Investigation of novel preforming technologies for large-scale composite production

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Andreas Schnabel
C. Greb, D. Michaelis, J. Haring und T. Gries

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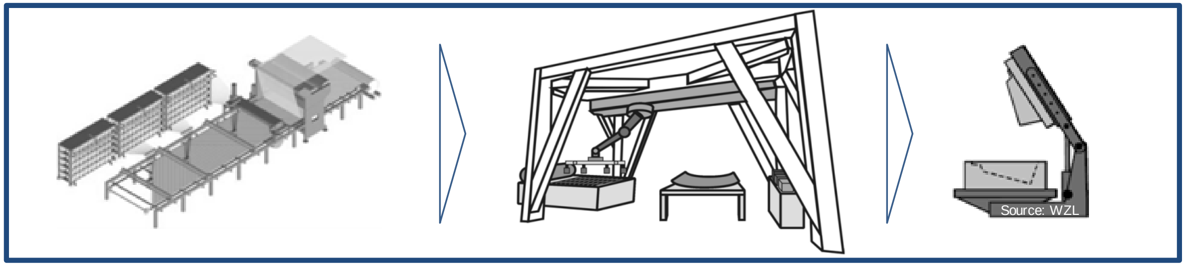
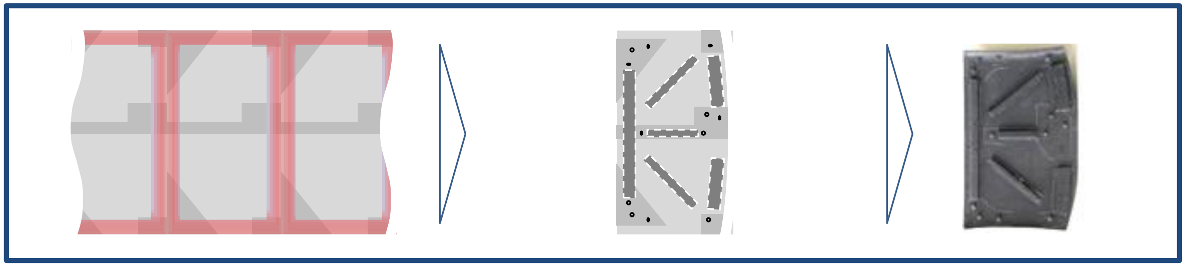
- Introduction
- Single-step preforming
- Multi-step preforming
- Preliminary case study
- Case Study
- Conclusion





RWTH Aachen University

- founded in 1870 by industrial initiative
- 31.500 students in 106 courses of study
- 450 chairs
- 4400 assistant lecturers (mostly PhD positions)
- 2500 non-academic members of staff
- 650 apprentices
- 650 Mill. € total budget
- thereof 30 % third party funding

Aachen - in the heart of Europe, close to

- Düsseldorf
- Cologne
- Belgium
- The Netherlands
- Paris

Institut für Textiltechnik at RWTH Aachen University

Departments

- Man made fibers
- Textile machinery
- Smart & medical textiles
- Fiber-reinforced composites

Numbers

- 85 scientists
- 55 members of service staff
- 150 graduate research assistants
- Budget 14,3 mio. €

Fiber-reinforced composites at ITA

Technologies and process chains for the production and quality assurance of preforms for fiber-reinforced composites

- Development of new processes, machines and textile reinforcement structures
  - Design
  - Simulation
  - Prototyping
  - Production

Reinforcement fibers:

- Carbon, glass, aramid, ceramics, high strength polymers

Matrices:

- Thermosets, thermoplastics, concrete, metals

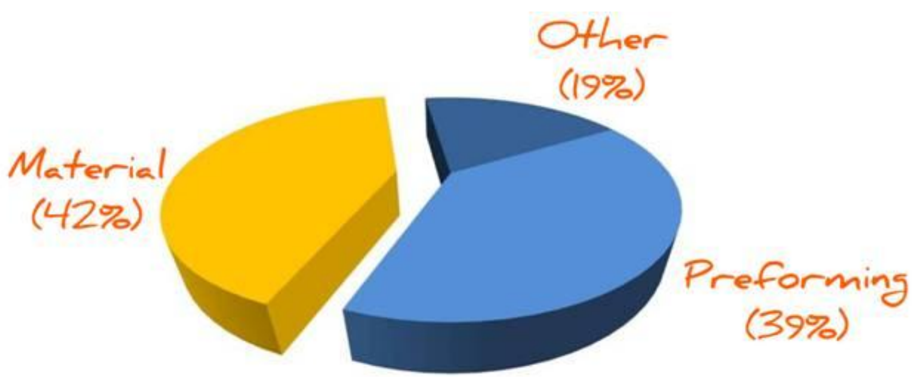
Mass production technologies for textile reinforcement structures

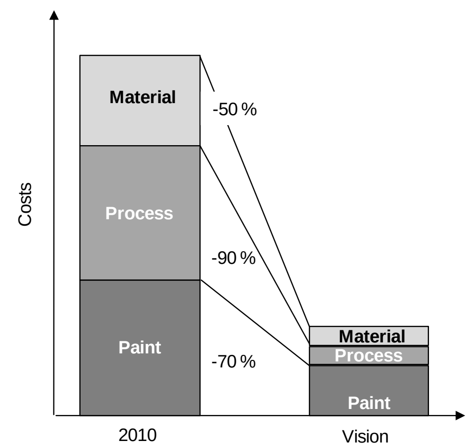
Motivation

- Increasing fuel costs and electric vehicle concepts require lighter car body structures
- Fiber-reinforced plastics (FRP) have great potential for weight saving (excellent weight/strength ratio)

Problem

- High cycle times due to manual and semi-automated production
- High production costs due to the production of textile reinforcement structures





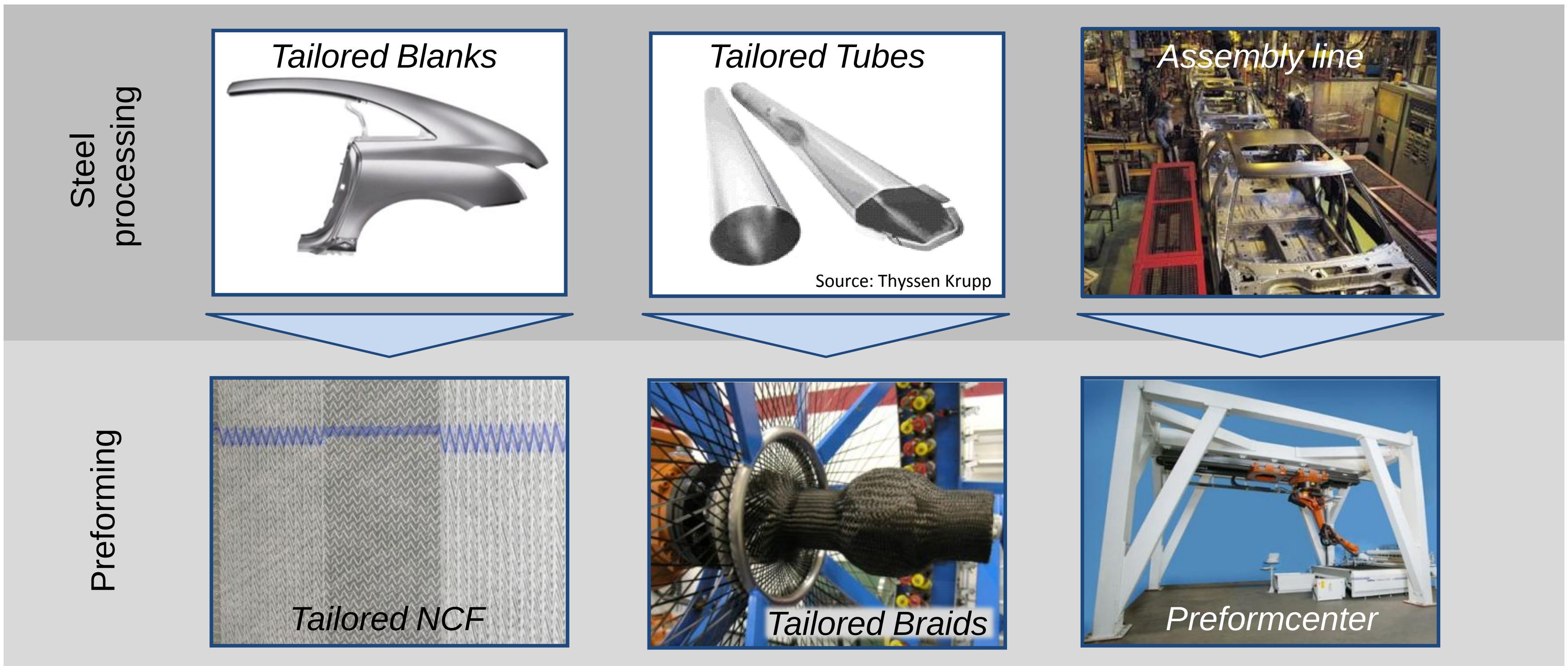
Source: Audi

Automated production technologies for textile preforms are essential for cost reduction and for sufficient production rates!

Approach

Combination of *single-* and *multi-step preforming*

- *Single-step preforming:* production of „Tailored Textiles“ with locally adjusted properties
- *Multi-step preforming:* converting „Tailored NCF“ and „Tailored Braids“ into near-netshape preforms in a sequence of automated process steps



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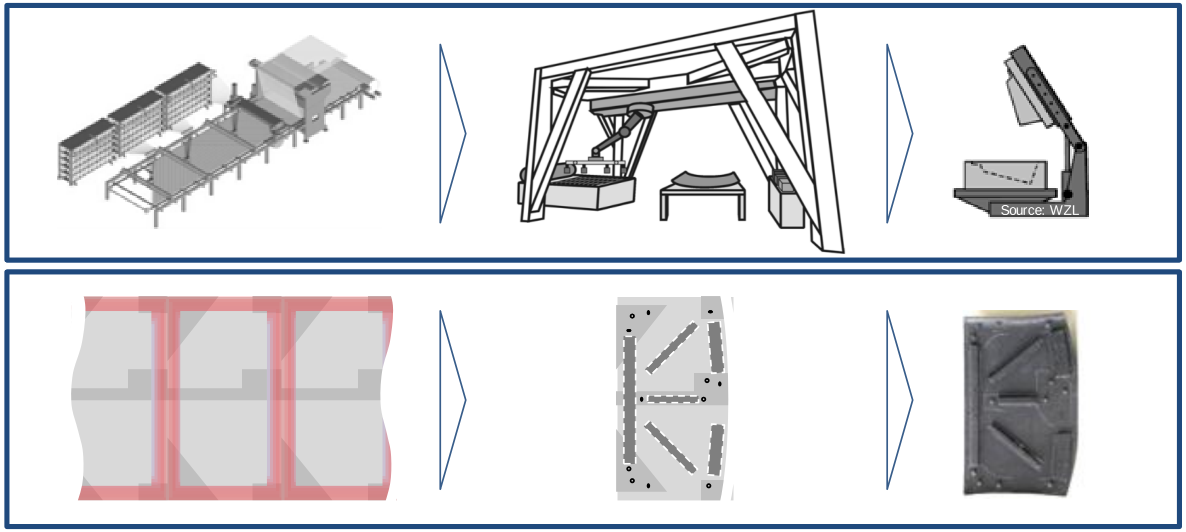
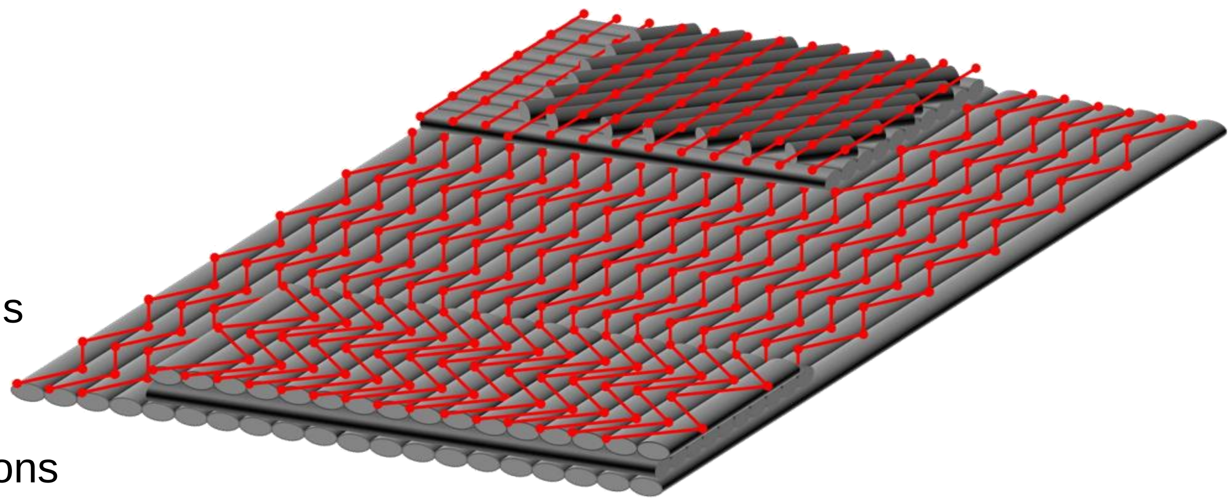


