ADDMANU – An Austrian Lighthouse Project for Additive Manfacturing

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***Abstract*— AddManu is a national Austrian flagship project for research, development and the establishment of additive manufacturing. There are four topics defined as key technologies for additive manufacturing: Lithography based manufacturing (LBF), Fused Filament Fabrication (FFF), Laser beam melting (LBM) and the InkJet printing. These have, from today's perspective, the highest potential for applications and further developments. The first results (process concept and first printing trails) of Inkjet printing of the project are presented in the paper.**

Keywords: Additive manufacturing, 3D Printing, Lithography Based Manufacturing (LBF), Fused Filament Fabrication (FFF), Laser Beam Melting (LBM), InkJet printing

I. INTRODUCTION

To reach a significant progress beyond the state of the art in additive manufacturing, an extensive discussion of various technologies, which can be achieved only by a large consortium with various technology know-how, is necessary. This is the idea of the lead project AddManu.

The process of InkJet printing on 3D curved surfaces has different challenges which must be solved in the project (Materials, Process, Quality Control). The issue of appropriate materials as well as a precise knowledge of the process must be integrated in a suitable system. Each component of the system must work exactly with all others and must be optimized in hard- and software. The idea of robot-based InkJet printing is the key issue and it is described in this paper, together with the material, soft and hardware requirements. The purpose of the article is also the presentation of the first results after the concept phase.

The rest of the paper is structured as follows. Section II presents an overview of the consortium, the project goals and the motivation as well as the key facts of the project. Section III shows a general overview of the technical work, followed by a more detailed description of PROFACTOR´s work inside the consortium. This is focused on the development of basics for a multimaterial hybrid manufacturing technology based on InkJet printing. In addition, the concept of robot-based ink jet printing and material development is presented. Section IV provides an overview of the first results. Section V concludes the paper.

II. THE ADDMANU PROJECT

A. General project description

The Lead-project AddManu [1] will form a national research network with an international scientific board in order to find recognition and acceptance within the Austrian economy. Four AM (Additive Manufacturing) technologies are brought into focus (Lithography-based AM, Fused Filament Fabrication (FFF), InkJet and Selective Laser Melting), which have the largest potential for industrial application and further development (Figure 1). The most important families of engineering materials, i.e., ceramics, polymers and metals are included. Based on longtime expertise of consortium partners and intensive research work, the project will deal with those problems, which can be considered as barriers for further developments and economic use or which have a very high innovation potential. Within AddManu.at, the R&D-activities (Research & Development) are divided in four areas: materials development, design and dimensioning, process-specific and application-oriented aspects, each for metals and non-metals. Cross-sectional issues, like system integration are covered in a separate working package.

B. Key facts

The work of AddManu was launched in May 2015 and will run until April 2018th. The projects involve 19 different partners from research and industry, which are the key players for additive manufacturing in Austria [5]. The partners are situated along the manufacturing value chain from basic research to industrial implementation, from material development, process development to manufacturing and product development.

The following industrial sectors were addressed:

- Materials/Surface Technologies
- Plant Construction
- Machine Building Industry and Engineering
- Automotive
- Aerospace Industries
- Research, Science and Education

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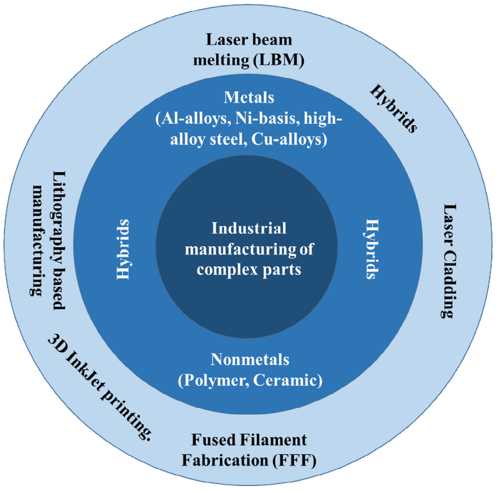

Figure 1. AddManu´s overall concept [1]

C. Objectives:

The most important objectives are:

