams and biocomposites. A co-operation between VTT, Lahti University of Applied Sciences (LAMK) and various companies, funded by project partners and Tekes.

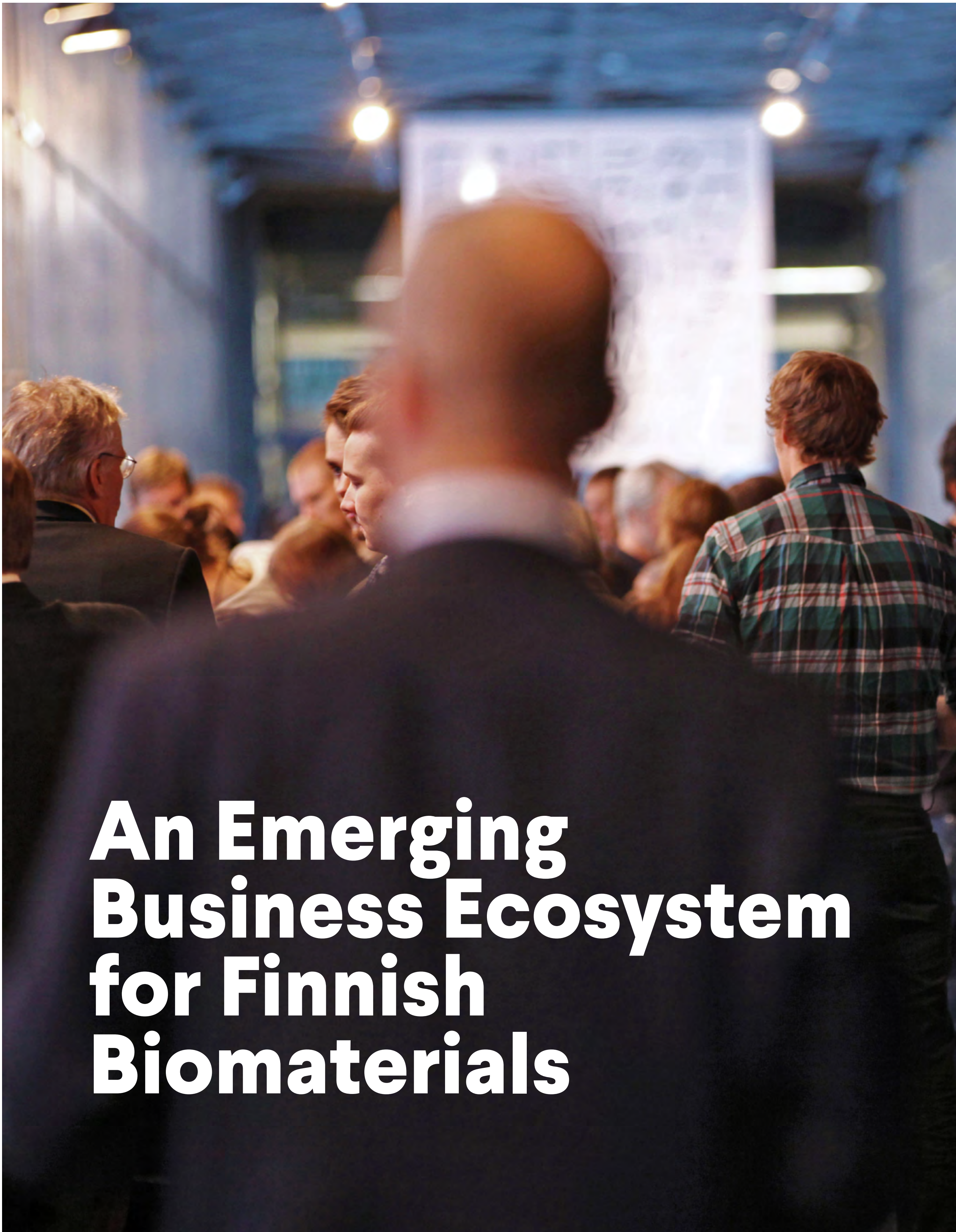
The most common 3D printing materials are thermoplastics, metals, ceramics and more recently, food-based materials. However, there are several opportunities for wood-based materials and other bio-based materials to be more sustainable and biocompatible solutions for future 3D printed applications. VTT, the Technical Research Centre of Finland Ltd, has developed new concepts and materials for the printing of bio-based hydrogels for decorative elements and prototypes. There is also a growing interest in the use of 3D bio-printing for biomedical applications. The novel biomaterial blends can also be attractive alternatives for biomedical applications like artificial bone and tissue engineering.

The goal of the NoMa (*Novel structural materials with multi-scale fibre components*) project has been to develop different material combinations that are strong enough to produce elastic and rigid structures that have good shape fidelity. The printing pastes have been formed with different bio-based ingredients like alginate and cellulose nanofibrils (CNF). CNF material has been used as an ingredient for 3D printing paste due to its superior properties for example, enhancing mechanical strength, rheology modification and biocompatibility. However, its low dry solids content usually needs to be compensated for and in this case study this has been done by using inorganic fillers and non-volatile components in material mixtures. The common challenges in the printing of bio-based hydrogels are shrinkage during drying and the collapsing of printed structures. The NoMa-project results show that by increasing the share of non-volatile components and by using an effective strength additive like CNF, we can avoid the collapsing and shrinkage in bio-based printing pastes.