Single-step preforming

Production of near-netshape semi-finished parts in one production process

- Non-crimp fabrics (NCF) with locally adjusted properties → *Tailored NCF*
  - Fiberorientation
  - Thickness
  - Drapability
  - Bending stiffness
- Benefits for preforming
  - Reduced cutting operations
  - Reduction of scrap
  - Reduced handling operations
  - Eased handling operations

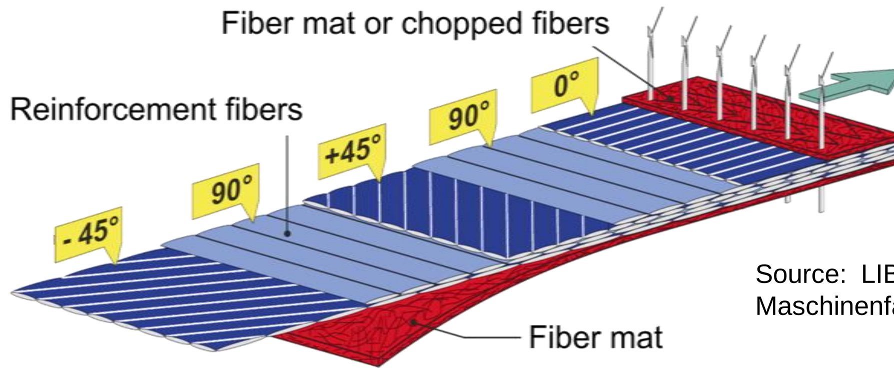


Production of Tailored NCF requires enhanced production technologies

Single-step preforming

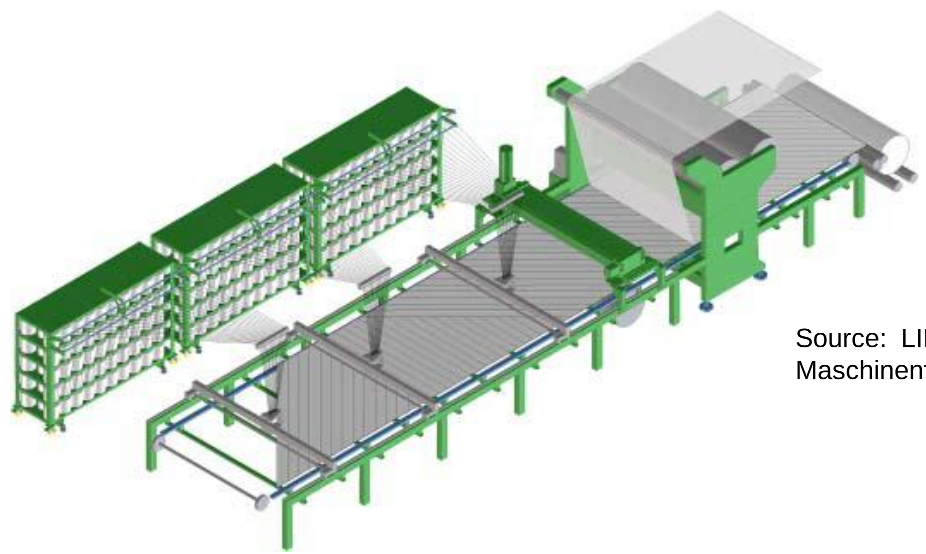
State of the art: NCF and production technology

- Non-crimp fabrics (NCF)
  - Adjustable fiber orientation
  - Adjustable number of layers
  - Constant drapability
  - Constant layer set-up



Source: LIBA Maschinenfabrik

- Production technology
  - Warp-knitting machine with multiaxial weft-insertion
  - High productivity
  - Industrial established

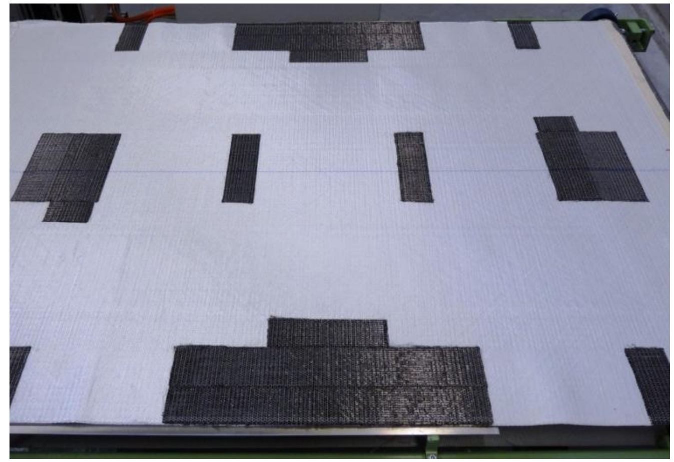


Source: LIBA Maschinenfabrik

Production technology for *Tailored NCF*

Enhancement of multi-axial warp-knitting machinery

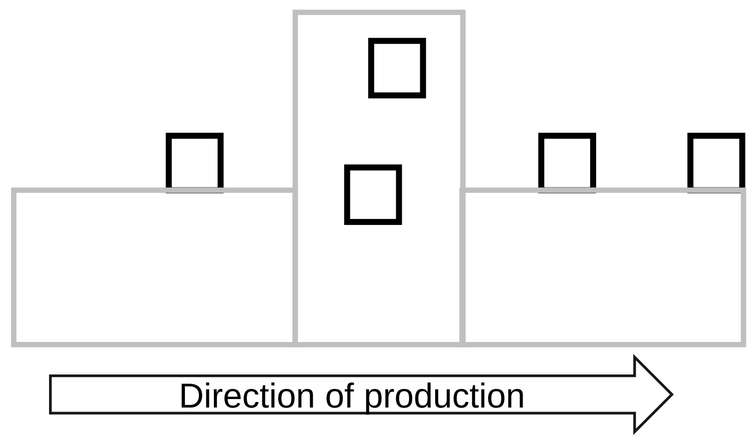
- Tailored NCF
  - Locally adjusted thickness
  - Locally adjusted fiberorientation
  - Locally adjusted drapability



Local reinforcements on NCF

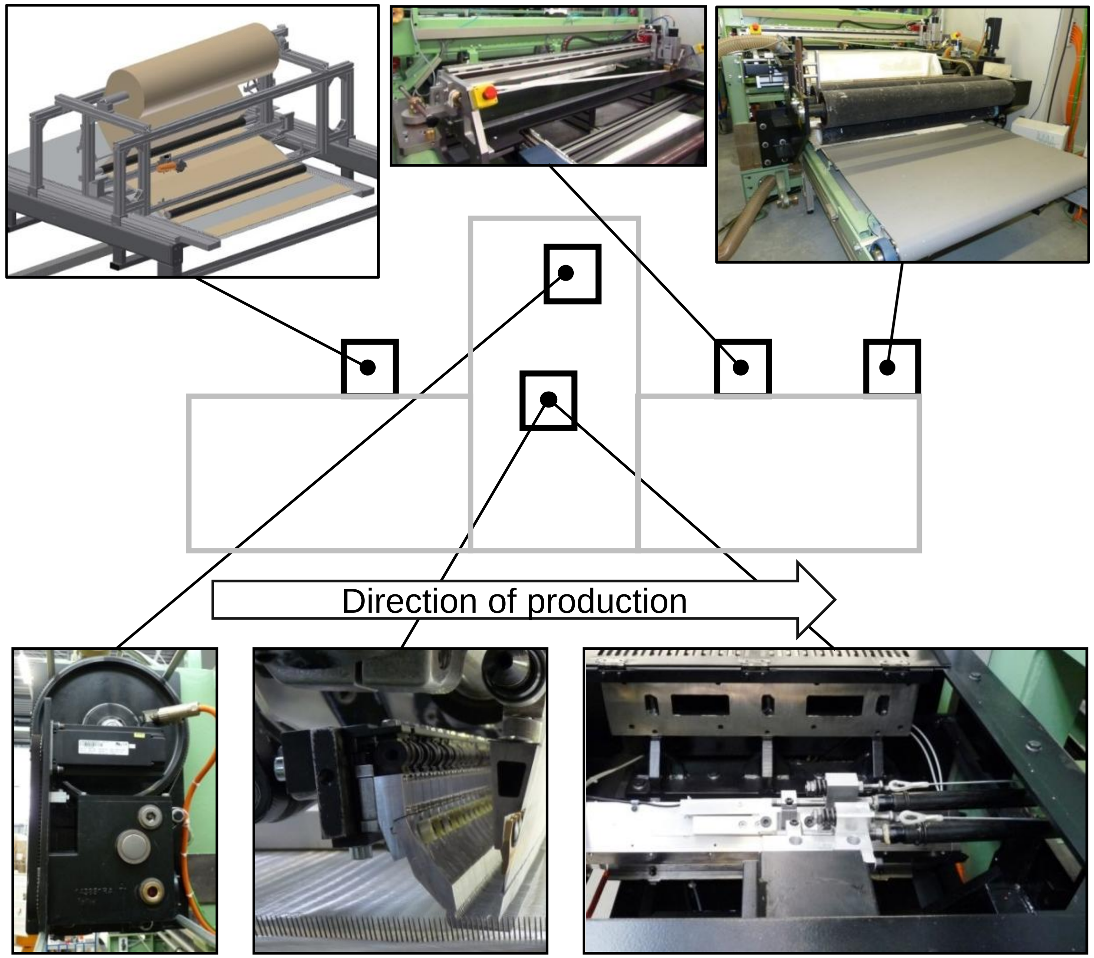
adjusted stitch type

- Production technologies
  - Feeding module
  - Adaptive pillar thread bar
  - Electro-mechanical driven guide-bar
  - Electro-mechanical driven beam drive
  - Cutting and stacking modul



