23º Seminário Internacional de Alta Tecnologia

4 OUT 2018
Teatro Erotides de Campos
Engenho Central | Piracicaba SP

DESENVOLVIMENTO DE PRODUTOS INTELIGENTES: DESAFIOS E NOVOS REQUISITOS

Renomados pesquisadores, especialistas e profissionais apresentarão os desafios, oportunidades e riscos da 4ª Revolução Industrial.

ANAIS

Editado por Klaus Schützer

23° Seminário Internacional de Alta Tecnologia

Desenvolvimento de Produtos Inteligentes: Desafios e novos requisitos

Editor

Prof. Dr.-Ing. Klaus Schützer
Lab. de Sistemas Computacionais para Projeto e Manufatura
Faculdade de Engenharia, Arquitetura e Urbanismo

04 de Outubro de 2018

Teatro Erotides de Campos – Engenho Central, Piracicaba, SP

SCPM
Lab. de Sistemas Computacionais
para Projeto e Manufatura
Prof. Dr.-Ing. Klaus Schützer
FEAU - UNIMEP

Arte e Edição:

Carolina Sallati
Eng. Júlia de Andrade Bertazzi
Silvia Regina Fronza Feltrin

Seminário Internacional de Alta Tecnologia (23. : 2018 : Piracicaba, SP)

S471a Anais do 23. Seminário Internacional de Alta Tecnologia, Piracicaba, SP, Brasil, 4 out., 2018 / editor Klaus Schützer. – Piracicaba: UNIMEP, 2018.
249 p. : il. ; 30 cm.

Tema central: Desenvolvimento de Produtos Inteligentes: Desafios e novos requisitos.

ISSN 2175-9960

1. Seminários (Estudo) - Tecnologia de ponta. I. Schützer, Klaus. II. Título.

CDU – 62

Laboratório de Sistemas Computacionais para Projeto e Manufatura

O Laboratório de Sistemas Computacionais para Projeto e Manufatura (SCPM) é um dos mais de 30 laboratórios da Faculdade de Engenharia, Arquitetura e Urbanismo da Universidade Metodista de Piracicaba. Na sua maioria, esses laboratórios estão voltados primordialmente ao ensino, possibilitando aos estudantes um primeiro contato com a realidade que enfrentarão no mercado de trabalho.

O SCPM, no entanto, foi criado com foco na pesquisa, residindo aí o seu diferencial, ou seja, sua finalidade primeira é possibilitar o desenvolvimento científico, através de projetos a serem desenvolvidos pelos estudantes sob supervisão dos professores deste laboratório. Esse é o papel que vem desempenhando ao longo dos seus mais de 20 anos de existência, sem descuidar da preservação da indissociabilidade das duas outras colunas de sustentação de uma universidade: o ensino e a extensão.

As primeiras atividades de pesquisa do SCPM foram apoiadas em dois projetos, o KIT #123 - FBaseDsgn, financiado pela Comissão Europeia, e o projeto para implantação de infraestrutura, financiado pelo *Deutsche Ausgleichsbank*. Em torno desse trabalho, aglutinou-se um grupo de alunos de graduação e pós-graduação que ajudou no planejamento e organização da primeira versão do que se tornou o Seminário Internacional de Alta Tecnologia. O primeiro evento, em 1996, introduziu no Brasil a temática da “Usinagem com Altíssima Velocidade”, que hoje é aplicada em diversas empresas.

Este grupo de pesquisa criou também o Núcleo para Projeto e Manufatura Integrados (NPMI), incluído no Cadastro Nacional de Grupos de Pesquisa do CNPq desde 1995, e que oferece a interface para integração de outros professores e pesquisadores aos trabalhos desenvolvidos no SCPM, além de participar ativamente de projetos de pesquisa em parceira com outras universidades brasileiras.

O SCPM conta hoje com uma equipe de pesquisadores em tempo integral composta de um professor titular, um professor colaborador, doutorandos, mestrandos, alunos de iniciação científica e pessoal técnico de apoio. As atividades científicas desenvolvidas são financiadas na sua maioria com recursos gerados através de projetos de pesquisa nacionais e internacionais, além da prestação de serviços e projetos em parceria com diversas empresas. A estratégia de desenvolver seus projetos de pesquisa o mais próximo possível das indústrias viabiliza uma rápida implementação dos resultados tecnológicos obtidos.

Reunir parceiros para desenvolver projetos mais arrojados tem sido a marca do trabalho do SCPM, o que resultou em parcerias estratégicas desde a sua criação, destacando o *Institut für Produktionsmanagement, Technologie und Werkzeugmaschinen* (PTW) e o *Fachgebiet Datenverarbeitung in der Konstruktion (DiK)*, ambos da *Technische Universität Darmstadt* na Alemanha. Essas parcerias já resultaram em inúmeros projetos de pesquisa em conjunto e em um contínuo intercâmbio de alunos de graduação, mestrado e doutorado, além de professores de ambos os lados.

Desde 2005, o SCPM possui também uma parceria com o *Institut für Werkzeugmaschinen und Fabrikbetrieb* (IWF) da *Technische Universität Berlin*, Alemanha, e mais recentemente com a *Hochschule RheinMain* em Rüsselsheim, Alemanha.

O SCPM dispõe de modernos recursos de hardware e software para o desenvolvimento dos trabalhos de pesquisa, atuando em quatro linhas de pesquisa: Manufatura Inteligente e Fábrica Digital; Desenvolvimento Integrado do Produto; Usinagem com Altíssima Velocidade; e Monitoramento do Processo de Usinagem; além de oferecer suporte a pequenas e médias empresas para especificação, escolha e implementação de sistemas CAD/CAPP/CAM/PDM.

Adicionalmente, o SCPM possui uma Máquina de Medir por Coordenadas Tesa Micro-Hite DCC e um Sistema de Calibração Laser Renishaw, que possibilitam o desenvolvimento de projetos de pesquisa tanto com o foco na integração digital da cadeia CAD/CAM/CAQ, como também no desenvolvimento de métodos para comparação da representação de superfícies complexas nos sistemas CAD e do modelo real após a usinagem, permitindo a avaliação de estratégias de corte e métodos de interpolação da trajetória da ferramenta.

Procurando atender às novas necessidades de empresas de pequeno e médio porte, o SCPM iniciou trabalhos de pesquisa voltados ao Gerenciamento do Ciclo de Vida do Produto (*Product Data Management* - PDM; *Product Lifecycle Management* - PLM). E hoje possui um ambiente de desenvolvimento do produto com as características de uma indústria, chamado de Fábrica para o Ensino do Processo de Desenvolvimento do Produto, atuando no projeto do produto e em simulações do processo de gerenciamento de dados do produto ao longo de todo o ciclo de desenvolvimento.

Ainda dentro de seu objetivo de trabalhar com sistemas computacionais que representem o estado da arte, o SCPM criou um grupo de trabalho para atuar no Planejamento Digital de Processos, tendo como foco o desenvolvimento de competências para atuar na temática Fábrica Digital, e hoje já realiza projetos de pesquisa nesta área em parceria com renomadas empresas.

O material didático desenvolvido pela equipe do SCPM nas áreas de projeto e manufatura auxiliados por computador, bem como em gestão do produto, tem sido utilizado não só nos cursos de engenharia da FEAU, mas também por muitas outras universidades de diferentes lugares do Brasil. Esta atuação pautada pelo trinômio pesquisa-ensino-extensão tem sido um importante processo realimentador de todo o trabalho.

Desta maneira, o SCPM, além de uma forte inserção na área de pesquisa, tem conseguido interagir de maneira positiva na definição das grades curriculares dos cursos de engenharia, trazendo o que existe de mais inovador em desenvolvimento integrado do produto, contemplando desde a concepção até a manufatura.

Atualmente, o SCPM desenvolve projetos financiados pela CAPES, CNPq e pelo DFG, além de projetos em parceria com a Volkswagen do Brasil Ltda. e a Robert Bosch Ltda.

Mesmo enfrentando as dificuldades e os desafios inerentes à conjuntura brasileira e à uma universidade particular, o projeto do SCPM visa uma formação ampla de seus pesquisadores e estudantes, enfatizando o aspecto da pesquisa e a inserção internacional de sua equipe através de intercâmbios, destacando-se assim dentro do projeto institucional como um moderno provedor de serviços, dedicado às necessidades dos alunos que atuam no laboratório, das indústrias com as quais tem desenvolvido projetos e da sociedade no seu todo.

Visando ampliar a sua atuação em pesquisa aplicada junto às empresas localizadas no Brasil e na prestação de serviços, o SCPM passou também a atuar, a partir deste ano, através da microempresa SCPM Soluções Computacionais para Projeto e Manufatura Ltda., o que lhe garante a agilidade, confiabilidade e atenção requeridas para sua atuação no mercado.

Universidade Metodista de Piracicaba
Faculdade de Engenharia, Arquitetura e Urbanismo
Lab. de Sistemas Computacionais para Projeto e Manufatura
Rod. Luis Ometto (SP 306), Km 24
13.451-900 Santa Bárbara d´Oeste, SP
Tel: (19) 3124-1792 Fax: (19) 3124-1788
E-mail: labscpm@scpm.unimep.br
Home Page: http://www.scpm.eng.br

Parceiros SCPM

Principais Projetos em desenvolvimento no SCPM

Programa BRAGECRIM
Projeto Micro-O

Lab. Sistemas Computacionais para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
FEAU - UNIMEP

BRASIL DEUTSCHLAND

Micro-O: Micro-milling Process Optimization

Otimização do Processo de Microfresamento

Objetivos

- Melhoria no planejamento do processo de corte, analisando os fatores que influenciam na precisão e no tempo da geração da trajetória da ferramenta e de setup do processo
- Análise e melhoria das condições de corte para obtenção de melhores resultados em relação ao tempo de processo, segurança, desgaste da ferramenta, precisão e vibração na manufatura
- Melhoria no processo de controle das peças para aumento da eficiência, reduzindo-se o tempo de medição e mantendo-se a precisão requerida
- Utilização de simulações para dar suporte às análises e melhorias apontadas nos itens anteriores

SCPM IWF — Análise e melhoria do Planejamento do Processo de Usinagem

IPT SCPM IWF CECS — Melhoria de Setup do Processo e Parâmetros de Usinagem

IPT CECS — Monitoramento do Processo e melhoria de controle das peças

IWF SCPM — Utilização de Simulações para análises e melhorias no Microfresamento

Parceiros

Apoio

Contato: Dra. Luciana W. S. L. Ramos
swluciana@ipt.br

Manufatura Inteligente e Fábrica Digital

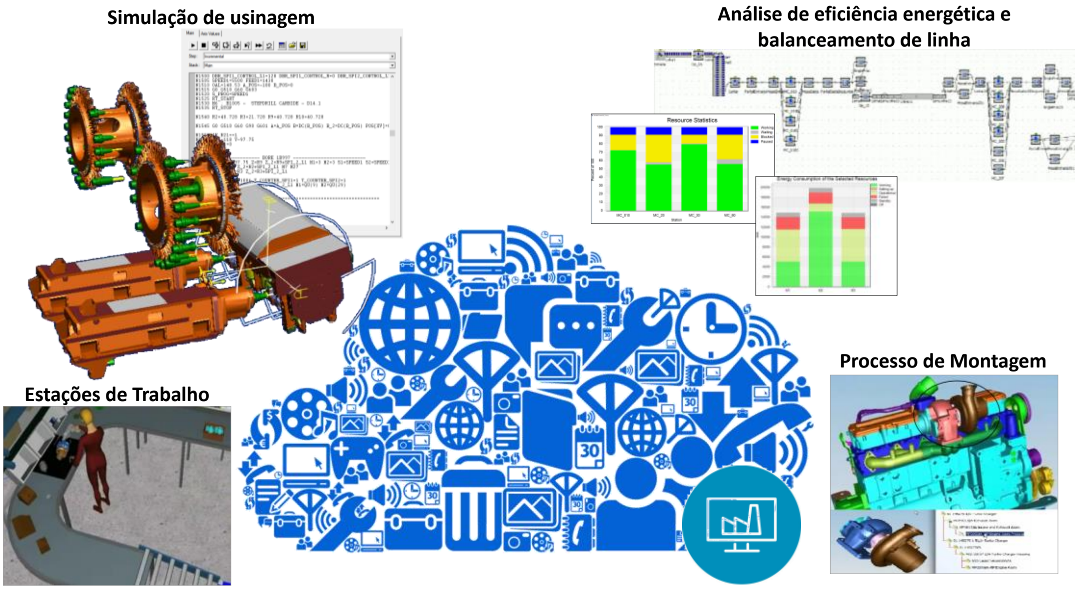
Lab. Sistemas Computacionais para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
FEAU - UNIMEP

Temas da linha de pesquisa

- Produtos e manufatura inteligente
- Sistemas físico-cibernéticos de produção
- Comunicação componente-componente, componente-máquina e máquina-máquina (M2M)
- Critérios para seleção e implantação de sistemas para representação da Fábrica Digital
- Digitalização e simulação do processo produtivo

Projetos desenvolvidos

- Implementação de ferramentas de simulação no conceito de Fábrica Digital
- Construção de um modelo virtual para simulação e comparação com um processo de manufatura real da indústria
- Otimização da trajetória de ferramenta em processos de usinagem visando ganho de tempo no processo de produção
- Balanceamento de linha visando eliminação de gargalos
- Utilização da simulação visando a otimização de eficiência energética de uma linha de produção



Parceiros

UNIMEP Universidade Metodista de Piracicaba
Volkswagen
GROB
SIEMENS

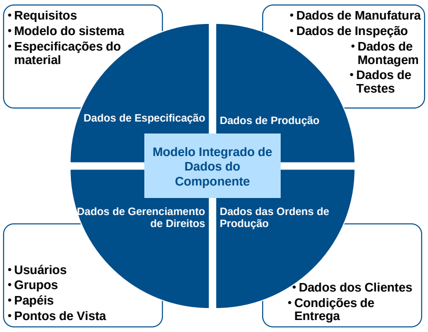
Contato: MSc. Felipe A. O. Perroni
felipe.perroni@scpm.unimep.br

Programa BRAGECRIM
Projeto SCoPE

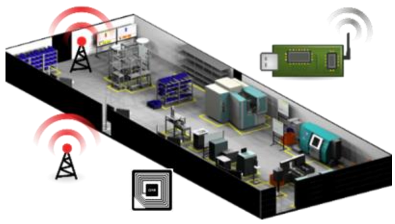
Lab. Sistemas Computacionais
para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
FEAU - UNIMEP

SCoPE
Smart Components within Smart Production Process and Environments
Componentes Inteligentes num Ambiente de Produção Inteligente

- **Objetivo**
  - Possibilitar a criação de sistemas de produção inteligentes que permitam a interação e troca mútua de informações entre componentes do produto e recursos de produção



- Transformação de componentes físicos em portadores de informações
- Integração de produtos, informações baseada em internet e tecnologias de comunicação



- Incremento das possibilidades de rastreabilidade dos processos de fabricação de componentes individuais
- Utilização dos dados de componentes individuais para formar pares otimizados de componentes em processos de montagem complexos

Parceiros

Apoio

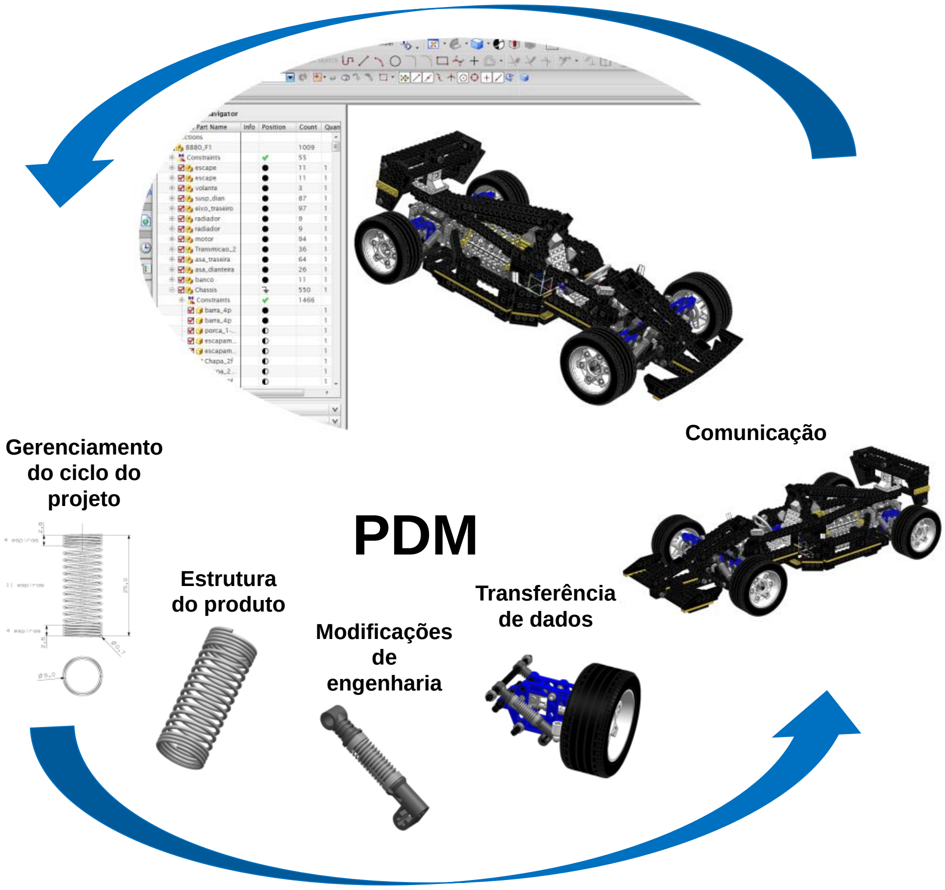
Contato: Prof. Dr.-Ing. Klaus Schützer
schuetzer@scpm.unimep.br

Grupo de Aplicação de PDM
(*Product Data Management*)

Lab. Sistemas Computacionais para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
FEAU - UNIMEP

Objetivo do Projeto

- Desenvolver um ambiente de Desenvolvimento de Produto Integrado com suporte de PDM
- Capacitar pessoal técnico na área de Desenvolvimento de Produto
- Contribuir para o aperfeiçoamento técnico de alunos na Ferramenta PDM
- Avaliar vantagens e desvantagens da Ferramenta PDM em um ambiente de Engenharia Simultânea
- Criar estruturas do produto
- Criar *workflow* para o Desenvolvimento Integrado do Produto
- Implementação de ferramentas de modificação do produto



Parceiros

SCPM
UNIMEP
Universidade Metodista de Piracicaba
SIEMENS
UGS PLM Software

Contato: Prof. Dr.-Ing. Klaus Schützer
schuetzer@scpm.unimep.br
Eng. Júlia de Andrade Bertazzi
julia.bertazzi@scpm.unimep.br

Apresentação

O Laboratório de Sistemas Computacionais para Projeto e Manufatura (SCPM) realiza anualmente desde 1996 o **Seminário Internacional de Alta Tecnologia**, abordando temas focados em duas grandes áreas: Manufatura e Desenvolvimento Integrado do Produto, alternadamente.

O potencial deste evento para trazer para o público brasileiro a inovações que estão sendo implantadas hoje nos países desenvolvidos e a curto e médio prazo serão necessariamente implantadas no Brasil pode ser claramente observado desde o primeiro seminário realizado em 1996, quando trouxemos para o Brasil o tema “Usinagem com Altíssima Velocidade” (*High Speed Cutting* - HSC). O evento realizado em 2001 trouxe para a discussão o tema “Manufatura Avançada” onde se discutiu a integração digital ao longo de toda a cadeia de produção e, desta maneira, se antecipando em 15 anos as discussões que iniciaram sobre este tema em 2016.

Mantendo-se como um referencial no Brasil para a apresentação e discussão dos desafios tecnológicos, foram abordados os temas: Engenharia Distribuída e Colaborativa em 2004, Manufatura Digital em 2007, Fabrica Virtual em 2011 e *Smart Products* em 2012. Todos esses temas foram discutidos anos à frente de outros eventos realizados no Brasil.

Desde 2014 o Seminário aborda outro tema de grande impacto, a “4ª Revolução Industrial”, nos seus mais diversos aspectos desde o desenvolvimento do produto até à produção. Como na cadeia de produção a organização do trabalho possui um papel central, trouxemos para o programa do último evento em 2017, o tema Organização Digital do Trabalho (Trabalho 4.0).

Hoje este evento é reconhecido como um referencial no Brasil na divulgação de novas tecnologias e métodos de trabalho, devido à atualidade e ao nível técnico dos temas abordados, atraindo a atenção e a participação de pessoal técnico qualificado das mais renomadas empresas localizadas no Brasil e de professores e pesquisadores de diversas universidades.

Desenvolvimento de Produtos Inteligentes: Desafios e Novos Requisitos

O que é um Produto Inteligente? Ou o que faz com que um produto seja chamado de Produto Inteligente, ou *Smart Product*, como é denominado nos meios técnicos e acadêmicos? O que é servitização? Quais requisitos os novos produtos devem atender? Quais funcionalidades devem oferecer? Essas são questões que se apresentam frente aos desafios propostos pela 4ª Revolução Industrial, a chamada Indústria 4.0, para os produtos tanto durante o seu processo produtivo, como no seu posterior uso até a reciclagem ou descarte.

Também nos deparamos com processos produtivos, que não podemos chamar mais de inéditos por já estarem no mercado há alguns anos, como é o caso específico da Manufatura Aditiva. Este processo ganha hoje um enorme destaque dentro do ambiente produtivo da 4ª Revolução Industrial. Entretanto, os engenheiros já inseridos no mercado de trabalho, bem como os que se encontram em processo de formação, recebem tradicionalmente fundamentos de desenvolvimento do produto focados em processos convencionais com destaque para o que poderíamos chamar de “manufatura subtrativa” (fresamento, torneamento, retificação, furação, etc.) e também em conformação, e fundição. O advento da Manufatura Aditiva como um processo industrial comercialmente viável e que oferece ampla flexibilidade, tanto na forma do produto como no tamanho do lote, impõe a necessidade de conhecimentos para o desenvolvimento de produtos que atendam aos requisitos deste processo. Portanto, a pergunta natural é como desenvolver produtos para Manufatura Aditiva? Quais os novos requisitos a serem atendidos? Como se configura a cadeia digital do ciclo de desenvolvimento do produto? Quais os conhecimentos necessários para desenvolver adequadamente um produto para este novo processo?

Os desafios atuais avançam em direção à proposição da digitalização de todos os processos produtivos, o que significa ter um modelo digital do produto, do processo e dos meios de produção que reproduzam os processos reais, de tal forma que as informações sobre os processos produtivos estejam disponíveis em tempo real, permitindo a ação dos gestores sobre os modelos digitais e, por meio deles, a consequente aplicação das decisões nos sistemas reais.

Essas são questões que nos inquietam na busca de manter as empresas competitivas no cenário da 4ª Revolução Industrial. O Seminário Internacional de Alta Tecnologia, fiel à tarefa de trazer para o seu público os desafios tecnológicos atuais, ilustrados por casos de sucesso de empresas que estão enfrentando com competência e criatividade esses desafios, quer justamente discutir este ano questões relativas ao Produto Inteligente, *Smart Product*. Para tanto está trazendo um elenco de professores, pesquisadores e profissionais de reconhecimento internacional para apresentarem suas experiências e desenvolvimentos realizados.

É com essa visão que convidamos as comunidades industrial e acadêmica brasileiras para participarem da 23ª edição do Seminário Internacional de Alta Tecnologia. Entre os enfoques principais estão:

- Produtos Inteligentes na Indústria 4.0;
- Desenvolvimento de Componentes Sensorizados;

- Digitalização do Ciclo de Desenvolvimento do Produto;
- Desenvolvimento de Produto para Manufatura Aditiva;
- Sistema Produto-Serviço;
- Mobilidade como Serviço.