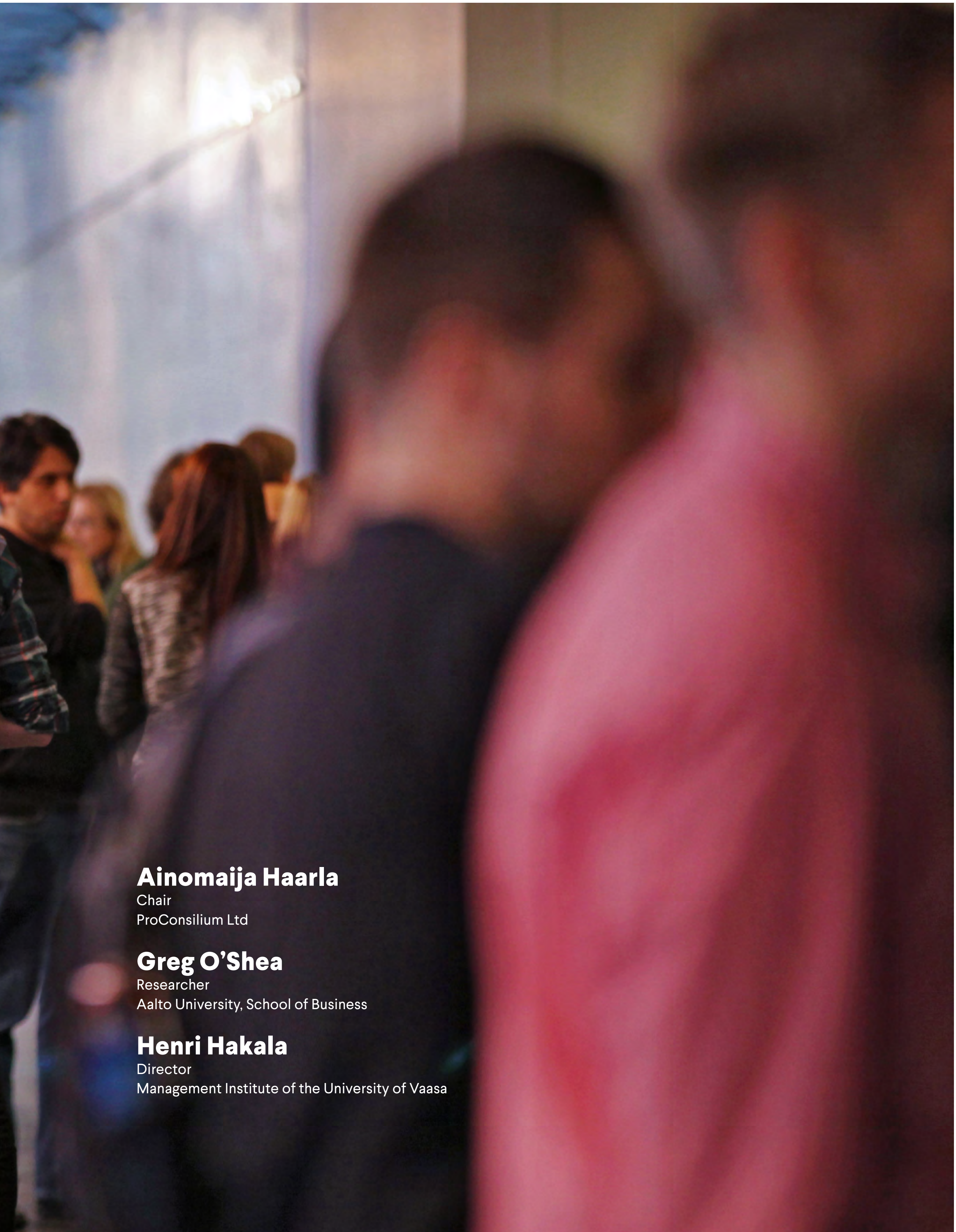
Biocomposites are made of polylactic acid PLA and Finnish hemp by VTT material researchers and Panu Isokangas Ltd.

The material for 3D printed green birch leaf is bio-based hydrogel. It has been produced in NoMa project by Susanna Kettunen from Lahti University of Applied Sciences in collaboration with VTT material researchers.

Ainomaija Haarla, Henri Hakala & Gregory O'Shea



An Emerging Business Ecosystem for Finnish Biomaterials



Ainomaija Haarla
Chair
ProConsilium Ltd

Greg O’Shea
Researcher
Aalto University, School of Business

Henri Hakala
Director
Management Institute of the University of Vaasa

Ainomaija Haarla, Henri Hakala & Gregory O'Shea

Finnish trees are presently growing faster than they are used. Traditionally, many companies in the forestry sector have focused on producing printing paper and simple raw materials for the construction industry. However, the emergence of an electronic media has decreased the demand for printing paper worldwide, while e-commerce has contributed towards increasing demand for packaging materials.

Ainomaija Haarla

Greg O'Shea

The long history of a wood based economy has bequeathed to Finland a high level of both technology and knowledge in wood processing and favourably shaped a willingness to utilise the wood resources in a sustainable manner. The need for traditional wood and paper products is not going to disappear any day soon, but awareness of the need for strategic change and exploration of new, additional and sustainable ways to produce wealth from the forests has begun. Consumer attitudes have been moving positively towards ecological solutions, away from oil-based products. As an example the use of traditional plastic bags will be forbidden in many European countries and alternative products are already being launched and taking hold in markets. In this regard the Finnish company Paptic has a range of plastic replacing applications, such as carrier bags and flexible packaging based on a new wood-fibre based material, which combines the recyclability and renewability of paper, with the functionality of plastic. Retail chains and materials manufacturers are also searching for more ecologically friendly materials to replace cotton because of cotton's huge drain on water resources.