Production technology for *Tailored NCF*

Enhancement of multi-axial warp-knitting machinery



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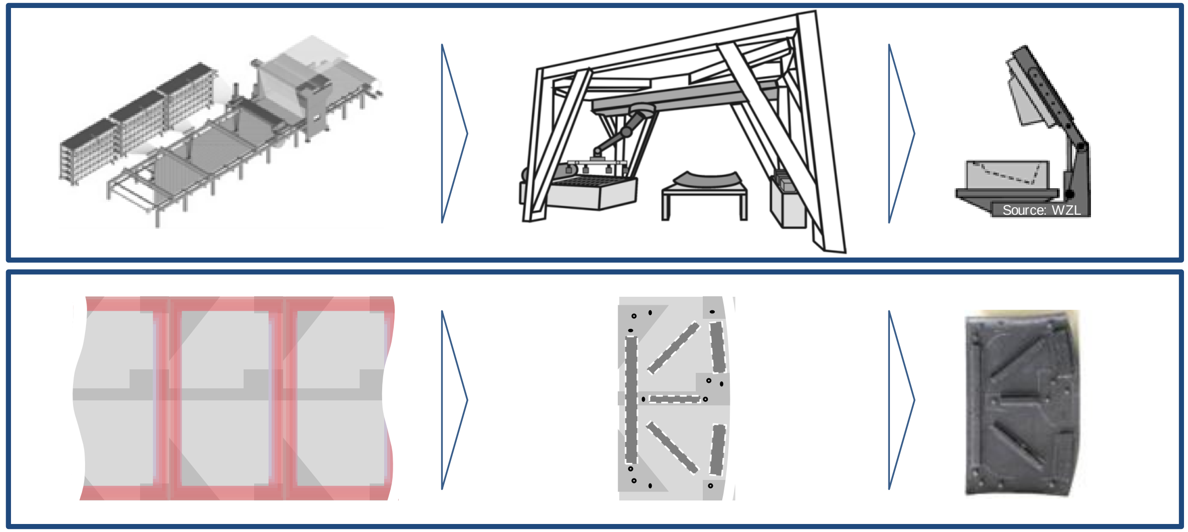
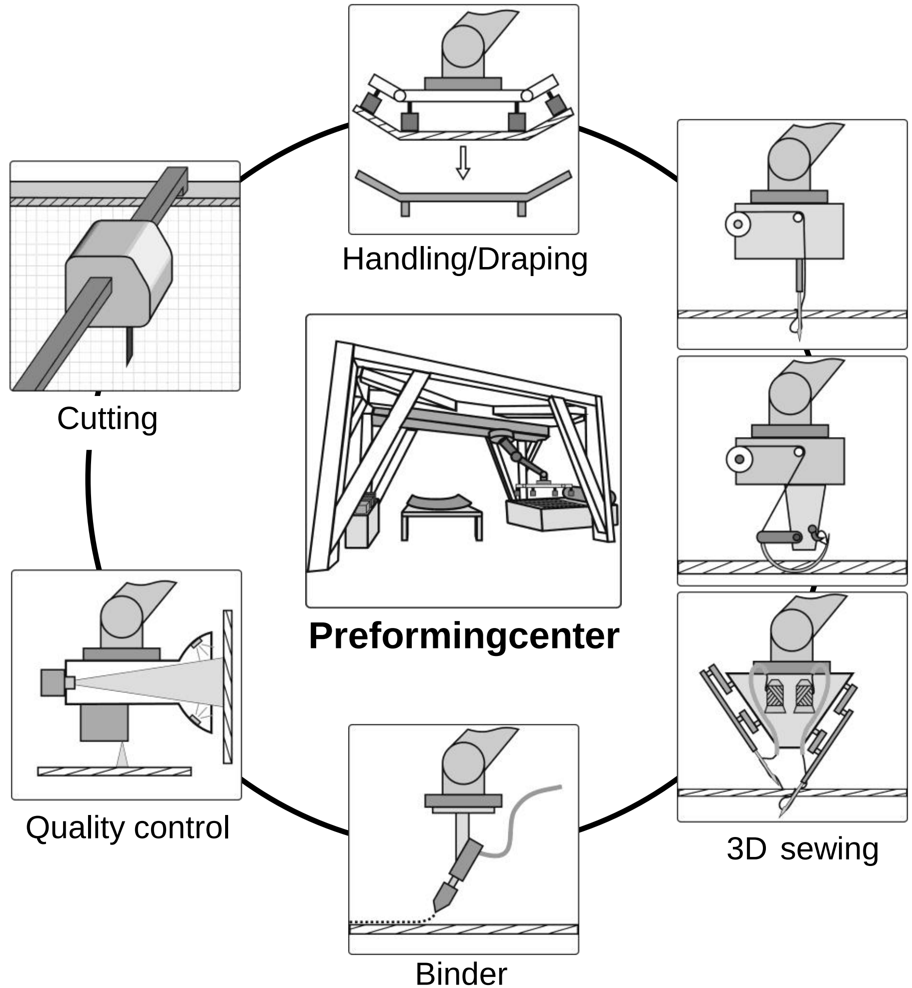


Multi-step preforming

Automated preform assembly

- Efficient and quality-oriented production technologies for textile preforms via
  - Use of Tailored NCF
  - Increased production speed of single process steps
  - Parallelization of process steps
  - Transition from a sequentiel to a continuous production

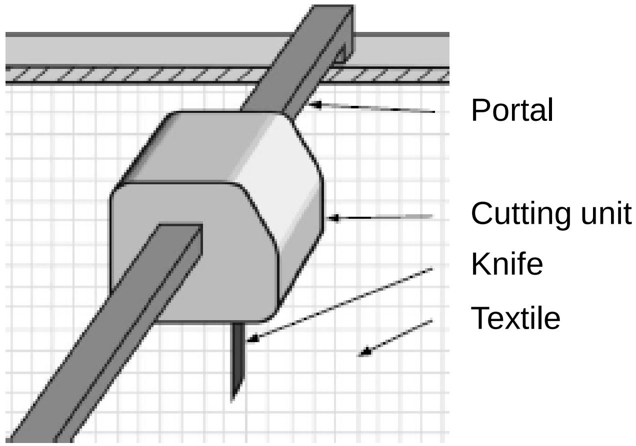


ITA-Preformcenter

Multi-step preforming: Cutting

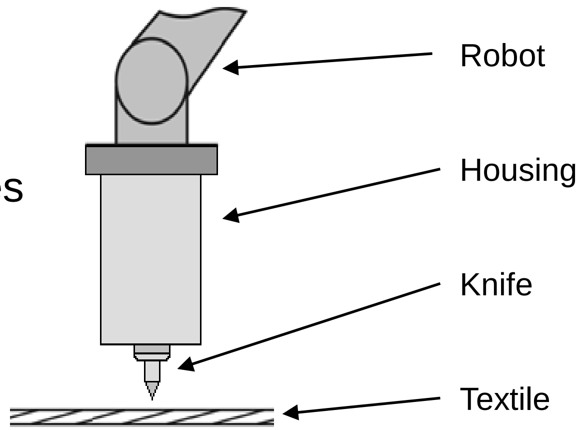
Cutting of reinforcement textiles

- CNC-cutter-tables (2D)
  - Oscillating knife
  - Rotation cutting disc
  - Laser



CNC-Cutter
Source: MAG

- Three-dimensional edge-trimming
  - Robotically guided
  - Ultrasonic knife
  - Cutting of complex geometries



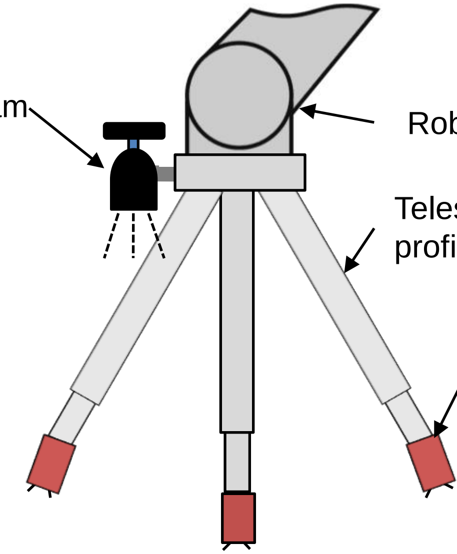
Ultrasonic 3D-Cutter

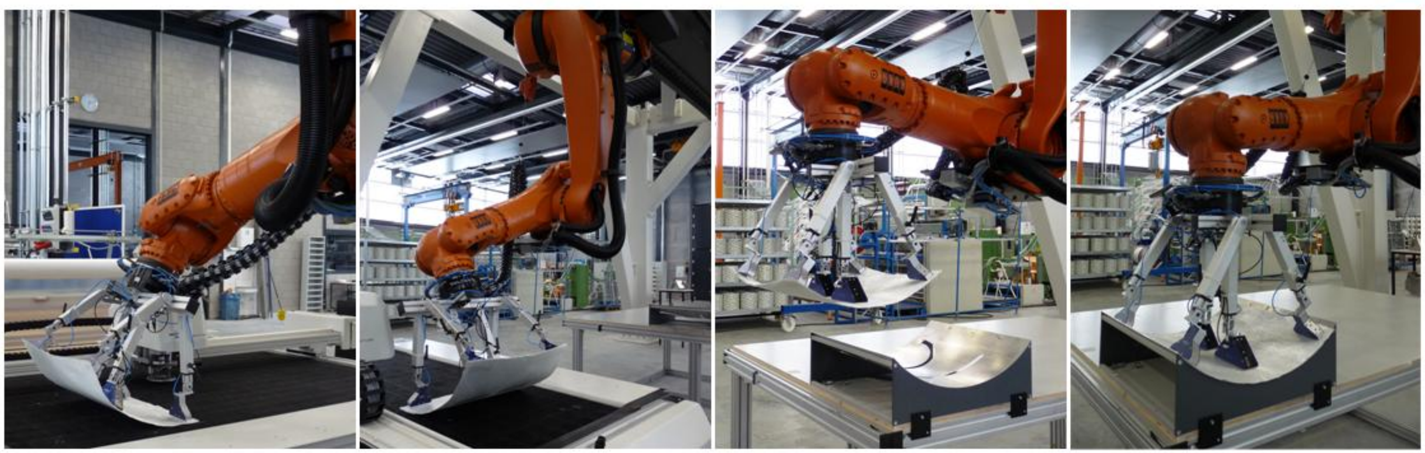
Multi-step preforming: handling

Handling device

- Robot guided needle gripper device
- Fast and reproducible pick & place operations
- Onboard charge coupled device (CCD) Camera for quality assurance (QA) and positioning