Laboratório de Sistemas Computacionais para Projeto e Manufatura

Lab. de Sistemas Computacionais para Projeto e Manufatura Prof. Dr.-Ing. K. Schützer FEAU - UNIMEP

Universidade Metodista de Piracicaba - UNIMEP
Laboratório de Sistemas Computacionais para Projeto e Manufatura - SCPM
Prof. Dr.-Ing. Klaus Schützer

Figura 1

© SCPM'18 SCPM_Por K. Schützer

Áreas de Pesquisa e Equipe

Lab. de Sistemas Computacionais para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
FEAU - UNIMEP

Indústria 4.0

- **Manufatura Intel… …brica Digital**
- **Desenvo… …integrado do Produto**
- **Tecnologia de Usinagem com Altíssima Velocidade**
- **Fábrica para Ensino para o Desenvolvimento do Produto**
- **Seminário Internacional de Alta Tecnologia** (evento anual)

- **1 Professor Titular**
- **1 Professor Colaborador**
- **Doutorandos: 2**
- **Mestrandos: 4**
- **Estudantes IC: 1**
- **Estudantes de Intercâmbio: -**
- **Suporte Técnico: 2**

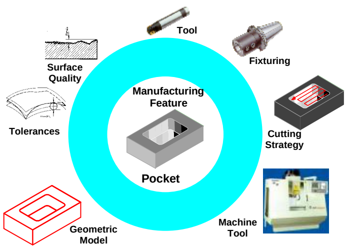


Figura 2

© SCPM'18 SCPM_Por K. Schützer

Seminário Internacional de Alta Tecnologia

Lab. de Sistemas Computacionais para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
FEAU - UNIMEP

- **Parceiros**

TECHNISCHE UNIVERSITÄT DARMSTADT — PTW — DiK — POLI USP

- **22 Edições: 1996 a 2017**

Figura 3

© SCPM'18 SCPM_Por K. Schützer

Evento inovador com foco na indústria

Lab. de Sistemas Computacionais para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
FEAU - UNIMEP

- **Os temas discutidos contam sempre com o binômio universidade-**
- **Evento pioneiro em discutir os principais temas tecnológicos:**
  - 1996 – Tecnologia HSC
  - 1998 – PLM e Normas STEP
  - 2001 – Manufatura Avançada
  - 2007 – Manufatura Digital
  - 2011 – Fábrica Digital
  - 2012 – *Smart Products*
  - 2014 – *Industrie 4.0*
  - 2017 – Trabalho 4.0
- **Evento sólido com 23 anos de tradição**

Figura 4

Seminário Internacional de Alta Tecnologia

Lab. de Sistemas Computacionais para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
FEAU - UNIMEP

- **Mais de 4.450 Participantes**
- **210 Palestrantes de 13 países**
  - 100 de Universidades e Centros de Pesquisa
  - 102 de Indústrias
  - 8 de Órgãos Governamentais e Associações

Brasil	Alemanha	Áustria
Bélgica	Canadá	China
EUA	França	Holanda
Inglaterra	Itália	Japão
Suiça		

Figura 5

© SCPM'18 SCPM_Por K. Schützer

Seminário Internacional de Alta Tecnologia

Lab. de Sistemas Computacionais para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
FEAU - UNIMEP

7 Órgãos de Fomento já apoiaram a realização deste evento:

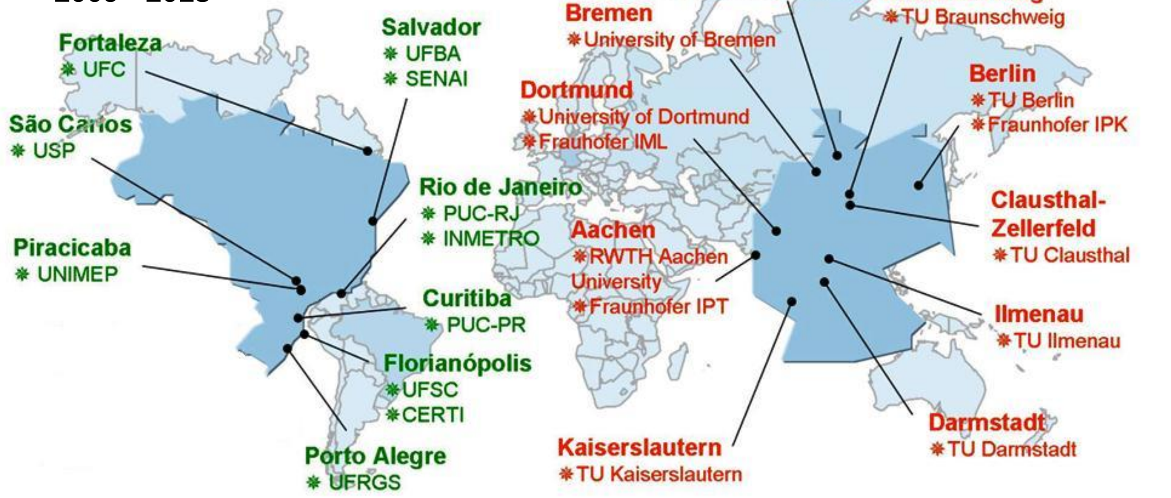
34 Empresas já apoiaram a realização deste evento:

© SCPM '18 SCPM_Por K. Schützer

Brazilian-German Collaborative Research Initiative on Manufacturing

Lab. de Sistemas Computacionais para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
FEAU - UNIMEP

CAPES - DFG
2009 - 2018



Call for Proposals 2018
Brazilian-German Collaborative Research Initiative on Smart Connected Manufacturing

Figura 7

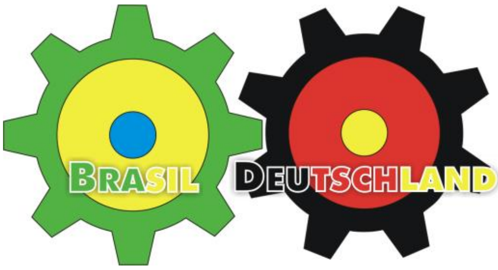
© SCPM '18 SCPM_Por K. Schützer

BRAGECRIM #027/14 – SCoPE

Lab. de Sistemas Computacionais para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
FEAU - UNIMEP

Smart Components within Smart Production Processes and Environments – SCoPE

Componentes inteligentes num ambiente de produção inteligente



Coordination:

Prof. Dr.-Ing. Klaus Schützer (UNIMEP-SCPM - Brazil) – Brazilian Coordinator

Prof. Dr.-Ing. Reiner Anderl (TUD-DiK - Germany) – German Coordinator

UNIMEP Universidade Metodista de Piracicaba
SCPM
ESCOLA POLITÉCNICA DA USP
LGI
TECHNISCHE UNIVERSITÄT DARMSTADT

Figura 8

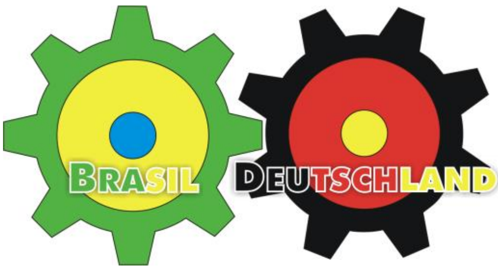
© SCPM'18 SCPM_Por K. Schützer

BRAGECRIM #028/14 – Micro-O

Lab. de Sistemas Computacionais para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
FEAU - UNIMEP

Micro milling process optimization – Micro-O

Otimização do processo de micro fresamento



Coordenação:

Dra. Luciana Wasnievski da Silva de Luca Ramos (BioNanoManufatura-IPT - Brazil) – Brazilian Coordinator

Prof. Dr.-Ing. Eckart Uhlmann (TUB-IWF - Germany) – German Coordinator

UNIMEP Universidade Metodista de Piracicaba
SCPM
ipt INSTITUTO DE PESQUISAS TECNOLÓGICAS
Universidade Federal do ABC

Figura 9

© SCPM'18 SCPM_Por K. Schützer

Comitê Científico

Prof. Dr.-Ing. Klaus Schützer – SCPM/FEAU – UNIMEP – Presidente

Prof. Dr. Alvaro J. Abackerli – Embrapii

Dr.-Ing. Bernd Pätzold – ProSTEP AG, Alemanha

Prof. Dr.-Ing. Dirk Biermann – TU Dortmund, Alemanha

Prof. Dr.-Ing. Eberhard Abele – PTW – TU Darmstadt, Alemanha

Prof. Dr. h.c. Dr.-Ing. Eckart Uhlmann – Fraunhofer IPK, Alemanha

Prof. Dr. Eduardo de Senzi Zancul – POLI-USP

Prof. PhD. Elso Kuljanic – Università degli Studi di Udine, Itália

Prof. Dr. Erik Gustavo Del Conte – Universidade Federal do ABC

Prof. Tit. Dr.-Ing. Henrique Rozenfeld – NUMA – EESC-USP

Prof. Dr. Jan Helge Bøhn – Virginia Tech University, Estados Unidos da América

Prof. Dr.-Ing. Joachim Metternich – PTW – TU Darmstadt, Alemanha

Dra. Luciana Wasnievski da Silva de Luca Ramos – IPT-SP

Prof. Dr.-Ing. Michael Abramovici – Ruhr – Universität Bochum, Alemanha

Prof. MSc. Patrick G. Serraferro – Ecole Centrale de Lyon, França

Prof. Dr. Pedro Filipe Cunha – Escola Superior de Tecnologia de Setúbal, Portugal

Prof. Dr.-Ing. Rainer Stark – TU Berlin – IWF, Alemanha

Prof. Dr.-Ing. Habil. Ralph H. Stelzer – TU Dresden, Alemanha

Prof. Habil. Dr.-Ing. Reiner Anderl – DiK – TU Darmstadt, Alemanha

Prof. Dr. Reginaldo Teixeira Coelho – NUMA – EESC-USP

Dr.-Ing. Teresa De Martino – European Commission – Directorate General XIII, Bélgica

Prof. Dr. Sc. Toma Udiljak – Croatian Association of Production Engineering, Croácia

Comitê Organizador

Prof. Dr.-Ing. Klaus Schützer – Presidente

Prof. Dr. Eduardo de Sensi Zancul – Vice-Presidente

Marcela Santana da Silva Romão – Secretária Executiva

Silvia Regina Fronza Feltrin – Secretária Executiva

Bruno Henrique Claus – Analista de Sistema

MSc. Felipe Alves de Oliveira Perroni

MSc. Marcelo Octavio Tamborlin

Carolina Sallati

Eng. Júlia de Andrade Bertazzi

Eng. Karine Melissa de Queiroz Rigon

Realização

SCPM

UNIMEP
Universidade Metodista de Piracicaba

Índice

Artigos Técnicos

Technical Papers

Prof. Dr.-Ing. Reiner Anderl

Prof. Anderl was born in 1955 and studied mechanical engineering at the Universität Karlsruhe, Germany, where he received his diploma in 1979. He received the Dr.-Ing. degree in Mechanical Engineering at the Universität Karlsruhe in 1984. From 1984 to 1985 he served as technical manager of a medium sized company. He then returned as a senior engineer to the Institute for Applied Computer Science in Mechanical Engineering (RPK) at the Universität Karlsruhe. In 1991 he has habilitated and in 1992 he has received the Venia Legendi, which includes the authorization to teach CAD/CAM technology. In April 1993 he accepted the call for the professorship for computer integrated design (Fachgebiet Datenverarbeitung in der Konstruktion, DiK) at the faculty Mechanical Engineering, Technische Universität Darmstadt, Germany. At the Technische Universität Darmstadt, he served as the dekan (dean) of the faculty in Mechanical Engineering from 1999 until 2001, during which time the new bachelors and masters program in mechanical engineering, mechatronics and computational engineering was defined and implemented; the first of such in Germany. He has served on numerous faculty and university committees and commissions, including serving as prodekan where he managed the mechanical engineering faculty business office. He is a member of the Zentrale Evaluierungs- und Akkreditierungs-agentur (ZEvA), a national accreditation council based in Hannover, Germany, where he works on issues related to bachelor- and masterprogram accreditation. Prof. Anderl has served as vice president at the Technische Universität Darmstadt from January 2005 until December 2010.

✉ anderl@dik.tu-darmstadt.de

DiK, TU Darmstadt

The Department of Computer Integrated Design (DiK) is part of the Faculty of Mechanical Engineering of the Technische Universität Darmstadt. It is directed by Prof. Dr.-Ing. Reiner Anderl. The integration of information technology as integral part of modern mechanical engineering and the linkage of research and education to industrial needs are our fundamental targets. One core competence is the virtual product development. The principles and methods of processing product data are still quite challenging. To understand product data, product data flows and product data processing, the holistic approach of Virtual Product Development has been chosen for education and research. Besides the virtual product development, additive manufacturing, IT security and Industrie 4.0 are further core competences and research fields. The competences are represented with the help of different demonstrators in the DiK research lab, which was opened in 2017 and welcomes since then visitors of industry and other research institutes.

Digital Workflow for Additive Manufacturing – Shaping the Future through Innovation

Abstract

Additive Manufacturing is a promising key technology for innovative products and efficient production processes. Additive Manufacturing enables the production of product shapes with complex geometry and innovative features as well as individualization and personalization in production. A key approach for Additive Manufacturing is the digital workflow, which starts with a digital representation of the product shape designed through using an appropriate CAD-system and which provides numerical control data for controlling the additive manufacturing process. Within this contribution, the digital workflow is presented through its major steps indicating the state of the art as well as research approaches for future improvement. Furthermore it is explained how innovation is been created within the digital workflow.

Keywords

Additive Manufacturing (AM); Hybrid Manufacturing Technologies; Mold and Die; Dental Applications; Costumer Specific Cutting Tools; Industry 4.0; Networks.

1 Introduction

Additive Manufacturing is a new and innovative manufacturing technology, which is based on the principles of generative manufacturing [VDI-2016], [aca-2017]. The technology has been developed about 25 years ago and was industrially applied as Rapid Prototyping and Tooling (RPT) technology. Since the last ten years, the generative manufacturing methods and tools have become more and more advanced and mature, in particular by providing new materials and advanced laser technologies. Thus, Rapid Prototyping and Tooling (RPT) has been successfully further developed as additive manufacturing and has been introduced into industrial production environments.

A major approach of Additive Manufacturing is the importance of the digital process chain, which starts with a digital 3D-solid model described through 3D geometric modelling functionalities of a 3D-CAD System (Computer Aided Design). Digitally represented parts are then located in a 3-dimensional working space, which is mainly represented as a 3D cube. After the working space contains the parts to be produced, the cube is been sliced into layers containing areas of intersectional surfaces which are allocated to the parts. For each surface an algorithm generates manufacturing paths and numerical control code (G-code) to control the operation of the manufacturing tool, which is typically a laser beam or an extruder.

Additive Manufacturing technologies are based on appropriate physical principles. The main principles are structured in Figure 1.

- Fused Layer Manufacturing (FLM)
  This approach is also known as Fused Deposition Modelling (FDM) where plastic filament is extruded and successive layers are produced by hot melt adhesive bonding.

- Selective Laser Sintering (SLS)/Selective Laser Melting (SLM)
  The concept of SLS is based on sintering by using a laser beam being directed into semi crystalline thermoplastics. The SLM technology also uses a laser beam, however, it is directed into metal powder causing melting of particles.

- 3D-Printing (3DP)
  This principle is based on powder particles being bonded using a liquid binder.

- Laminated Object Manufacturing (LOM)
  This technology cuts paper or polymer foils or paper into bounded surfaces and glues the surfaces layer by layer.

- Stereolithography (SL)
  This approach is based on polymerization of epoxy resins by using a laser beam.

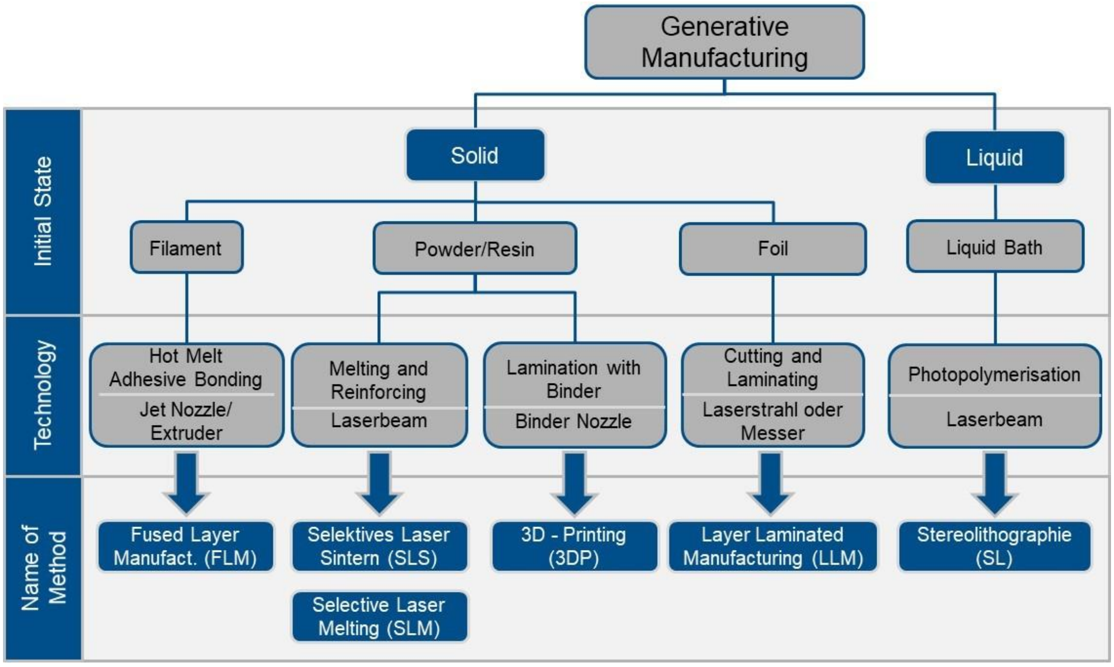


Figure 1: Additive Manufacturing principles

Additive manufacturing is used in an increasing number of application areas. The most prominent application area is mechanical engineering [aca-2017]. In further application areas, additive manufacturing, however, is becoming more and more important. These application areas comprise:

- Civil engineering, where additive manufacturing is used to create buildings generatively;
- Medical technology, where individualized and personalized prosthesis are produced;
- Artificial organs, a new application area where organic cells are produced through additive manufacturing;
- Food production, where additive manufacturing is used to produce food with complex shapes and various ingredients;
- And many more.

The significant advantage of additive manufacturing is that the generative manufacturing technology allows creating complex geometric shapes produced layer by layer. This unique advantage supports the individualization and personalization of products as well as the production of lot size 1 parts or small part series. Thus, application areas such as e.g. high tech motor sports, high tech products, medical engineering, repair parts and many more are of interest.

To enable an enterprise to use additive manufacturing industrially, know how about the digital process chain from design to additive manufacturing is an essential prerequisite. Therefore, a profound analysis of the digital process chain is required.

2 Digital Process Chain for Additive Manufacturing

Additive Manufacturing is based on a digital process chain starting with 3-dimensional solid modelling of parts to be produced until the Additive Manufacturing control code (G-code). The digital process chain represents a seamless digital workflow where the digital 3-dimensional representation of a designed part is being transformed into a numerical control code, the so-called G-code to control the Additive Manufacturing system. In Figure 2 the digital process chain for Additive Manufacturing is explained.

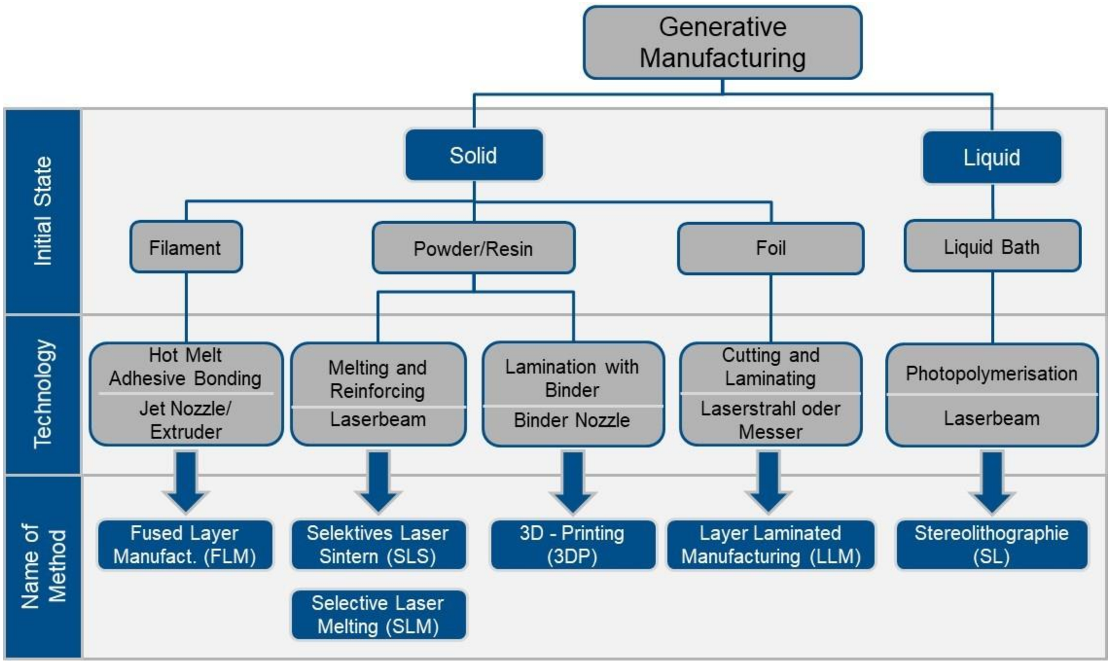


Figure 2: Digital process chain for Additive Manufacturing

The digital process consists of 8 successive steps:

- Step 1: Solid modeling for Additive Manufacturing
  During step 1 geometric modelling of the part to be manufactured is performed. The aim is to create a 3-dimensional solid model of the part, taking into account design guidelines for the definition of part shape designed for additive manufacturing. Typically, a CAD-system is used to create the digital representation of a 3-dimensional solid model. The result of this step, however, is available as a so-called native digital representation, which means it is CAD-system specific.

- Step 2: Transformation of native CAD-data into a standardized data format
  Step 2 uses the native CAD-representation of the 3-dimensional solid model and transforms this representation into a standardized representation. The most used format is STL (Standardized tessellation language). STL represents the surface of the part through a tessellated representation, which consists mainly of triangulated geometry. Besides STL, however, a number of further formats are available.

- Step 3: Pre-Processing
  Step 3 contains the so-called pre-processing. Pre-processing is structured into four sub-tasks. The sub-tasks comprise validation of geometry, nesting, support structure generation and slicing. Validation of geometry uses a number of checking algorithms, which justify the consistency of the triangulated part surface. In case of any inconsistency, the algorithms are even able to repair geometric inconsistencies. Nesting algorithms are locating triangulated part surface representation into the workspace of the additive manufacturing machine. Typically, not only one part is manufactured during the additive manufacturing process but many. Therefore nesting algorithms are optimizing the location of triangulated part surface representations with respect to optimal part quality (e.g. stiffness) and economical and energy efficiency. Support structures are required very often and are necessary to enable an optimal manufacturing process. The last sub-task is slicing. Slicing is required to generate the intersectional surfaces, which are then used for defining the G-code for the tool movement to create the physical surfaces for both, the part to be manufactured and the support structure. For slicing methods of constant slicing depth or for adaptive slicing depth are available.

- Step 4: G-code generation
  In step 4 G-code is being generated for each surface allocated to the slicing layer. This task is very important because the movement of the additive manufacturing tool (e.g. laser beam or extruder) is dependent of the movement strategy. The movement strategy defines how an intersectional surface is being manufactures and if the intersectional surface is completely filled up with material or is based on an inner structure.

- Step 5: Machining
  During step 5 additive manufacturing of the physical part is performed. Here, it is very important to mention that depending on the principle of additive manufacturing safety requirements have to be taken into account, such as laser environments of poisoning flue gases.

- Step 6: Removal of manufactured parts
  Step 6 comprises the removal of manufactured parts. The challenge of this step is depending on the additive manufacturing principle and typically is performed manually.

- Step 7: Part Finishing
  During step 7 post-processing is being performed. Typical post-processing tasks are surface finishing, feature integration (e.g. threat), and others more.

- Step 8: Application of the Manufactured Part
  The part which has been produced through Additive Manufacturing in being industrially used.

As explained in this chapter the digital process chain is a key innovation driver for Additive Manufacturing and the algorithms and tools used in the digital process chain have a strong impact on the success of Additive Manufacturing and the competitiveness of the enterprise using Additive Manufacturing.

3 Approaches for Increasing Competitiveness

Enterprises introducing Additive Manufacturing and implementing a digital process chain can increase their profile of competitiveness through know how and competencies. Competitiveness in particular with respect to the digital process chain is based on four major competencies, methods and tools: Design for Additive Manufacturing, Additive Manufacturing Strategies, Manufacturing Part Structures and Individualization in Additive Manufacturing Processes.

3.1 Design for Additive Manufacturing

For Additive Manufacturing the competence Design for Additive Manufacturing is required. As Additive Manufacturing is a generative manufacturing process, the modelling of complex geometries becomes possible and optimizations and restrictions, which have to be taken into account for traditional manufacturing technologies (Design for Manufacture, DfM), need to be developed, dedicated to Additive Manufacturing. Thus, new design guidelines dedicated to Design for Additive Manufacturing have to be specified and considered. Although the catalog of design guidelines typically is an open catalog, there exist some fundamental recommendations as listed in Figure 3.

Current research activities aim at implementing recommendations for Design for Manufacturing in CAD systems making use of boundary representation (B-Rep solids) structures. Thus, design guidelines are implemented is modeling functionalities and use approaches of constraint modeling.