The need for ecological solutions is a global megatrend and a massive opportunity for Finland. This is because we really can create sustainable super materials from wood. Finnish knowledge in wood chemistry and continuing investment in the development of new technologies that better utilise the different components that can be extracted from wood puts us in a good position to be a global leader in the new era of wood processing. The new wood based materials already developed have significant technical advantages. Fire retardancy, lightness, hardness, durability, foldability and above all, sustainability, will be important features of new wood based materials that allow them to be an alternative to materials like cotton and plastic. Finland also has designers who are willing to experiment with these new renewable, recyclable and ecological materials. There are multiple elements in place to create a convincing story and conditions to develop many things that are novel and valuable.

Research, development and technological exploration are key issues for the renewal of businesses, but do not alone guarantee business success. In order to take advantage of these megatrends, complex value networks linked to our new biomaterial innovations need to be created and a viable business ecosystem developed. With business ecosystems, we mean structures of interdependent firms that are intentionally formed to accomplish a purpose. The ecosystem view stresses the importance of collaboration between firms. This is crucial, since individual firms often do not have the capabilities and resources to create complete systems, but, by utilising 'network resources', entirely new value systems can emerge. Such an ecosystem is viable, if it is capable of surviving in a given environment and if it is able to respond to unexpected future changes in that environment. But how to build such an ecosystem around the new wood based materials?

Viable business ecosystems

One possible way to look at the construction of a viable business ecosystem is to evaluate it against the Viable System Model (VSM), developed by Stafford Beer for understanding the performance of man-made systems on the basis of natural ecosystems. The idea proposes that any viable system needs five distinct, but interrelated elements, that communicate effectively with each other: strategy, coordination, control, development and production. The VSM is particularly suitable for analysing the sets of problems that our ecosystem faces, as the actors in our system are fairly unitary in their values, but the context is complex and the problems therefore difficult.

Henri Hakala

Strategy, in this respect, is concerned with the ecosystems' place and direction in the wider world. We need to have a shared understanding of where we are going and how we will go there. The role of shared strategy and values is much greater in ecosystems than in traditional forms of organisation. In a network of independent organisations, the members do not have to accept how the system will be controlled, coordinated and developed, but they will accept it, if they mutually share a deep understanding, strong values and common strategy.

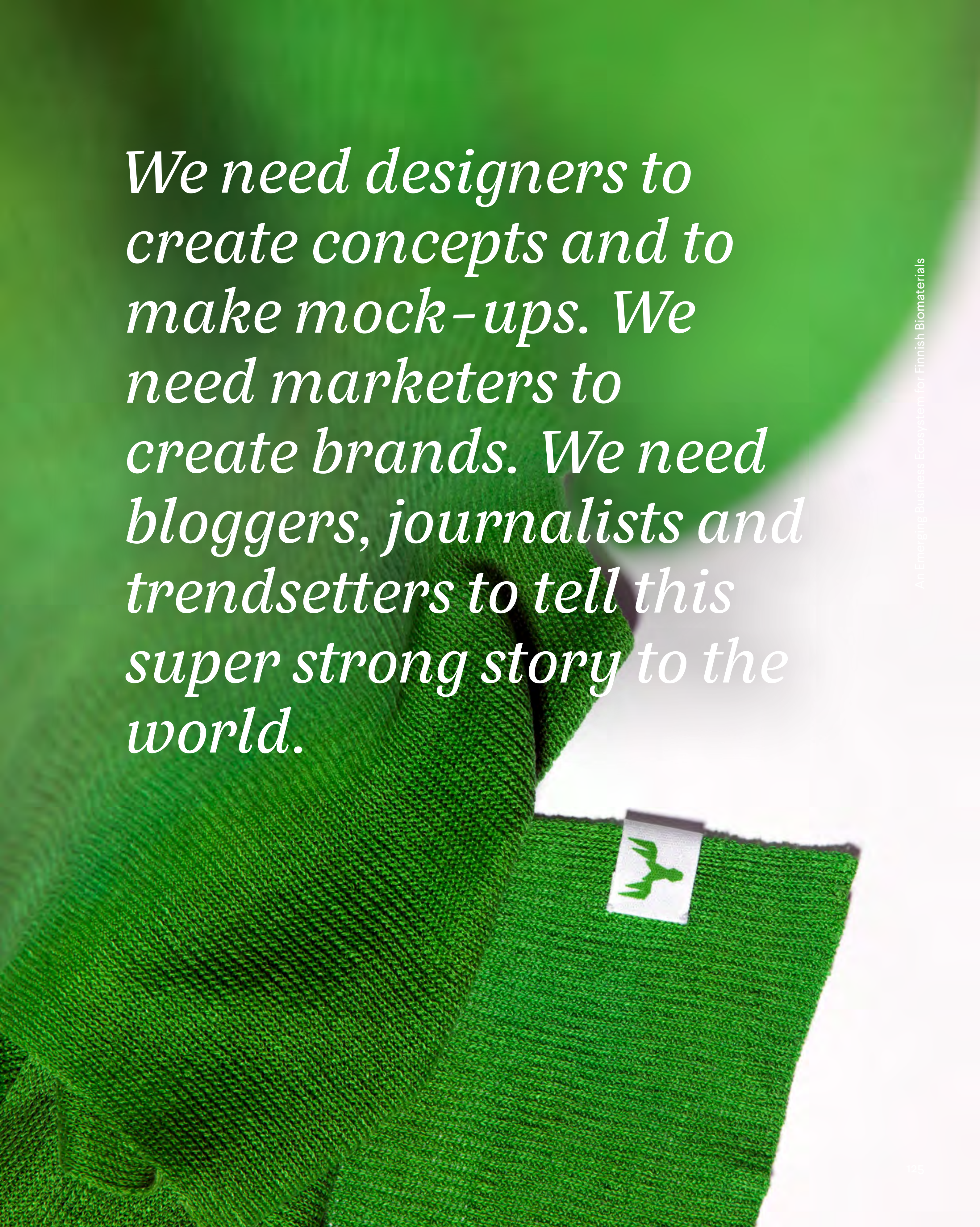
Hence, it is important that the strategy is representative of the key ecosystem actors, not just those formally leading it, but also that it is tuned together with key stakeholders. Going forward the ecosystem also needs a process for co-creation between various partners and spaces, both physical and virtual, that will allow for 'accidental' emergence of breakthrough ideas in products, services and business models. On top of stakeholder involvement, the ecosystem needs to build more public awareness, and more interaction and commitment from all stakeholders within Finnish society.

