Recent Advances in the Development of Wood- and Cellulose- Based Materials

Bo Kasal, Fraunhofer WKI Braunschweig, Germany
PELICE,
CNN Center Atlanta, GA, USA
April 14, 2018

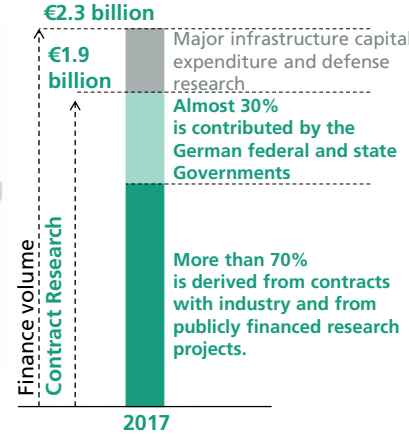
Fraunhofer WKI

The Fraunhofer-Gesellschaft at a Glance

The Fraunhofer-Gesellschaft undertakes applied research of direct utility to private and public enterprise and of wide benefit to society.

24,500 staff

72 institutes and research units



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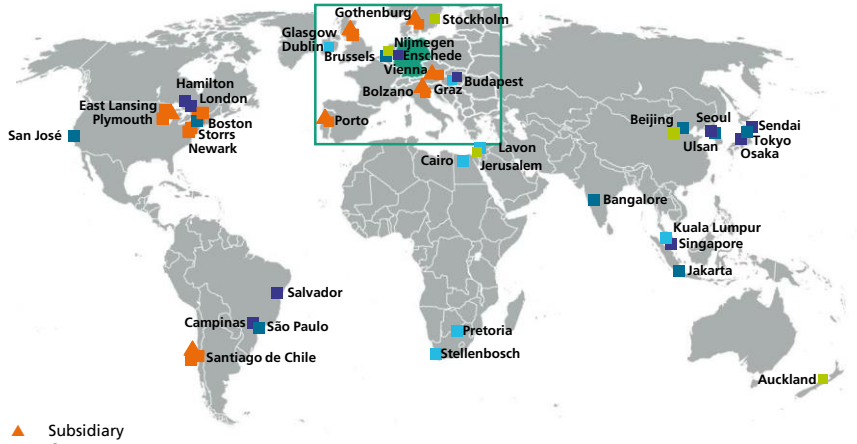
Fraunhofer Worldwide



- Subsidiary
- Center
- Project Center
- ICON / Strategic cooperation
- Representative / Marketing Office
- Senior Advisor

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Fraunhofer USA

Company

Headquarters: Plymouth, Michigan
Date of incorporation: 09/14/1994
Non-profit 501(c)(3) organization

Revenues

$41 Million total Contract Revenue

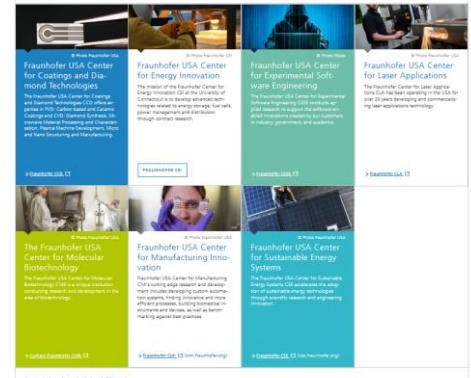
Customers

300+ active projects
64% US Industry projects
24% US Government projects
8% International projects
4% Internally funded projects

University Partners

Michigan State University
Boston University
University of Maryland
University of Delaware
University of Connecticut

Fraunhofer USA Centers



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Fraunhofer fields of research

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Fraunhofer Groups

Innovation Research

IAO, ISI, INT, IMW

Microelectronics

EMFT, ENAS, FHR, HHI, IAF, IIS, IISB, IMS, IPMS, ISIT, IZM
Gäste: AISEC, ESK, FOKUS, IDMT, IKTS, IMWS, IZFP

Information and Communication Technology

AISEC, ESK, FIT, FKIE, FOKUS, IAIS, IDMT, IESE, IGD, IOSB, ISST, ITWM, IVI, MEVIS, SCAI, SIT
Gäste: HHI, IIS, IAO

Production

IEM, IFF, IML, IPA, IPK, IPT, IWU, UMSICHT
Gast: IMW

Life Sciences

EMB, IBMT, IGB, IME, ITEM, IVV, IZI

Defense and Security VVS

EMI, FHR, FKIE, IAF, ICT, INT, IOSB
Gäste: HHI, IIS, ISI

Light & Surfaces

FEP, ILT, IOF, IPM, IST, IWS

Materials and Components – MATERIALS

EMI, IAP, IBP, ICT, IFAM, IKTS, IMWS, ISC, ISE, IWES, IWM, IZFP, LBF, **WKI**
Gäste: IGB, ITWM, ISI

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Pooling expertise
Fraunhofer Alliances

The Fraunhofer Alliances facilitate customer access to the services and research results of the Fraunhofer-Gesellschaft. Common points of contact for groups of institutes active in related fields provide expert advice on complex issues and coordinate the development of appropriate solutions.