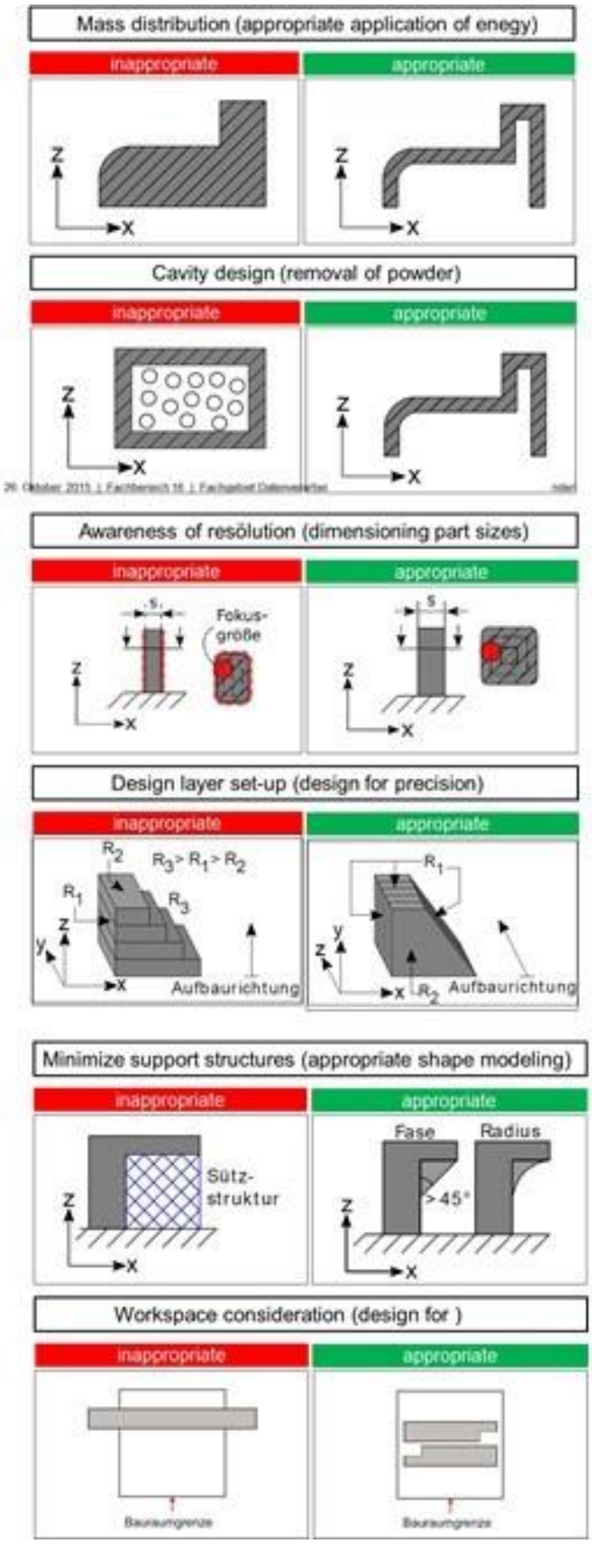


Figure 3: Recommendations: Design for Additive Manufacturing (except)

3.2 Additive Manufacturing Strategies

Additive Manufacturing strategies are very important and define how a number of parts are manufactured within one workspace. The key issue is how to package a workspace with parts. Some important physical effects, however, have to be considered, such as temperature distribution due to energy influx, necessity of support structures or stiffness due to localization and orientation of parts in the workspace. Figure 4 illustrates the influence of localization and orientation of parts in the workspace on stiffness.

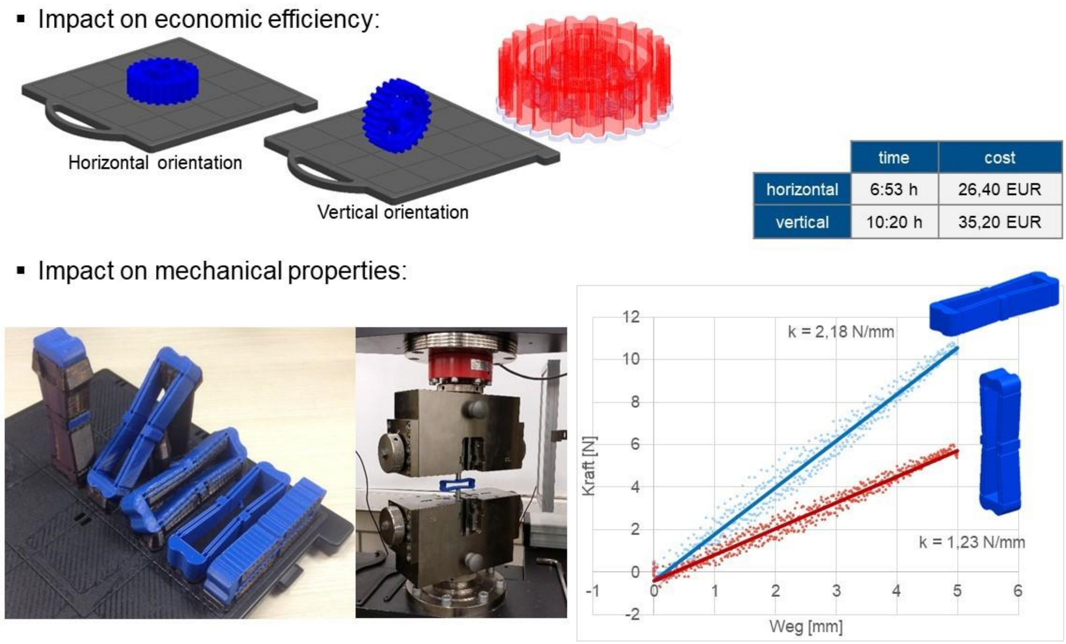


Figure 4: Influence of localization and orientation of parts in the workspace on stiffness (source: [Arn-2016])

Strategies to perform high quality additive manufacturing are dedicated to a prospective planning and optimization activity of the workspace packaging taking into account the physical effects of the respective additive manufacturing principle.

3.3 Manufacturing Part Structures

Furthermore, Additive Manufacturing is also influenced by the part structure, which is to be manufactured. Here are two major approaches in focus: strength optimized part structure and solid part structure.

Strength optimized part structures are generated based on a load scenario where material, which is not contributing to increase the parts strength, is being removed. Typically, this shape generation process is supported through optimization software systems based on the finite element analysis method.

An interesting approach is to define solid part structures. This approach is dedicated to specify the inner structure of a part and thus determines the stiffness and the weight of a part. In Figure 5 some examples for the definition of the inner part structure are shown as well as G-code generation strategies to produce the solid part structure.

This definition has to be decided taking into account the slicing process.

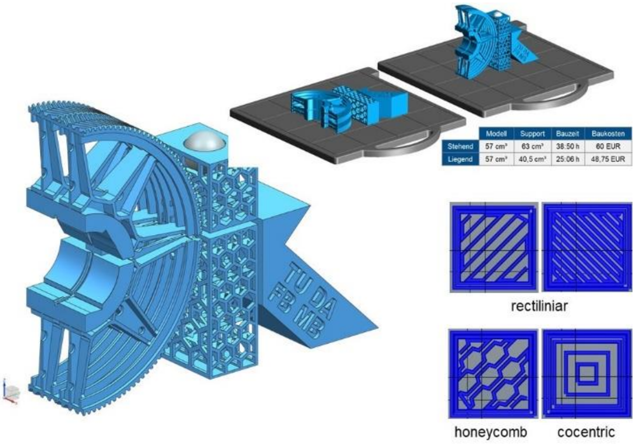


Figure 5: Solid part structure examples

3.4 Individualization in Additive Manufacturing Processes

Many branches of industry are faced with the challenge to more individualize and personalize their products, e.g. for dental applications. Furthermore, new innovative products fulfilling the requirements of individualization and personalization, are conquering the markets. Additive Manufacturing is an innovative technology that is perfectly dedicated to produce individualized and personalized products.

Due to this opportunity many enterprises have recognized this new business opportunity but they are faced with the challenge on one hand to individualize and personalize and on the other hand to manufacture efficiently. A major challenge is to package parts in the workspace optimally and on the other hand to keep track with the recognition of the manufactured part and its allocation to the specific manufacturing order. For this purpose, identification and marking technologies have to be considered [Arn-2018]. In Figure 6 some identification and marking approaches are illustrated.

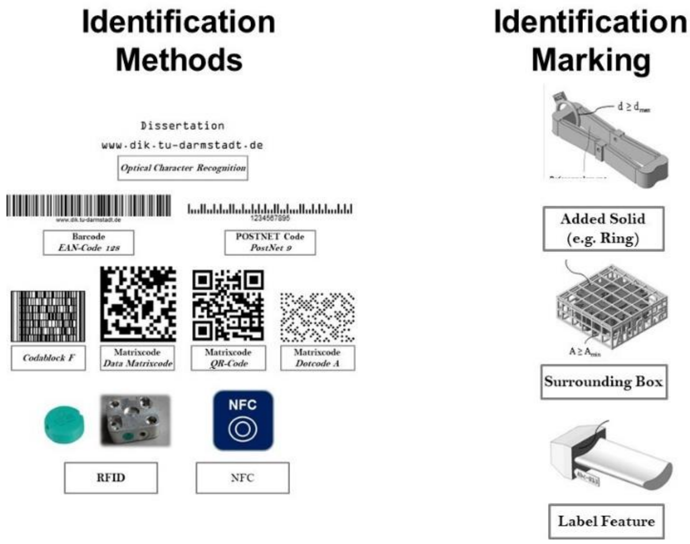


Figure 6: Identification methods and identification marking approaches (source: [Arn-2018])

As a result, of the strategy to manufacture individualized and personalized parts the consideration of the complete additive manufacturing process is a major prerequisite.

4 Management Issues and Research Demands

Although Additive Manufacturing provides significant advantages and enables the establishment of new business models enterprise management has to be aware about major issues. Among others such as cost structures and economic requirements, IT-security and sustainability have to be considered.

4.1 IT-Security for Additive Manufacturing

It-security is a very important issue. It becomes even more important as Additive Manufacturing can be applied remotely. The scenario for such an application aims at manufacturing repair parts close to the customer while the company’s manufacturing facilities are located somewhere else (Figure 7).

In such a scenario, data streams are very important and should not be manipulated by un-authorized persons. Therefore, data stream protection is a key issue. Furthermore, also the Additive Manufacturing machine tool has to be protected.

Figure 7: Remote Additive Manufacturing

A profound IT-security concept meets the five strategic requirements: confidentiality, integrity, availability, authenticity and liability. Among the methods for IT-security the most important ones are fire wall technology, encryption, digital signature and identity management.

4.2 Holistic View on Additive Manufacturing

Management awareness has also to be created with respect to sustainability of Additive Manufacturing and the sustainability of additive manufactured products. To take sustainability into account a holistic view on additive manufacturing is required from cradle to grave [Aut-2018]. This holistic view starts with raw material and material production covers additive manufacturing and post-processing and concludes with recycling and demolishing used products.

4.3 Research Demand

Additive Manufacturing is an innovative technology. Although the technology is advanced and mature, some research areas still need to be addressed. Major research demands comprise:

- Material research,
- Reliability analysis,
- Data format development,
- Packaging optimization methods, and
- Digital twin technology [And-2018].

Furthermore, Additive Manufacturing is predestinated as an integral technology of *Industrie 4.0* environments [Arn-2015]. Due to its fully digital process chain from design to manufacture Additive Manufacturing, its fundamental approach is well prepared for interconnecting Additive Manufacturing machine tools for both vertical and horizontal integration. The vertical integration aims at a seamless digital data flow from design to manufacture, while the horizontal integration aims at connecting with further machine environments e.g. with robot systems. Provided inter-connectivity is available, communication between Additive Manufacturing machine tools and other machines can be established. An appropriate communication between Additive Manufacturing machine tools and other production equipment is also part of further research questions.

5 Conclusions

Additive Manufacturing is an innovative technology, sometimes even understood as a disruptive technology. In fact, in many branches, Additive Manufacturing changes traditional production technologies and with respect to their big advantages to manufacture individualized and personalized products, Additive Manufacturing has become a technology increasing the competitiveness of enterprises. Additive Manufacturing, however, is not dedicated to mass production.

As Additive Manufacturing contributes to the competitiveness of a manufacturing enterprise, management needs to become aware about the technological and organizational challenges. This contribution addresses technological issues such as the digital process chain from design for Additive Manufacturing to Additive Manufacturing itself, competencies to use the competitive potential of Additive Manufacturing and management issues as well as research demands.

6 Literature

[aca-2017] acatech – National Academy of Science and Engineering, German National Academy of Sciences, Leopoldina, Union of the German Academies of Sciences and Humanities (Eds.) (June 2017): Additive Manufacturing. Munich, 64 pages

[And-2018] Anderl R.; Haag S.; Schützer K.; Zancul E. Digital Twin Technology – An Approach for Industrie 4.0 Vertical and Horizontal Lifecycle Integration, June 2018, it - Information Technology 60(3), DOI: 10.1515/itit-2017-0038

[Aut-2018] Auth, C.; Arndt, A.; Anderl, R. Development of a concept for a holistic knowledge-based additive manufacturing over the entire lifecycle, in: IFIP 15th International Conference on Product Lifecycle Management, 01.-04.07.2018, Torino, Italy.

[Arn-2018] Arndt, A. Bauteilindividuelle und verfahrensspezifische Kennzeichnung und Identifikation für die Additive Fertigung, Shaker Verlag , Aachen, [Dissertation, http://tuprints.ulb.tu-darmstadt.de/7450/], (2018)

[Arn-2016] Arndt, A.; Anderl, R. Additive Manufacturing - Automation in Customized Production, in Schützer, Klaus (ed.): 21º Seminário Internacional de Alta Tecnologia, 06.10.2016, Piracicaba, São Paulo, Brazil.

[Arn-2015] Arndt, Alexander ; Anderl, Reiner ; Bäumer, Lars Nutzung von Synergiepotentialen zwischen den Technologietrends Industrie 4.0 und additiver Fertigung im Produktentstehungsprozess, in Gabbert, Ulrich; Grote, Karl-Heinz; Karpuschewski, Bernhard; Kasper, Roland; Lindemann, Andreas; Schmidt, Bertram; Ihlow, Günter (eds.): 12. Magdeburger Maschinenbau-Tage 2015: Smart, Effizient, Mobil. Magdeburg (2015) ISBN 978-3-944722-26-9

[VDI-2016] VDI (2016) Handlungsfelder - Additive Fertigungsverfahren. Verein Deutscher Ingenieure e.V.. ISBN 978-3-931384-82-1, Düsseldorf.

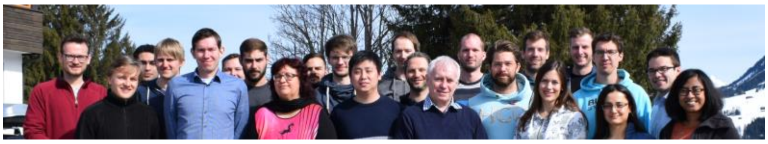
Digital Workflow for Additive Manufacturing

Shaping the Future through Innovation

TECHNISCHE UNIVERSITÄT DARMSTADT

Prof. Dr.-Ing. Reiner Anderl

Computer Integrated Design
(Datenverarbeitung in der Konstruktion, DiK)
Fachbereich Maschinenbau
Technische Universität Darmstadt
Otto-Berndt-Straße 2
D-64287 Darmstadt
Email: anderl@dik.tu-darmstadt.de



October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl

Digital Workflow for Additive Manufacturing
Shaping the Future through Innovation

TECHNISCHE UNIVERSITÄT DARMSTADT

Overview

1. **Introduction**
2. **Digital Process Chain Additive Manufacturing**
   - Design for Additive Manufacturing
   - Data Transformation and Manufacturing Planning
3. **Individualization and Personalization**
4. **Remote Additive Manufacturing and Data Driven Manufacturing Platform**
5. **Summary**

October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl

Computer Integrated Design
Fachgebiet Datenverarbeitung in der Konstruktion (DiK)

TECHNISCHE UNIVERSITÄT DARMSTADT

Overview:

- Computer Integrated Design
- Head: Prof. Dr.-Ing. R. Anderl
- 20 Research Assistants
- 5 Technical and Administrative Staff, ~ 50 Teaching Assistents

International Competence and Experience in the Fields of:

- Virtual Product Development using Smart Engineering,
- Sustainable Product Lifecycle Management (PLM)
- Process Integration / Optimization
- Industrie 4.0

acatech DEUTSCHE AKADEMIE DER TECHNIKWISSENSCHAFTEN | NATIONAL ACADEMY OF SCIENCE AND ENGINEERING

PACE
Partners for the Advancement of Collaborative Engineering Education
GM Autodesk hp ORACLE SIEMENS

Wissenschaftliche Gesellschaft für Produktentwicklung WiGeP
Berliner Kreis & WGMK

October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl

High-tech Strategy 2025
of the German Federal Government

TECHNISCHE UNIVERSITÄT DARMSTADT

The new German High-Tech Strategy 2025 has been published on September 5th, 2018

Three fields of action:

1. **Challenges for the society**
   1. Health and health care
   2. Sustainability, climate protection and energy
   3. Mobility
   4. Urban and suburban enviroment
   5. Security
   6. Economy and working life 4.0
2. **Competences of the future**
   1. Technology
   2. Skilled and qualified employment
   3. Participation of the society
3. **New culture for innovation and venture**
   1. Knowledgetransfer
   2. Start-up and innovation spirit in SMEs
   3. Innovative networks for knowledge exchange worldwide

Source: BMBF 2018

October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl

Trends in Information and Communication technology

TECHNISCHE UNIVERSITÄT DARMSTADT

Cyber-Physical Media interconnected and communicating systems

Connectivity
Communication

Industrie 4.0 component

Industrial Internet

2015

Future Media
Smart Networking

5G

Artificial Intelligence
Machine Learning
Pattern Recognition
Smart Contracts
Engineering Smart Systems
Collaborative Roboting

Additive Manufacturing
Individualized and Personalized Products
Remote Manufacturing

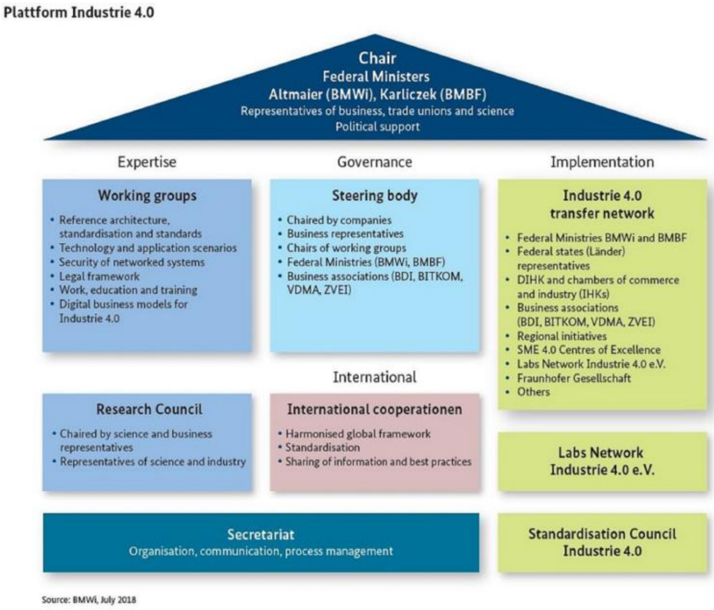
Future Industrial Internet

2020

October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl   Folie 6

The „Plattform Industrie 4.0“

TECHNISCHE UNIVERSITÄT DARMSTADT



Sourcs: Plattform Industrie 4.0

October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl   Folie 7

Members of the Research Council of the Plattform Industrie 4.0

TECHNISCHE UNIVERSITÄT DARMSTADT

Mitglieder des Forschungsbeirats:

Wissenschaftliche Mitglieder

Reiner Anderl
TU Darmstadt

Thomas Bauernhansl
Universität Stuttgart, Fraunhofer IPA

Manfred Broy
TU München

Angelika C. Bullinger-Hoffmann
TU Chemnitz

Claudia Eckert
TU München, Fraunhofer AISEC

Ulrich Epple
RWTH Aachen

Alexander Fay
Helmut-Schmidt-Universität, Hamburg

Jürgen Gausemeier
Universität Paderborn

Hartmut Hirsch-Kreinsen
TU Dortmund

Gerrit Hornung
Universität Kassel

Gisela Lanza
Karlsruher Institut für Technologie

Peter Liggesmeyer
TU Kaiserslautern, Fraunhofer IESE

Wolfgang Nebel
Universität Oldenburg, OFFIS

Frank Piller
RWTH Aachen

Sabine Pfeiffer
Universität Erlangen-Nürnberg

Gunther Reinhart
TU München, Fraunhofer IWU

Thomas Schildhauer
HIIG, IEB

Rainer Stark
TU Berlin, Fraunhofer IPK

Michael ten Hompel
TU Dortmund, Fraunhofer IML

Wolfgang Wahlster
DFKI, Saarbrücken

Mitglieder aus der Industrie

Heinrich Arnold
Deutsche Telekom AG, Köln

Klaus Bauer
TRUMPF Werkzeugmaschinen GmbH + Co. KG, Ditzingen

Hans Beckhoff
Boeckhoff Automation GmbH & Co. KG, Verl

Jackson Bond
Relayr GmbH, Belin

Stefan-Maria Creutz
Bizerba, Bailingen

Jan-Henning Fabian
ABB AG, Ladenburg

Andreas Fehring
Airbus Deutschland, München

Dietmar Goericke
VDMA Verband Deutscher Maschinen- und Anlagenbau e.V., Frankfurt

Sven Hamann
Robert Bosch GmbH, Stuttgart

Markus Klaiber
SCHUNK GmbH & Co. KG, Lauffen

Uwe Kubach
SAP SE, Walldorf

Peter Post
Festo AG & Co. KG, Esslingen

Harald Schöning
Software AG, Darmstadt

Georg von Wichert
Siemens Corporate Technology (CT), München

Quelle: acatech DEUTSCHE AKADEMIE DER TECHNIKWISSENSCHAFTEN

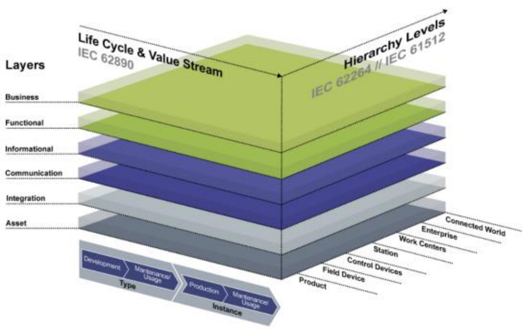
Stand: Mai 2018

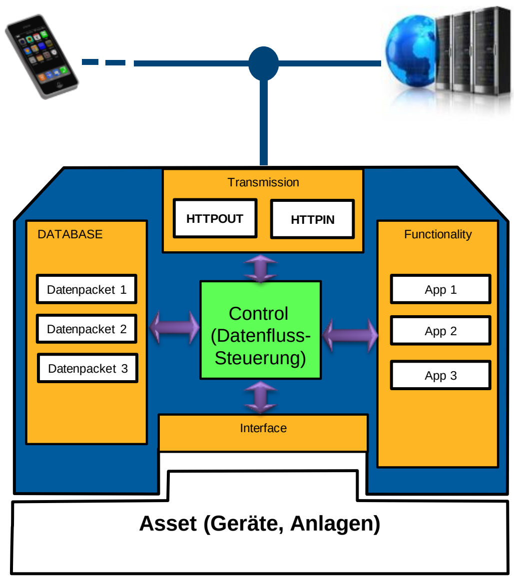
October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl Folie 8

RAMI 4.0 and Industrie 4.0 Component Approach

TECHNISCHE UNIVERSITÄT DARMSTADT

Referenzarchitekturmodell RAMI 4.0

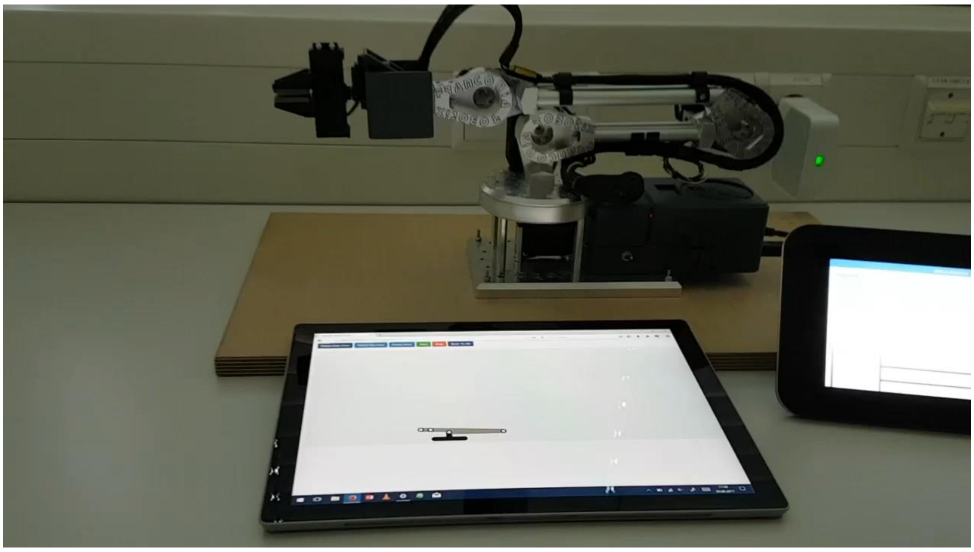




October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl Folie 9

Example of an Industrie 4.0 Component Robotarm

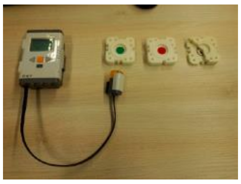
TECHNISCHE UNIVERSITÄT DARMSTADT

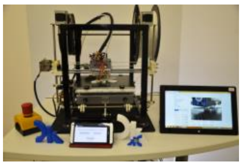


October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl   Folie 10

Strategy to Transfer Industrie 4.0 to Industry

TECHNISCHE UNIVERSITÄT DARMSTADT





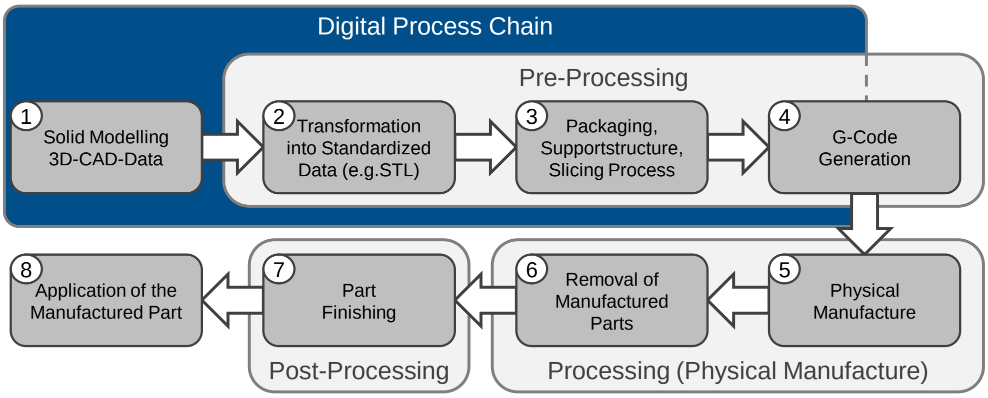
Research and Development Labs | **Demonstration and Learning Centers** | **Competence and Transfer Center** | **Prototyping and Testbed Centers**

October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl   Folie 11

Digital Process Chain – Additive Manufacturing

TECHNISCHE UNIVERSITÄT DARMSTADT

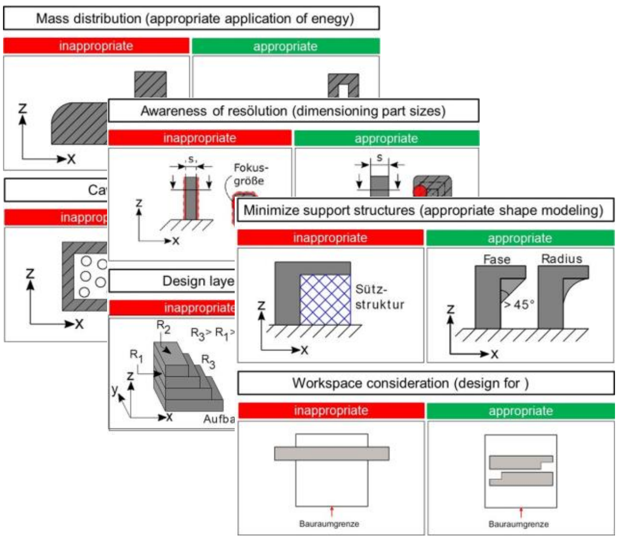
Additive Manufacturing is a fully digital process, from product design through manufacturing planning to manufacturing!