In a viable ecosystem, guidelines for coordination and control are derived from the shared strategy, and may hence be arranged very differently in different ecosystems. Sometimes one firm may be the "hub-firm", a leading firm that controls most of the activity in the ecosystem, while at other times the control might be much more equally distributed between the members of the ecosystem, creating a much more self-organising system.

Our cellulose ecosystem is in its early stages of development and at this point in time it is a self-organised 'community of exploration". It could be that for future development, towards a 'community of business", we need the presence of strong hub firms that will coordinate and control how the ecosystem works through market relations and more formal partnerships.

Development activities are concerned with analysing the future state of the environment, research and development, market research and strategic planning. One of the greatest challenges for the development element of the viable system is to filter the relevant information about an unknown future. Assuming that the future may not be a logical continuation of the past, this development activity needs to have some sort of criteria for deciding what will be relevant for the ecosystem in the future. For example in the DWoC project,development activities are an essential and visible part of how the new ecosystem is emerging through the research work of VTT and of the university partners, Aalto University, Tampere University of

Knitted Ioncell-F scarf produced for Metsä Fibre by multidisciplinary team from Aalto University



We need designers to create concepts and to make mock-ups. We need marketers to create brands. We need bloggers, journalists and trendsetters to tell this super strong story to the world.

Technology and the University of Vaasa. It is critical that researchers and scientists continue to increase their understanding of raw materials, raw material combinations and material processing and production, as this will provide an important platform from which new businesses can grow.

Finally, the production of things, whether they are products or services, material or immaterial, is at the core of the ecosystem. Simply put, someone needs to do something. Any one ecosystem can have an infinite number of implementation and production units, and usually it is the task of the entrepreneur to organise the production activity. Luckily we already have most of the fundamentals in place. Finland has effective and efficient systems for harvesting the wood from the forests, transporting the wood to cellulose mills and turning the wood into pulp suitable for producing paper, cardboard etc. Thereafter, we lack scalable new business models and our new ecosystem is lacking production units that would take the development of wood fibres into new directions by commercialising the innovations. Innovations in how to develop wood fibres into new materials are emerging from the laboratories of scientists, but the actors organising the commercial scale production of these new materials are often missing and it is against this background that we need to see the next and most important set of actions.

Entrepreneurial ecosystem

We already have consumers who value and look for ecological solutions. Now we need a broad network of various actors in the forestry and wood materials sector and then raw material suppliers and producers, who can reliably provide small (and eventually large) volumes for experimenting and piloting (and eventually full production and manufacture). This will allow for more agile product development and shorter lead times to test concepts and products in the market. We need designers to create concepts and to make mock-ups. We need marketers to create brands. We need bloggers, journalists and trendsetters to tell this super strong story to the world. We need promoters such as architects and designers who understand the value of wood raw material and the advantages it can offer. We need investors with deep pockets who believe passionately in the potential of wood raw material and are ready to support a new, global, enlightened industry.