- Adaptronics
- Additive Manufacturing
- AdvanCer
- Ambient Assisted Living
- AutoMOBILE Production
- Battery
- Big Data
- **Building Innovation**
- Cleaning Technology
- Cloud Computing
- Digital Media
- Embedded Systems
- Energy
- Food Chain Management
- Lightweight Structures
- Nanotechnology
- Photocatalysis
- Polymer Surfaces
- Simulation
- Space
- **Technical Textiles**
- Traffic and Transportation
- Vision
- Water Systems (SysWasser)

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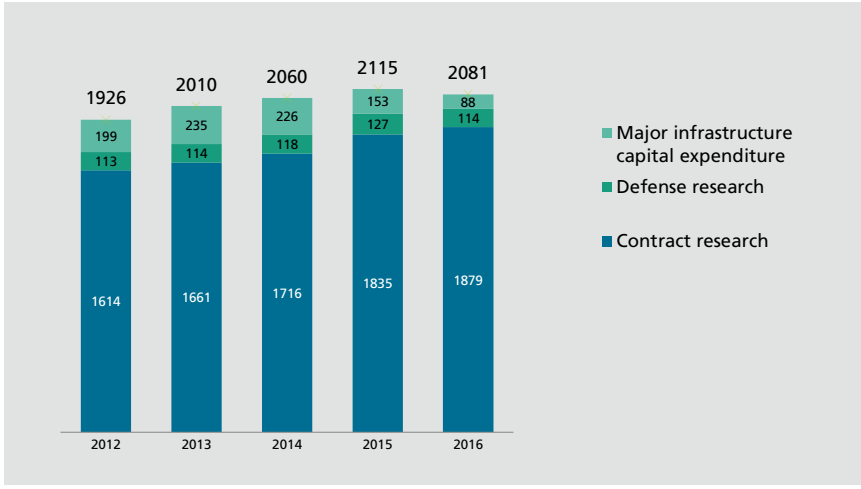
Financial volume of the Fraunhofer-Gesellschaft 2012-2016 in Mi €



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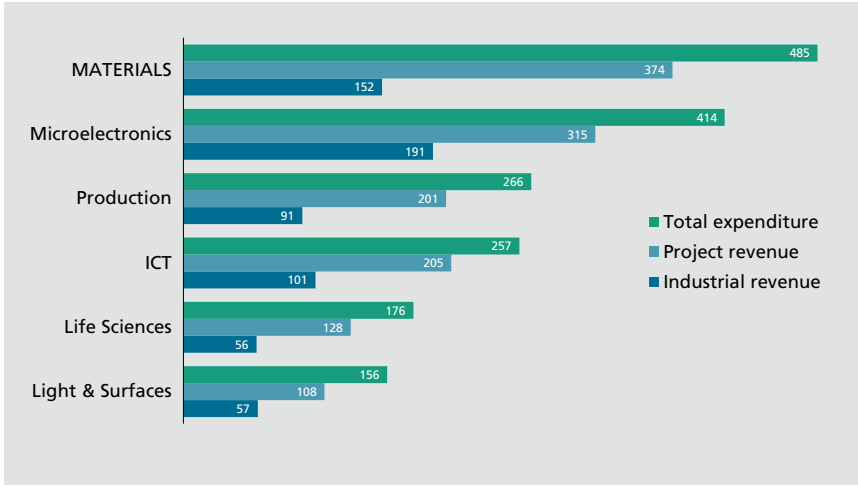
Fraunhofer Associations: Expenses and income in the performance area Contract research 2016 Mi €



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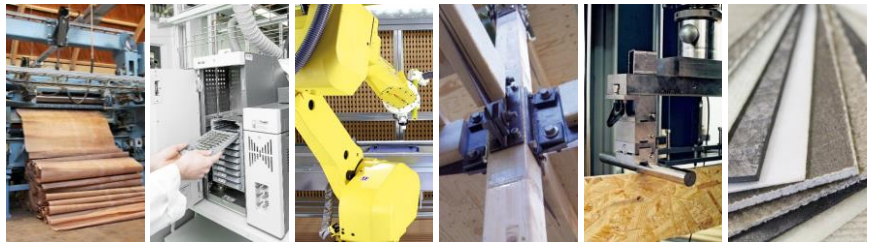
FRAUNHOFER INSTITUTE FOR WOOD RESEARCH, WILHELM-KLAUDITZ-INSTITUT WKI



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Locations

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Wood as key material

- Essential for solving environmental and economical challenges
- Utilization of wood is an important economic factor and significant driver of bio-economy
- Wood and other lignocellulose-based materials are versatile…

… but also highly complex!

Economic benefits and effective implementation need advanced expertise.

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Sustainability defines our activities

Miners clear forest land, Illustration from Agricola's »De re metallica«, 1556 „Georgius Agricola Erzsucher". Licenced under public domain by Wikimedia Commons

Carlowitz formulated ideas for the "sustainable use" of the forest in the 18th Century

Hans C. von Carlowitz, 1713

Klauditz wanted to find new ways to supplement a reduced amount of strong timber by using inferior wood. The first research task of the WKI.

Dr. W. Klauditz, 1946

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Wood Research with Responsibility

Vision

A world-class research institute that addresses current and future questions related to the use of renewable lignocellulose-based resources considering environmental impacts.

Mission

The responsible use of renewable raw materials for a sustainable improvement of quality of life.