- Material developments for improved processing and service properties of AM-built components, like new powder materials and hybrids (composites, segmented structures, etc.)
- The innovation potential of AM-processes will primarily depend on the designer's creativity and the use of sophisticated FEM (Finite element method) [14] -software packages for light weight design. By adaption of methods like topology and shape optimization to AM-specific issues and coupling with extremely fine lattice structures, novel solutions are generated and new user markets can be generated.
- Process developments for AM-technologies, lithography-based AM, Fused Filament Fabrication and InkJet.
- The industrial implementation of novel AM-concepts within the fundamental R&D areas will be done in separate working packages, which are dedicated to the branches mechanical engineering, tooling, automotive engineering, semiconductor industry, refractory industry and aerospace industry. Solutions will be searched, which offer significant competitive advantages.

The most important deliverables and findings will be:

- Development of new materials (metal powders, ceramics and thermoplastic photopolymers) with significantly improved material properties.
- Development of an AM-concept to build hybrid components made of metal/ceramics, steel/aluminum
- Development of novel lithography-based AM-processes with significantly improved resolution and higher operational capacity.
- Development of post-processing-methods to improve the surface quality of AM-built products.
- Development of new industrial applications taking into account the whole processing chain.

D. Thesis of AddManu

Success stories for additive manufacturing show us that a simple substitution of existing manufacturing technologies without increasing the complexity of part geometry or/and a better integration of the part functionality is not really productive.

Therefore the AddManu project is mainly based on four leading hypotheses: These four hypotheses determined the research agenda of the project, the objectives, the project structure and the consortium. These hypotheses are also aligned with the defined goals of the call and the definition of a "lead project" and with the industrial needs.

HYP1 Freedom of Design: Additive manufacturing allows manufacturing of complex parts with significantly less financial effort and with reduced equipment compared to conventional technologies. So, a cost neutral "Freedom of design" exists and leads to a higher integration of functionalities in parts or units. Examples are light weight constructions or manufacturing without assembly. One result of this is that, overtaking existing or classic design from the conventional manufacturing into additive manufacturing, a main benefit from additive manufacturing is not taken into account.

HYP2 Flexibility of fabrication: Additive manufacturing requires, in general, no tooling costs and also low set-up costs. The outcome of this is a massive advantage in logistics, so new business models for custom made parts are possible. An on-side production is of great interest again, and additive manufacturing is a key component for Europe's Re-Industrialization.

HYP3 Rules of scaling: The up-scaling of the part costs in additive manufacturing is directly proportional to the manufactured volume. Costs of additive manufactured parts are not really depending on lot sizes. This is in contrast to tooling based manufacturing (injection molding, forging). So, additive manufacturing has its advantage in manufacturing of high complex parts and small lot sizes.

HYP4 Process integration and shortening the value chain: The classic manufacturing chain consists of independent suppliers for material, design (CAD/CAM - (computer-aided design/manufacturing) and production (milling/CNC - Computerized Numerical Control - machines). Additive manufacturing benefits from fewer requirements as far as design for manufacturability is concerned, but knowledge from the whole manufacturing chain (material to production) is needed at almost every step in the manufacturing chain to be able to profit from potential benefits. Design, material and process are dependent on each other. New business models must face this fact from the beginning to be successful.

III. PROFACTOR´S TASK

The project partner PROFACTOR [9] is inside AddManu Workpackage Leader and is developing a basis for a multi-material hybrid manufacturing technology based on InkJet

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printing. The challenge is that InkJet printing should be done on 3D curved surfaces of parts which are pre-manufactured with other processes or technologies developed in AddManu, i.e., an advanced FFF process. The goals of the tasks are divided in 4 different parts which enable a new process technology (Figure 2).

- Development of UV (ultra violet) curable Inks for multi-material hybrid manufacturing technologies
- Research on printing processes using InkJet printing on FFF pre-manufactured free-form parts.
- System and process development of free-form printing using a robot based Ink-Jet printing system.
- Development of a non-destructive quality control system using machine vision.

The general approach of the new multi-material hybrid manufacturing process is that additive technologies promise new functionality.