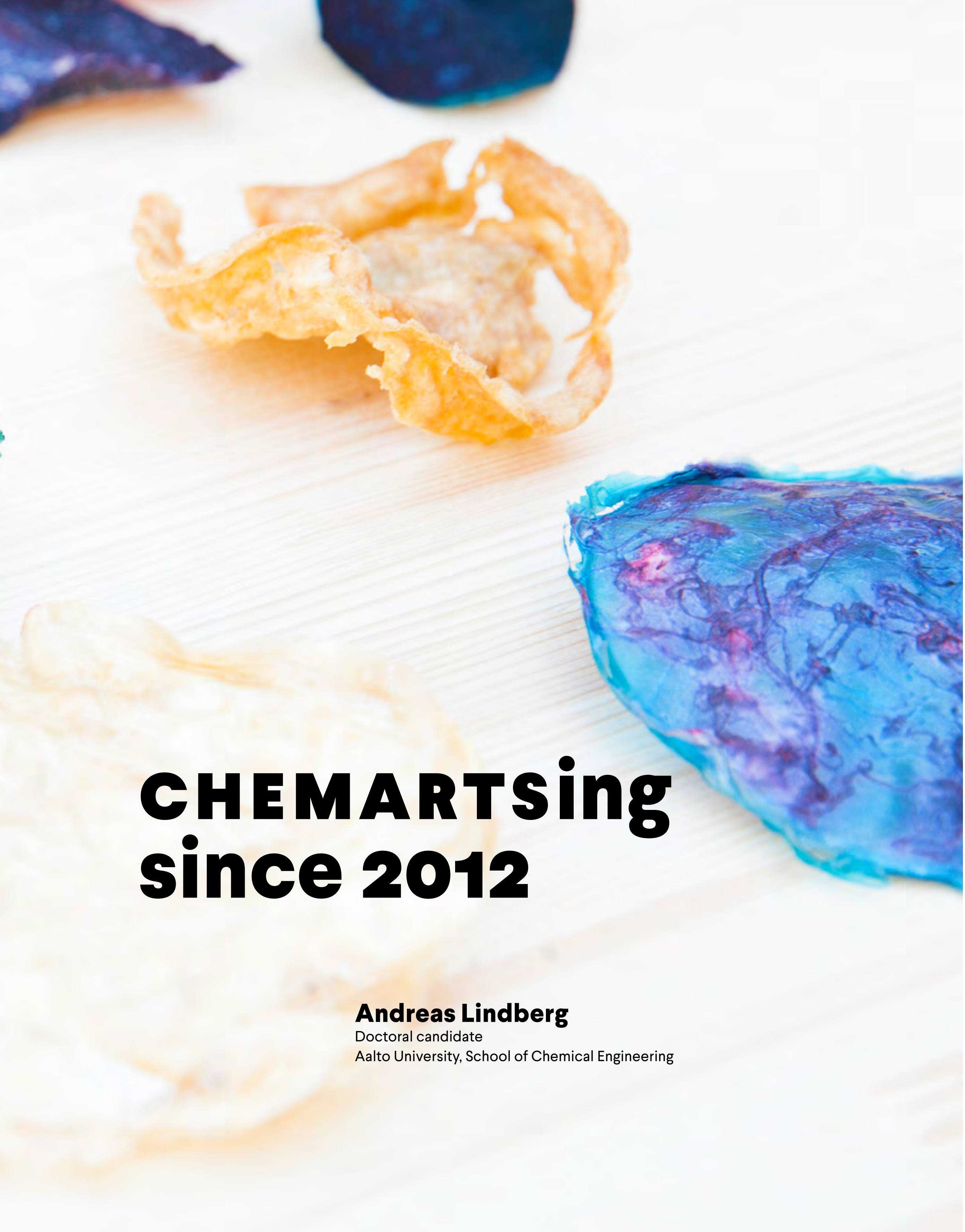
Above all, in all of this, we need skillful, ambitious and brave entrepreneurs.

'Designing Cellulose for the Future II' seminar and exhibition 2016.

Paptic's carrier bags are produced out of a new wood-fibre based material. www.paptic.fi

NOTES FROM THE JOURNEY LOG

Experimental biomaterial samples by CHEMARTS students.



CHEMARTSing since 2012

Andreas Lindberg
Doctoral candidate
Aalto University, School of Chemical Engineering

Andreas Lindberg

My personal journey from a CHEMARTS student to a CHEMARTS tutor has been a truly interesting one. I was fortunate enough to take part in the inaugural CHEMARTS summer school in the summer of 2012. Multidisciplinary collaboration was a completely new term to me as I was a somewhat traditional engineering student with a fairly technical and science driven approach. Nevertheless I was more than excited when I learned about the possibility to take part in this completely new venture between the two schools of Aalto CHEM and Aalto ARTS.

Andreas Lindberg

I can honestly say that after the introductory CHEMARTS summer I was a changed man. I was inspired by the seemingly limitless potential of such a multidisciplinary collaboration and perhaps most of all I was excited of at how well our summer project was received within the Aalto community – there was genuine excitement in the air about the future of cellulose.

The fundamental change that the CHEMARTS collaboration had in me was the courage to curiously and fearlessly seek out new solutions outside of my own comfort zone and also outside my own scope of knowledge. I learned to keep an open mind and identified the necessity to always pursue new possibilities and applications for cellulose and other forest based biomaterials.

After spending some time in the Finnish forest industry as an engineer I desperately wanted to return back to my CHEMARTS roots in Aalto University. The seeds planted in the first CHEMARTS summer project had sprung into a fully-fledged research program combining state-of-the-art cellulose sciences with advanced design practices.

As a PhD student within the CHEMARTS community I'm fortunate enough to work with an incredible diverse group of people, witness the ideology of CHEMARTS evolve further and through the work that we do to reach out to new people with fresh perspectives. Scientists and designers alike are again excited about the countless possibilities of cellulose.

Coloured bacterial cellulose paintings grown by Matilda Tuure, CHEMARTS Summer School 2016.

Future of Textile Materials

Matilda Tuure
CHEMARTS student 2016
Aalto University, School of Arts, Design and Architecture

Coloured bacterial cellulose.

What can happen in 20 years? In 1996 I was 10 years old. I have been sitting in the front row watching the technology revolution happen. Around 1997 I was taking my first steps in the World Wide Web, when MMMbop was playing everywhere, I typed the first web page address I ever visited www.hanson.com and it was amazing! So many things have changed since those days. Our everyday life is not the same anymore; smartphones, Internet everywhere, the world getting smaller and smaller, our days are full of information, both useful and useless. There are days when I'm thinking that we already have it all, what more could we need, but the world is not listening to me. New technology is running over me, 3D printing, flexible touch screens, even smarter devices measuring my every step, breath, sleep, calories, stress levels and giving me advice on how I could live an even better life. Our world is running fast and I just have to keep running with it.

When I think about the word material, it means only textiles to me. This is the first time that I have actually stopped to think how narrow my point of view really is. And when I'm saying textiles, I mean functional or smart textiles, sport textiles, laminated textiles, and breathable or recycled textiles. Oh, now I'm in a trouble. How to even think about the future of materials when there are MILLIONS of materials in the world. And it is not just that; now we are at a breaking point in materials development, probably everything will be totally different in the future.