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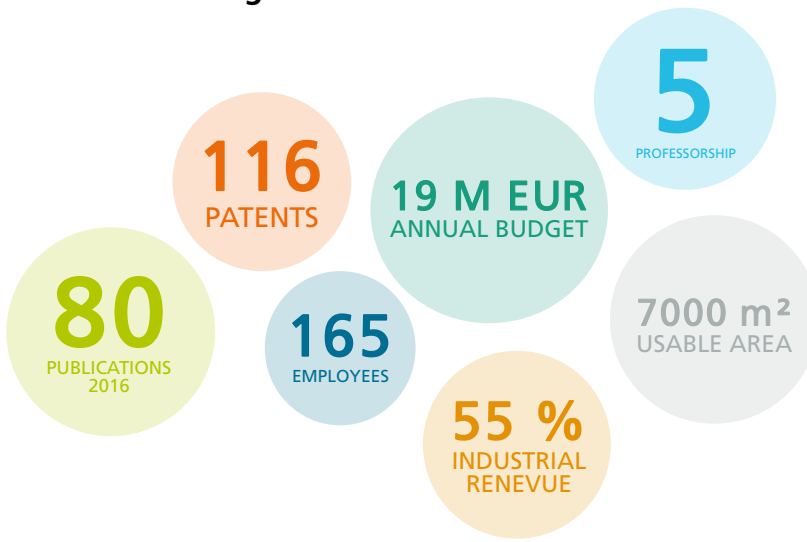
The Institute in figures



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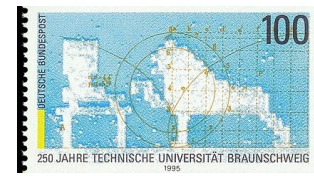
Carolo-Wilhelmina University Braunschweig, Germany

- Established 1745
- 20,000 students
- 6000 faculty and staff
- 225 professors



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Carl Friedrich Gauß

Mathematiker

Johann Carl Friedrich Gauß war ein deutscher Mathematiker, Astronom, Geodät und Physiker. Wegen seiner überragenden wissenschaftlichen Leistungen galt er bereits zu seinen Lebzeiten als Princeps Mathematicorum.

Wikipedia

Lived: 30. Apr 1777 - 23. Feb 1855 (age 77)

Spouse: Johanna Osthoff (m. 1805 - 1809) · Friederica Wilhelmine Waldeck (m. 1810 - 1831)

Field of study: Mathematik

Written works: Disquisitiones Arithmeticae +

Education: Universität Helmstedt · Technische Universität Braunschweig · Georg-August-Universität Göttingen

Awards: Copley-Medaille (1838) · Lalande-Preis (1810)

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Innovation in wood and natural fiber-based materials

General observations (already discussed in 2015 and still true)

- Contrary to common belief, the wood industry is highly innovative and has relatively short cycle between R&D and implementation
- Examples include: LVL, Parallam, MDF, CLT…
- Number of innovations came directly from the industry
- In recent years, non-wood fibers gained interest
- Other bio-based products find their way either in wood composite industry or in other industrial applications (coatings, adhesives, hybrid textiles, matrix-dominated composites…)

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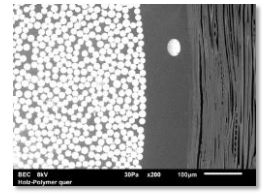
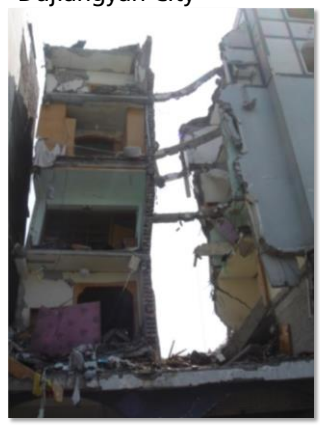
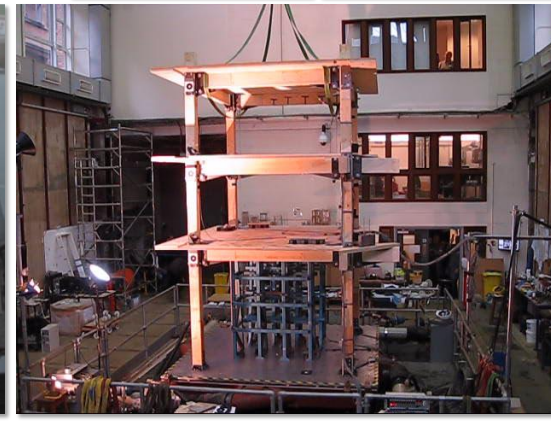
Hybrid Systems

2008 Sichuan earthquake
Dujiangyan City







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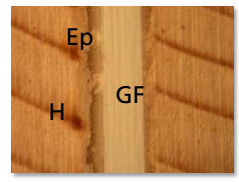
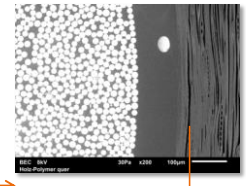
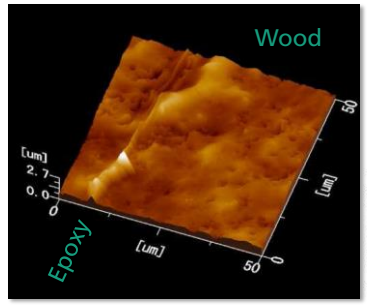
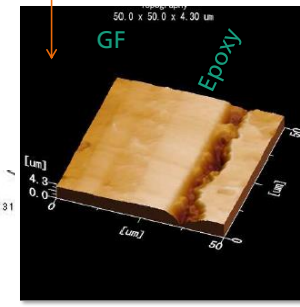
Wood-high-strength composites