October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl

Design for Additive Manufacturing

TECHNISCHE UNIVERSITÄT DARMSTADT



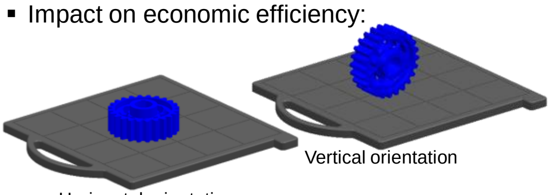
October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl

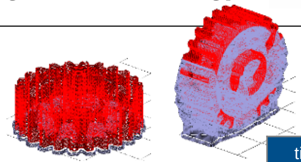
Manufacturing Planning: Nesting

Examples for nesting parts (positioning and orienting)

TECHNISCHE UNIVERSITÄT DARMSTADT

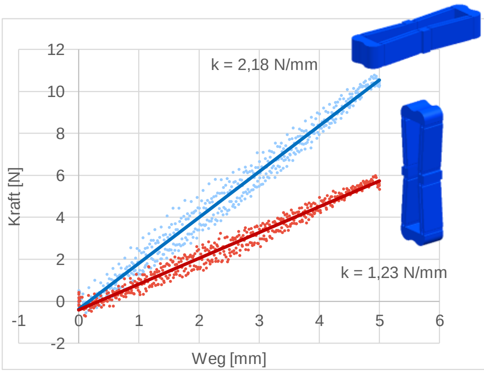
- Impact on economic efficiency:





	time	cost
horizontal	6:53 h	26,40 EUR
vertical	10:20 h	35,20 EUR

- Impact on mechanical properties:

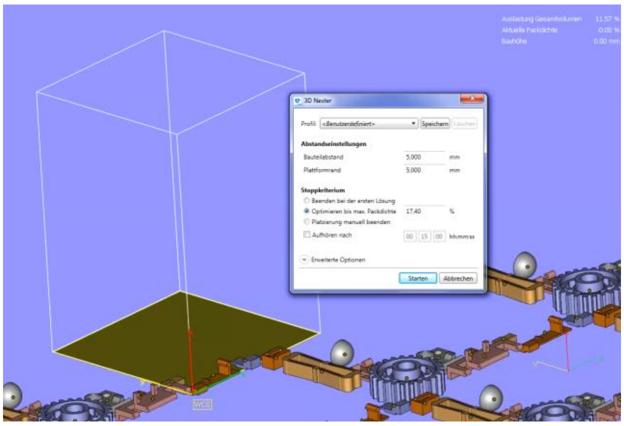


Example for Parts´ Nesting

TECHNISCHE UNIVERSITÄT DARMSTADT

Parts nesting:

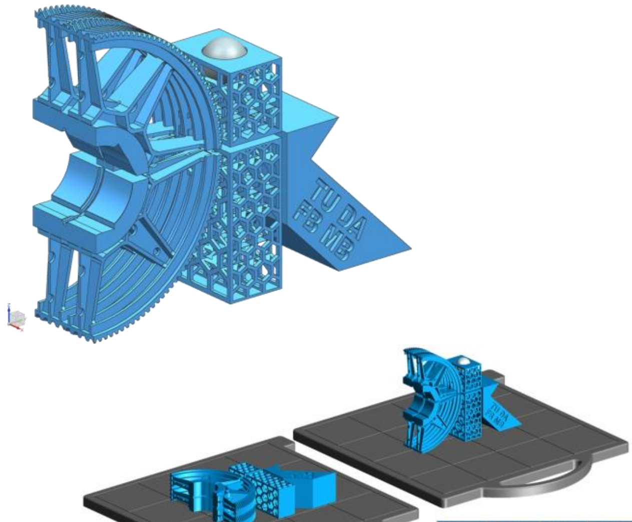
- Definition of position and orientation of parts in the manufacturing space.
- Algorithmic optimization of manually nested parts.



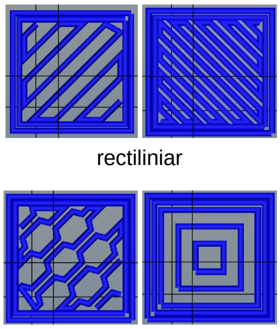
Manufacturing space with nested parts delivers the information
- for slicing and
- for G-code b´generation

G-Code Generation (path strategies)

TECHNISCHE UNIVERSITÄT DARMSTADT



	Modell	Support	Bauzeit	Baukosten
Stehend	57 cm³	63 cm³	38:50 h	60 EUR
Liegend	57 cm³	40,5 cm³	25:06 h	48,75 EUR

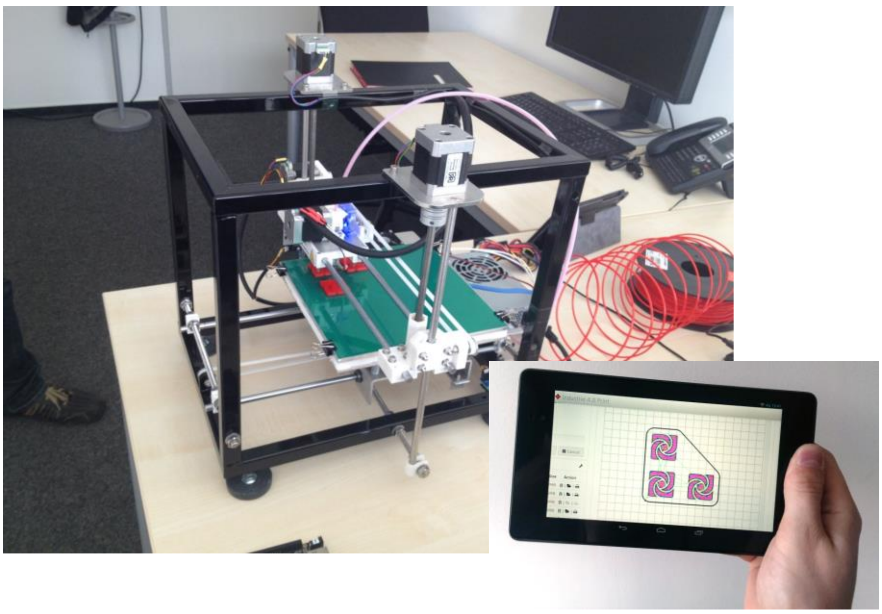


October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl

Folie 17

Additive Manufacturing Machine Tool connected to Smart Devieces

TECHNISCHE UNIVERSITÄT DARMSTADT



October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl

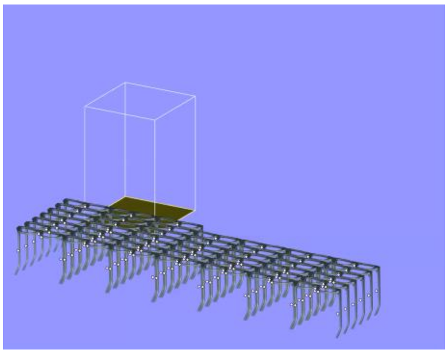
Folie 18

Individualization for additive manufacture of personalized Glasses

TECHNISCHE UNIVERSITÄT DARMSTADT

Additive Manufacturing of personalized glasses

- Measurement of human head biometry
- Design of glasses including frame parts
- Nesting of parts of various personalized glasses in the manufacturing space
- Additive Manufacturing
- Individualized assembling of parts for personalized glasses



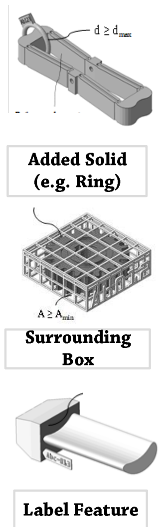
October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl Folie 20

Identifications Methods and Identification Marking

TECHNISCHE UNIVERSITÄT DARMSTADT

Identification Methods

Identification Marking



October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl Folie 21

Example for integrating a RFID Tag

TECHNISCHE UNIVERSITÄT DARMSTADT

Integration of a RFID Tag for individual identification of parts

October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl — Folie 22

Industrie 4.0 – Internet based Services

Cyber-Physical Production Systems (CPPS)

TECHNISCHE UNIVERSITÄT DARMSTADT

October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl — Folie 24

Platform Solution for Additive Manufacturing Process Chain

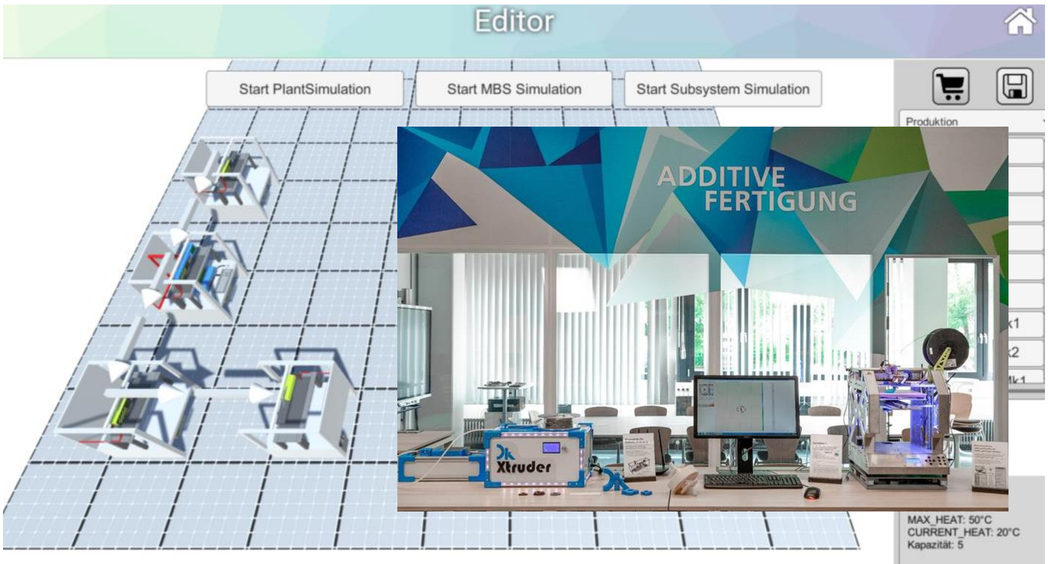
TECHNISCHE UNIVERSITÄT DARMSTADT

October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl

Folie 25

Platform Solution for Additive Manufacturing Process Chain

TECHNISCHE UNIVERSITÄT DARMSTADT



October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl

Folie 26

Conclusions

TECHNISCHE UNIVERSITÄT DARMSTADT

The German High-Tech strategy decided and published by the German Government has defined Digitalisation as a strong emphasis.

Key fields of action comprise challenges for the society, competences of the future as well as a new culture for innovation and venture..

Additive Manufacturing and its digital process chain plays an significant role for the digitalisation strategy and is also dedicated to support the individualization and personalization of products and associated services. Future research issues comprise

- new design paradigms dedicated to Additive Manufacturing,
- smart manufacture planning approaches,
- individualization and personalization methods as well as
- lifecycle consideration and lifecycle management.

New advanced engineering methods are required to make use of the full potenial of Additive Manufacturing.

October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl

Thank you very much for your Attention
Obrigado pela sua atenção!

TECHNISCHE UNIVERSITÄT DARMSTADT

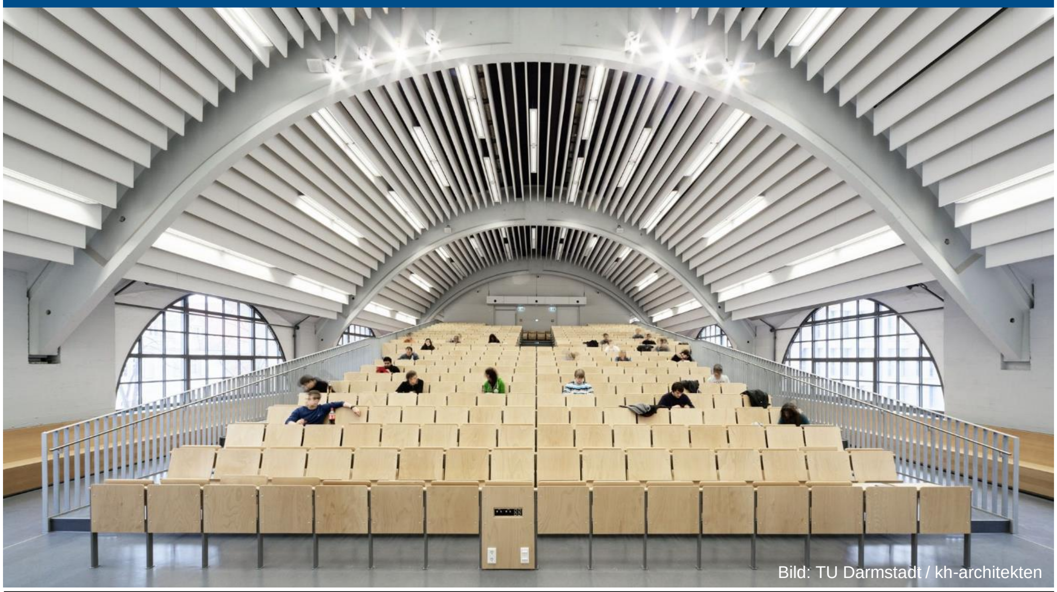


Bild: TU Darmstadt / kh-architekten

October 04th, 2018 | Department Mechanical Engineering | Computer Integrated Design | Prof. Dr.-Ing. R. Anderl

Prof. Dr.-Ing. Rainer Stark

Prof. Dr.-Ing. Rainer Stark studied mechanical engineering at Ruhr University Bochum and Texas A&M University. From 1989 to 1994 he worked as research assistant at the Chair of Design Engineering / CAD of the technical faculty of the University of Saarland. His PhD thesis is entitled “Development of a mathematical model on tolerance for the integration in (3D-) CAD systems”. From 1994 to 1997 he worked as a System Engineer in the Body Engineering department at Ford-Werke AG Cologne. In the following he focused on methods in virtual product creation and was promoted in 1997 to Technical Specialist for CAD, product modeling and product information management. Between 2002 and 2008 he was leading as European Technical Manager regional and global activities in Virtual Product Development and Methods within Ford Motor Company. During this time he also gave numerous guest lectures and presentations at the University of Bochum, the Saarland University Saarbrücken and at the University of Applied Science of Aix-la-Chapelle. Since February 2008 Prof. Rainer Stark is professor for Industrial Information Technology at the Technical University of Berlin and Director of the Virtual Product Creation division of the Fraunhofer Institute for Production Systems and Design Technology (IPK) and from April 2011 until March 2013 he was the Managing Director of the Department for Machine Tools and Factory Management (IWF). Prof. Stark is member of the German Academy of Technical Sciences (acatech), the scientific societies WiGeP (Scientific Society for Product Development), Design Society and CIRP (International Academy for Production Engineering) and board member of the ProSTEP iViP association. He is also an active member of the VDI (Society of German Engineers) board Product Development and Mechatronics, the Scientific Board of Industry 4.0 as well as the expert group National Competence Monitoring.

rainer.stark@tu-berlin.de
rainer.stark@ipk.fraunhofer.de

IIT, TU Berlin

The Department of Industrial Information Technology is engaged in the advancement of digital solutions for the improvement and the enlargement of engineering operations in the entire cycle of virtual product creation. Areas of research are the intuitive and contextual modeling, intuitively operable and functionally tangible virtual prototypes, the functional product development as well as development processes and methodologies for product design. The most important element of the teaching concept of our field of expertise is the content of engineer and information technology.

Industrielle Informationstechnik

Fraunhofer IPK

At Fraunhofer IPK in Berlin as an institute of the Fraunhofer-Gesellschaft we conduct applied research and development across the whole process spectrum of manufacturing industry – from product development, production processes, maintenance of investment goods, and product recycling to the design and management of manufacturing companies. We also transfer production technology solutions to areas of application outside of industry such as transport and security. The Virtual Product Creation division brings to life the vision of a completely digitalized product creation process. From product planning to maintenance and overhaul, digital techniques, processes and methods are an essential part of any product lifecycle.

Fraunhofer IPK

Smart Engineering capabilities for new generation product offerings

Abstract

This paper deals with the core question of which "smart engineering" capabilities are key for the presence and future of product and manufacturing companies within such volatile and fast changing environments. It describes results from several research projects with industry and provides an insight into the current state of existing industrial engineering capabilities, their associated challenges and limitations as well as the new capabilities that are essential for successful "smart engineering".

Keywords

Smart Engineering Capabilities; Model-based Engineering; Lifecycle Engineering; Virtual Engineering.

Authors

Prof. Dr.-Ing. Rainer Stark
IIT, TU Berlin – Fraunhofer IPK
rainer.stark@tu-berlin.de
rainer.stark@ipk.fraunhofer.de

Dr.-Ing. Kai Lindow
Fraunhofer IPK
kai.lindow@ipk.fraunhofer.de

Dr. rer. nat. Diana Reich
IIT, TU Berlin
diana.reich@iit.tu-berlin.de

Dipl.-Ing. Thomas Vorsatz
Fraunhofer IPK
thomas.vorsatz@ipk.fraunhofer.de

1 Introduction

Currently, global and regional industrial enterprises face significant “game changer” situations of different flavors such as:

- Swiftly developing political situations such as Brexit, volatile and difficult free regional / global trade zones, treaties and irritations (e.g. G6 vs G7 or G8 agreements), decreasing adherence to WTO rules & regulations, increasing combat and social conflict potentials within and across the regions, ongoing and increasing corruption, strategic competition in landscape investments to ensure access to critical raw materials;
- Substantial digital technology innovations (e.g. internet of things, IoT, Industrie 4.0, new type of human-machine interactions) which shift innovation streams away from physical and electronics towards software control, data and digital usage;
- Rapidly evolving market situations due to new and different customer and user expectations in combination with new technology opportunities (e.g. prosumers based on new 3D printing skills, or crowd development and open design based on global internet collaboration platforms);
- New digital data driven business models (“smart services”) with high ambiguities around what and how to deliver new products to customers and users;
- Rising societal expectations towards sustainability and stringent political pressure to establish circular economy systems and associated new enterprise and business collaborations set-ups.

All of the above mentioned change drivers put enormous pressure on product and manufacturing companies to overhaul, modify, extend and partly to disruptively change their market offering (i.e. what to produce and how to deliver it), as well as costumer engagements. Moreover, it raises the difficult question of how to innovate and modify their approach of developing such new types of “smart” products, services and production facilities and how to interact with costumers, consumers and users early on. The underlying engineering capability faces significant changes, both from information and digital model perspective and from validation and verification perspective.

2 Need for smart engineering capabilities

Nowadays less and less products can be considered purely mechanical – even “simple” bottle openers are available as “intelligent” mechatronic products creating a pop sound when the beverage has been opened or behave “smart” by informing friends via connected social media apps immediately after the bottle has been opened (see examples in Figure 1).

*Figure 1: **A:** basic mechanic products have become mechatronic (talkingbottle-opener.net/SanFranciscoGiants/); **B:** a clever one hand operated bottle opener with the ability to trigger app based internet communications (box-bottle-opener-x-smart-bottle-opener)*

This requires product development approaches including virtual validation integrating the controller and software content of the future product – an undertaking that has not been satisfyingly resolved thus far.

Smart products (see Figure 2) impose new challenges on product developers and users: they add new dimensions to commonly known and practiced methodologies such as Systems Engineering by actively introducing new IT enabler elements.

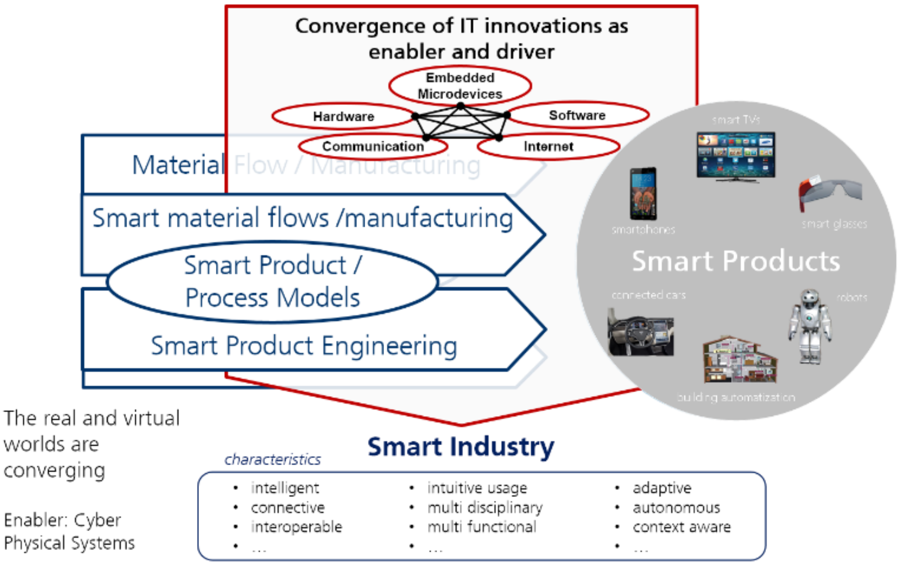


Figure 2: Smart products as convergence of the virtual and real world [Abramovici/Stark 2013] and [Abramovici 2015]

[Abramovici/Stark 2013] first presented the directional concept of these new IT enabler elements as part of the conference keynote at the CIRP Design Conference in 2013 in Bochum. Eventually this concept was introduced as formal definition in 2015 as part of CIRP Encyclopedia of Production Engineering as follows (compare Figure 3):

“Smart Products are cyber-physical products/systems (CPS) which additionally use and integrate internet-based services in order to perform a required functionality. CPS are defined as “intelligent” mechatronic products/systems capable of communicating and interacting with other CPS by using different communication channels, i.e., the internet or wireless LAN.” [Abramovici 2015].

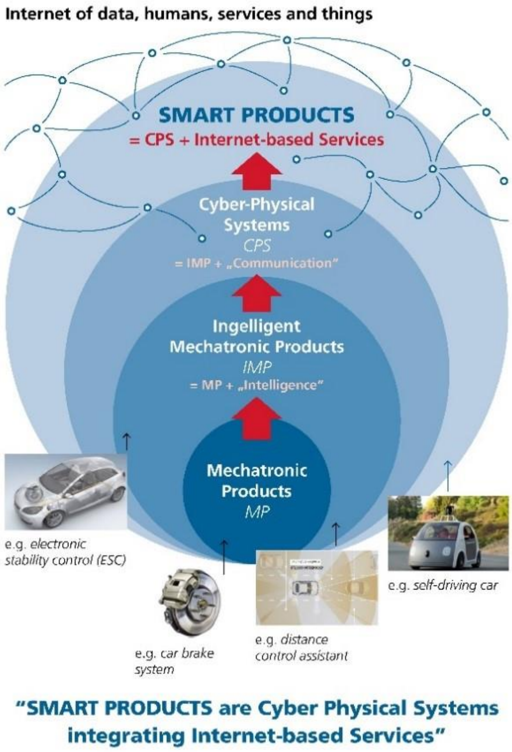


Figure 3: From mechatronic products to interconnected products providing internet-based services [Abramovici 2015]

The challenges engineers need to cope with are resulting new market trends in consumer and professional products and those become part of new product offerings such as:

- Context aware system readiness & interaction (e.g. a smart car door);
- Intelligent product-user interactions and services (e.g. intelligent guidance to operate a technical system);
- Self-learning and remote actionable products (e.g. autonomous cars and machines such as robots using smart data analytics);
- Circular re-usable across lifecycles (resilient components with flexible interfaces).

When it comes to new offerings regarding the lifecycle of products, new challenges and opportunities crop up with respect to data networking and information / data driven engineering. Several data levels and sets need to be combined, processed and analyzed in order to draw conclusions on business intelligence (via smart services) and engineering intelligence (via smart products). Data networking and data driven engineering heavily depends on the progress made in applied data science research (e.g. semantics, AI, ML) with an applicable focus on engineering activities. Smart products and services form new capabilities in connecting information and data sets across all lifecycle phases by means of new IT platforms (e.g. IoT) and technologies (e.g. CPS).