I truly believe that all kinds of materials will be more sustainable and ecological in the future. As a fashion designer it is easy to think like this as the fashion industry has been under the microscope for such a long time. Piles of textile waste, toxic chemicals, bad working conditions, child labour… I remember that around 1996 it was kind of cool when your Barbie dolls came from Malaysia, China or Cambodia. It's not cool anymore. I don't believe that we can move industry back to western countries, but we can consider our material choices, production and manufacturing processes, we can use less water and toxics and we can take better care of the nature around us, and of course offer a safer working environment for factory workers.

So what might the future bring us?

Recycled and recyclable materials are already quite common nowadays. I personally believe that in the clothing field different kinds of non-woven materials will be a huge opportunity to make garments in a new way. We might be able to grow our own clothes through bacteria or fungus. Or clothes could also be made with moulds and liquid materials. At the moment, all kinds of smart technology, chemicals and particles can be attached at a later stage to our present fabrics but in the future the fabric material can be smart and intelligent by itself. Maybe we will go so far that materials will have their own DNA just as they now have fibres.

During the next twenty years, 3D printing will take a bigger role in production and easy-to-use home printers will be more common. Using open source services it will be possible to download and print objects without any specific education or knowledge. That will boost material improvements and innovation in filaments and other 3D printable materials. The first steps in that direction are printable wood and ceramics. However, flexible nice-to-wear materials are much more complicated to print than cups and hard spare parts.

For sure in the future there will be printed textiles that remind us of woven fabrics, fleece, or mesh, but there is still a long way to go to make printed fabrics actually better than the fabrics that we have now. When that happens, our production chain will change dramatically, because we can then produce just the items that we 'pre-order'. No more mass production, big seasonal sales and clothes that no one will buy!

In 2035 we might use more local materials. We could replace some of our cotton consumption with plants growing here in the northern countries, for example with nettle or hemp. Why should I wear a shirt made of bamboo when bamboo is not growing nearby? It could be useful to find new materials so that we are not always robbing poor countries and destroying their nature. We should expand our knowledge of the local possibilities that we could have. That could also support the local economy and improve the whole production chain, because we will not be ready to destroy our own surroundings in the same way we as we are destroying others'.

These thoughts might be impossible to execute before the year 2035. Each of them would make our ways to consume and produce smarter and more sustainable. And every single step towards them will make a difference in the end.

This fabric can be called 'Woven wood'. It is made of new Spinnova fibre yarn mixed with cotton and produced by Justus Kantokoski 2017 at Aalto ARTS. www.spinnova.fi

Cellulose-based material samples made by Tiina Härkäsalmi.

Material World 2035

Suvi Kyyrö
CHEMARTS student 2016
Aalto University, School of Chemical Engineering

We live in a consumer society in which the quantity of goods produced, consumed and destroyed is more than the planet can bear. The direct and indirect effects are numerous – increase of cheap labour, exploitation of sweatshop workers, growth in the gap in income and living standards between rich and poor, depletion of biodiversity and natural resources, pollution of the environment and disasters caused by climate change such as floods and hurricanes. Unfortunately, the first victims of overconsumption have been, and will continue to be, those with the least opportunities to have an impact on current developments: the poor and populations in developing countries. There are therefore many problems, and there are no magical fix-all solutions on offer. I myself believe that achieving change requires both a fundamental shift away from a consumer culture and also new kinds of sustainable solutions from experts in a variety of fields.

In the best possible scenario, it would be possible to replace the majority of oil-based materials and scarce metals with ecologically more sustainable alternatives within the next twenty years. Although it will be possible in the future to produce electricity with solar energy and wind power, new alternatives also need to be found to replace the chemicals and materials currently obtained from oil. Sustainable alternatives also include simple material recycling and products produced from renewable natural resources. Over the last years, Finland has invested more resources into sustainable development. The bioproduct mill constructed at Äänekoski uses raw materials as diversely as possible, which will hopefully inspire the construction of future biorefineries.

The bioproduct mill concept involves making use of a raw material in its entirety and offering new opportunities for replacing ecologically unsustainable products with new alternatives. In the process of refining the raw materials, different kinds of secondary flows are produced. We will be learning over the next twenty years how to utilise these flows more and more effectively. For example, a lot of lobster shells are produced as a by-product of food production. These shells contain chitin, which thanks to nanotechnology can be used in the future in areas such as medicine, cell technology, paints, coatings, and biosensors.

The optimal situation would be that by 2035 we would be living in a world in which natural resources can be utilised sustainably and in such a way that those in developing countries would also get to benefit from the new innovations. Bioproduct mills are exemplary forerunners in bringing about this kind of development.

Glossary

3D PRINTING
Additive manufacturing method that enables transforming digitally designed objects into real tangible items.

AALTO UNIVERSITY
A Finnish university, bringing together various fields from business to engineering and design. www.aalto.fi

AALTO ARTS
Aalto University School of Arts, Design and Architecture

AALTO BIZ
Aalto University School of Business

AALTO CHEM
Aalto University School of Chemical Engineering

AALTO ENG
Aalto University School of Engineering

AALTO SCI
Aalto University School of Science

AALTO ELEC
Aalto University School of Electrical Engineering

ALGINATE
An anionic polysaccharide distributed widely in the cell walls of brown algae, where through binding with water it forms a viscous gum.

ARABINOSE
A monosaccharide with five carbon atoms, found in nature in hemicellulose and pectins.

ASSOCIATIVE MATERIAL QUALITY
Typically culturally dependent on the view of individuals and society toward material properties.

BIODEGRADATION
Material degradation taking place in biological environment, e.g. in soil or water.