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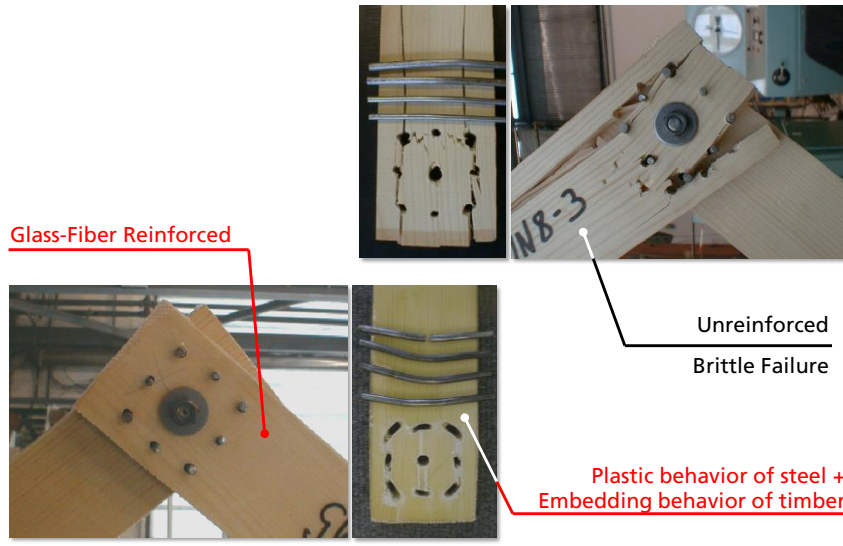
GF reinforcement of connections



Source: A. Heiduschke, B. Kasal, P. Haller. Analysis of small-scale timber frames under earthquake loads. WCTE Portland, OR. 2006.

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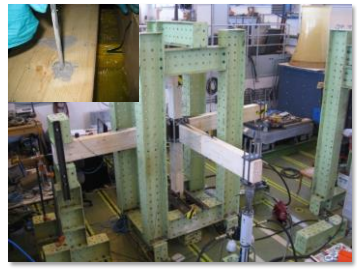
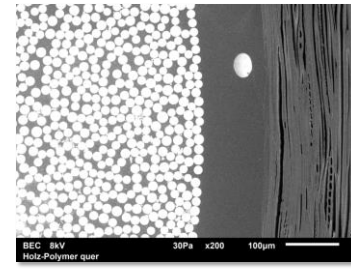
Composite material versus composite cross-section (hybrid system)

- For a composite material one can calculate (estimate) the properties of the composite from known parameters of its components.
- In a hybrid system, one cannot do that and other consideration must be employed (such as cross section transformation).
- In both cases one assumes that materials are Hookean but other assumptions must enter the consideration (such as compatibility).





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Advantages of hybrid systems

- Let´s start with the drawbacks that wood as a material have in structures
  - non-isotropic material with low (close-to-zero) strength in tension perpendicular to fibers
  - material with unequal strength in tension and compression along fibers
  - material with low modulus of elasticity
  - material that is brittle in tension (along and across fibers) and in compression along fibers
  - other issues such shrinkage and swelling or biodegradation are not directly solvable by material combination

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Can a combination of wood with other materials mitigate the negatives?

- If so,
  - what is expected from the addition of such materials?
  - what properties must the materials have?
  - what is the long term performance of hybrid system?
  - is the entire proposition economically and technically feasible?

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Why hybrid?

- Primary advantages:
  - costs, weight
  - sustainabilty
  - functionality and function
  - energy demand
  - .....
- Secondary advantages:
  - weight
  - transport
  - .....

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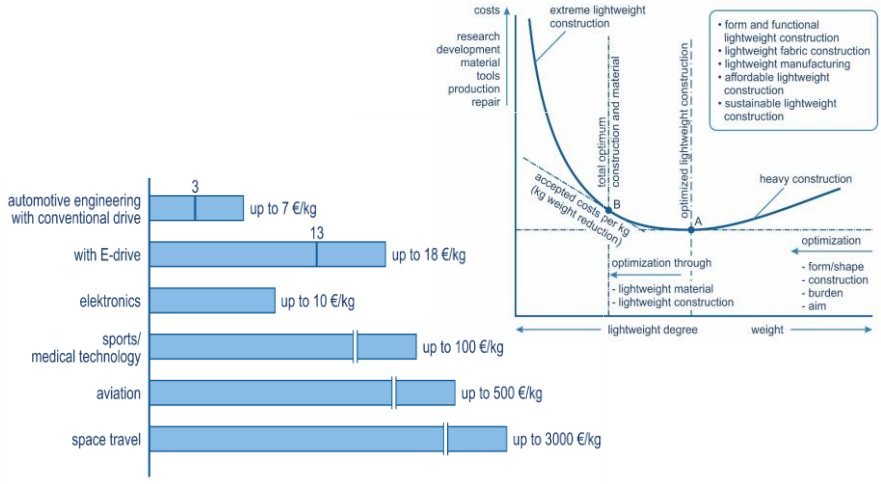
Is leightweight in construction possible?