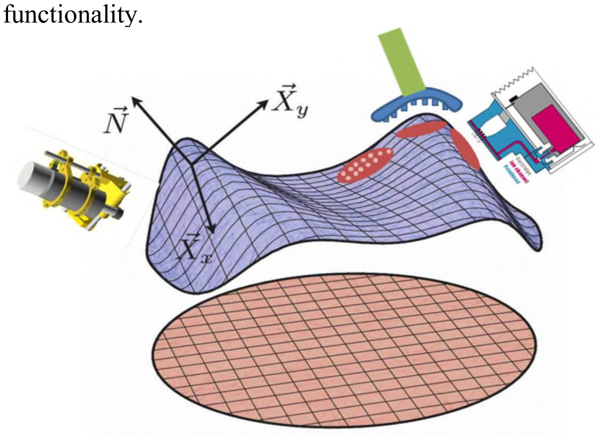

Figure 2. InkJet printing on curved sufaces with robots and inspection systems

To design a pilot system, several challenges must be solved. These challenges include: InkJet printing to apply the imprint material on the right spot (Figure 3) and 3D machine vision [2] (Figure 4) in combination with robotics [3][4] (Figure 5) to position the print head above the 3D-printed surface.

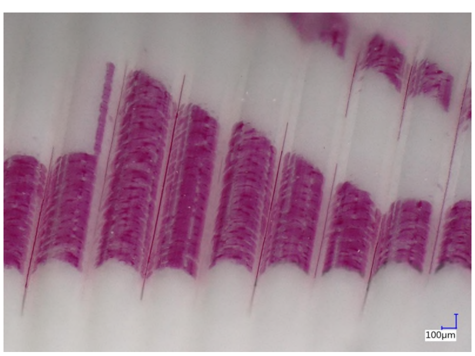

Figure 3. Optical micrograph of InkJet printed UV-curable ink on a 3D-printed surface.

The curvature resulting from the 3D-printing process can clearly be seen in Figure 3.

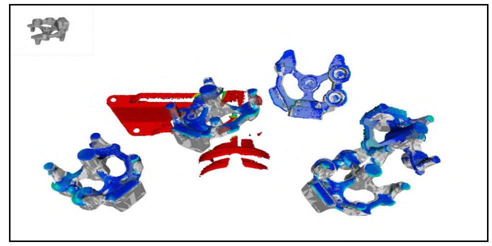

Figure 4. Illustration of the use of the Candelor software library to identify objects (grey/blue) within a 3D pointcloud (red). [2]

Figure 5. Photograph of a robot while measuring

A detailed work plan with different steps and milestones is defined to reach the goal for a prototype installation.

A. *Description of activities*

The first step is the development of functional special inks which optimize the 3D surface of an FDM manufactured part with respect to chemical/mechanical stability and water tightness printable on 3D FFF surfaces. Additional to this, a second special Ink is developed. This Ink is for surfaces with special haptics (rubber like).

These special Inks will be printed by a robot-controlled Ink Jet head on 3D free form surfaces.

The robot assisted 3D InkJet system and the necessary process planning software respecting the critical parameters (printing distance, angle of printing head to the vertical, printing velocity and angle to the substrate) and a collision free path planning will be designed and developed. Enabling a constant coating (printing) speed flow rate and quantity will be coordinated and highly dynamic.

Recognizing the topography of the substrate to be coated and for determination and controlling of critical parameters it is necessary to implement a 3D-control system. This could be also used as quality control system. Surface roughness and other fails are registered, rated and corrected if necessary.

The goal is a proof of concept demonstrator for a multilayer printing of FFF manufactured 3D printed freeform parts using InkJet printing. It will be only printed on the areas where it is necessary for correction of geometry or functionalisation of the part. The technology to be developed is based on existing PROFACTOR Knowhow [10].

B. *Method:*

According to concept descript above, special InkJet Inks for multi-material hybrid-manufacturing will be developed.

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A test bed for robot assisted 3D InkJet Printing will be built in parallel and the necessary software for the control system developed. Developed InkJet Inks will be tested and evaluated against their printing behavior and their functionality. For identification of the part topography an adequate 3D control system will be designed and implemented.

C. *Deliverables*

- Functional special Inks with optimised properties (chemical/mechanical stability, water tightness) printable on 3D FFF surfaces.
- Functional special Inks with optimised haptics printable on 3D FFF surfaces.
- Robot controlled InkJet printing head with process control for printing on 3D free forms.
- Non-destructive quality control system based on machine vision.