In order to position new and smart engineering capabilities, it is necessary to reflect on the existing situation within engineering. Over the last years, the research teams of Fraunhofer IPK and TU Berlin have developed a holistic system that relates key elements of engineering to each other. This system is designated as *Engineering Operating System (EOS)*, compare details in [Lünnemann et. al. 2017b]. The core principle of the EOS places human engineering activities in the center of the model in interaction with processes and organization, different types of artefacts (physical & digital), as well as with tools and IT systems (compare Figure 4).

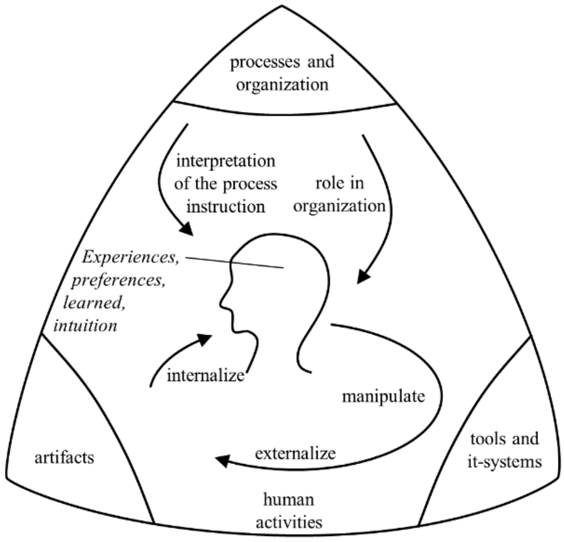


Figure 4: Core principal of the EOS

The resulting EOS model is illustrated in Figure 5. The three sets of "processes and organization", "tools and IT systems" and "virtual and physical artifacts" form the basis of the description model. Based on these three sets and the interplay between them, the actual value-creating activities are carried out by humans within their roles (e.g. engineer). A deeper insight to the EOS principles and working mechanisms is provided in [Lünnemann et. al. 2017b].

During the last years, it became evident that the desire to develop “smartness” into modern products and into our daily working environment has been increasingly rising. Even marketing initiatives by major global companies such as *smarter planet* have been started to express a certain degree of better control of technical systems in different types of environments (cities, enterprise, grids etc.). New technology opportunities in sensors and actuators combined with additional software control and new IoT (Internet of Things) capabilities provide a new base for “smartness”. Nevertheless, no consolidated definition yet exists for the term “smartness” in the context of products and engineering capabilities.

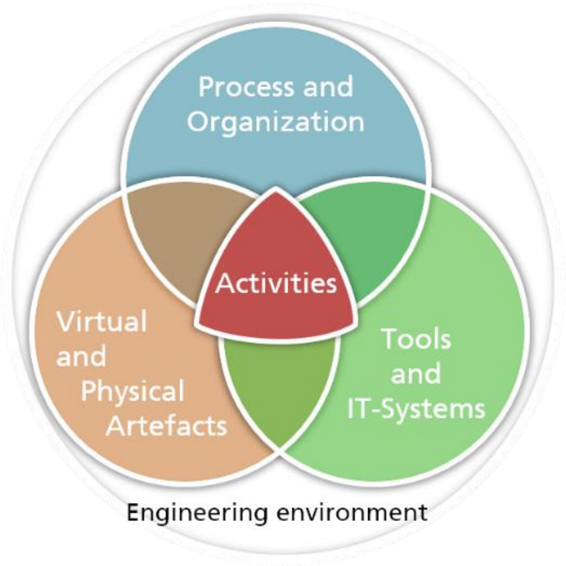


Figure 5: The EOS model illustrated as a Venn diagram

Nowadays, *smartness* is often associated as follows:

- Quick or prompt in action; like a human;
- Having or showing quick intelligence or ready mental capability;
- Shrewd or sharp, as a person in dealing with others or as in business dealings;
- Clever, witty, or readily effective, as a speaker, speech, rejoinder, etc.;
- Self-regulating part of a machine, system, etc. equipped with electronic control mechanisms and capable of automated and seemingly intelligent operation;
- Having properties that can be changed in response to stimuli or environmental conditions, self-regulating.

In order to provide a meaningful set of *enabler categories* which can be used in order to realize and drive smartness dimensions in products and engineering the authors introduce the following first conceptual framework for the realization of smartness (using the 5 letters of the word "smart" as memory function) following the general understanding of smart (see above):

S: Systems engineering to enable Sustainability

M: Multi-disciplinary & Model-based

A: Adaptive + Autonomous

R: Robust + Renewable

T: Team and Technology

The rationale behind these enabler categories to achieve smart capabilities is as follows:

- In order to find suitable implementations of smartness it will be necessary to use paradigms of systems engineering, consciously taking interconnecting and influencing mechanisms in between partial systems into account. Smartness by itself is not necessarily a meaningful target, unless it supports the goals of sustainability by best compromising between the three dimensions of ecology, society and economy.

- *Smartness* with such high ambitions will only be able to be achieved if the development approach starts to engage knowledge and capabilities of *different disciplines*, spanning from different fields of engineering (mechanical, hydraulic, pneumatic, electric, electronic etc.), logic, control and software up to cognitive engineering, human interaction and process reasoning. The execution of *models* and their co-simulated interplay will be decisive to achieve a high degree of digital processing in order to achieve a high number of synthesis alternatives and gaining intelligence from training execution.

- Both, from point of view of engineering and operation of technical systems, *smartness* needs to be realized in properties of *adaption* (to existing or neighbor environments) and *autonomy* (self-learning and optimizing). Otherwise, the expected intelligent behavior is limited and does not provide extension and scalability.

- All members in industry and economy, as well as the society itself, are depending that *smartness* does not violate the ground rules of *robustness*, i.e. errors should not stress the system to extreme and unknown behaviors. In order to guarantee true sustainability, it must be guaranteed that *reliability* in operations and maintenance of technical systems is provided.

- As balanced set-up in ownership and accountability is key to allow short, mid and long term viability of technical systems. Hence, the right degree of balance between team approach (i.e. human beings in their individual roles) and technology will form the success factor of smart operation and decision execution.

3 Current research on Smart Engineering Capabilities

This section of the paper deals with *smart engineering capabilities*, which have been identified und picked up by the research work of the division *Virtual Product Creation* of Fraunhofer IPK and the chair *Industrial Information Technology* of TU Berlin during the execution of fundamental problem analysis projects with partners in industry and within research projects with scientific teams and communities.

In the following section, the authors distinguish *Smart Engineering Capabilities* (SEC) according to the following four sub-categories:

a) Smart Digital Engineering

b) Smart Virtual Engineering

c) Smart (model-based) Systems Engineering

d) Smart Lifecycle Engineering

3.1 Smart Digital Engineering Capabilities

Digital Engineering, in general, describes the tasks and capabilities of the engineering workforce in creating computer-aided models, in handling digital models within databases in a consistent manner and in generating resp. using information sets along digital workflows.

First, it will be essential to provide fundamental smart capabilities in understanding today's digital engineering operation with respect to engineering workforce task portfolios. Hence, the following capability is key and constitutes the starting point for smart digital engineering:

Definition:

Smart Digital Engineering capabilities will address new digital assistance and intelligence in creating, revising, exploring, collaborating, testing, signing-off and releasing diverse sets of traceable artefacts as part of digital engineering workflows, processes and activities.

Identification of digital work behavior (Smart Engineering Capability #1, type: digital)

- Localization within the EOS:
  In order to understand the new digital engineering work behavior, it is helpful to illustrate the causal dependencies within the EOS model: as depicted within Figure 6 the digital work behavior is driven by the interaction of the engineer with digital models, models and data in the context of IT-tools and applications. This digital work behavior then is the base for the process steps activities in engineering.

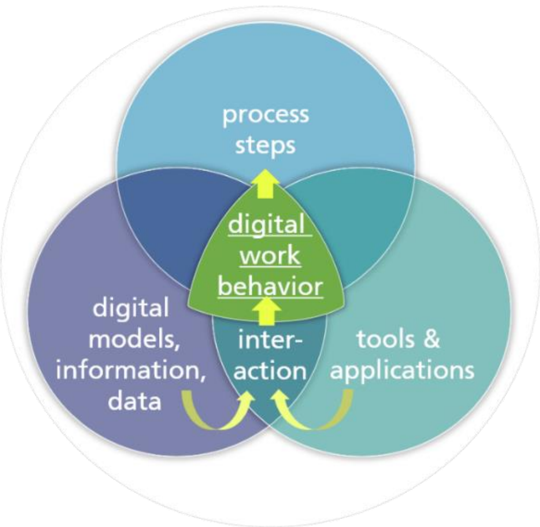


Figure 6: Smart Digital Engineering Capability "Identification of digital work behavior" within the EOS cause & effect relationship

- Problem description
  Today, the engineering workforce and its management faces severe limitations to properly identify and understand which type of digital work is executed within digital computer applications during typical engineering work patterns and associated collaboration scenarios.

- Solution requirement description
  In order to improve engineering activities patterns and styles with respect to quality, efficiency, relevance and compatibilities, it must be possible to seamlessly identify and recognize digital work behaviors for individuals and teams. Since the amount of digital work and its associated activities will steadily grow, both, within technical engineering tasks and within administrative resp. collaborative tasks, optimization of time commitments and user centered IT-application interaction and final digital result achievements will be essential in future workplace and work pattern arrangements.

- Current research concepts and demonstrators
  Existing approaches for the identification and analysis of development activities are based on F. W. Taylor's fundamental idea of "Scientific Management" [Taylor]. Further analyses up to the establishment of engineering activities by [Zanker] represent the status of development activities assumed by engineers. The influence of digitized work environments has been neglected so far [Lünnemann et. al. 2017 a]. Necessary activities of information procurement, agreements and documentation in computer applications have not yet been taken into account in the scientific research community. Subsequently, first laboratory experimentation at Fraunhofer IPK in Berlin (Germany) could highlight the anticipated delta between actual activities of the engineers and the existing documentation of these activities [Lünnemann et. al. 2017 a].

- Potential first implementation experiences
  Individual digital behavior patterns of engineers at computer workstations are identifiable and can be linked to specific development activities. This is achieved by automated identification and comprehensive analysis of such activities in alignment with development task, digital tools in interplay, work processes and digital models. The Fraunhofer IPK research team meanwhile can show that individual working methods not only depend on the development environment but also on the experience of the development engineer [Lünnemann et. al. 2017 b].

3.2 Smart Virtual Engineering

Virtual engineering addresses a range of scientific, technological, organizational and business activities using advanced information and communication technology and methods with major focus on process and systems integration, immersive visualization and “human-machine-human” interaction (Ovtcharova, 2011).

This causes an important redefinition of the overall product development process for supporting the coordination, assessment and concretion of engineering results of all involved partners due to virtual artefacts.

Thus, the overall aim of virtual engineering is the early, continuous, networked (process view) and integrated (system view) support of the entire product life cycle concerning collaboration, assessment, concretion and validation of products and processes with participation of all partners using virtual artefacts.

Smart Hybrid Prototyping (Smart Engineering Capability #2, type: virtual)

- Localization within the EOS
  The idea of smart virtual engineering is validation as early as possible in the product development process (see Figure 7, 1). For this purpose, the most suitable virtualization tools are selected (2). In order to validate e.g. user interfaces with VR technologies as early as possible, suitable models are required (3a). Some of these required models need to be newly developed and transformed first (3b).

- Problem description
  The requirements for the new engineering capability of Smart Hybrid Prototyping (SHP) is derived from higher-level objectives to fix industrial challenges of virtual engineering, e.g. the growing complexity of product and process requirements while drastically reducing time-to-market and classical physical product prototyping. Additionally, there is a need to experience sheer virtual models (e.g. CAD models). This can be achieved by using haptic devices, which enable forced feedback, and therefore, interaction with virtual models. This principle is used to reach another level of virtual product development and validation called Smart Hybrid Prototyping.

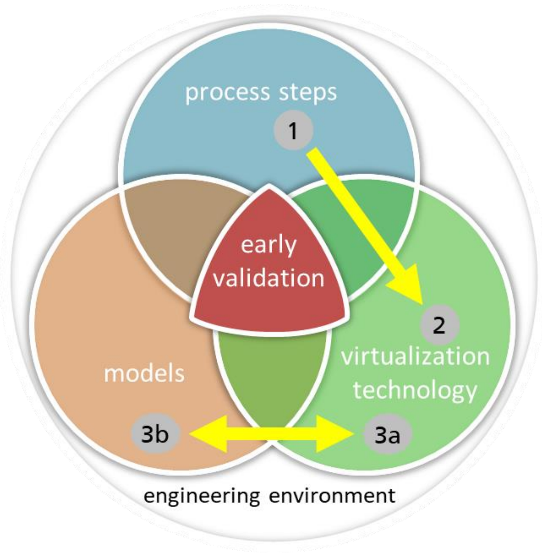


Figure 7: Smart Virtual Engineering Capability "Early Validation of User Interface" within the EOS cause & effect relationship

- Solution requirement description
  The Smart Hybrid Prototyping (SHP) approach is defined as a combination of physical prototypes and digital models in a Virtual Reality in order to enable a realistic experiencing of a mechatronic system [Stark et. al. 2010]. Furthermore, it enables a multimodal experience of mechatronic products, which means that the human factor is given much greater prominence when validating the overall system in real-time.

- Current research concepts and demonstrators
  In order to understand the idea behind and the need of SHP, an overview of some other technologies, which provide the base for SHP, is required. In particular, these are visualization technologies like Virtual, Augmented and Mixed Reality, modeling and simulation technologies with physics-based game engines or professional tools like MATLAB/Simulink or Dymola, interaction technologies and human machine interfaces (HMIs) like computer haptics and Tangible User Interfaces (TUIs).

- Potential first implementation experiences
  The SHP technology was validated by developing, assembling and testing a passenger car's tailgate device [Auricht et. al, 2013]. The tailgate test setup is shown in Figure 8.

3.3 Smart (model-based) Systems Engineering Capabilities

Model-based Systems Engineering (MBSE) is an interdisciplinary field of engineering and engineering management that focuses on how to design and manage complex systems over their life cycles. At its core, systems engineering utilizes systems thinking principles to organize this body of knowledge.

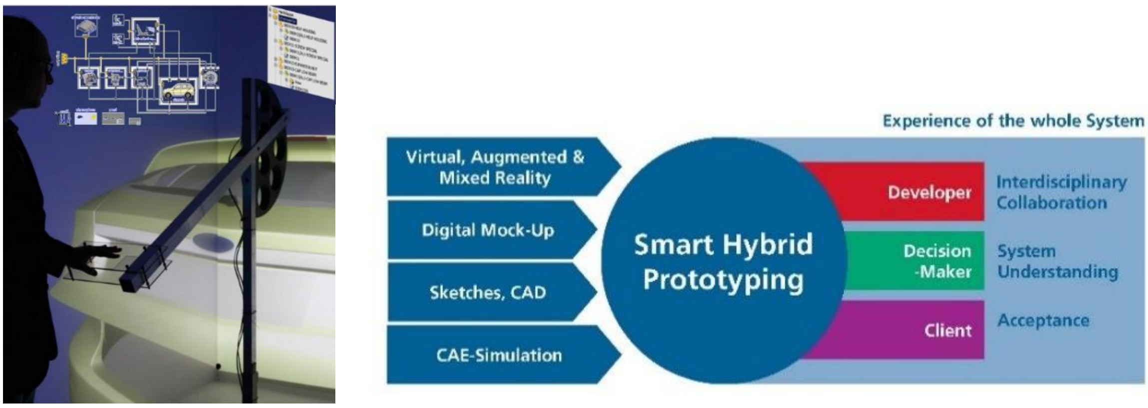


Figure 8: SHP demonstrator (top) and process (architecture)

Issues such as requirements engineering, reliability, logistics, coordination of different teams, testing and evaluation, maintainability and many other disciplines are necessary for successful system development, design, implementation, and ultimate decommission and become more difficult when dealing with large or complex projects. Systems engineering deals with work-processes, optimization methods, and risk management tools in such projects.

Model Intelligence for IoT and Industrie 4.0 (Smart Engineering Capability #3, type: model based)

- Localization within EOS

  From product development up to commissioning and final realization of the product / production system, each process step requires different types of digital models and their respective data. These two triggers drive the model-based systems engineering tasks and operations (see Figure 9).

  The latter need to be processed by IT tools and applications that allow lossless information transition and storage as well as accessibility during lifecycle phases, across engineering domains and across company boarders. The new challenge here is to establish a meaningful feedback to design channel: information from product operation back into design and engineering phases and to provide services and capabilities to handle models and data appropriately.

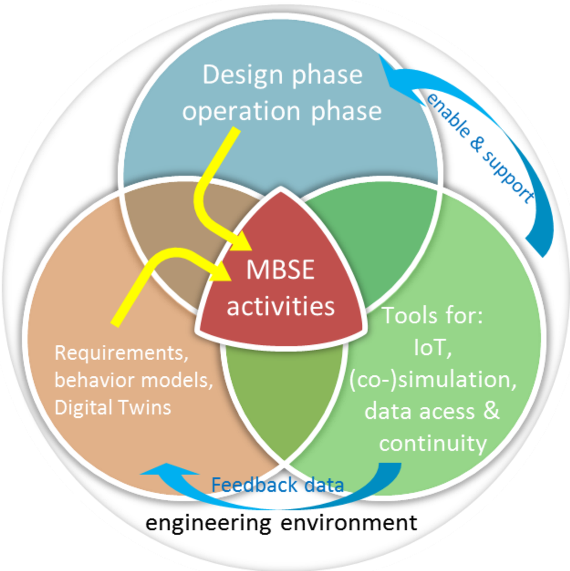


Figure 9: MBSE in the EOS: Requirements, behavior models and digital twins form the basis for all activities in the design and operation phase of products and production systems. The IT tools enable the models and data to be processed and their information to flow (back) into the according process steps

- Problem description

  Nowadays, new types of products come into play, which all require interconnectivity, provide services and need to communicate with their production plant during manufacturing processes [Fraunhofer IPT]. Existing development processes and methods lack the consideration of those aspects, yet Systems Engineering becomes even more important to cope with the complexity of even simple looking products. The extension to Model-based Systems Engineering is driven by the fact, that a significant amount of software and electronics currently needs to be designed, managed, tested and integrated as part of the product.

Furthermore, there are no commonly accepted and spread technologies and formats of how to define interconnectivity and services of the future products during the product development phases especially when it comes to multi-domain and cross-company development projects. Data exchange and co-simulation are major barriers to successful development (see the challenges from product engineering up to manufacturing execution in Figure 10).

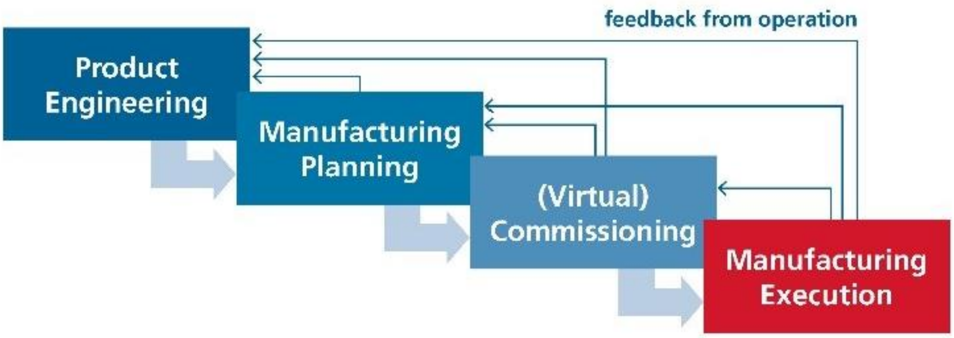


Figure 10: data continuity and data & model exchange along phases from the first idea until start of production and beyond impose tremendous challenges due to heterogeneous tool landscapes and their format (in)compatibilities

- Solution requirement description

  This calls for sophisticated models that integrate all domains of engineering. Even further, models need to be intelligent, adaptable and re-usable. In addition, models need to become real-time executable to enable products and production lines for Digital Twin implementations. Real time execution will be used to feed back in-process data for optimization, health monitoring, intelligent manufacturing organization.

  To achieve the above mentioned mission it becomes yet even more crucial to solve the basic problems of exchanging data and validating their “correctness”, especially when it comes to co-simulation of larger systems. This calls for standardization of data formats on the one hand as well as for methods that prove the integrity of simulation models.

  Last but not least, in the field of manufacturing machine design, training of workers becomes necessary as early as possible, whereas in the field of product design validation of user acceptance becomes crucial already in the phase of pure virtual engineering. Both needs can be met by utilizing Digital Twins along with technologies of prior mentioned Smart Virtual Engineering capabilities (see section before).

- Current research concepts and demonstrators

  The demonstration cell *‘Smart Factory 4.0’* of Fraunhofer-IPK is a miniature production line for conducting research and act as a testbed for tool and component vendors. The Smart Factory itself can be considered smart to an extent as it manufactures individualized batch-size one products right after the customer has entered his/her product definition into the system. The base here is a set of simulation models that interact intelligently with each other and based upon sensor data created in the physical as well as in the virtual production line. Both worlds are interconnected by using IoT technology (compare Figure 11).

Figure 11: Digital Factory Twin and Digital Product Twin as "life-time" companions to their physical entity connected via IoT technology amongst others

IPK will produce IoT products on such a production line soon. Thus, a product is going to be manufactured which can sense and communicate by itself. It is customizable and shall provide services to the user after it left the production line. In addition, it will communicate with the factory itself for self-organization, optimization with the primary goal to speed up production, maximize machine load factor, improve product quality and reduce manual efforts.

- Potential first implementation experiences

  Fraunhofer-IPK's and the TU Berlin research teams are providing services to cross-company societies and working groups such as "Production Lifecycle information Management" (PLiM) and "Smart Systems Engineering" of the prostep ivip association. In both groups, the topics of Data Continuity in the process of production line planning, as well as (simulation) model exchange, are specifically addressed, as industry seriously lacks suitable tools, in terms of methods and standards.

  Furthermore, Fraunhofer-IPK has developed, built and implemented an IoT-based worker tracking system for workers of a large automotive OEM in Germany. Finally, the team has successfully set up a Digital Factory Twin for in-house R&D for another automotive OEM in Germany.

3.4 Smart Lifecycle Engineering

Smart products and services require new capabilities in connectivity of information and data sets across all lifecycle phases. Additionally, new IT platforms (e.g. IoT) and technologies (e.g. CPS) change common methodologies in engineering design, business development and lifecycle thinking.

Smart Services (Smart Engineering Capability #4, type: lifecycle)

- Localization within EOS
  Products are becoming smarter and services are offered across the entire lifecycle. In the understanding of EOS, the digital and physical artefacts are changing (see Figure 12, 1). At the same time, new IT tools, applications and systems are evolving (2). Traditional engineering companies will have to adapt their processes and organization eventually. That way, they establish new ideas for products and services (3) and new digital and physical artefacts come along.

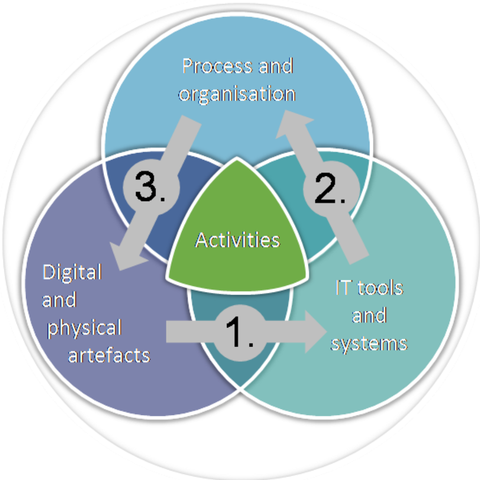


Figure 12: Transformation from digital and physical artifacts (1) to the use of new IT tools and applications (1) towards new products and services within a company (2). Eventually, business in terms of process and organization drives the need for new digital and physical artifacts (3)

- Problem description
  Smart products and smart services require new engineering capabilities for development, manufacturing, use and End-of-Life (EoL). Information and data needs to be constant across the entire life cycle – regarding single as well as entire sets of products and services. Dedicated data and connectivity management is required: data and information creation, collection, analysis, use and linking of artefacts across the lifecycle become essential for different stakeholders, and especially in engineering.

- Solution requirement description
  Solutions are needed for (a) engineering processes and (b) lifecycle processes. Harmonized interaction of artefacts requires synchronized data management and

information standards up to business model (e.g. pre-processing, post-processing, analysis, actions). Harmonized system landscapes (PDM/PLM vs. IoT platforms) are necessary.

- Current research concepts and demonstrators
  In the future, data on a business level is one of the main resources since it is transformed into valuable information, thus it is systematically integrated into a value proposition. That way, a solution approach to create a data-driven business model has been developed at Fraunhofer IPK. The model of capability stair steps defines the digital transformation of a company. The model can be adapted, specified and detailed based on the data driven business model regarding specific use cases. Eventually, a strategic stair step will describe the transformation, including action recommendations and specific success factors. With regard to the engineering level, product related data can be semantically linking with each other – without copying and creating a new data silos. At the current state of research, prototypical implementations of a product data assistance system that fulfils the demand of information provision in engineering are carried out – following the vision of the users (engineers, buyers, etc.) who can easily browse the data they are looking for and quickly find an answer for newly formulated questions in context. A semantic network database that allows the (automatic) connection of previously unrelated data is created. The solution approach brings context to product data by enriching data with semantic (context, meaning, metadata) information thus technologies which are able to handle semantic information models by using semantic data structures, algorithms and machine learning in order to optimize information flow are developed.
  On a production system design level, the current state of industry is a highly manual task and engineers must perform a large number of repetitive tasks. In the research of Fraunhofer IPK, existing artificial intelligence approaches (e.g. clustering, regression analysis and neural networks) are adapted to automatize the design of production systems for body-in-white. The developed software prototype creates initial production system configurations, which determine necessary production resources for specific assembly processes. As a result, artificial intelligence undertakes a majority of the repetitive tasks in production system design, giving developers more time and flexibility in solving design issues that require creativity and design knowledge.