BIOECONOMY
An economy which utilises the biological natural resources and turns them into food, energy, and other products and services. It is characterized by the use of clean technologies which save the environment and by efficient recycling of materials.
www.biotalous.fi

BIOSYNTHESIS
An enzyme-catalysed process, where substrates are converted into complex products in living organisms. In trees, it involves the biosynthesis of its various components, including lignin, cellulose and hemicellulose.

DWOC
Design Driven Value Chains in the World of Cellulose (2013–2018), a multidisciplinary research project aiming for cellulose material innovations.
www.cellulosefromfinland.fi

CELLULOSE
The most abundant polymer in the world. One of the three main chemical components of wood, two others being hemicellulose and lignin.

CELLULOSEFROMFINLAND.FI
A website that showcases cellulose-based multidisciplinary materials research, projects and information.

CELLULOSE NANOFIBRILS (CNF)
Nano-scale cellulose fibrils, manufactured by mechanical treatments, for example grinding, homogenisation or microfluidisation, often combined with enzymatic or chemical pre-treatment.

CELLULOSE NANOCRYSTALS (CNC)
Nano-scale cellulose crystals, produced by acid hydrolysis, breaking the amorphous regions of the cellulose fibrils.

CELLULOSE NANOMATERIALS (CN)
Due to their unique, nano-specific properties, such as small size, high aspect ratio (length / width ratio), large specific surface area, high strength and stiffness, gelation and shear thinning behaviour, the liquid crystalline behaviour of CNC, reactive surface, inherent film formation tendency etc. cellulose nanomaterials have many potential application areas.

CHEMARTS
A long-term collaboration since 2011 between two Aalto University schools, The School of Chemical Engineering (CHEM) and The School of Arts, Design and Architecture (ARTS). CHEMARTS focuses on biomaterials, especially on wood-based cellulose. It consists of interdisciplinary study courses and workshops, events and exhibitions.
chemarts.aalto.fi

CHEMARTSING
A verb created by Tino Koponen to describe the special way of working in the CHEMARTS courses.

CHEMICAL RECYCLING OF TEXTILE FIBRES
Recycling as polymers by disintegration of textile fibres into polymer (or into monomer) level and rebuilding new fibres.

CIRCULAR ECONOMY
An industrial economy, where the aim is to reduce waste and pollution by designing material flows in a circular manner. A contrast to linear economy.

CN FILM
Cellulose nanomaterial film, transparent or translucent film. made of nano-scale cellulose materials.

COMPOSITE
A material made of two or more materials with different chemical or physical properties. Resulting composite material's characteristics differ from its original material components.

FILAMENT
Continuous textile fibre that is often cut in staple fibres for yarn production. Synthetic filaments and silk are also used as such in textile production.

FOAM FORMING
A process where a structure is formed from fibres and other raw materials suspended in wet foam.

GELATION
Solidification by freezing.

HEMICELLULOSE
One of the three main chemical components of wood, two others being cellulose and lignin.

IONCELL-F
New technology to produce cellulosic textile fibres out of pulp, paper, cardboard or cotton waste. It is based on research performed at Aalto University and the University of Helsinki. www.ioncell.fi

ITERATIVE PROTOTYPING
A cyclic process of testing and analysing the prototypes and improving the outcome step by step.

LIGNIN
One of the three main chemical components of wood, two others being cellulose and hemicellulose.

MECHANICAL RECYCLING OF TEXTILE FIBRES
Recycling as fibres by disintegration of used textile mechanically into fibres that can be used to produce new materials.

NON-WOVEN FABRIC
A planar structure of fibres or filaments bonded together mechanically, thermally or chemically.

PACK-AGE
A packaging design course and minor programme between Aalto ARTS, Aalto BIZ, Aalto CHEM, Lahti University of Applied Sciences LAMK and Helsinki University.

PERCEPTUAL MATERIAL QUALITY
How materials are experienced and perceived by the five senses.

POLYMER
A molecule which consists of small repeating building blocks called monomers. In the case of cellulose, the repeating building blocks are single units of glucose (sugar). / Andreas Lindberg, Aalto University

POST-CONSUMER TEXTILES
Textiles that have been used and discarded by consumers.

PRE-CONSUMER TEXTILE WASTE
Textile waste produced in manufacturing, e.g. cutting waste from garment factories.

PULP, PULPING PROCESS
Pulp is obtained from wood (and also from non-wood raw materials, such as annual plants) by the pulping process, aiming to separate the different wood components. Usually, the target is to separate lignin from cellulose, but there are also lignin-preserving pulping methods, e.g. mechanical pulping. The most common use for pulps is papermaking.

REACTIVE DYES
Water soluble dyestuffs that form strong co-valent bond with the cellulosic fibre.

RECYCLABLE MATERIALS
Able to be processed through a system again for further treatment or use.

RECYCLING
Unused or waste materials being reused or transformed into new materials and objects.

RENEWABLE RAW MATERIALS
Relating to a natural resource, such as solar energy, water, or wood, that is never used up or that can be replaced by new growth.

RHAMNOSE
A monosaccharide with five carbon atoms in the ring structure and one methyl group, commonly bound to other sugars in nature.

SHEAR THINNING
Dispersions become running under stress when e.g. mixed with adequate force.

TECHNICAL MATERIAL QUALITY
Refers to measurable material characteristics.

TEKES
The Finnish Funding Agency for Innovation.

VIABLE SYSTEM MODEL (VSM)
System developed by Stafford Beer (1972) for understanding the performance of man-made systems on the basis of natural eco-systems. The idea proposes that any viable system needs five distinct, but interrelated elements that communicate effectively with each other: strategy, coordination, control, development and production.