Needle gripper





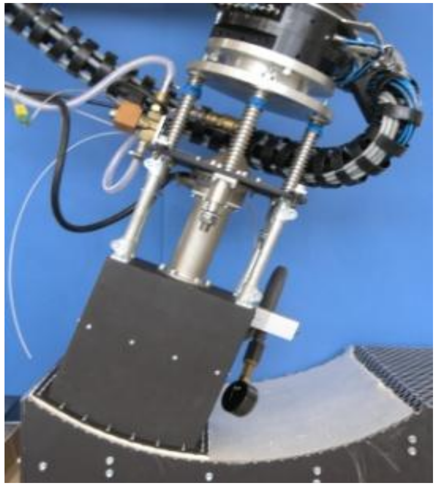
Handling device

Multi-step preforming: joining

Binder application

- Thermoplastic binders
- Bisphenol-A based epoxies
- Permanent adhesive coating

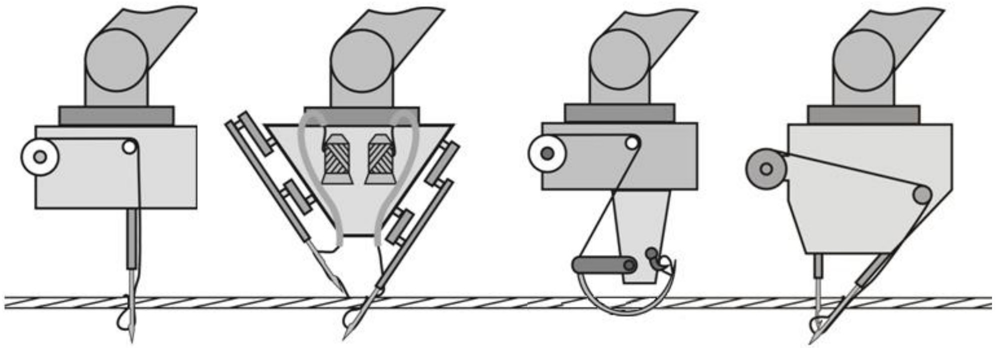
Binder application



Binder activation

Onesided sewing

- Tufting
- Onesided ITA-Stitching
- Blindstitch
- Onesided stiching (OSS)



Onesided sewing technologies

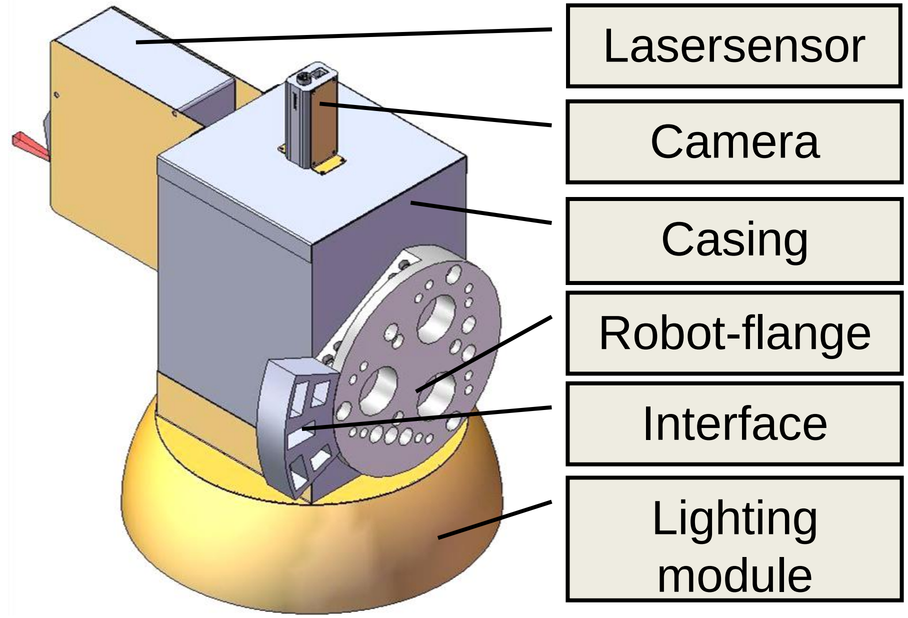
Multi-step preforming: quality control

FALCON (fiber automatic life control)

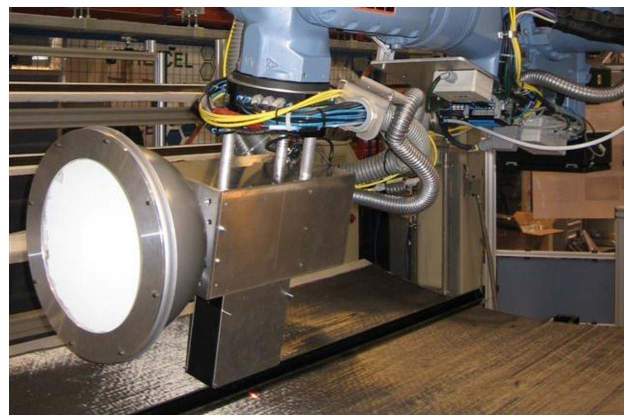
- In-line-monitoring-system for
  - Textur (material, textile type)
  - Orientation and geometry of textiles
  - Defects in textiles (gaps, foreign objects)
  - Positioning-quality of cuts

Perspective

- Miniaturization of monitoring device
- Integration into various end-effectors
- Establishment of closed loop control for automated preforming processes



Monitoring end-effector



Prototype at CTC GmbH

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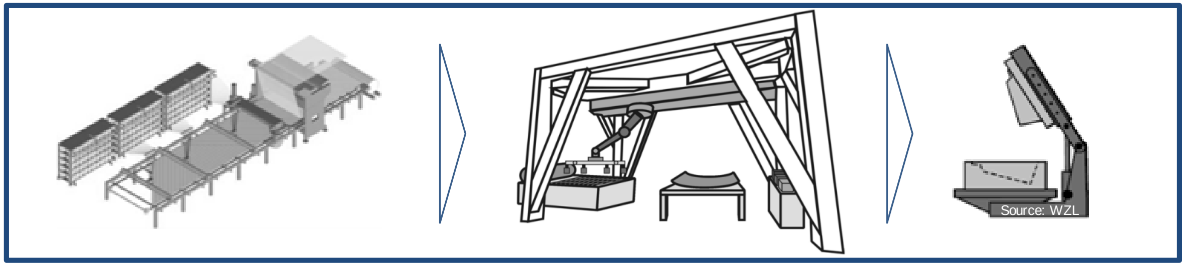
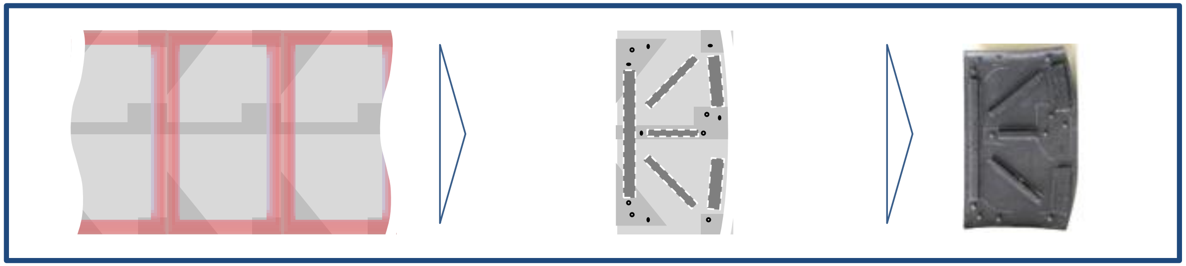


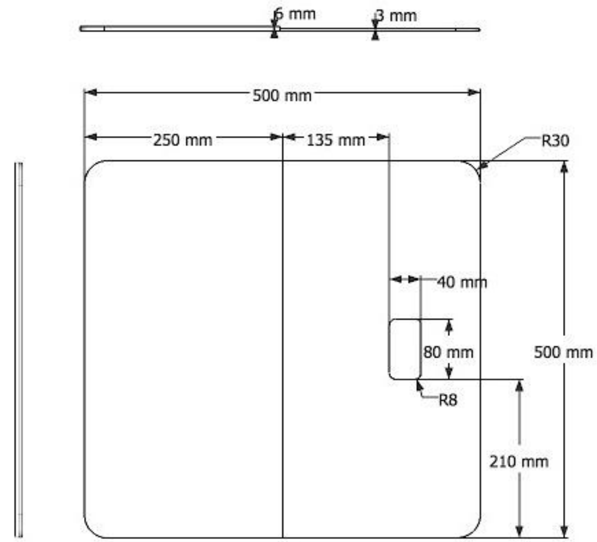


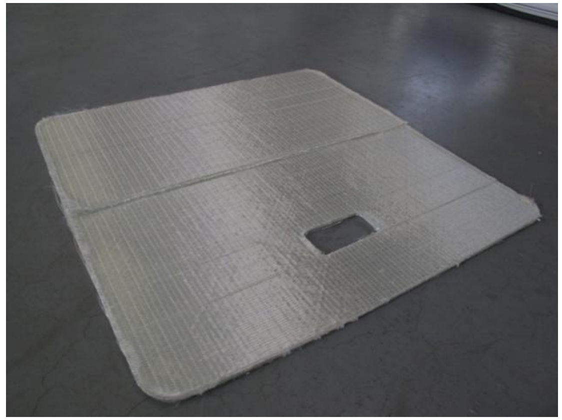
Case study: Square shaped part with local reinforcement

Shell: 16 layers of glass fibers, quasi-isotropic

Reinforcement: 16 layers of glass fibers, quasi-isotropic

Cut-out: 80x40 mm





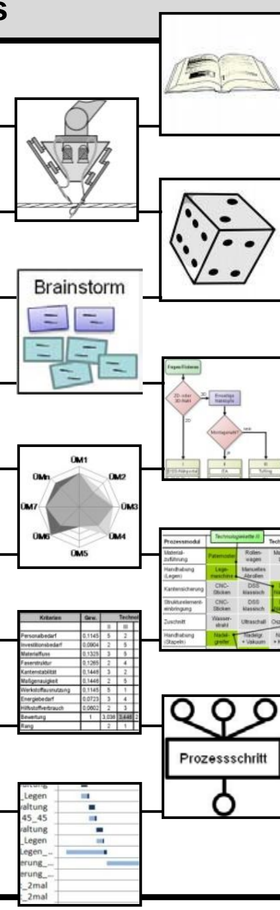
Practical Relevance

- Wall linings in airplanes
- Floor structures in cars / trains

Case study: development of process chains

4-step methodology

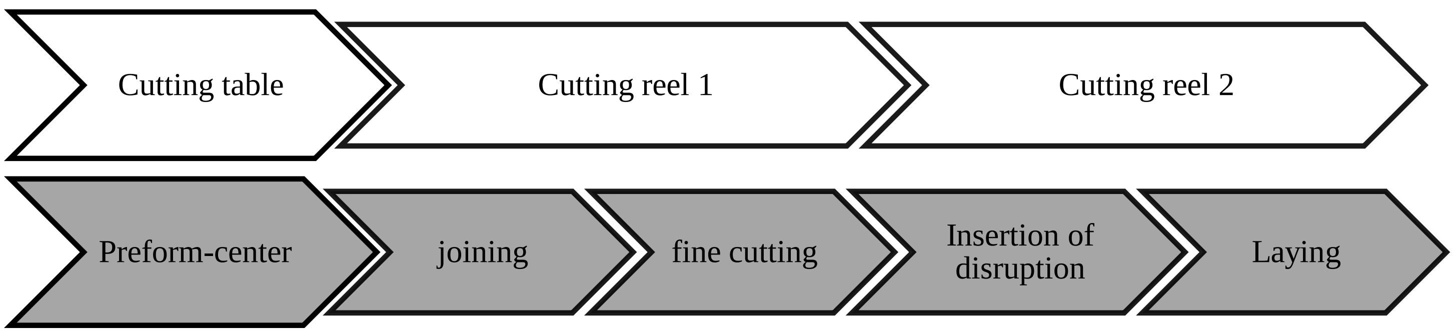
Step	Tools	Results
1. Creation of a decision basis	Inquiry Experiments	• Product data • Technology data • Economical data
2. Combination of process modules	Free combination Creativity methods	• Process chain alternatives
3. Developement of technology chains	Pictograms Spider-diagrams Technologiy matrices	• Choice of technologies • Technology chain alternatives • Choice of technology chains
4. Process chain development	Efficiency analysis Product web EcoPreform	• Production facility • Operation chart • Quantitative and qualitative process chain evaluation