Source: Klein B. 2011. Leichtbau-Konstruktion, DOI 10.1007/978-3-8348-8321-6_3 Vieweg+Teubner Verlag Springer Fachmedien Wiesbaden GmbH.

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Costs of going light

- - 30 % design costs (concept, design)
- - 40 % optimization
- - 20 % experimental work (prototype, test)
- - 10 % design again (concept, design)

This means, that about 80% of the work is theoretical in nature.
Experiments and prototyping represent about 20%.

Source: Klein B. 2011. Leichtbau-Konstruktion, DOI 10.1007/978-3-8348-8321-6_3 Vieweg+Teubner Verlag Springer Fachmedien Wiesbaden GmbH.

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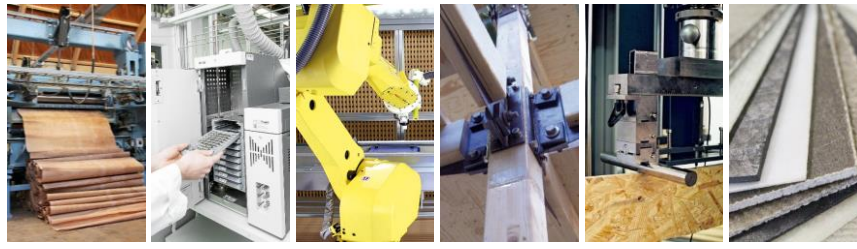
RECENT DEVELOPMENTS AT WKI



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Very volatile organic compound (VVOC) emissions from wood and wood-based materials

Gaschromatographic column.

1m³-stainless steel emission test chamber.

Task

- Evaluation of VVOC-emissions
  - from wood & wood-based materials
  - in indoor air of prefabricated houses

Result

- Development of an analytical method for quantitative determination of VVOCs in indoor air (TDS-GC/MS)
- Emission sources of VVOCs
- Occurrence of VVOCs in indoor air

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Prediction of Indoor pollutant concentrations from chamber tests

Test house at Thünen Institute Hamburg.

30 m³-chamber at WKI loaded with wall construction.

Challenge

- Can we predict indoor air quality by measuring material emissions?

Approach

- 4 test houses and corresponding walls
- Measurement of
  - VOC-emissions from used materials and walls in chambers
  - indoor VOC concentrations in houses
- Correlation of the results

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Wood Foam – From Tree to Foam


Wood foam developed at Fraunhofer WKI consisting of 100 percent renewable resources.


Sandwich-material, packaging, building-element with textile rein-forced concrete

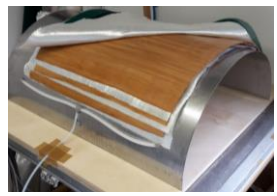
Task

- Natural foam of 100% lignocellulosic materials
- Activation of wood own´s binding
- No synthetic binder

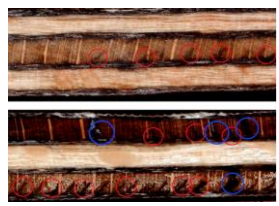
Result

- Wood foam with a high compression strength
- Low swelling
- No harmfull emission
- Low density
- Open-celled structure

Fiber Reinforced Veneer for Bridge Constructions



Glass fiber reinforced veneer produced with vacuum infusion.



Vacuum infusion fills small lathe checks (red circles) and large shrinkage cracks (blue circles) with resin.

Task

- For lightweight pedestrian bridges, bended wood elements would be preferable.
- Unfortunately neither dried veneer nor laminated wood are easy to press in a curved form without crack formations.

Result

- A very strong 3-D wooden hybrid can be produced from fresh peeled veneer in combination with glass or carbon fibers reinforced plastic.

New wood-based Hybrid Materials

Lateral strengthening strut of a production car.

Task

- Structural assemblies based on sustainable wood-based material systems for reducing mass and environmental impacts on road and rail vehicle constructions

Result

- A 3-D wooden hybrid was produced
- The use of phenol adhesive is increasing the tensile strength of the individual layers
- Extraction strength resistance can be increased by using circular blanks
- Acetylation improves the hygric characteristics significantly

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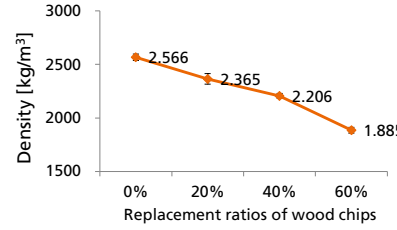
Natural Flax FRP Tube-Wood Chip Concrete (FFRP-WCC)

Failure modes: Plain concrete PC (top) and 60%-WCC (bottom).