IV. FIRST RESULTS

The first results of the project are available at this time, after one year from the start of the project, and are represented mostly by theoretical/concept level results. The design of the robot based process is finished and an analysis of possible technologies for vision control systems was done. Additionally, the first experimental results of printing trials on curved surfaces are available.

A. *Robot controled InkJet printing head with process control for free form printing*

The work was divided into software and hardware related research.

Hardware: The necessary hardware is the printing head, ink transport system, meniscus control system, drivers for the printing head with master control unit und slave control unit and the software for controlling the printing head and to integrate the head into the robot.

Parameters which were important for the decision of the printing head included only one supplier for all components and also an open software system. At the end, a Ricoh Gen 4 [11] printing head was chosen (Figure 6).

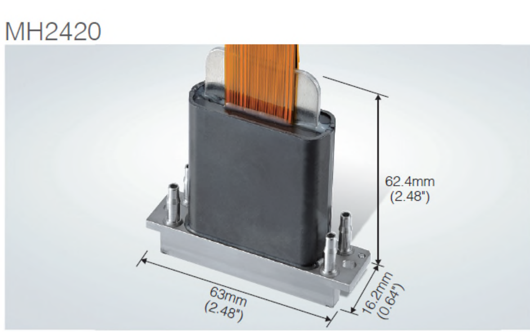

Figure 6. Ricoh Gen 4 MH2420 printing head

Reasons for the decision:

- Compact Dimension: In general, compact dimensions are an advantage for the integration on the robot. Additional it's a benefit for printing on curved surfaces if the printing area is not too broad. Other printing heads are broader, e.g., Dimatix Spectra 150mm, Xaar 501 125mm. Konica Minolta 512 printing head is match-able with 67mm wide (32,4mm printing wide). A smaller printing enables a better printed image over the total printed area, because the variation of the distance from printing head to the surface can be better controlled.
- Integrated heating: If we use a printing head with integrated heater, then inks which do not have a suitable viscosity at room temperature could also be used. It is not necessary to heat the Ink transport system and therefore the whole system could be easier integrated into the robot system.
- Dumping: The printing head could be also used in a dumped or sloped position for printing. This is an essential feature for printing on curved surfaces.
- Compatibility with project partner TIGER´s [8] Heavy Duty Ink: TIGER Inks were already tested with this printing head.

Mechanical design and construction: Based on an analyses of accessibility the most convenient robot position (Industrial Robot model Stäubli TX90L) [12] for a square working space (800x800mm) was determined (Figure 7).

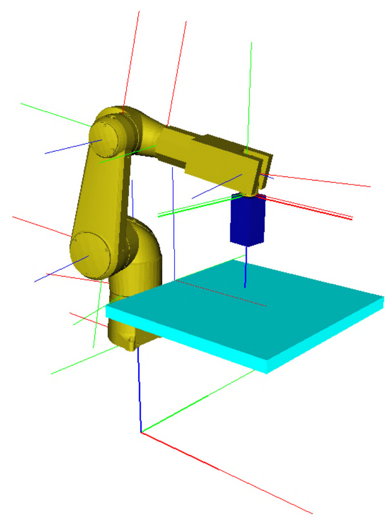

Figure 7. Simulation – Analyses of accessibility

Requirements to the tool holder are

- Automatic tooling system for an easy demounting of the printing head from the robot arm
- Mechanical fixtures for
  - Printing head (Ricoh Gen IV MH2420)
  - Driver board (Ardeje)
  - Ink-storage (2 nozzles with connecting tubes)
  - Automatic tooling system
- For safety reasons the robot system has to operate behind a mechanical disconnecting safety installation (fence)

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- A PC-working place is situated near the system
- The controller for the printing head must be situated close to the robot caused by limited length of wires (robot foot)

For the robot assisted InkJet printing process, the necessary system components are shown in Figure 8.