Process chain 1

Automated processing of standard NCF

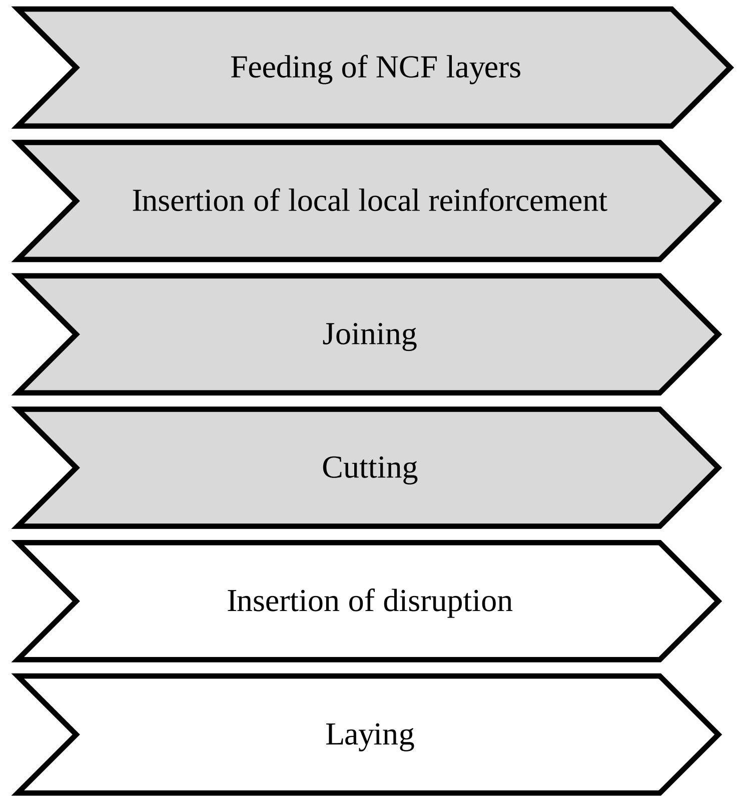
- Parallel work of preformcenter (automatic) and cutting table (controlled by a worker)
- Cutting table
  - Cutting both fabric typs
  - Positioning
- Preformcenter
  - Handling and joining
  - Edge-trimming and insertion of disruption
  - Handling / Storage



Process chain 2

Automated processing of Tailored NCF

- Synchronous execution of process steps
  - Feeding of non-crimp fabric layers
  - Insertion of local reinforcement
  - Joining of all layers
  - Cutting
  - Insertion of disruption (stamping)
  - Handling / Storage



Economic evaluation

EcoPreform:

- xls.-tool developed at ITA
- Flexible, easy to use and able to analyze various process chains
- Cycle time and costs

Approach:

- Entering basic data into EcoPreform
  - Database (experimentally generated)
  - E.g. costs, speeds, materials, machines,...
- Modelling process modules
- Modelling the described process chains
- Calculating cycle time and costs for different lot sices

Economic evaluation

- EcoPreform

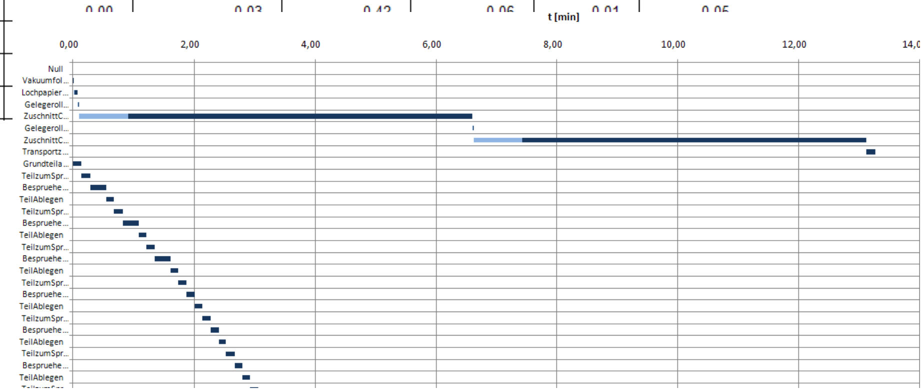
Preformcenter	
Anschaffungspreis (€)	500.000,00 €
Nutzungsdauer (Jahre)	10
Zinssatz (%)	
Benötigte Fläche (m²)	
Leistung lt. Leistungsschild (kW)	
durchschnittliche Leistungsausnutzung (%)	
durchschnittliche Leistungsaufnahme (kW)	
Anteil der gesamten Instandhaltungskosten am Anschaffungspreis (%)	
berechnete Instandhaltungskosten (ges.)	

ZuschnittCutter	Daten eingeben	Eingabedaten löschen	Gesamtkosten	Maschinenkosten	Lohnkosten	Materialkosten	Gesamtzeit	Nebenzeit	Hauptzeit	Prozess
		Übersicht Prozessschritt:	5,87 €	0,11 €	5,71 €	0,04 €	6,50	0,80	5,70	

Tätigkeit	Element		Einzelwert	Einheit	Verbrauch	Kosten
Vorbereitung Material	Bediener		0,538833333	€/min		- €
	Cutter	CuttertischEinzelrollenzufueh	0,02	€/min		- €
Vorbereitung Maschine	Bediener		0,538833333	€/min	0,8	0,86 €
	Cutter		0,02	€/min	0,8	0,01 €
	Schneidwerkzeug	CuttertischKlinge	10	€/Stück	0,004	0,04 €
Cutten	Bediener		0,538833333	€/min	2,50	2,69 €
	Cutter		0,02	€/min	2,50	0,04 €
	Cutter Zusatzzeit		0,02	€/min	1,20	0,02 €

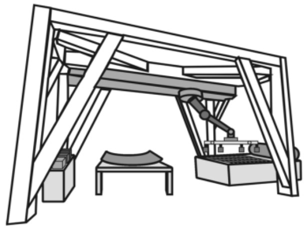
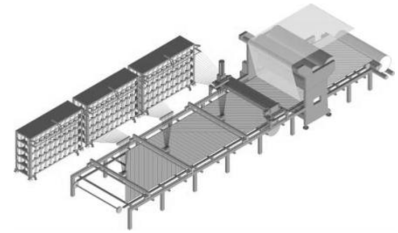
Parameter	Einzelwert	Einheit
Schnittgeschw.	2,00	m/min
Schnittlänge	4500	mm
Komplexitätsfaktor	90,00	%
Standzeit Wkz.	600,00	min/Stück
#Bediener Vor Mat	2	
#Bediener Vor Mas	2	
	2	
	2	

Prozesskette	Index	Rüstfaktor	Verhältnis zum vorherigen Schritt	var.Start	Gesamtkosten	Maschinenkosten	Lohnkosten	Materialkosten	Gesamtzeit	Nebenzeit	Hauptzeit
Null	1	1,00			-	-	-	-	-	-	-
VakuumfolienrolleEinlegen	14	1,00	○ par ◉ seq ○ A seq ○ A par ○ var		0,19	0,00	0,01	0,18	0,02	0,00	0,01
LochpapierrolleEinlegen	13	1,00	○ par ◉ seq ○ A seq ○ A par ○ var		0,45	0,00	0,03	0,42	0,06	0,01	0,05
GelegerolleEinlegen	2	1,00	○ par ◉ seq ○ A seq ○ A par ○ var		3,07						
ZuschnittCutter	3	1,00	○ par ◉ seq ○ A seq ○ A par ○ var		5,87						
GelegerolleEinlegen	2	1,00	○ par ◉ seq ○ A seq ○ A par ○ var		3,07						

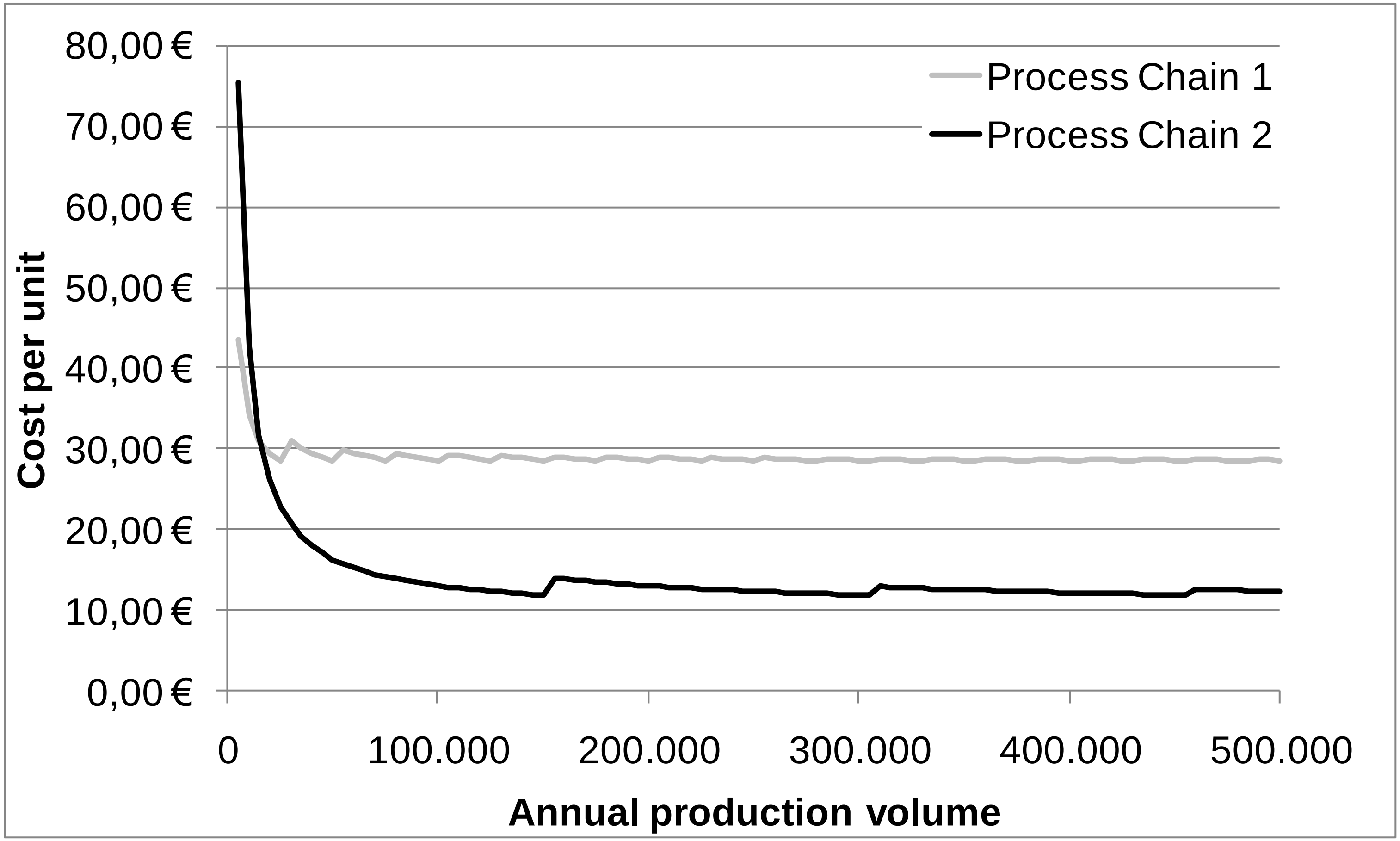


EcoPreform (screenshots)