Task

- To evaluate wood chip replacement ratio (0, 20, 40 and 60% by mass) for coarse aggregate on concrete properties
- To evaluate FFRP tube confinement effect on WCC properties

Results



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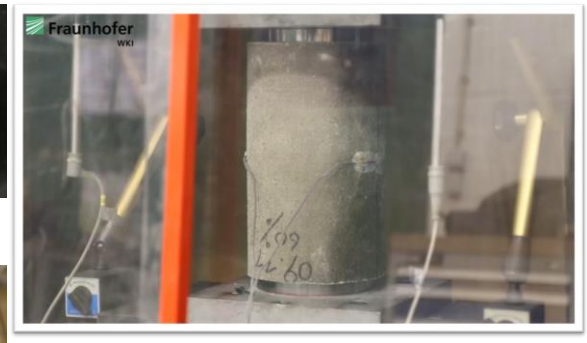
Concrete Test

Tube before and after the test.



Video of the concrete test.

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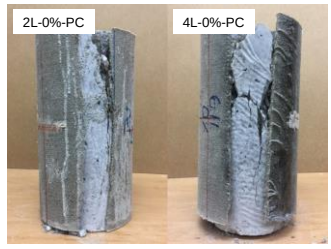
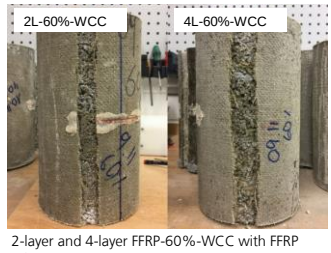
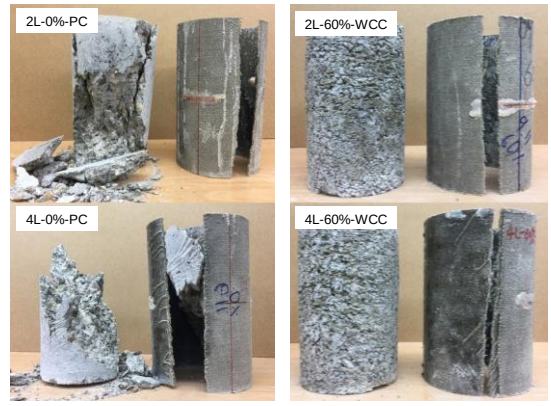
Failure modes of FFRP-WCC



2-layer and 4-layer FFRP-PC with FFRP tube.



2-layer and 4-layer FFRP-60%-WCC with FFRP tube.



After removed FFRP tube: PC cores (left) and 60%-WCC cores (right).

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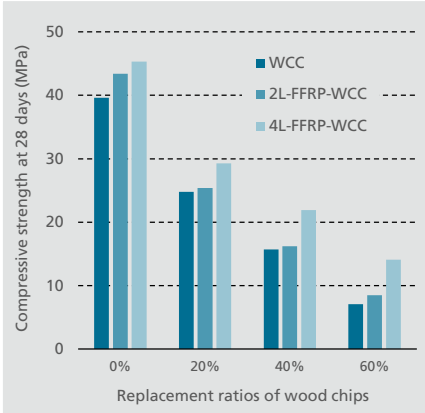
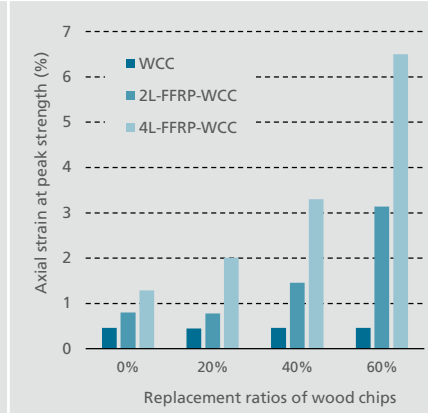
Compressive strength and strain of WCC and FFRP-WCC





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Natural Flax Fabric and FFRP Reinforced Geopolymer Concrete

Pull out test of flax fabric from geopolymer.

Task

- To optimize the mix design formula of fly-ash based geopolymer
- To evaluate the feasibility of flax fabric as internal reinforcement and flax fabric reinforced polymer (FFRP) composite as external reinforcement of geopolymer
- To evaluate the feasibility of geopolymer as a fire protective coating of natural fibre
- To evaluate the interfacial bond between natural fabric and geopolymer

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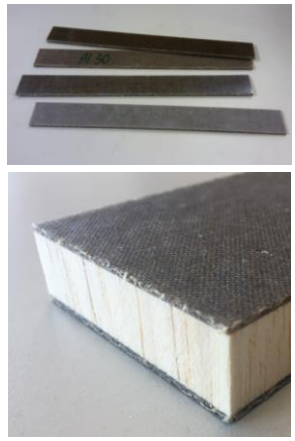
Natural Flax FRP skinned – Balsa Wood Sandwich



Flax FRP (top) and Flax FRP skinned – balsa wood sandwich (bottom).