VTT
VTT Technical Research Centre of Finland Ltd (Est. 1942) is a research and technology company.

WOOD CELL
The basic unit of the wood structure, plant cell.

XYLOSE
Sugar derived from hemicellulose. Monosaccharide containing five carbon atoms, i.e. pentose.

Index

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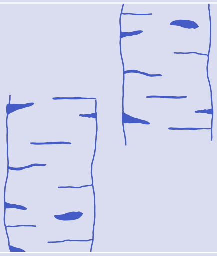
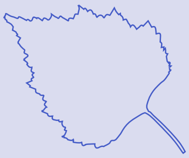
The printing of this book generated 3,670 kg of CO_2. All emissions have been completely offset by contributing to forest protection in Kasigau Wildlife Corridor, Kenya.

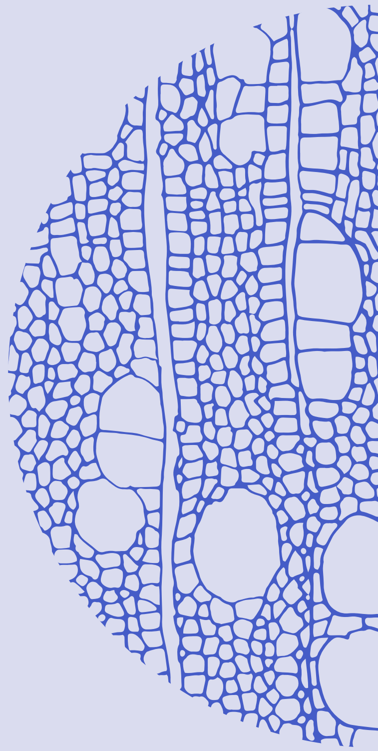


The pale endpapers resemble the silky and luminous skin of birch bark in the spring.

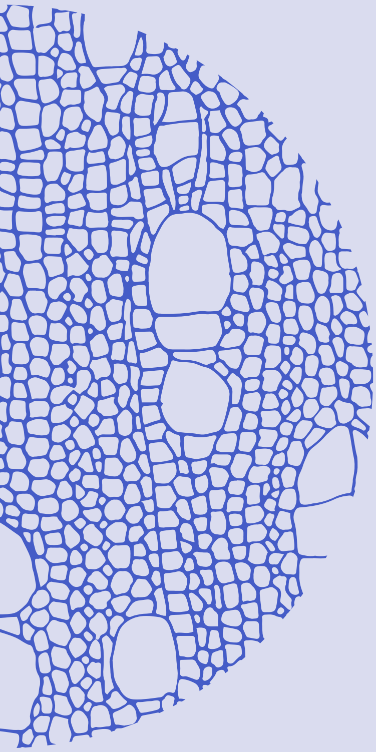


The translucent endpapers are inspired by the newborn green of spring leaves.

LumiSilk, the printed paper stock is manufactured in the northern city of Oulu by Stora Enso Paper.



CHEMARTS.AALTO.FI
CELLULOSEFROMFINLAND.FI



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EDITORS
Pirjo Kääriäinen & Liisa Tervinen

WRITERS
Ainomaija Haarla, Henri Hakala, Ernesto Hartikainen, Pirjo Heikkilä, Ulla Häggblom, Tiina Härkäsalmi, Markus Joutsela, Heli Kangas, Kirsi Kataja, Jukka Ketoja, Ville Klar, Suvi Kyyrö, Pirjo Kääriäinen, Panu Lahtinen, Andreas Lindberg, Kirsi Niinimäki, Greg O'Shea, Nani Pajunen, Carlos Peralta, Eveliina Pokela, Markku Remes, Anna Salminen, Riitta Silvennoinen, Eugenia Smirnova, Marjaana Tanttu, Liisa Tervinen, Katariina Torvinen, Heidi Turunen, Matilda Tuure & Tapani Vuorinen

PHOTOGRAPHER
Eeva Suorlahti

PRODUCER
Sanna Tyyri-Pohjonen / Aalto ARTS Books

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Lingsoft Language Services Oy
Greg O'Shea

GRAPHIC DESIGN
Safa Hovinen / Merkitys

TYPEFACES
Silva (Daniel Sabino)
Larsseit (Nico Inosanto)

MATERIALS
Geltex Reflejos Dorado Pearl 125 g/m²
Curious Translucents Spring 100 g/m²
LumiSilk 150 g/m²

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In this visually enchanting book, top science, business and design professionals give a good glimpse of the emerging New Biomateriality movement in Finland. How could Finnish natural resources, renewable biomaterials – such as cellulose – replace oil-based resources and how could we create new business and service models for society through design and collaboration? Inspiring cases and stories by researchers working with biomaterials suggest how a more sustainable future could be achieved.

Aalto-C 9/2017

Editors

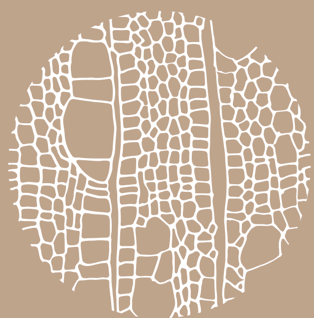
PIRJO KÄÄRIÄINEN is a designer and CHEMARTS facilitator, with roots in the Finnish forest and work experience in textile industry and in higher education.

LIISA TERVINEN is a designer and producer, who has worked in a variety of fields of new media, craft, design and biomaterials.

Photos

EEVA SUORLAHTI is a designer and photographer who is working among visual research, fine art and communication through pictures and materials.

CHEMARTS



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