Economic evaluation: results

	Process chain 1 	Process chain 2 
Cycle time [min]	13,4	2,3
Cost per piece [€]	28,6	11,9
Share of material costs [%]	25,7	57,0
Share of wages [%]	61,2	24,5
Share of machine costs [%]	13,1	18,4
Purchasing cost [€]	573.400	2.190.500

Economic evaluation: cost/unit over annual volume



Economic evaluation

Final evaluation of process chain 1 and 2:

- Process chain 2 (Tailored NCF) is more suitable for production of shaped part with local reinforcement
  - Lower unit costs
  - Reduced cycle time
  - Reduced processing time

➢ High potential of Tailored NCF for mass production

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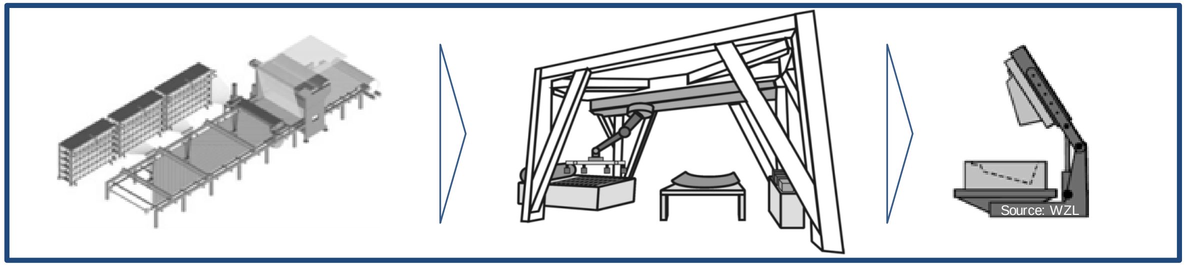
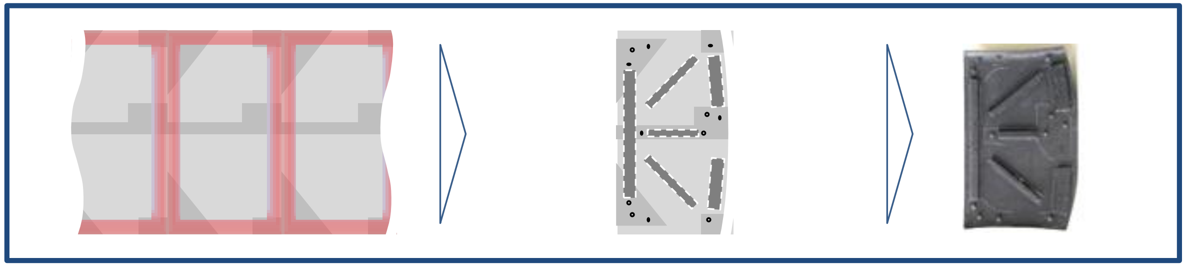
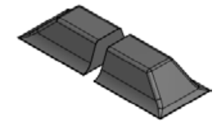


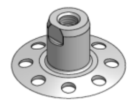


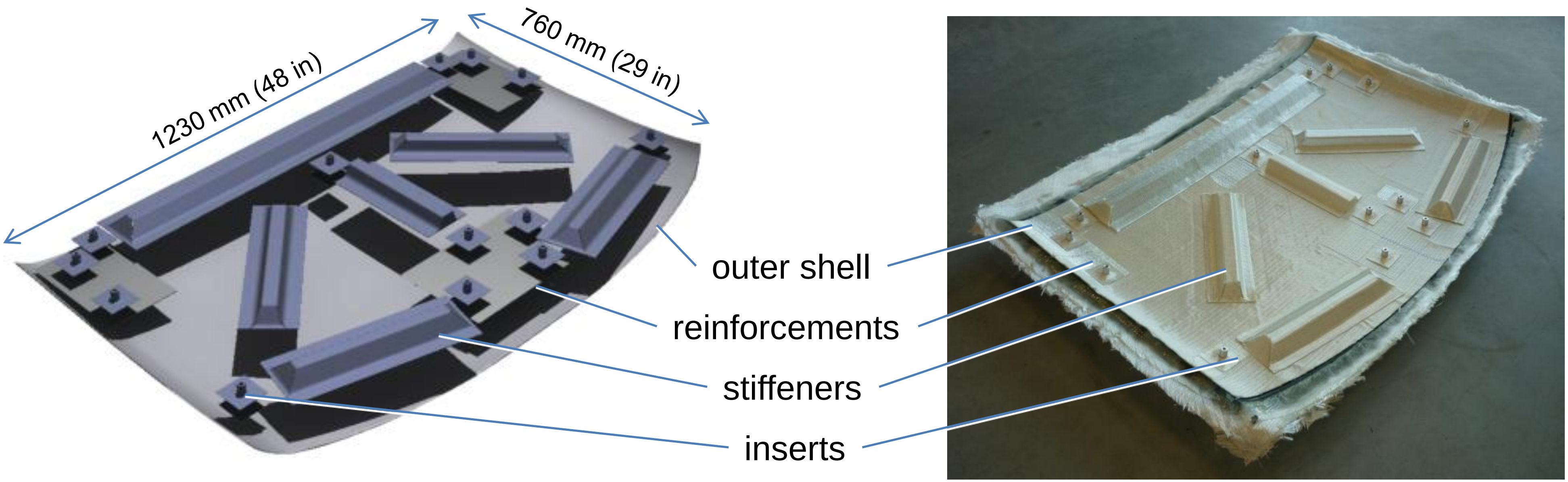
Case study: BMW 3 series convertible roof segment

Shell: 8 layers of glass fibers, quasi-isotropic (0°, 90°, ±45° | ±45°, 90°, 0°), 210 g/m² each

Reinforcements: 4 layers of fibers

Stiffeners: Polymethacrylimid (PMI) foam core with 8 layers glass fiber draping 

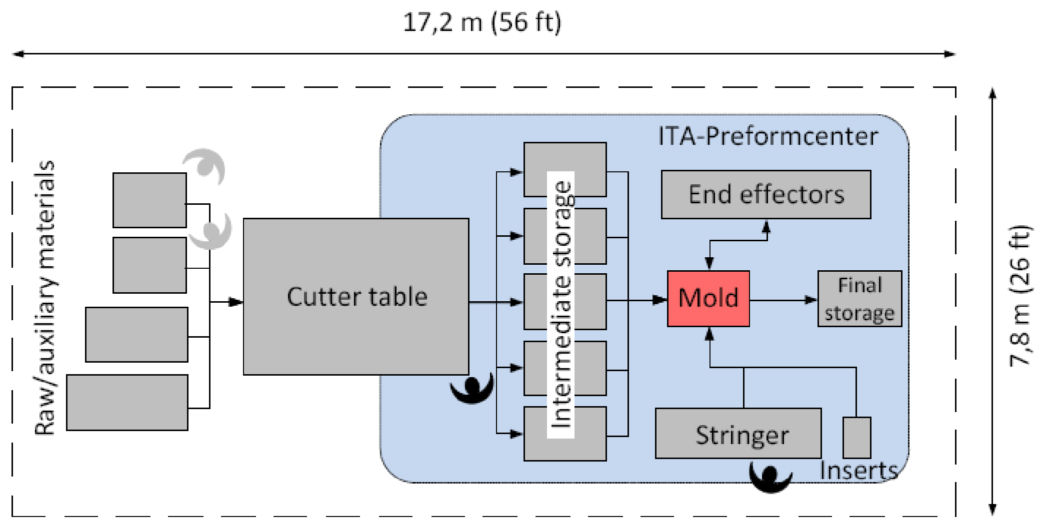
Inserts: CNC-machined aluminum 



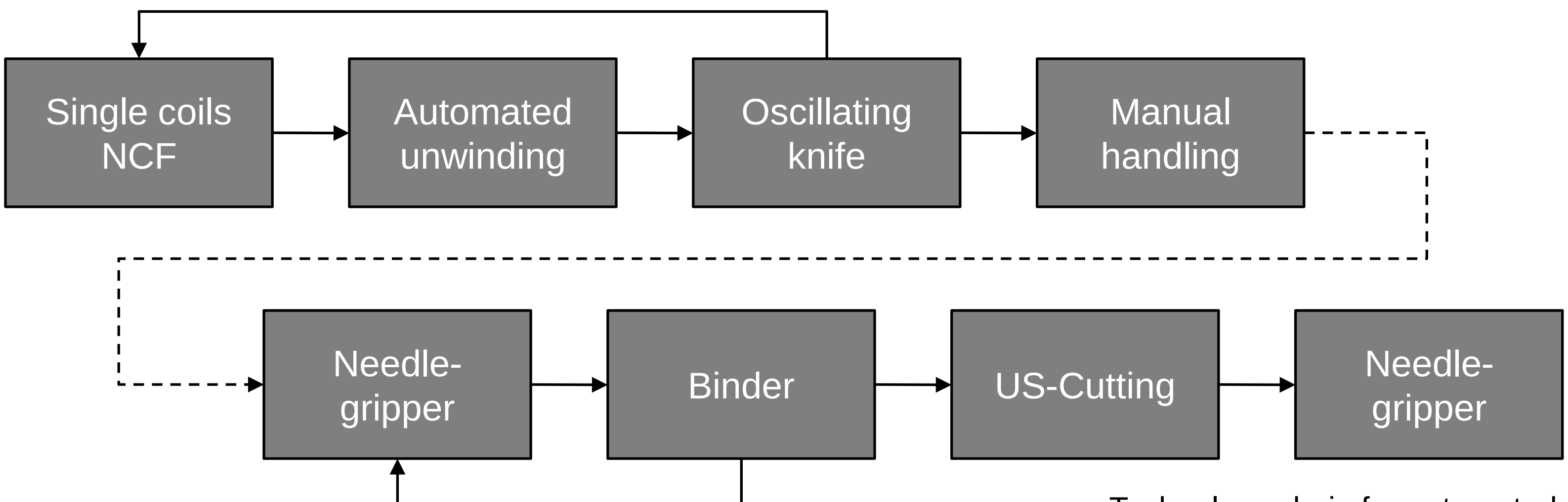
Process chain 1

Automated processing of standard NCF

- 36 process steps
- 2 parallel processes
  - *Cutting*
  - *Preforming*



Layout process chain 1

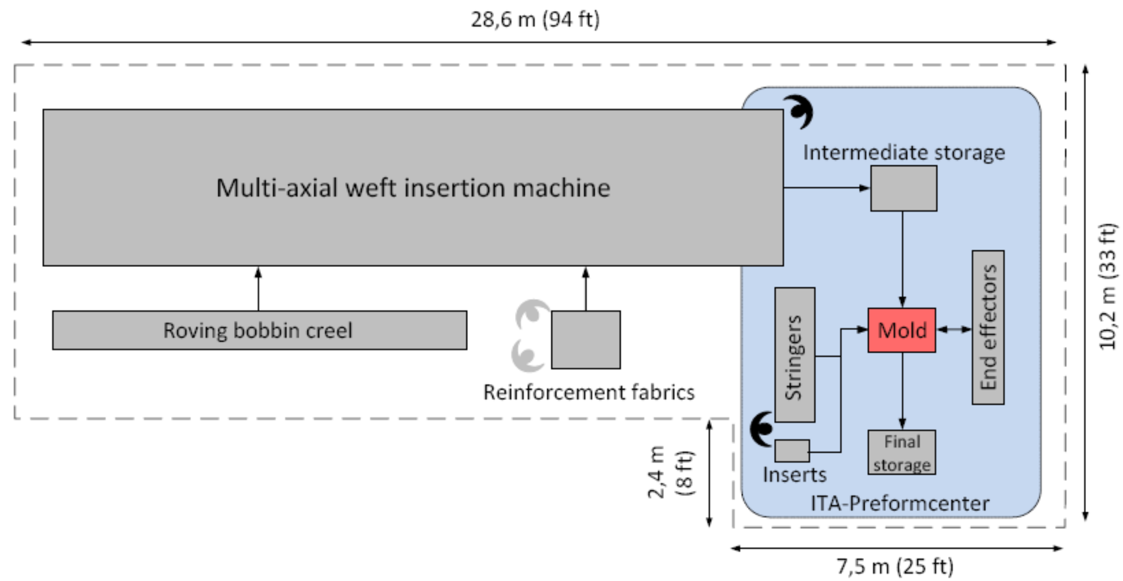


Technology chain for automated processing of standard NCF (process chain 1)