- Potential first implementation experiences
  In general, data networking and information / data driven engineering are the major challenges in smart lifecycle engineering. Several data levels and data sets (e.g. sensor data, product system behavior data) need to be combined, processed and analyzed. Based on that, engineering conclusions can be drawn. Different heterogeneous data needs to be linked and be prepared for analysis. Consequently, working on a semantic level seems to be a key enabler for gaining serious results in the understanding of engineering. Artificial intelligence plays an important role. From an engineering

perspective, it is not about developing new algorithms, but to understand existing ones and apply them to engineering tasks.

4 Discussion

The authors developed the smart engineering framework and introduced four different types of smart engineering capability within this paper. Smart engineering capabilities are built upon the foundations of virtualization and digitalization.

Virtualization is the methodical procedure of transferring a real object and its environment into a computer-based digital model. With the help of visual presentation possibilities, the real behavior of the functional system can be simulated [Spur, 2001] and a virtual model with a variety of characteristics will be produced.

Digitalization describes the transformation of real systems in digital models to handle numerical values by using digital technologies, like computers simulated [Spur, 2001]. This means that analogical information will be transferred to digital mediums. This continuing changing process is called digital transformation [Keuper et al., 2013]. In lieu of this work, virtualization in product development is seen as a subsequent step after digitalization. Based on the foundation of digital transformation, virtualization transforms real technical systems and their environments (field, traffic, other products and systems, factory etc.) into virtual models by using digital information sets and appropriate synthesis and analysis IT applications. Similar to digital transformation, the continuing change process towards such virtual model capabilities in product development can be called *virtual transformation*, which is a key mission of modern virtual product creation.

All those major transformations are necessary to provide a proficient set of engineering capabilities in order to design and operate smart products and production systems. The crucial role of models, information and data as one key elements for the future smart engineering capabilities has become evident.

The Engineering Operation System (EOS) has been proven to be well capable of systematically describing the interrelations of the critical elements of each one of the smart engineering capabilities types: digital, virtual, model-based and lifecycle.

5 Conclusion and Future Work

The presented Smart Engineering Capabilities form the basis for the aforementioned new product offerings. While virtual validation is becoming increasingly available due to higher computing capacities, as well as established IT tools on the market, and while digital engineering as common ground is not under discussion anymore, those new technologies, tools and amounts of data available, amongst others, streaming permanently from products and production systems during operational phases, need to be handled wisely. This requires expert knowledge and steady training of engineers to cope with the new challenges and their new roles within companies applying Smart Engineering.

Regarding Lifecycle Engineering, the gap between traditional lifecycle concepts and its implementation is closing due to new intelligent technologies that support data and information flow across the lifecycle. New offerings require integrated smart lifecycle approaches from data collection up to business models.

In the near future, there will be a need for the harmonization of data models for lossless information exchange between all stakeholders during the product development process. The current lack of interoperability between domains and especially across company borders needs to be closed. This can be achieved by R&D of Technical Universities, Fraunhofer institutes, amongst others, as partners with industry and their expert groups by defining standards and methods, which need to be implemented by tool vendors. Converting Big Data into Smart Data is another pillar in the successful digital transformation. IoT and AI are no direct engineering solutions, but they represent rather channels and mechanisms providing new opportunities for the presented types of smart engineering capabilities.

The next years will have to deliver extensive research programs to establish full understanding of such new ways of engineering and its associated smart engineering capabilities. It will be crucial for industries to invest heavily on all aspects of the EOS, especially on transforming the knowledge and activity understanding of the next generation of engineers. Otherwise, competitiveness will suffer and comprehensive changes for circular economy systems will not be achievable.

6 References

[Abramovici/Stark 2013] Abramovici, M.; Stark, R.: Smart Product Engineering – Proceedings of the 23rd CIRP Design Conference, Bochum, Germany March 11th – 13th 2013; Berlin Heidelberg: Springer-Verlag; 2013; ISBN: 978-3-642-30816-1

[Abramovici 2015] M., Abramovici: The International Academy for Products, CIRP Encyclopedia of Production Engineering, 2015, Springer Berlin Heidelberg

[Taylor] F.W.Taylor: Die Grundsätze wissenschaftlicher Betriebsführung ISBN 3-621-27267-4

[Zanker] Zanker, Winfried: Situativenpassung und Neukombination von Entwicklungsmethoden. Zugl.: München, Techn. Univ., Diss., 1999. Als Ms. gedr. Aachen: Shaker, 1999 (Reihe Konstruktionstechnik München 36)

[Lünnemann et. al. 2017a] Lünnemann, P.; Wang, W. M.; Stark, R.: Methodische Analyse der Entwicklungs-aktivitäten. In: K. Brökel, K.-H. Grote, R. Stelzer, F. Rieg, J. Feldhusen, N. Müller und P. Köhler (Hg.): 15. Gemeinsames Kolloquium

Konstruktionstechnik. Interdisziplinäre Produkt-entwicklung. Essen: Universität Duisburg-Essen, S. 89–98; 2017, ISBN: 978-3-940402-15-8

[Lünnemann et. al. 2017b] Lünnemann, P.; Wang, W. M.; Ibánez Manteca, P.; Stark, R.: Engineering Activities – Considering Value Creation from a holistic Perspective. In: Proceedings of the 2017 International Conference on Engineering, Technology and Innovation (ICE/ITMC), Funchal, Madeira Island, Portugal. 27 - 29 June, 2017. ISBN 978-1-5386-0774-9/17

[Stark et. al. 2010] Stark, R.; Beckmann-Dobrev, B.; Adenauer, J.: Ein interdisziplinärer Ansatz zur multimodalen funktionalen Absicherung mechatronischer Systeme am Beispiel einer PKW-Heckklappe, Grazer Symposium Virtuelles Fahrzeug, 2010

[Auricht et. al, 2013] Auricht, M.; Lindow, K.; Stark, R.: Erlebbare Entwicklung und Absicherung technischer Systeme. In: Stuttgarter Symposium für Produktentwicklung (SSP), Fraunhofer Verlag, Stuttgart, S. 8-17, 2013, ISBN: 978-3-8396-0573-8

[Fraunhofer IPT] Studie: Systems Engineering in der industriellen Praxis, Heinz Nixdorf Institut, Fraunhofer IPT, Unity AG, 2013

[Spur] Spur, G.: “Begriffe in der Produktionstechnik“, in Zeitschrift für wissenschaftlichen Fabrikbetrieb (ZWF), Volume 96, Carl Hanser Verlag, Munich, pp. 141, April 2001

[Keuper] Keuper, F.; Hamidian, K.; Verwaayen, E.; Kalinowski, T. and Kraijo, C.: “Digitalisierung und Innovation“, Springer Verlag, Wiesbaden, 2013

SMART ENGINEERING CAPABILITIES FOR NEW GENERATION PRODUCT OFFERINGS

23rd International Seminar on High Technology - Smart Product Development – Challenges and new requirements – October 4, 2018, Piracicaba, Brazil

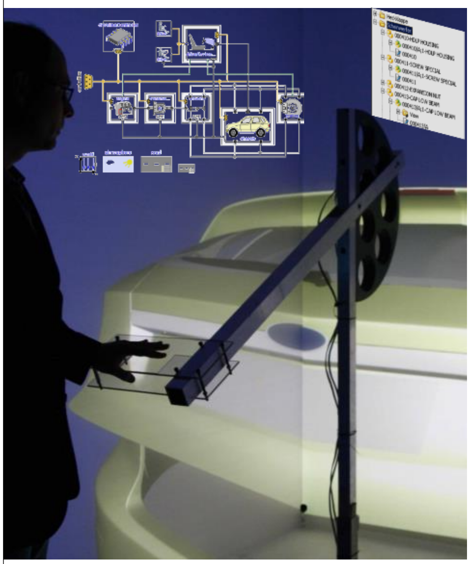
Prof. Dr.-Ing. Rainer Stark

Director of the chair Industrial Information Technology
Technische Universität Berlin
School of Mechanical Engineering and Transport Systems
Department of Machine Tools and Factory Management (IWF)

Director of the division Virtual Product Creation
Fraunhofer-Institute for Production Systems and Design Technology (IPK)

Fraunhofer IPK – Institute Production Systems and Design Technology
Technische Universität Berlin
Industrial Information Technology

STRUCTURE



- Introduction of speaker
- Drivers for digital transformation in value creation
- Smart Products require Smart Engineering
- Current R&D on smart engineering
  - Smart Digital Engineering
  - Smart Virtual Engineering
  - Smart (model-based) Systems Engineering
  - Smart Lifecycle Engineering
- Projects with industry
- Conclusion and Outlook

Fraunhofer IPK | Industrial Information Technology | 1

Prof. Dr.-Ing. Rainer Stark

- Study of Mechanical Engineering at Ruhr-University Bochum
- Integrated 1-year study at Texas A&M University, USA, in Mechanical Engineering (research projects with NASA)
- Research Assistant at the Chair of Design Technology / CAD in the Technical Faculty of the Saarland University in Germany
- System Engineer within Body Engineering in Ford of Europe
- (Senior) Technical Specialist CAD, Product Modeling and Product Information Management in Ford of Europe
- Technical Leader / European Manager Virtual Product Creation & Methods in Ford Motor Company
- Director Industrial Information Technology at the Berlin University of Technology (School of Mechanical Engineering and Transport Systems) and
  Director Virtual Product Creation at the Fraunhofer Institute for Production Systems and Design Technology
- Member of
  - acatech (German academy of technical sciences)
  - acatech research board of industrie 4.0 platform
  - CIRP, The International Academy for Production Engineering
  - ProSTEP iViP Association (board, 180 companies)
  - WiGeP Scientific Association for Product Development
  - VDI Association of German Engineers (board)

Technische Universität Berlin

Fraunhofer IPK
INSTITUT PRODUKTIONSANLAGEN UND KONSTRUKTIONSTECHNIK

Fraunhofer IPK — Industrial Information Technology — -3- — 3

FRAUNHOFER PROJECT CENTER FOR ADVANCED MANUFACTURING @ ITA

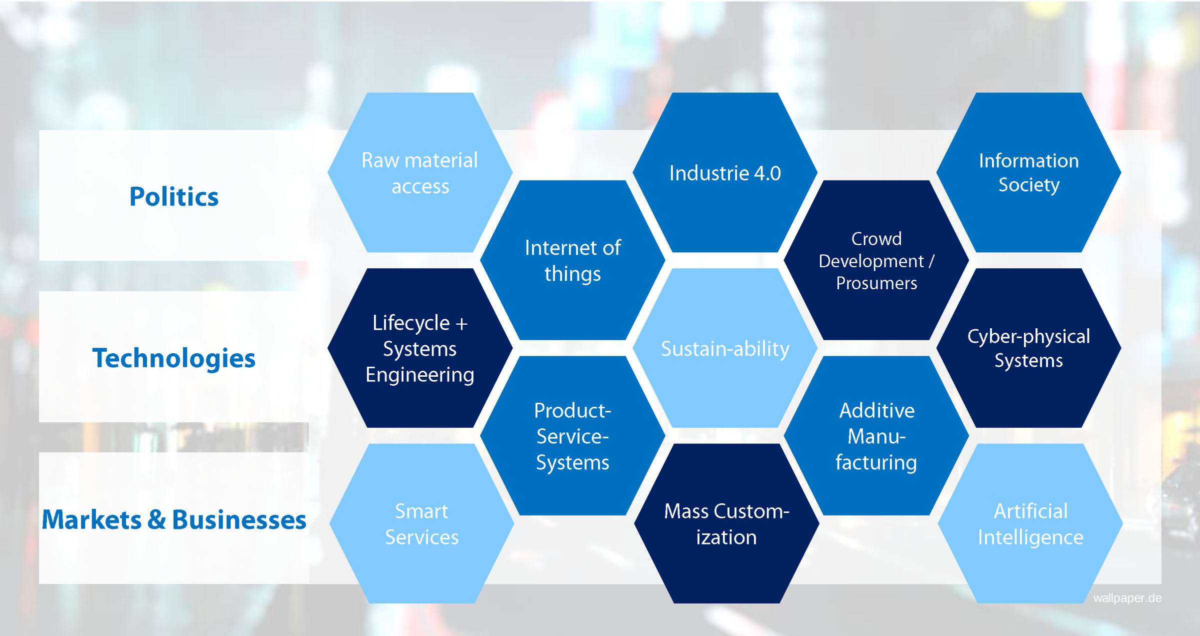
STRATEGIC OBJECTIVES AND FRAMEWORK

- Support the **scientific, technological and economic development** in Brazil and in Germany
- **Support the Brazilian, German and European** industries in Brazil with applied research and innovation projects
- Acquire and execute joint RD&I projects with industry in Brazil, in cooperation **between CCM/ITA and FhG/IPK**
- Focus at ***Industrie 4.0* solutions**

- **Project Duration**: 3 years
- **Investment**: 2 million €

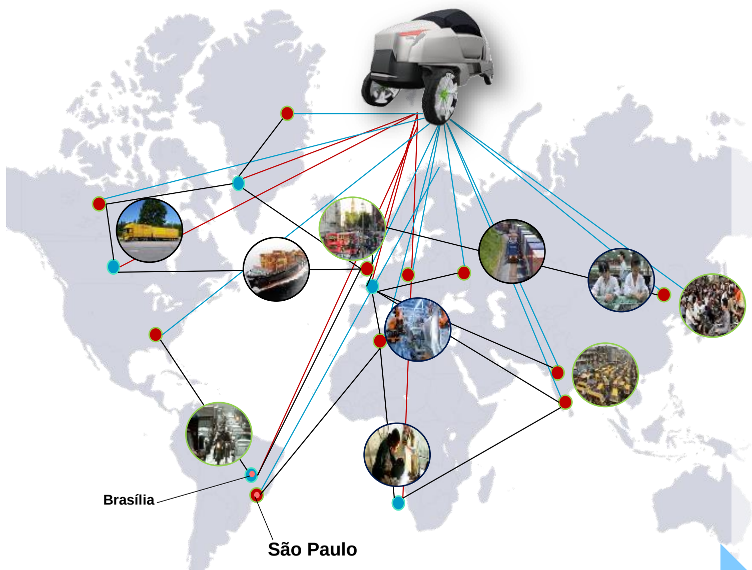
ITA — CENTRO DE COMPETÊNCIA EM MANUFATURA — Fraunhofer IPK INSTITUTE PRODUCTION SYSTEMS AND DESIGN TECHNOLOGY — Fraunhofer

(Change) drivers to future products and their manufacturing companies



Fraunhofer IPK | TU berlin Industrial Information Technology | 6

Characteristics of global value creation today

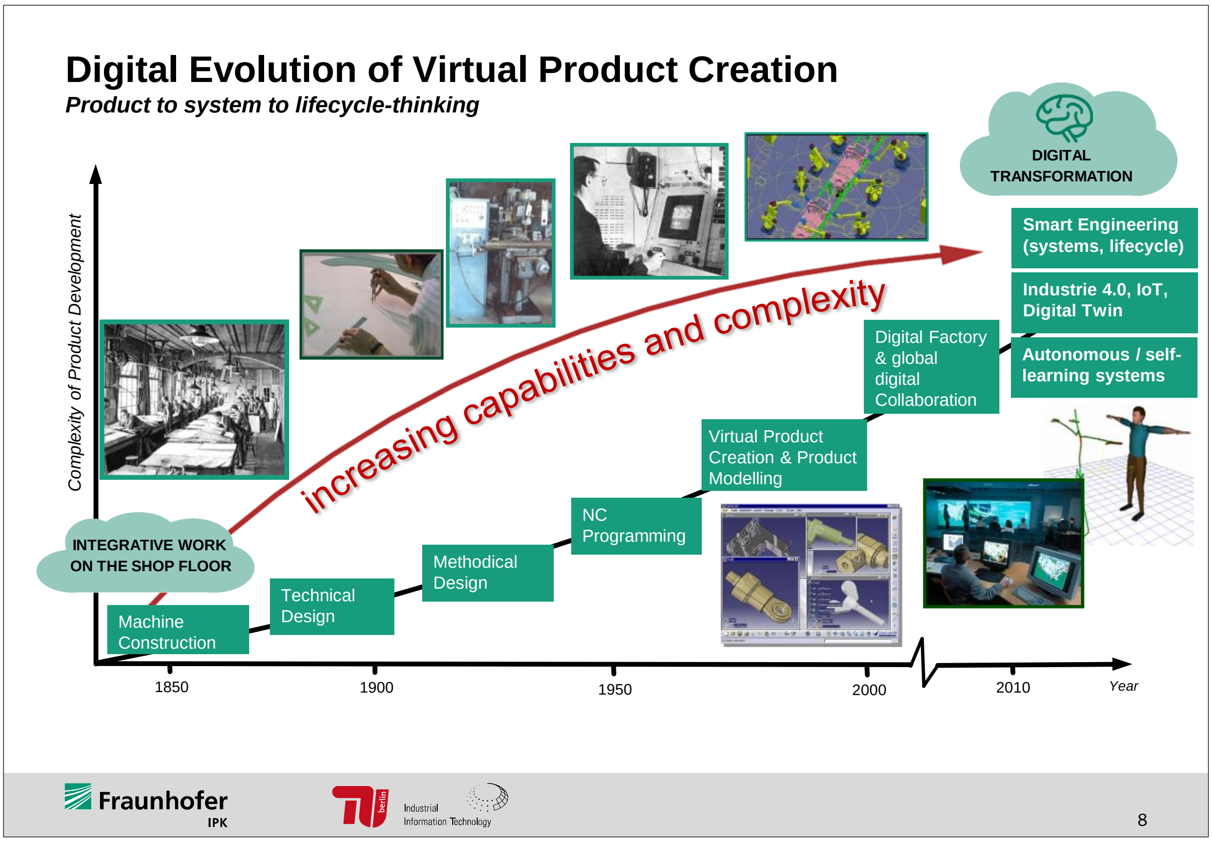


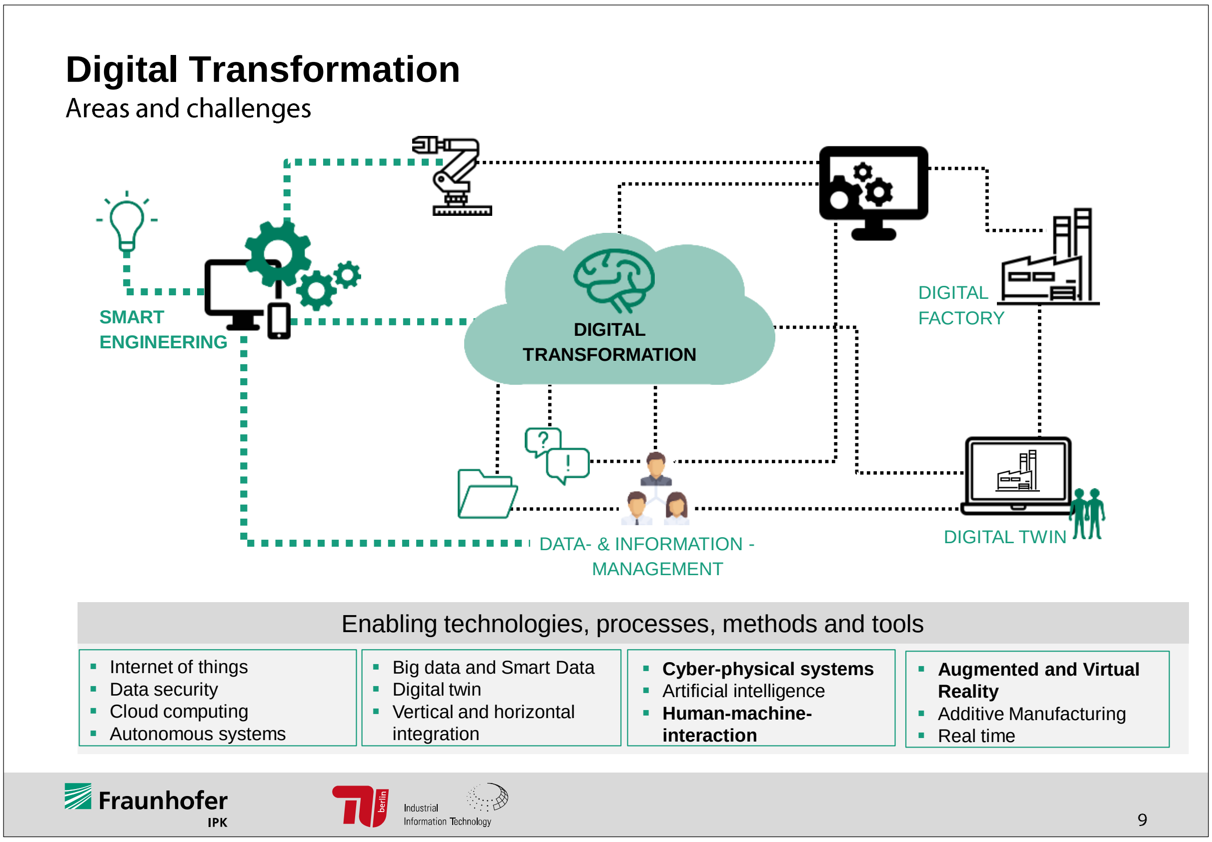
diverse set of regional regulations increase the efforts of globally operating enterprises to comply with global sustainability development targets!

- Main characteristics
  - Complex mechatronic products and systems
  - Global markets
    - Diverse requirements and regulations
  - Distributed development and production
    - Parallel processes with a high need for coordination
    - Distributed and heterogeneous information sources
    - Collaboration of diverse teams with different skills in different setups
  - Interconnected supply relations
    - Dynamic supply-chains
  - Individualization of markets

Picture source: linde-wiemann.com

Fraunhofer IPK | TU berlin Industrial Information Technology | 7


Digital Evolution of Virtual Product Creation
Product to system to lifecycle-thinking
DIGITAL TRANSFORMATION
Smart Engineering (systems, lifecycle)
Industrie 4.0, IoT, Digital Twin
Autonomous / self-learning systems
Digital Factory & global digital Collaboration
Virtual Product Creation & Product Modelling
NC Programming
Methodical Design
Technical Design
Machine Construction
INTEGRATIVE WORK ON THE SHOP FLOOR
increasing capabilities and complexity
Complexity of Product Development
1850
1900
1950
2000
2010
Year
Fraunhofer IPK
Industrial Information Technology
8

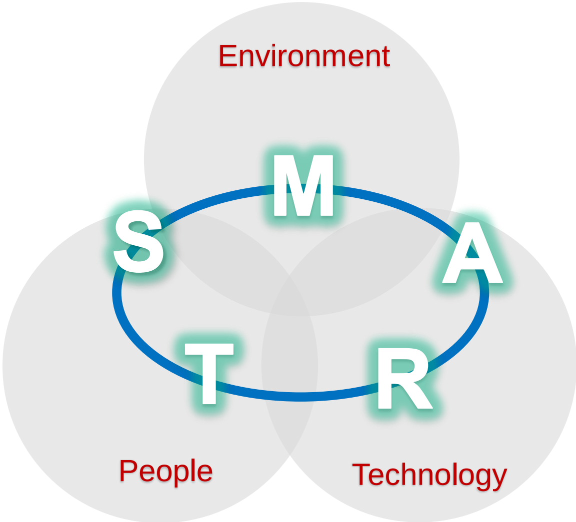

Digital Transformation
Areas and challenges
SMART ENGINEERING
DIGITAL TRANSFORMATION
DIGITAL FACTORY
DIGITAL TWIN
DATA- & INFORMATION - MANAGEMENT
Enabling technologies, processes, methods and tools
Internet of things
Data security
Cloud computing
Autonomous systems
Big data and Smart Data
Digital twin
Vertical and horizontal integration
Cyber-physical systems
Artificial intelligence
Human-machine-interaction
Augmented and Virtual Reality
Additive Manufacturing
Real time
Fraunhofer IPK
Industrial Information Technology
9

What is smart?

The difference between general trend and specific approach

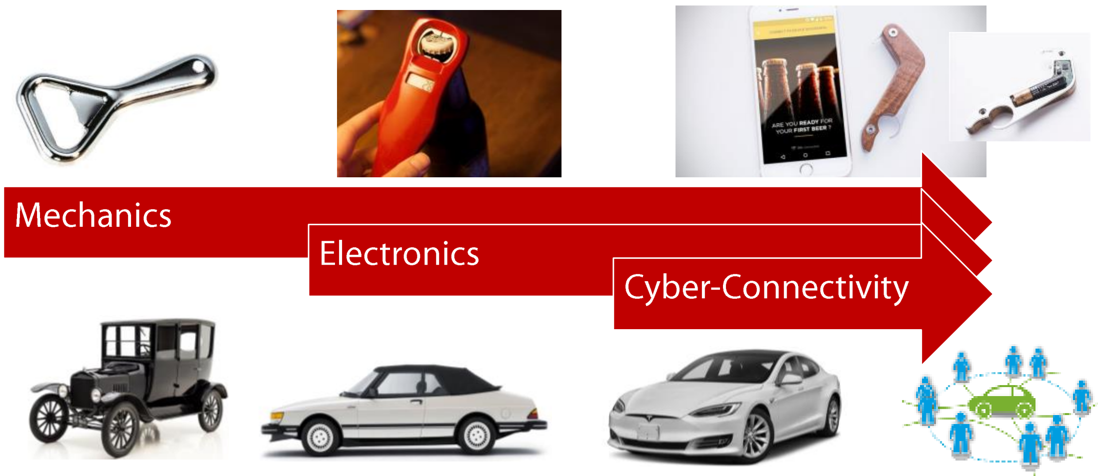
Smart means the intelligent junction of *technology*, *environment* and *people* to create growth within a highly competitive market.