Task

- To improve fire retardancy of flax fabric reinforced polymer composite
- To evaluate fire performance of FFRP skinned balsa wood sandwich
- To evaluate mechanical properties of FFRP skinned balsa wood sandwich

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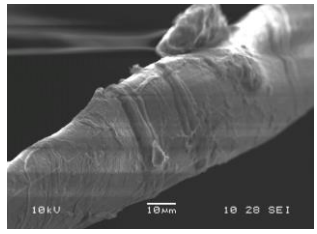
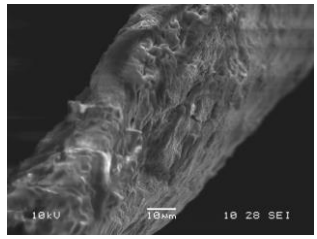
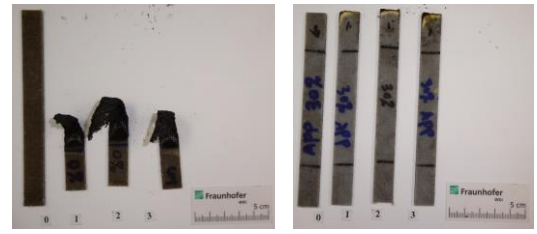
Natural Flax FRP skinned – balsa wood sandwich





SEM of flax fiber: untreated (top) and coated with flame retardant.



UL-94 vertical tested FFRP: without (left) and with (right) flame retardant.

UL-94 vertical tested FFRP-balsa wood: without (left) and with (right) flame retardant.

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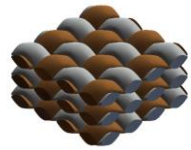
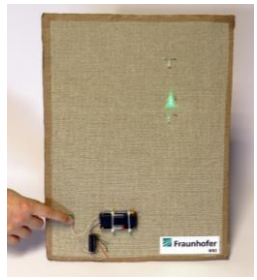
Hybrid fabrics with function integration



Multi-layer fabric made from flax (brown) and carbon (black).



Flax multi-layer fabric with integrated LED.

Task

- Realization of tailor made technical fabric structures by a double rapier weaving machine

Approach

- Independent insertion of different materials into the fabric layers
  - Integration of matrix yarns and conductive yarns in textile semi finished products
- Manufacture of innovative multi-layer fabrics
- Implementation of various weave structures

Benefit

- Cost-optimized, sustainable high-performance composite production

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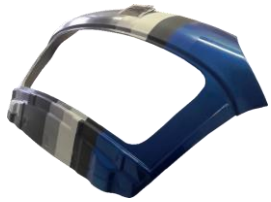
New Natural-Fiber-Reinforced Hybrid Materials

Linen fabric and hybrid laminate of carbon and linen fibre. © K. Morawietz



Trunk lid manufactured with hybrid laminate of carbon and linen fibre.

Task

- Lamination of natural and high-performance fiber fabrics with thermoplastic or thermoset matrices

Result

- Application-oriented development of new bio-hybrid composites
  - Application-specific material integration
  - Flexible mechanical properties
  - Improvement of crash behavior
  - Improvement of ecological performance
  - Etc.

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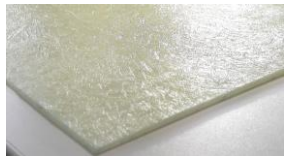
Robot controlled fiber spraying

Robot controlled fiber spraying.



Fiber sprayed, rayon-reinforced thermoset.

Challenge

- Unavailable processes for the production of natural fiber-reinforced plastics and additive reinforcement of existing components

Approach

- Automated production of short- to long fiber-reinforced bio-hybrid-„tailored composites“
- Reinforcement of stress-critical zones
- Near-net-shape production
- Reliable fiber length: 1-100 mm
- Processable fibers: natural, glass, carbon, basalt, rayon, thermoplastic polymer fibers, etc.

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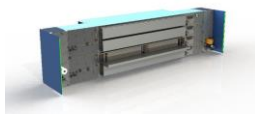
New Technologies
Continuous surface modification of yarns and textiles



Surface treatment facility (CAD).

Yarn treatment (exemplary equipment).

Task

- Development and application of sizing, functional coatings, coupling agents and particles

Technical data

- Textile width up to 50 cm / Speed: 15 m/min

Liquids

- Aqueous solutions, organic solvents, high-viscosity pastes, etc.

The start-up of the new facility

- November 2018

Specially constructed facility

- Manufacturer: Benninger Zell GmbH
- Funding organization: Fraunhofer Gesellschaft

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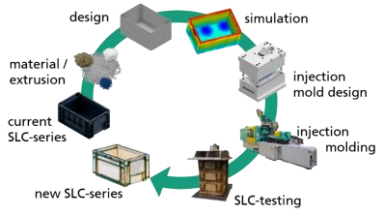
New wood-fiber-reinforced small load carriers (SLC) and vegetable box



Project steps for the development of a new SLC generation.

Small load carrier and vegetable boxes made out of polypropylene with wood fibers.

Task

- Weight reduction and increase of useful volume of SLC require a new development in terms of material use, construction and injection molding technology
- Automatic identification and data acquisition (AutoID) of the SLC is unavailable in the logistics chain between automotive suppliers and original equipment manufacturers (OEM) until now

Approach

- Wood-fiber-reinforced polypropylene
- Improvement of material properties and adaptation of the construction
- Integration of a soft material (TPE) and RFID technology

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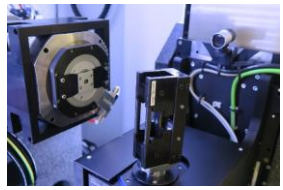
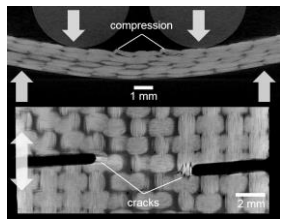
In-situ CT mechanical testing



In-situ-CT 4-point bending test of a hybrid fiber-reinforced plastic.