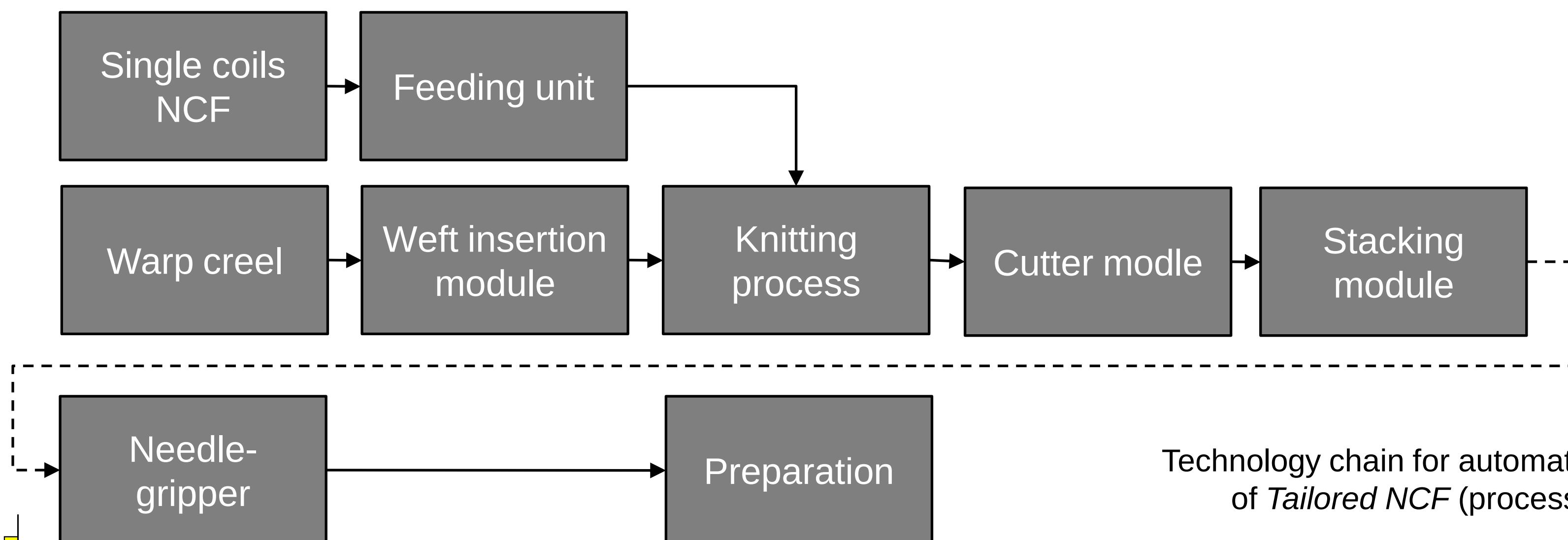
Process chain 2

Automated processing of *Tailored NCF*

- 17 process steps
- 2 parallel processes
  - *Single-Step Preforming*
  - *Multi-Step Preforming*



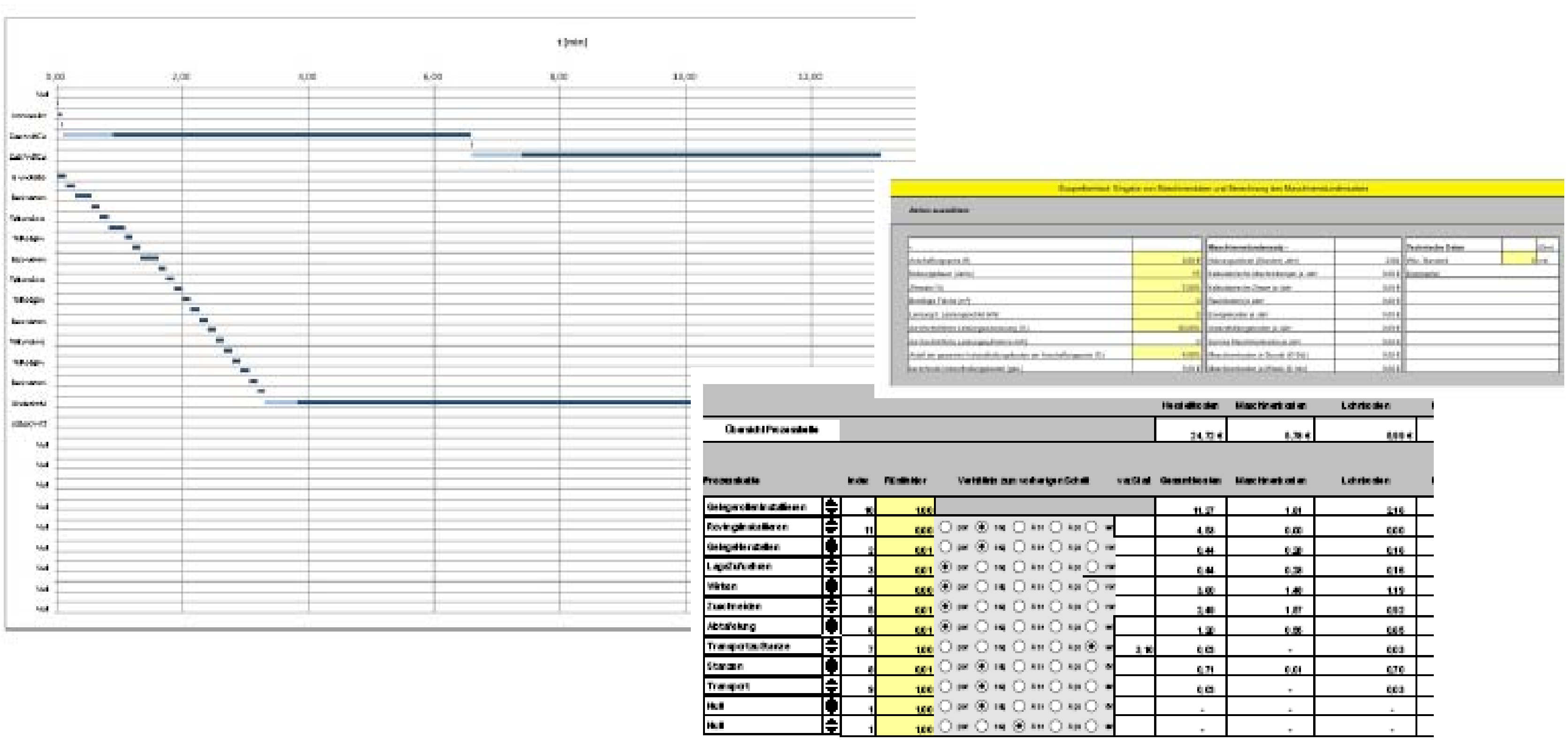
Layout process chain 2



Technology chain for automated processing of *Tailored NCF* (process chain 2)

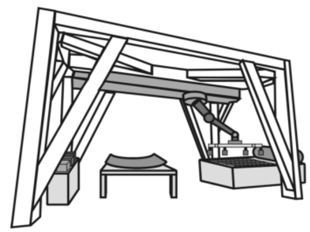
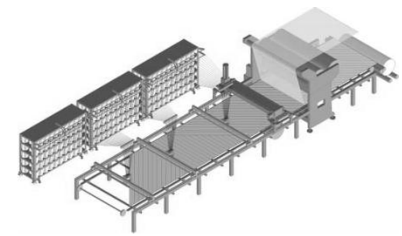
Economic evaluation

- EcoPreform
  - Production examined for one year periods
  - Linear depreceation of machinery within 10 years

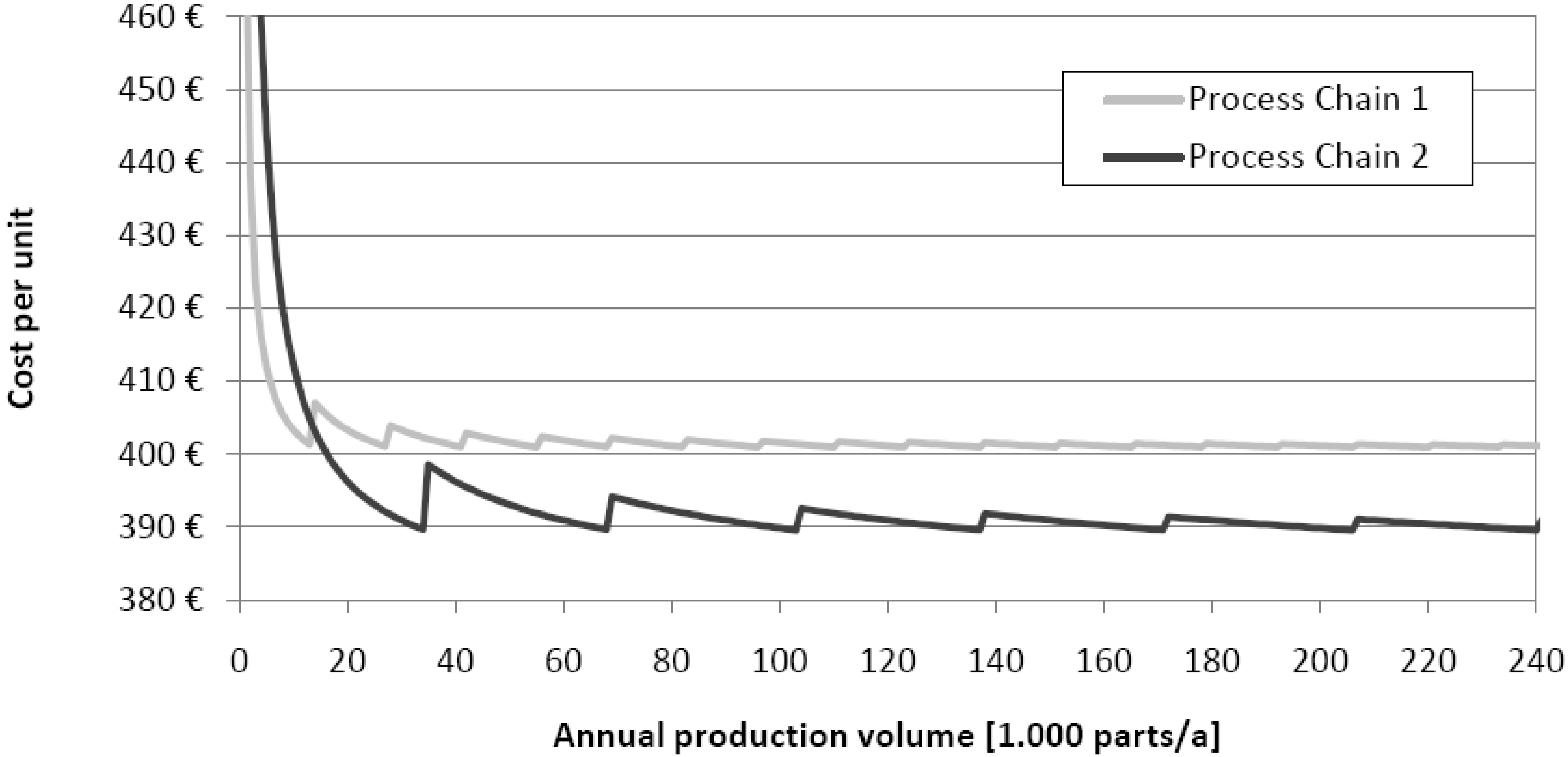


EcoPreform (screenshots)