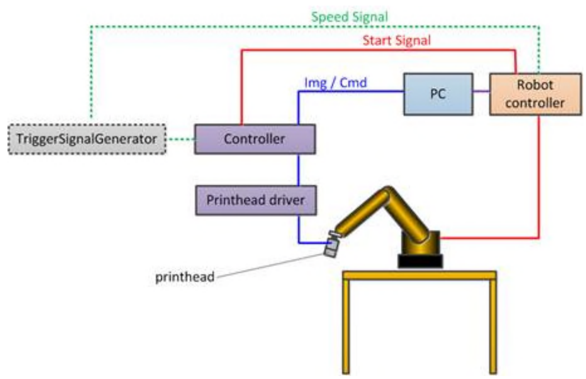

Figure 8. System overview of robot based printing system

A PC creates a robot program for guiding the printing head simultaneously with a command list for the (printing head) controller. This controller starts the real printing process. For synchronizing of single printing commands with the spatial position we cannot use path points, because the necessary high frequencies are not available. So we use between the sychronisation points a trigger signal which is generated by a frequency generator and depends on the instantaneous velocity.

Software: For the configuration and the activation of the control a firmware of the controller manufacturer is used. Figure 9 shows the suggested workflow for printing (disregarding the path planning for the robot).

Using the software module „Image composition“ a printing picture is created and prepared for the Printing Head controller by a special „Raster Image Processing“ Software - module.

In this step, vector-graphics are calculated into raster-graphics, resolutions are converted, color channels separated and color management processes executed. Precompiled information is sent to the controller. This controller needs afterwards only a start signal (Enable) and the “feed” signal (synchronized with the robot movement)

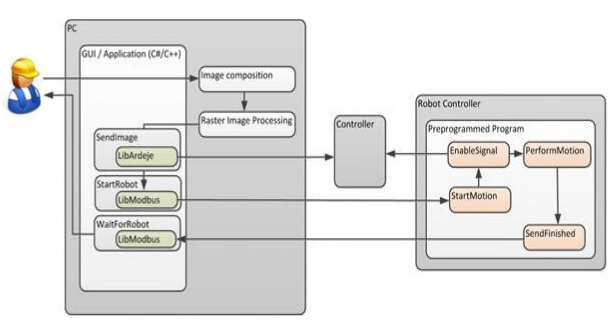

Figure 9. Work flow „priniting on an known path“

B. First printing trails with heavy duty ink on curved surfaces

First InkJet printing trials were done on 3D printed surfaces (FFF) using a Heavy Dury Ink from TIGER. Used Substrate were FFF printed parts without any pre-treatment. The material was white PLA (Polylactides from Orbi-Tech) [13] which was printed with a HAGE 3Dp-A2 printer in the Labs of PROFACTOR. The thickness was, in most cases 0.4mm printed at 210°C. The geometry of the teste samples was a simply cuboid (75x25x10mm³, 30% infill). The side areas were used for the InkJet printing (Figure 10).

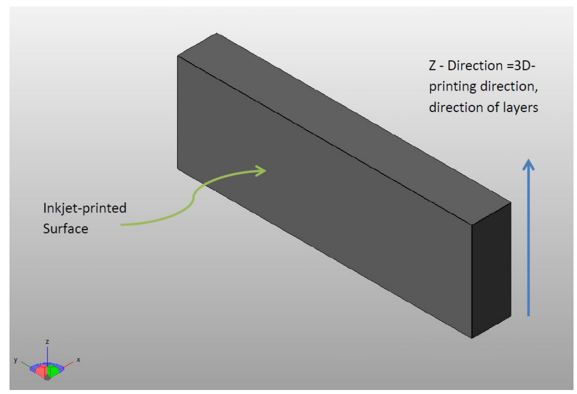

Figure 10. Explaination of test printing

In the first trails, the results are three important findings:

- Adhesion on PLA substrate is very good, even without pre-treatment of the substrate good results were reached.
- The printed image was strongly influenced by the capillary effects. These capillaries occur during the FFF process.
- Curing with UV-LEDS (Ultraviolet Light-emitting diode) (395nm) worked very well in a few seconds (also in Air).

Figures 11 -14 are showing the first test samples. Missing horizontal lines are caused by suboptimal parameters on the used Dimatix printer and are not dependent upon the 3D printed substrate.