In-situ-CT 4-point bending test (top) and tensile test (bottom) of a glass fiber reinforced plastic.

Challenge

- Investigation of failure mechanisms in fiber-reinforced composites and other materials

Approach

- In-situ computed tomography for non-destructive evaluation of specimens during mechanical testing
- Tensile, compression or bending tests under controlled temperature (-20 to +160 °C)
- Tests reveal load-dependant defect initiation and development inside the material

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New Polymeric Materials for Additive Manufacturing

Bio-sourced UV-curing resin.

3D-printed polymer with high impact and heat resistance.

Task

- UV-curing materials for additive manufacturing with high impact strength and heat resistance
- Compatible with applications in the automotive sector

Result

- UV-curing resins with improved properties compared to commercial materials
- Improved creeping properties at higher temperatures
- Compatible with standard processes such as DLP, SLA, and inkjet
- Bio-sourced material

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Formaldehyd-free Adhesive for Wood-based Materials

Wood-based materials bonded with a bio-sourced dispersion adhesive.

Challenge

- Formaldehyde in aminoplast adhesives are classified as mutagenic and carcinogenic
- Low cost alternatives?

Approach

- Dispersion adhesive for heat bonding
- Modified PVAc glue with high Tg
- High-Tg sugar acrylates

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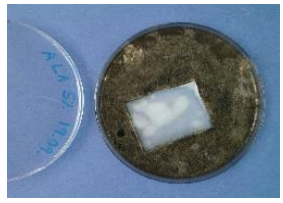
Antimicrobial Coatings

Antimicrobial dispersion in reactor.



Test fungi on nutrient medium in petri dish with antimicrobial coating film.

Task

- Fungicide-free coatings for exterior application
- No external supplement of biocides

Result

- Waterborne polyurethane or polyacrylate coating
- Antimicrobial functionality is covalent bonded to the polymer backbone
- No leaching of biocides

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Bio-sourced UV-curing Coatings for Exterior Coatings

UV-coated soft wood.

Demonstration object in Korntal
© Remmers Bauchemie for Fraunhofer WKI.

Task

- UV-curable bio-sourced polymer dispersion
- Fungicide-free coatings for exterior application
- The binder must be acrylate-free

Result

- UV-curing resins with excellent properties regarding weather resistance
- Transparent exterior wood coating 5 years without any defects
- Bio-sourced material

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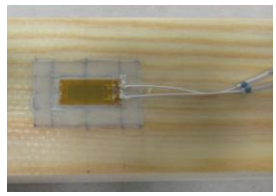
New Fiber-Reinforced Hybrid Materials

Fiberreinforced composite as guardrail.


Strain gauges (TU Braunschweig; Kasal).

Task
- development of wooden guardrails

Result
- demonstrator passed crash-test

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New Fiber-Reinforced Hybrid Materials – Guardrail

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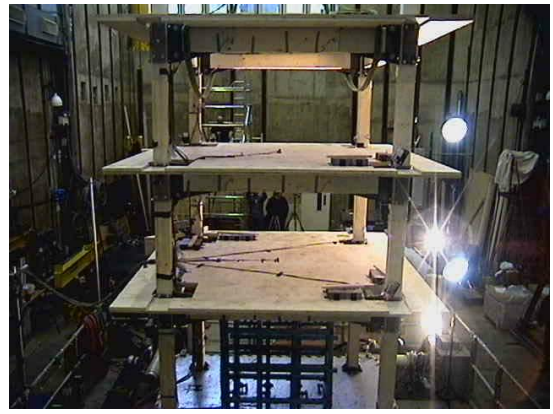
New Hybrid Structures



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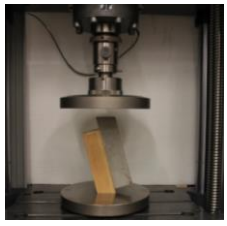
New Hybrid Elements



Testing of a shear connection.

Task

- Development of a prefabricated timber-concrete deck (10 m span)

Result

- Demonstrator tested

Timber-concrete element.

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Flame retarded natural insulation materials

Several natural insulation materials.

Task

- Investigation of the inflammability / glowing behavior, development of tests methods and of flame retarded natural insulation materials

Result

- Running project, targets will be reached

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Flame retarded natural insulation materials

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NON Flame retarded conventional insulation materials (polystyrene)

http://www.youtube.com/watch?v=1o34slPoa-8

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Low-formaldehyde bio-dispersion adhesives for wood-based materials

■ **Dispersion adhesives** on the basis of polyvinyl acetate (PVAc, known as "white glue") are low-emission and are widely applied in the furniture industry for cold bonding

■ **Project goal**

■ Further development to create a low-formaldehyde dispersion adhesive on the basis of a renewable raw material (sugar) for the heat bonding of surfaces and particles in the production of wood-based materials

Funding: BMEL / FNR, 2015 to 2018

Project partners (coverage of the entire value chain): JOWAT SE (alliance partner), 4 wood-based materials manufacturers, 1 raw materials supplier

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