Economic evaluation: results

	Process chain 1	Process chain 2
		
Cycle time [min]	20,8	8,3
Cost per piece [$]	598,6	590,3
Share of material costs [%]	93,6	95,6
Share of wages [%]	5,1	2,8
Share of machine costs [%]	1,3	1,6
Purchasing cost [€]	589.400	2.240.500

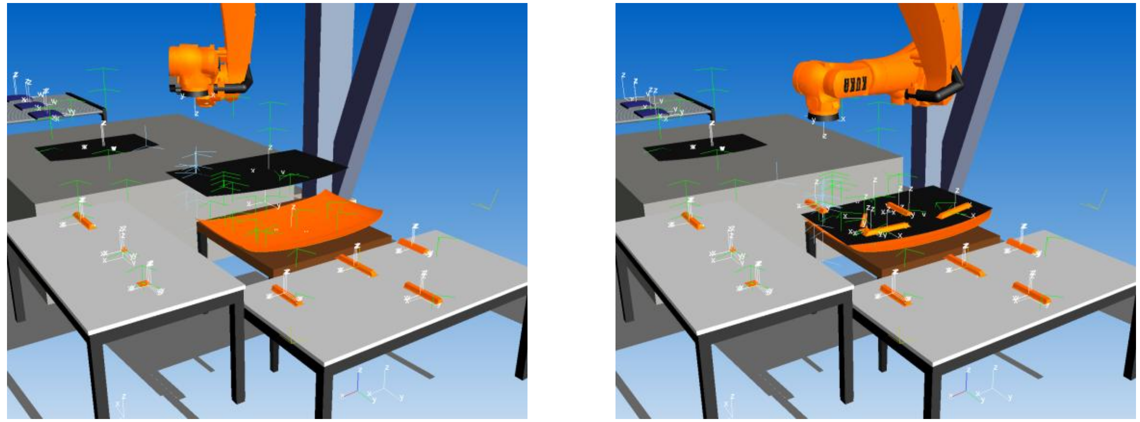
Economic evaluation: cost/unit over annual volume



Validation

Process simulation

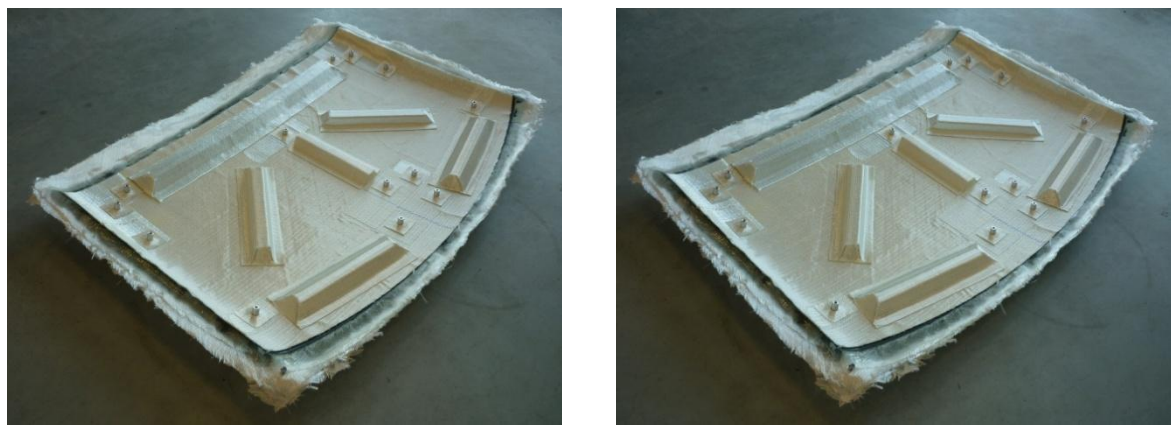
- Software *KukaSim Pro*



KukaSim Pro (Screenshots)

Praktikal validation

- Implementation of both process chains at ITA

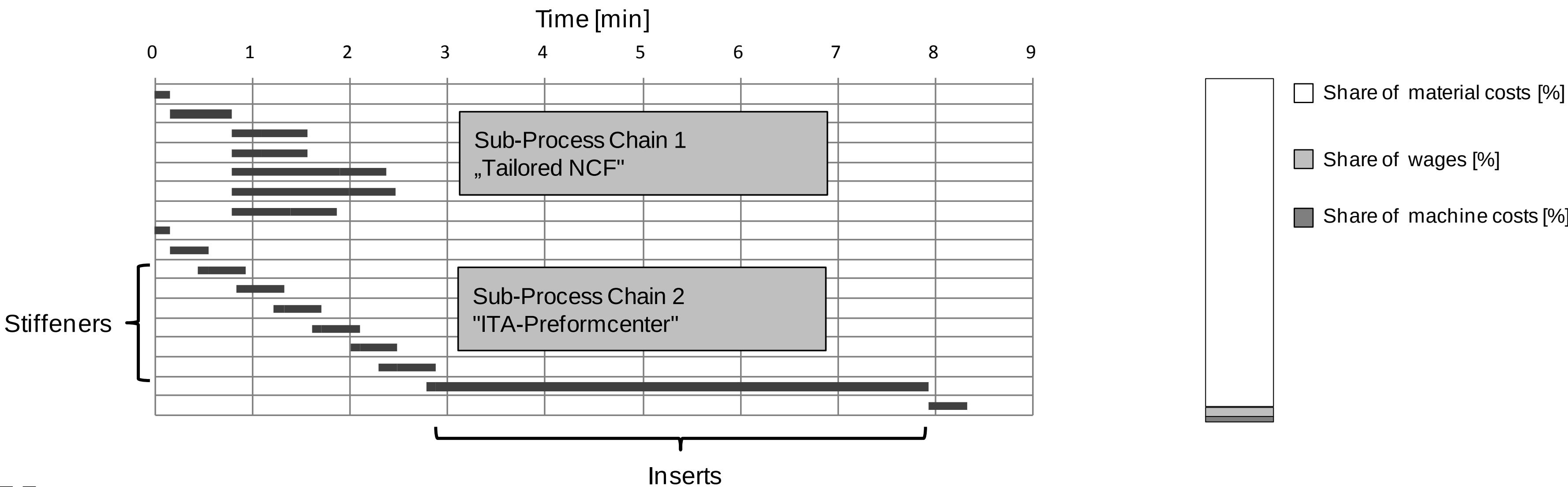


Demonstrator Preforms

Iteration / Optimization

Process analysis / optimization

- Process chains are dominated by material costs (~ 95%)
  - Expensive purchase parts (Stringer, Inserts (> 90%!))
  - No material-specific part design
- Cycle time can be reduced to 3.5 minutes
  - Parallelization of stiffener handling
  - Parallelization of Insert handling



Economic evaluation

Final evaluation of process chain 1 and 2:

- Process chain 2 (Tailored NCF) is more suitable for production of convertible roof segment
  - Lower unit costs
  - Reduced cycle time
  - Reduced processing time

➢ High potential of Tailored NCF for mass production

Extended economic evaluation

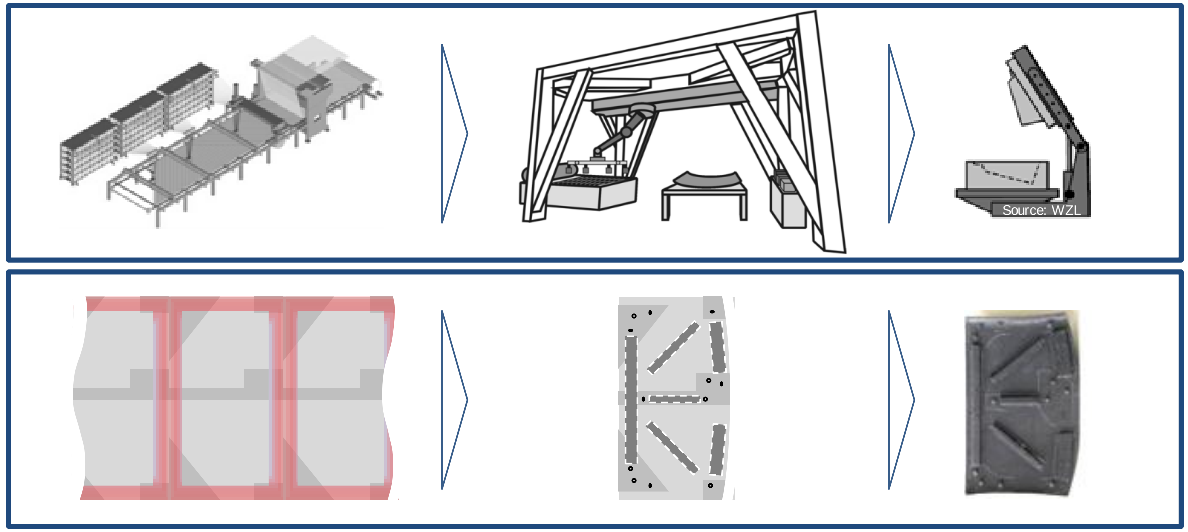
Extended evaluation

- Overhead costs (distribution structure)
- Dynamic economic evaluation
- Life cycle assessment (LCA)
  - Cradle to gate
  - Cradle to crave

Source: scienceinthebox.com

Content

- Introduction
- Single-step preforming
- Multi-step preforming
- Preliminary case study
- Case Study
- Conclusion



Conclusion

Automated production technologies for textile preforms are the key to a cost-efficient production of fiber reinforced plastics

- Continous production of Tailored NCF with locally adjusted properties
- Automated preform assembly for the production of complex, near net-shape textile reinforcement structures

- Both cycle time and costs can be reduced significantly
- Developed technologies have high potential for mass production

We would like to thank the Deutsche Forschungsgemeinschaft (DFG) for supporting and funding the FOR860 working group of researchers (“The development of new process chains for fibre-reinforced plastic components and the integration of preforming, forming and crosslinking processes”).

Thank you for your Attention!

Contact: andreas.schnabel@ita.rwth-aachen.de