Figure 11. Overview of printed sample, lenghth ~ 55mm

Figure 12. Details of printed sample

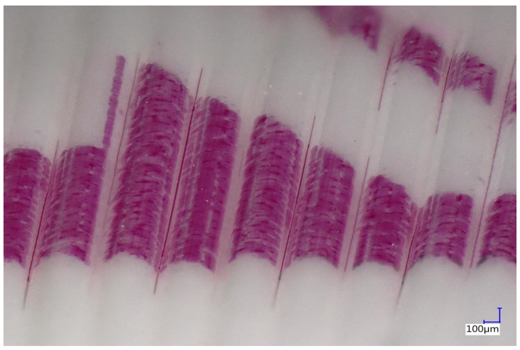

Figure 13. Angular view of sample, FFF Layers are visible well, luting caused by cappilary – effects

By choosing a greater distance between the drops the capillary effect could be reduced. It is better (for example) printing 2x50 µm drop distance than using 1x25µm. A smaller layer thickness (0.2mm instead 0.4mm) raised the possibility that drops are getting inside the small channels.

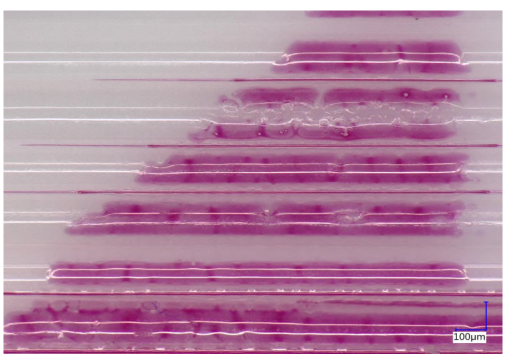

Figure 14. PLA 0.2 mm thickness-missing lines as a consequence of not using opmimized printer parameters

V. CONCLUISION AND FURTHER WORK

A. Conclusion

Multilayer printing on FFF manufactured parts needs a lot of processing and also material development to be successfully implemented and brought to Industry. The first steps of a proof of concept show promising results, but each component of the system has to be optimized on its own and in the system.

B. Further work and next planned steps

Based on the studies and on the results of the first printing tests, the next steps will be:

- Installation and implementing of printing head and robot in the PROFACTOR Lab
- Ongoing printing tests and generation of parameters for further Ink Development and for advanced Robot set up
- Trails for Quality control with existing equipment of PROFACTOR and implementing the best fitting technology into the printing system
- Surveying test samples from other project partner to find a set of parameters for quality control
- Ongoing Haptic- Ink development by project partner TIGER and testing this new inks at the lab and with the robot system
- Optimisation of printing parameters and comparison of equal inks with different colours.

All steps will be done in a strong interaction with industry to have a feedback and a "closed loop" development which meets the industrial requirements.

ACKNOWLEDGMENT

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REFERENCES

[1] AddManu: Avialable online at www.addmanu.at

[2] Candelor: Avialable online at http://candelor.com

[3] E. Weigl, W. Heidl, E. Lughofer, C. Eitzinger, and T. Radauer, On improving performance of surface inspection systems by on-line active learning and flexible classifier updates, Machine Vision and Applications, 27(1), 103-127, Jan. 2016, doi:10.1007/s00138-015-0731-9.

[4] E. Weigl, S. Zambal, M. Stöger, C. Eitzinger, Photometric stereo sensor for robot-assisted industrial quality inspection of coated composite material surfaces, QCAV 2015, SPIE Proceedings Volume 9534, 2015, doi:10.1117/12.2182750

[5] Austrias Key Players in Additive Manufacuring avialable online at http://www.addmanu.at/de/4886/ and http://www.addmanu.at/de/4885/

[6] BMVIT- Avialable online at www.bmvit.gv.at/en/index.html

[7] FFG – Avialable online at https://www.ffg.at/

[8] TIGER - Avialable online at http://www.tiger-coatings.com/

[9] PROFACTOR – Avialable online at www.profactor.at

[10] ANIPF project: Avialable online at: http://www.profactor.at/index.php?id=895&L=1

[11] Ricoh Gen 4: Avialable online at http://www.rpsa.ricoh.com/gen4.html

[12] Stäubli TX90L: Avialable online at: http://www.upc.edu/sct/documents_equipament/d_181_id-492.pdf

[13] Orbi-Tech: Avialable online at www.orbi-tech.de

[14] FEM Software: Avialabel online at: http://3dsim.com/