- **S**: **S**ustainable + context-**S**ensitive
- **M**: **M**odel-Based + **M**ulti-disciplined
- **A**: **A**utonomous + **A**daptive
- **R**: **R**obust + **R**ewarding
- **T**: **T**eamplay with **T**echnology



Fraunhofer IPK | TU berlin Industrial Information Technology | 11

From mechatronic products to interconnected products providing internet-based services



Model T – mechanic with simple electric devices

Automobile with simple electronic devices

Tesla – highly mechatronic and interconnected

Smart Mobility

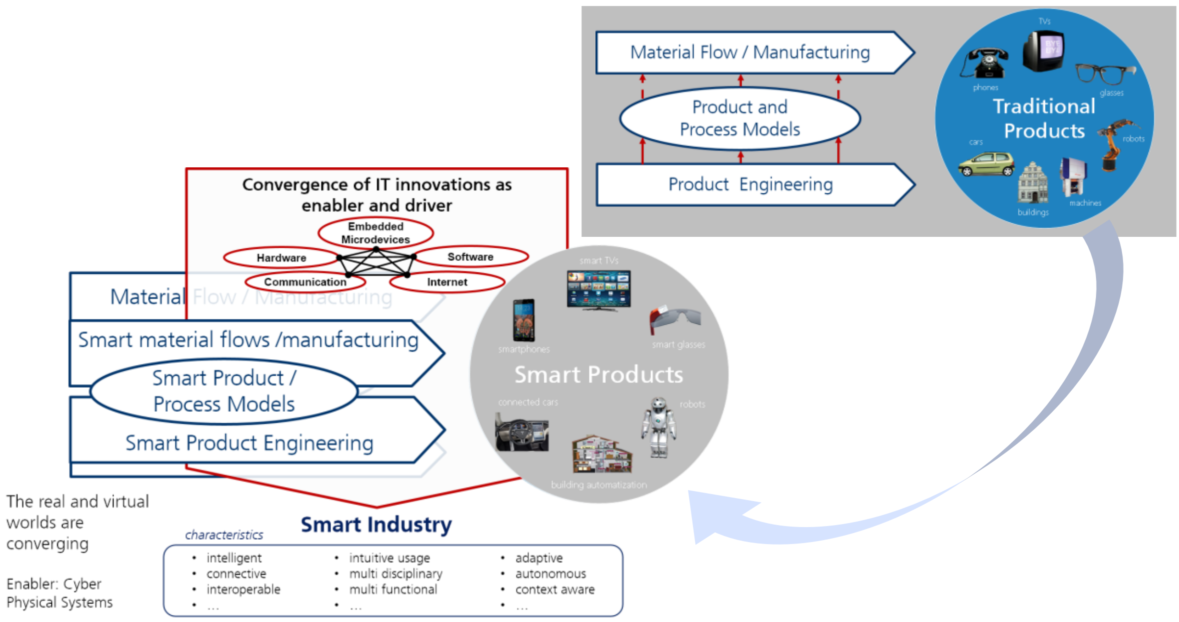
Smart Products are the integration of cyber-physical systems with internet-based services

Sources: left: ; mid: https://media.production.coolgift.com/s3fs-public/product/Talking%20Bottle%20Opener%2001.jpg; right: https://[illegible]content/uploads/2016/05/BOx-Smart-Bottle-Opener-by-HIKAMI-Featured-image-672x372.jpg

Fraunhofer IPK | TU berlin Industrial Information Technology | 12

From traditional products to smart products

Convergence of the real and the virtual world



Fraunhofer IPK — Industrial Information Technology — 13

Smart Products require Smart Engineering

Conclusion

- **Smart Products and their complex interplay of multiple disciplines require new Smart Engineering Capabilities to**
  - Manage complexity
  - Validate earlier and user-centric → make products functionally experienceable already at virtual stage
  - Synchronize domain-specific development to keep current time-to-market and even excel
  - Treat new product offerings as system of systems
  - Pay respect to life-cycle thinking
  - Consider products and its services as a mutual design goal

The solution: (New) Smart Engineering Capabilities

Smart Digital Engineering | Smart Virtual Engineering | Smart (model-based) Systems Engineering | Smart Lifecycle Engineering

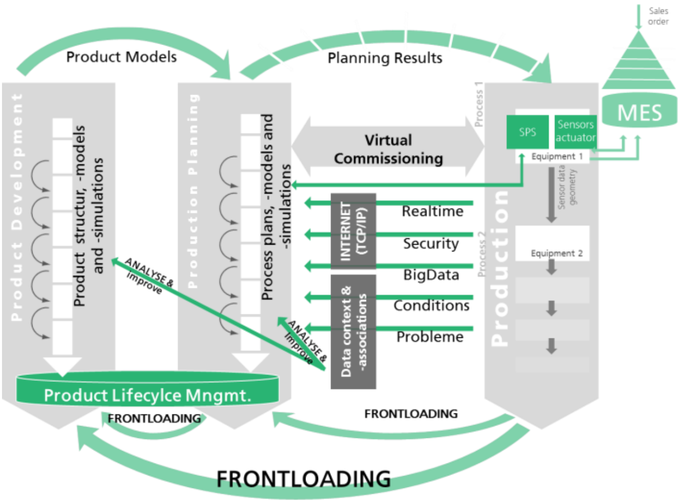
Fraunhofer IPK — Industrial Information Technology — 14

Smart Engineering for Developing Smart Products

Information feedback loop for agile development

- Developing Smart Products challenges engineers to holistically understand, design and validate products in their context
- Hence, a continuous information flow is decisive for effective and efficient design decision and validation
- PLM* enabled Virtual Commissioning allows virtual behavior validations of smart products in their system context in-the-loop
- The frontloading of engineering activities to virtual environments lead to massive amounts of data

* Product Lifecycle Management



New Product Offerings (NPO) call for new engineering capabilities

NPO: **Context aware system readiness & interaction**	• Example: a smart car door
NPO: **Intelligent product-user-interactions and services**	• Example: intelligent guidance to operate a technical system
NPO: **Self-learning and remote actionable products**	• Example: autonomous cars and machines such as robots using smart data analytics
NPO: **Circular re-usable across lifecycles**	• Example: resilient components with flexible interfaces

New engineering skills are required:

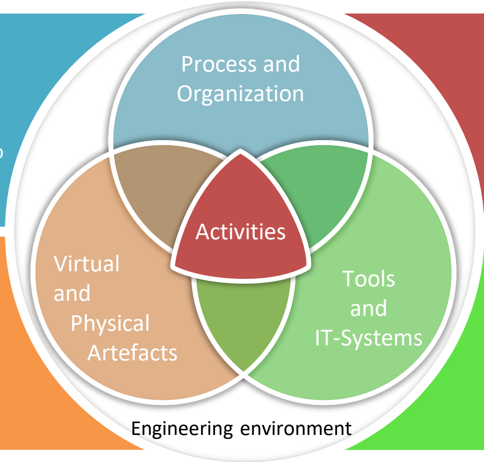
- Multi-domain simulation at early development stages with early user experience with high immersion levels
- MBSE for Systems of Systems for product-in-environment development and V&V
- AI and Data Analytics for feedback to design and data driven businesses
- Lifecycle engineering with full PDM support

Engineering Operating System

A Holistic Model representing the engineering environment

- **Assisting-**, **Management-** and **Core Processes**
- **Organization** (roles and responsibilities)
- **Processes**: who (role) should do what, which tools are used, and which results are expected

- **Virtual and Physical** Artefacts as well as models (data and information models)
- Are **generated or manipulated** in the product life cycle by activities



- Actions (**activities**) carried out by **people** and **IT systems** in product life
- Activities are **person-specific dynamic** or automated instantiations (IT activities) of the processes.

- **Information technology and physical tools**
- The IT infrastructure includes application systems and operating resources (hardware and software).

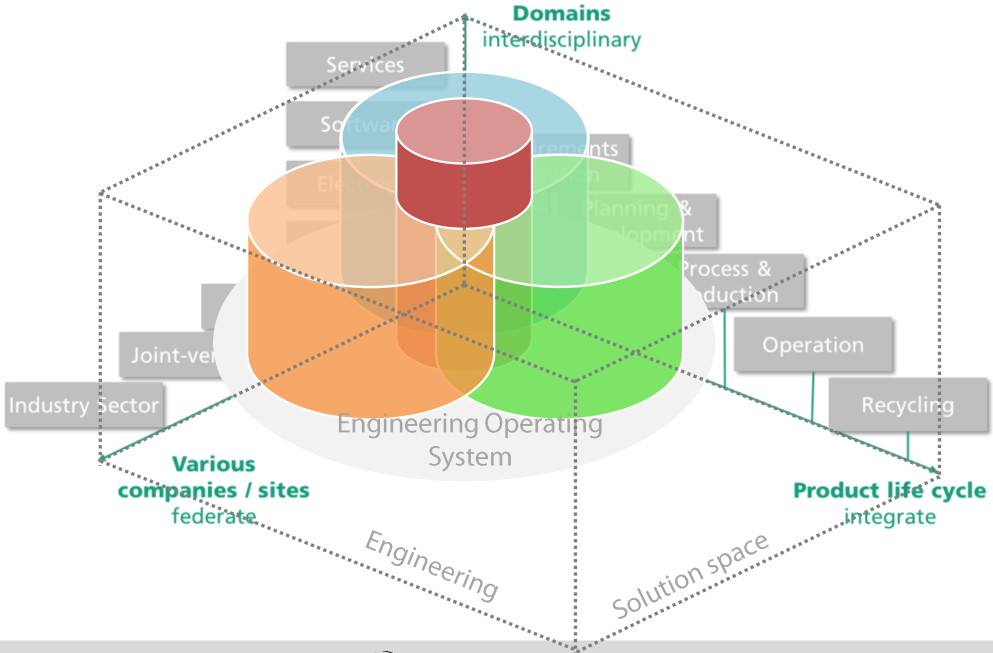
Lünnemann et. al. 2017

Fraunhofer IPK — TU berlin — Industrial Information Technology

18

Smart products – solution space

Engineering activities



Fraunhofer IPK — TU berlin — Industrial Information Technology

19

Smart Digital Engineering | Smart Virtual Engineering | Smart (model-based) Systems Engineering | Smart Lifecycle Engineering

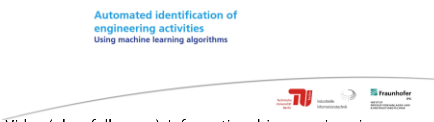
Identification of digital work behavior

Smart Engineering Capability #1

Smart Digital Engineering capabilities will address new digital assistance and intelligence in creating, revising, exploring, collaborating, testing, signing-off and releasing diverse sets of traceable artefacts as part of digital engineering workflows, processes and activities.

- Problem:
  - identifying and understanding which type of digital work is executed within digital computer applications during typical engineering work patterns
- Solution requirements:
  - optimization of time commitments and user centered IT-application interaction and final digital result achievements will be essential in future workplace and work pattern arrangements
- Examples of current solution concepts and demonstrators:
  - Data flow architecture design tool
  - Machine Learning for industrial factory process planning

Smart Digital Engineering Capability "Identification of digital work behavior" within the EOS cause & effect relationship



Video (plays fullscreen): Information driven engineering

Icon sources:
Problem:thenounproject.com/term/problem/770851/
Requirement:iconfinder.com/icons/1013963/check_list_checklist_checked_document_file_requirements_tasks_icon
Solution:thenounproject.com/term/problem-solving/8092/

Fraunhofer IPK | TU berlin Industrial Information Technology

21

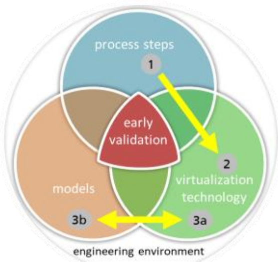
Smart Digital Engineering | Smart Virtual Engineering | Smart (model-based) Systems Engineering | Smart Lifecycle Engineering

Smart Hybrid Prototyping

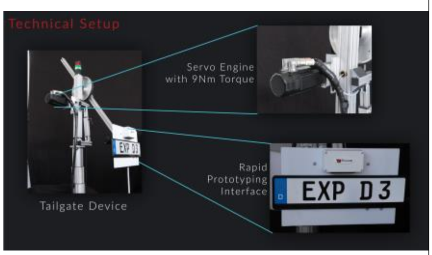
Smart Engineering Capability #2

Smart Virtual Engineering capabilities aim at the early, continuous, networked (process view) and integrated (system view) sup-port of the entire product life cycle concerning collaboration, assessment, concretion and validation of products and processes with participation of all partners using virtual artefacts

- Problem:
  - Growing complexity of product and process requirements while drastically reducing time-to-market and physical product prototyping as higher-level objectives
  - User need to experience virtual models (e.g. CAD models) within a specific & relevant task challenge
- Solution requirements:
  - *Smart Hybrid Prototyping* is using haptic devices, which enable forced feedback →interaction with virtual models
- Examples of current solution concepts and demonstrators:
  - Virtual Commissioning with Smart Hybrid Prototyping
  - Digital Cube Test Center / Functional Drive Simulator



Smart Virtual Engineering Capability "Early Validation of User Interface" within the EOS



Video (plays inline): SHP: Tailgate Validation

Icon sources:
Problem:thenounproject.com/term/problem/770851/
Requirement:iconfinder.com/icons/1013963/check_list_checklist_checked_document_file_requirements_tasks_icon
Solution:thenounproject.com/term/problem-solving/8092/

Fraunhofer IPK | TU berlin Industrial Information Technology

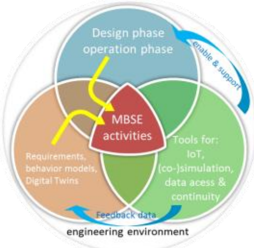
22

Model Intelligence for IoT and Industrie 4.0

Smart Engineering Capability #3

Smart Digital Engineering | Smart Virtual Engineering | Smart (model-based) Systems Engineering | Smart Lifecycle Engineering

Model-based Systems engineering is an interdisciplinary field of engineering and engineering management that focuses on how to design and manage complex systems over their life cycles. At its core, systems engineering utilizes systems thinking principles to organize this body of knowledge



MBSE in the EOS: Requirements, behavior models and digital twins form the basis for all activities in the design and opera-tion phase of products and production systems. The IT tools enable the models and data to be processed and their information to flow (back) into the according process steps.

- Problem:
  - Products require interconnectivity, provide services and need to communicate with their production plant during manufacturing processes
- Requirements:
  - (executable) multi-domain system models and methodology, interfaces and processes to create and maintain them
- Examples of current solution concepts and demonstrators:
  - Virtual Reality Twin
  - Democell ‚Smart Factory 4.0'

Video (plays fullscreen): Democell ‚Smart Factory 4.0'

Video (plays inline): Virtual reality twin

Icon sources:
Problem: thenounproject.com/term/problem/770851/
Requirement: iconfinder.com/icons/1013963/check_list_check-list_checked_document_file_requirements_tasks_icon
Solution: thenounproject.com/term/problem-solving/8092/

Fraunhofer IPK | Industrial Information Technology | 23

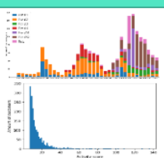
Smart Services

Smart Engineering Capability #4

Smart Digital Engineering | Smart Virtual Engineering | Smart (model-based) Systems Engineering | Smart Lifecycle Engineering

Smart Lifecycle Engineering is an approach to develop smart products and smart services considering the whole life-cycle and the according processes along that.

Emmy Scooter Sharing
(Source: https://emmy-sharing.de/)



Data analytics & visualization cockpit for feedback-to-lifecycle (design, manufacturing, use, end-of-life)

Transformation from digital and physical artifacts (1) to the use of new IT tools and applications (1) towards new products and services within a company (2). Eventually, business in terms of process and organization drives the need for new digital and physical artifacts (3)

- Problem:
  - Smart products and smart services require new lifecycle-oriented engineering capabilities
- Requirements:
  - Synchronized data management and information standards up to business model and IT-infrastructure
- Current solution concepts and demonstrators:
  - Analysis and development of robust data management and implementation of data driven value creation (Smart Services)

Video (plays fullscreen): Emmy Scooter renting and usage

Icon sources:
Problem: thenounproject.com/term/problem/770851/
Requirement: iconfinder.com/icons/1013963/check_list_check-list_checked_document_file_requirements_tasks_icon
Solution: thenounproject.com/term/problem-solving/8092/

Fraunhofer IPK | Industrial Information Technology | 24

INDUSTRY PARTNERS

Fraunhofer IPK | TU Berlin Industrial Information Technology

26

Projects with industry

Virtual Commissioning with Smart Hybrid Prototyping

Smart Digital Engineering | Smart Virtual Engineering | Smart (model-based) Systems Engineering | Smart Lifecycle Engineering

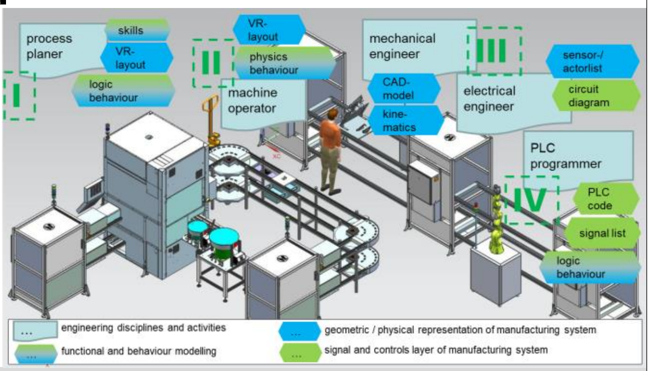
- How to handle the increasing **complexity**?
- How to shorten **development times**?
- How to **validate** functionality effectively?
- How to integrate new **Industry 4.0** technologies?
- How to integrate I4.0 **design processes, methods & tools**?

Video (plays inline):
Virtual Commissioning in VR

- Duration: 01.10.2014 – 30.09.2017
- This project aims to
  - medium-sized manufacturing system manufactures
  - and their component suppliers

  secure their future connectivity and innovation capability by supporting the product development process of manufacturing systems through virtual technologies

VIB-SHP



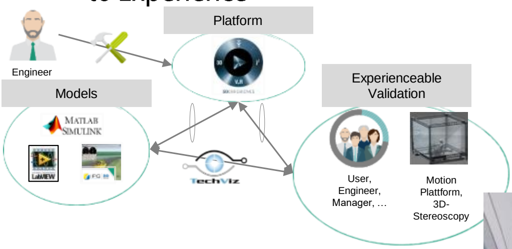
Fraunhofer IPK | TU Berlin Industrial Information Technology

27

Smart Digital Engineering | Smart Virtual Engineering | Smart (model-based) Systems Engineering | Smart Lifecycle Engineering

Projects with industry

Future core competencies: Systems Engineering to Experience



Electric car
(z.B. Packaging, Infotainment)

Video (plays inline):
SE2Experience Project Video

Fraunhofer IPK | TU berlin Industrial Information Technology | 28

Conclusion & Outlook

Opportunities

- New product offerings require Smart Engineering Capabilities
- Digital Engineering is common ground nowadays
- Virtual V&V becomes more and more accessible and common due to technological availability
- Intelligent technologies close gaps in information exchange and flow enabling true lifecycle engineering

Challenges

- technology requires well-trained personnel and wise handling of the increasing amount of data and information
- Data format and interface standards need to be steadily developed and models need to be harmonized
- Big Data is NOT Smart Data
- IoT and AI are not ready-to-use engineering solutions – they are tools

Extensive R&D programs are needed to fill gaps and provide understanding of new ways of engineering

Fraunhofer IPK | TU berlin Industrial Information Technology | 30

Fraunhofer IPK

Industrial Information Technology

31

CONTACT

Prof. Dr. Ing. Rainer Stark

Director of the division Virtual Product Creation	
Phone:	+49 30 39006-243
E-Mail:	rainer.stark@ipk.fraunhofer.de

Director of the chair Industrial Information Technology	
Phone:	+49 30 314-25 414
E-Mail:	rainer.stark@tu-berlin.de

QR-Code provides digital business card (vcf)

Fraunhofer IPK

Industrial Information Technology

32

Prof. Dr.-Ing. Eckhard Kirchner

Prof. Kirchner, born 1969, studied mechanical engineering and applied mechanics to former Technische Hochschule Darmstadt from 1990 to 1995, where he also received his Ph.D. for a thesis on nonlinear optimization problems in structural mechanics. Between 1999 and 2011 he held various positions at Adam Opel AG and GM Powertrain starting from Analysis Engineer for Structural Integrity up to Head of the Department for Shift System Design and Release with global responsibility within GM, always focusing on combustion powered vehicles. As an intermediate position he was Program Manager for the Concept stage build of G's dry dual clutch DCT program. From 2011 until early 2016 he changed subject and worked in the area of electric mobility with Schaeffler and Siemens. By April 1st he was appointed University Professor for Product Development and Machine Elements and has in the meantime started to build up new research fields and the respective test facilities. He authored a monograph book on vehicle transmissions during his industrial time and holds over 150 patents, mostly on automotive technology.

kirchner@pmd.tu-darmstadt.de

pmd, TU Darmstadt

The chair of product development and machine elements at Technische Universität Darmstadt is intrinsically linked to methodological research in the area of product development since five decades. Recently, driven by the appointment of Prof. Dr.-Ing Eckhard Kirchner, a re-orientation of the scientific interest has begun focusing on so-called mechatronic machine elements, which enable measurements close to the mechanical or physical process, literally speaking at the skeleton of mechanical engineering. Today, close to 20 people team up at pmd including 15 research associates.

pmd
product development
machine elements

Sensor Integrating Machine Elements – Key to In-Situ Measurements in Mechanical Engineering

Abstract

Emphasis of the presentation is both on the sensor integrating machine element as such as well as on the novel methodology to integrate those components into smart mechatronics systems. The main motivation for integrating sensors into standardized machine elements comes from industrial megatrends such as Industry 4.0, Internet of things and cyber-physical systems. For all these trends the scientific discussion mostly concentrates on generating large amounts of data and on data security, whereas little attention is being paid on how to generate high-quality robust data that require only a minimum usage of mathematical models and hence reduce uncertainty in the overall systems. For industrial applications, such sensor integrating machine elements offer the advantage of being easy to integrate due to the standardized interfaces and the simplicity of dimensioning of the mechanical component being maintained. This turns out to be especially useful in low-volume applications where dedicated computerized models to derive the target quantity are prohibitively expensive, e.g. for measuring the sealing force in pneumatically operated valves for chemical plants. The presentation will cover some first-hand examples of prototype testing and illustrates the complexity of integrating such sensors in mechanical drive systems to allow for instance in-situ measurement of operational torque in automation systems.

Keywords

Cyber-Physical Systems; Condition Monitoring; Sensors; Smart Engineering.

Authors

Prof. Dr.-Ing. Eckhard Kirchner
TU Darmstadt - pmd
kirchner@pmd.tu-darmstadt.de

Georg Martin, M.Sc.
TU Darmstadt - pmd
martin@pmd.tu-darmstadt.de

Sven Vogel, M.Sc.
TU Darmstadt - pmd
vogel@pmd.tu-darmstadt.de

1 Introduction

Digitalization has been an important trend in mechanical engineering for many years. The objective is to enhance the functionality of mechatronic systems with additional “smart” functions like self-diagnosis and even “intelligent” functions for cooperation with the user (see Figure 1).

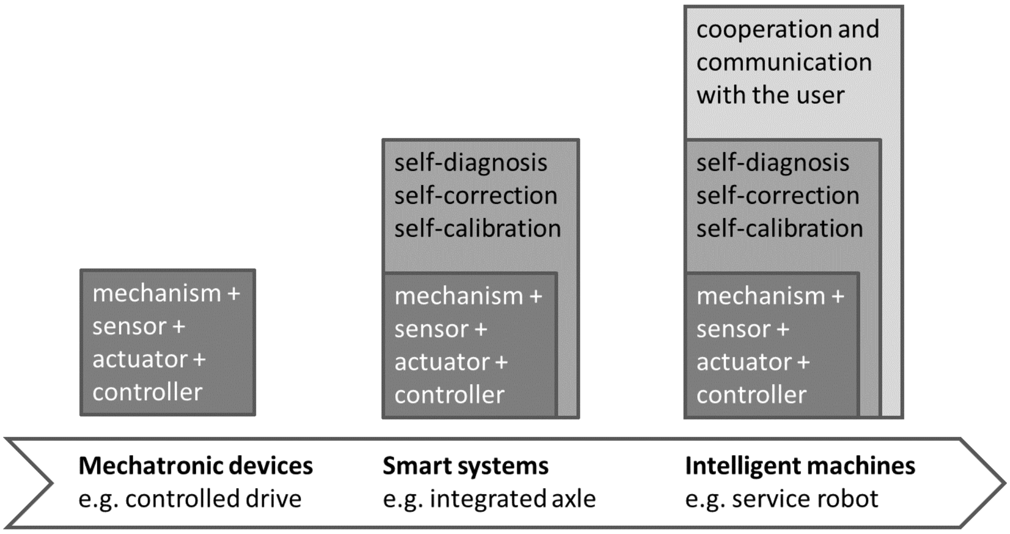


Figure 1: Development of intelligent machines, based on [1]

These additional functions are based on the use of data. Consequently, a lot of research deals with aspects of this data-driven approach, like collecting large amounts of available data, extracting meaningful information from this data, or securely transmitting and storing data. Another aspect is the question whether the data from today’s sensors provides a sufficient base for the additional functions, or whether new sensors, integrated deep in machines and close to the point of interest, are needed.

For the development of mechatronic products is applied in general, a methodical approach based on diverging and converging steps, a careful consideration of possible disturbances and sophisticated dimensioning methods is commonplace, e.g. according to the procedures of VDI 2206 and VDI 2221. In contrast, the choice of data sources for smart products of the actual sensor type and position is often characterized by a hands-on approach of trial-and-error and a more-is-better attitude. Possible disturbances acting in the use environment of the product are usually not considered, leading to unreliable sensor data. Unreliable sensor data can lead to unsatisfying functionality of the smart product, but this may become apparent only late in the development process during field-testing. Similar effects of unrespected uncertainty leading to malfunctions are known from e.g. [2] and [3] for the domain of purely mechanical design. The neglection of uncertainty in the design of a motor ignition switch lead to catastrophic accidents with loss of life.

One approach to deal with the uncertainty in sensor data is the acquisition of data “in situ”, i.e. close to the actual process or point of interest. In particular, sensor-integrating mechatronic machine elements, which offer the potential of in-situ measurements without extensive changes to the machine design as described in [4]. Difficulties arise with respect to the energy supply and data transfer of integrated sensors, and because new disturbances arise e.g. due to the harsh environment inside a machine. This paper deals with various aspects of in-situ measurements, in particular with sensor-integrating machine elements.

1.1 Potentials of sensor integrating machine elements: use case pneumatic valve

In this section, the potential of in-situ measurements is explained using the examples of a pneumatic valve and an electric drive system.

Figure 2 shows a rotary plug valve actuated by a linear pneumatic actuator, which is used to control and shut down the fluid flow for example in chemical plants. It is actuated by a pneumatic linear actuator, which is connected to the valve shaft by a transmission.

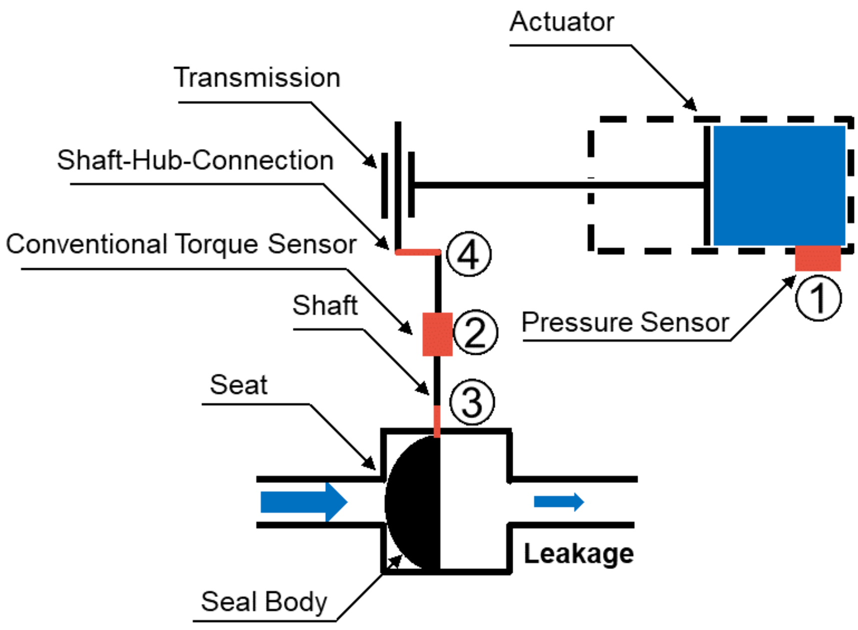


Figure 2: Schematic of a rotary plug valve with linear pneumatic actuator, showing possible sensor location: (1) pressure sensor in the pneumatic actuator, (2) dedicated torque sensor attached to the shaft, (3) shaft near the seal body, (4) shaft-hub-connection

Depending on the application, there is a high variance of the transmission parameters. In this case, a lever mechanism is used. One quantity of interest is the force of the sealing body pressing into the seat of the valve. Firstly, knowledge about the sealing force can be used for process monitoring of the leakage and of the chemical plant in general. Secondly, the sealing force is an indicator for the condition of the seal body and the seat, e.g. excessive wear due to abrasive fluids can lead to a higher leakage while the valve is closed. Since the sealing force is exerted by the shaft via an eccentric mechanism, a measurement of the shaft torque is sufficient to evaluate the sealing force. The torque on the shaft is also a quantity of interest in its own right with respect to safety. To ensure the controllability of the rotary plug valve the shaft must not be damaged due to exceeded maximum torque. Conventional safety methods limit the maximal pressure in the pneumatic actuator. Because of the uncertainty in the path of the signal to the pressure sensor, high safety factors have to be applied. Summing up, knowledge about the load on the actuation mechanism can be used for process monitoring, for machine condition monitoring and for additional functions, in this case safety functions.

Two important requirements for the shaft torque measurement are the robustness of the sensing system with respect to disturbances and the ease of use. Several options are available for measuring the shaft torque, shown in Figure 2. Firstly, it is possible to measure the pressure in the pneumatic actuator and deduce the shaft torque using a model of the transmission. In order to be accurate, this model would have to incorporate disturbances like the friction in bearings and seals in the transmission, and therefore the modeling effort to control the uncertainty would lead to higher cost for the product development. In addition, due to the high variance of transmissions and actuators, the model would be developed specifically for one application and could rarely be reused for other variants.

Another option for measuring the shaft torque is to insert a dedicated conventional torque sensor in the force flow. While this would eliminate the need for complicated application-specific models, it requires additional space and would therefore require major changes to the design of the valve or the transmission. Yet another solution for in-situ measurement is to integrate the torque sensing function into existing components, e.g. by applying strain gauges to the shaft. This would enable an in-situ measurement, but the sensor solution would have to be developed individually for each shaft variant. A solution for a self-contained in-situ measurement unit without additional space requirements is needed. These conditions are fulfilled by a sensor-integrating shaft-hub-connection, in this case a smart feather key. A feather key is used in all variants for connecting the lever to the seal shaft. The variant diversity is small, and the model for deducing the torque has to be developed only once for each feather key variant and can then be reused.

It can be seen that machine elements with integrated measurement functions have an advantage compared to conventional measurement solutions based on application-specific models or application-specific integrated sensors in applications where a major redesign of the machine or a costly (model) development effort are not feasible. This applies in many industries with small lot sizes and high variant diversity, especially for engineer-to-order products. Bearing in mind that one development trend of smart products is customization (“lot size one”), the potential of such machine elements with integrated sensors is clearly visible. The name is derived by the combination of the words “sensor-integration” and “machine elements” and shows that sensor-integrating machine elements integrate a sensor into the machine without the need for complicated models or changes to the machine’s design.

1.2 Potentials of sensor integrating machine elements: use case electric drive

Another example for in situ torque measurement can be found in electric drive systems (Figure 3). The output torque of an electric motor is an important information for control and safety aspects. The state of the art is the measurement of the electric current in the frequency inverter. A model of the electromechanical behavior of the drive system is then used to calculate the output torque. The advantage of this method is the technical simplicity of using the current measuring in the inverter. The disadvantage is the presence of disturbances along the transfer path between the inverter and the output shaft, e.g. electromagnetic and mechanical losses, which introduce uncertainty in the model for the relationship between measured current and calculated output torque.

A more direct way to determine the output torque is the use for example of a sensor-integrating feather key at the output shaft end. This way, the torque can be measured directly in situ, eliminating the need to take the uncertainties along the transfer path into account. Another potential of using a sensor-integrating feather key is the simplification of functional safety. In many cases, the use of two redundant, different methods for measuring the operational torque is necessary to fulfil functional safety requirements. Usually, the first method is inverter current measurement. By using a sensor-integrating feather key, the second method can be provided easily and robustly, enabling the use of the drive system in critical applications with stringent requirements for functional safety.

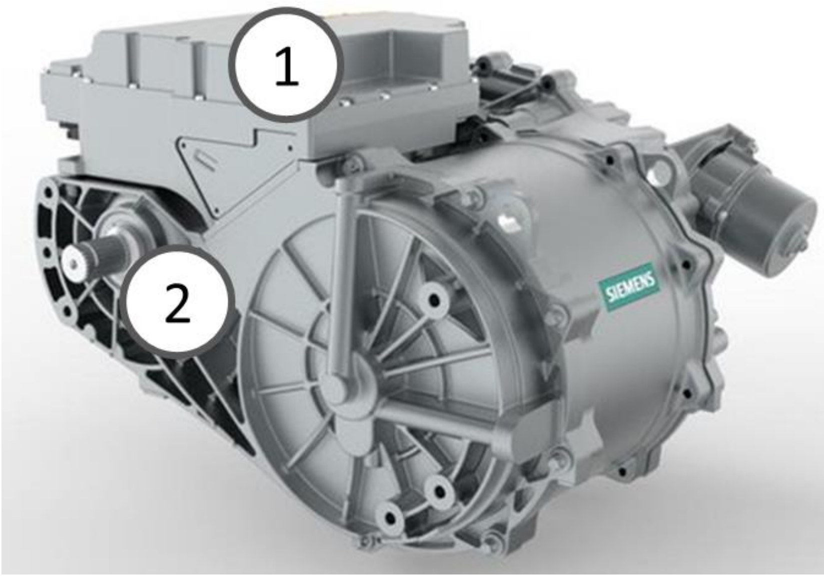


Figure 3: Determining the motor output torque by measuring the inverter current (1), and the torque at the shaft end (2), picture taken from https://twitter.com/siemensindustry/status/646746274276995072

Two conclusions can be drawn in the use case of the electric drive system: Firstly, substituting conventional torque measurement approaches based on motor current measurements by sensor-integrating machine elements has the potential for more robust torque measurement. Secondly, combining sensor-integrating machine elements with conventional approaches provides more reliable measurement results, which enable the use of such systems in safety-critical applications.

Another interesting application of sensor-integrating machine elements arises for testing and validation purposes. Often, a torque measurement at the shaft end of an electric machine is especially interesting for validating models and load assumptions during the product development process. A dedicated conventional torque sensor could be inserted between the shaft end and the attached machine, but this implies that the system under test is different especially with respect to its dynamic behavior than the actual product under use condition. Uncertainty arises whether the loads measured during testing are representative for the loads in the actual machine without the sensor unit. This can cause increased time and effort spent in the validation phase, or unexpected failures during field-testing or, even worse, after market launch during the use phase.

The use case of the rotary plug valve and the electric drive system show the potential of having standardized machine elements that are used across different industry sectors integrating sensors in different types of systems. One main advantage is the effort put into the development of a sensor-integrating feather key, for example considering the relevant disturbances, can be spread on many systems.

2 Robust Data Acquisition – reduction of uncertainty in data acquisition by sensor integrating machine elements

In Chapter 1, the potentials of sensor-integrating machine elements were discussed using two specific examples. In this chapter, the disturbances on the measurement signals will be examined more systematically in order to understand how sensor-integrating machine elements can contribute to robust data acquisition and which obstacles must be overcome to achieve this.

A schematic view of the signal flow from the source to the controller is shown in Figure 4. The signal of interest (“target quantity”) ST originates from a process, which is to be monitored. The signal is modified along the physical (e.g. mechanical) transmission path through the machine structure to the sensor. In the sensor, the measurand SM is converted to a (in most cases: electric) sensor signal SS. This signal is transmitted from the in-situ site to a controller, where the received signal SR is used for e.g. process control or condition monitoring. The controller uses models of the transmission path to interpret the electrical signal, i.e. to calculate the value of the measurand and of the target quantity.

Disturbances act on the transmission steps along the transmission path and on the signals themselves. These disturbances must be incorporated in the interpretation model, or they will lead to uncertainty in the measured signal. The effects of disturbances on each of these three transmission steps are discussed in this chapter.

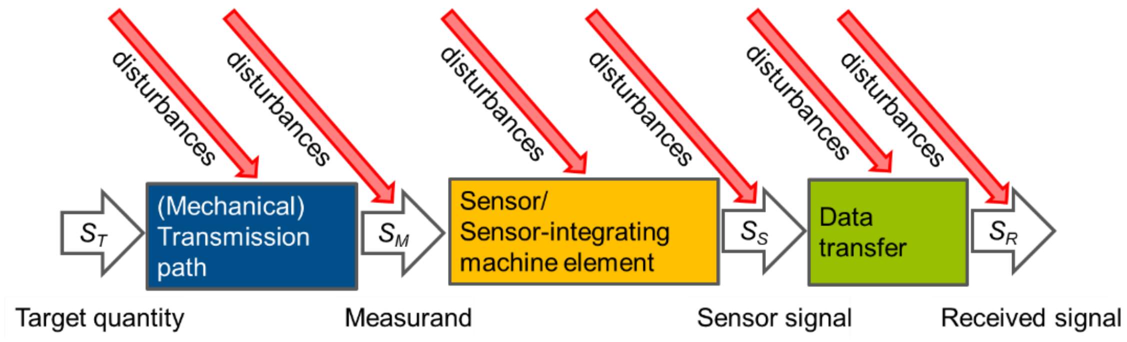


Figure 4: Signal flow from the source to the controller

2.1 Mechanical transmission through the machine structure

The application of this schematic model to the valve example (Figure 2) can be seen in Figure 5. Comparing a measurement in the pneumatic actuator with a measurement in the shaft-hub-connection (feather key), it can be seen that the transmission path to the feather key is shorter and influenced less by disturbances. On the other hand, disturbances arise in the shaft-hub-connection, e.g. friction in the shaft-hub-connection can cause a "shortcut" parallel torque flow that bypasses the feather key [5]. A measurement in the machine element offers potential for eliminating disturbances, but obviously new disturbances can arise and have to be controlled in order to enable a reliable measurement.

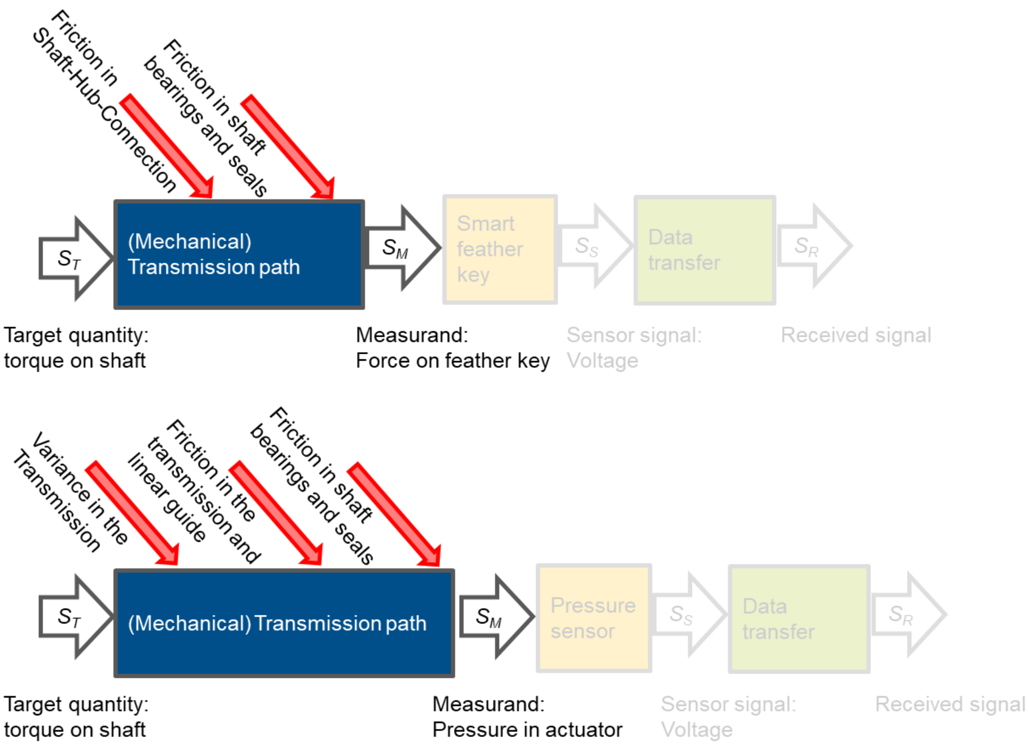


Figure 5: Schematic model of the signal flow to sensor positions in a rotary plug valve: sensor-integrating feather key (top) and pressure sensor (bottom)

Another example, which shows that the general model shown in Figure 4 is appropriate for other applications as well, is the condition monitoring of gear tooth root cracks, as discussed in [6]. An incipient tooth root crack in the gear causes a characteristic vibration excitation. Knowledge about the strength of this excitation can give valuable information for diagnosing the severity of the damage; therefore, the vibration excitation is the target quantity of the vibration measurement. In order to deduce the vibration excitation from measured vibration signals, the transfer path must be determined. In this case, the vibration is transmitted from the gear mesh through the gearwheel, the shaft-hub-connection, the shaft and the bearings to the housing. The vibration transmission characteristics of the bearings are known to be strongly nonlinear and very difficult to model, the influences causing this behavior act as disturbances. A measurement taken on the shaft close to the excitation – i.e. in situ – reduces the uncertainty in the relationship between the excitation and the measured vibration. In addition, the high-frequency components of the vibration are isolated by the compliance and damping characteristics of the bearings and are therefore masked by disturbing vibrations at the housing, resulting in a loss of information compared to a measurement on the shaft close to the source (Figure 6).

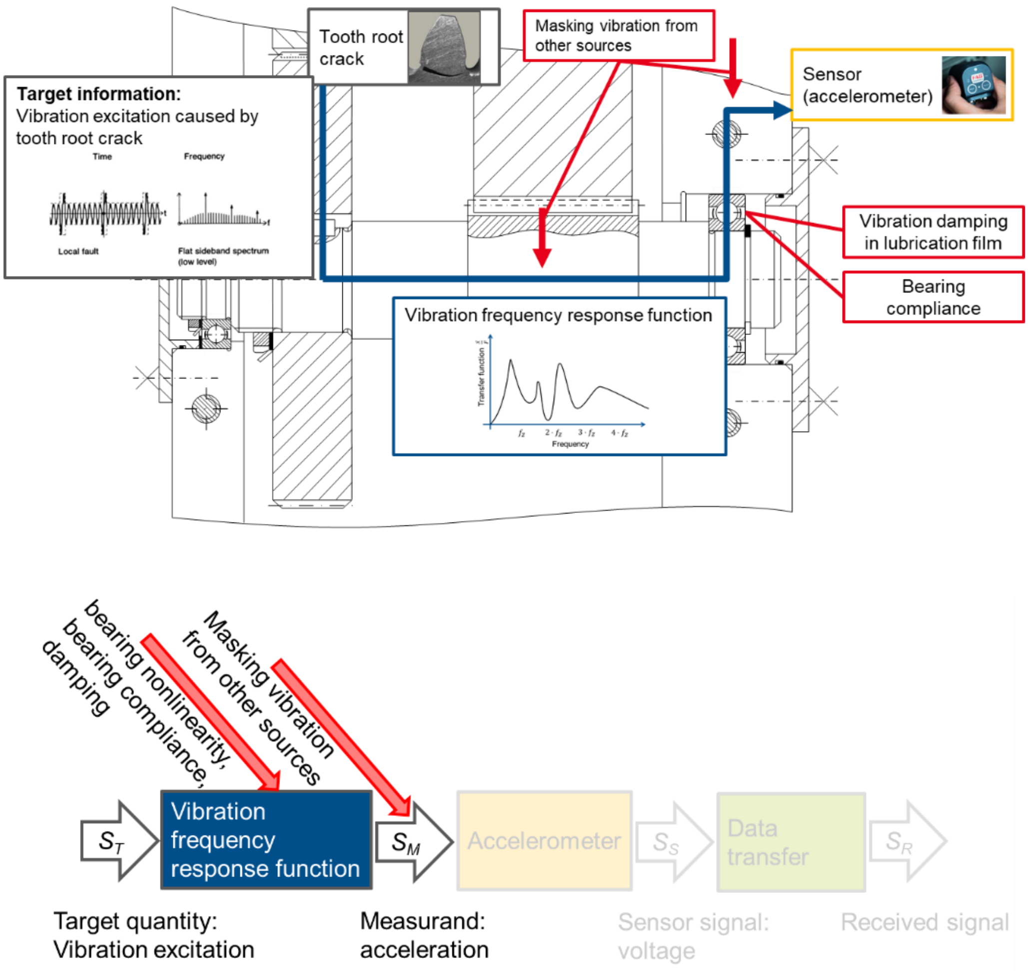


Figure 6: Signal propagation form the source to the sensor for condition monitoring if gear tooth root cracks: Physical signal path (top) and schematic model (bottom)

In the two examples discussed in this section, uncertainty and loss of information arise between the target quantity at the source and the measurand at the sensor location. Theoretically, this uncertainty could be reduced by incorporating the disturbances in the model, e.g. friction characteristics of the seals in the valve. However, this modeling-effort is very costly and the model is application-specific, and therefore only economical for large lot sizes. Therefore, it is a promising approach to choose sensor positions with minimal uncertainty in the transmission path, in many cases this means that the sensor should be placed close to source in situ. Since machine elements are often located in situ, they offer a solution for in situ data acquisition without application-specific sensor development or changes to the overall machine design.

2.2 Transmission in the sensor: Sensorial behavior of mechatronic machine elements

The second transmission depicted in Figure 4 is the transformation of the measurand, e.g. force or acceleration, into the sensor output signal. The sensor signal is almost invariably an electrical signal, either digital or analog. Similar to the transfer path discussed in section 2.1, disturbances influence the sensor behavior, causing uncertainty in the relationship between the sensor input (measurand) and the sensor output signal.

Schirra et al. [7] described a sensor-integrating ball bearing used to monitor loads in a spur gear transmission. The sensor concept is based on the electric capacitance of the Hertzian contact. It can be modeled as a plate capacitor whose area corresponds to the Hertzian area and whose plate distance corresponds to the lubrication film thickness (see Figure 7). Since the lubrication film thickness decreases and the Hertzian area increases with increasing load on the bearing, the capacity also increases.

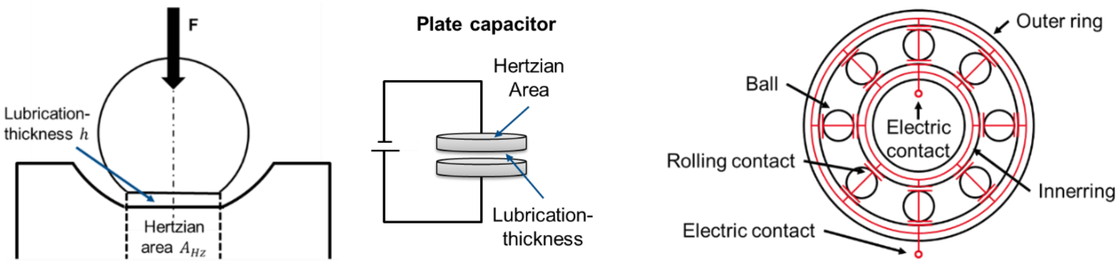


Figure 7: Concept of the force sensor integrating bearing: Mechanical (left) and electrical (middle) model of the Hertzian contact; connection of Hertzian contacts in a ball bearing (right)

The working principle of a rolling bearing can thus be used as a sensor without implementing changes to the mechanical design. However, since the bearing was never designed to work as a sensor, various disturbances act on the sensor-integrating bearing. In particular, the lubrication film thickness is strongly dependent on the temperature and the rotating speed of the bearing [7]. Similar to section 2.1, these disturbances have to be incorporated in the model for calculating the bearing load in order to mitigate the uncertainty. For example, the temperature und rotating speed can be measured by fairly inexpensive sensors without needing much installation space inside the bearing.

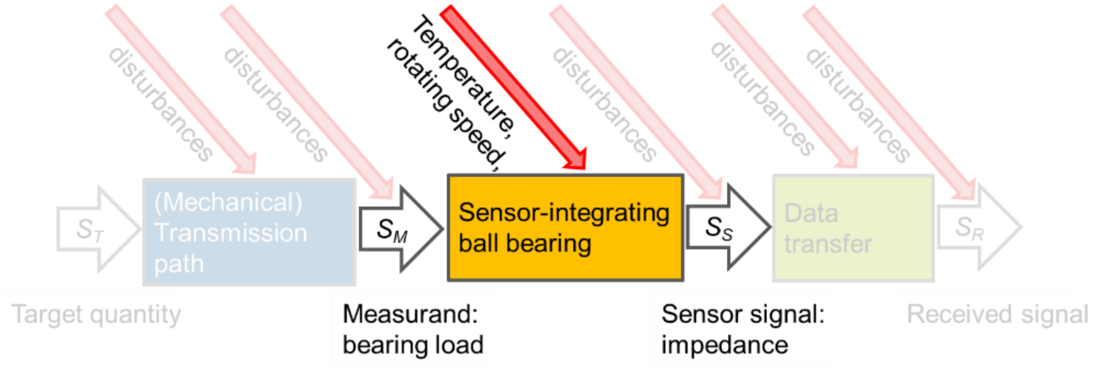


Figure 8: Schematic model of the signal transmission through a sensor-integrating ball bearing, including disturbances

Conventional sensors are designed specifically to minimize the influence of disturbances on the measurement accuracy, e.g. by arranging strain gauges in a full bridge arrangement to compensate for temperature influence. In the case of sensor-integrating machine elements, this approach is limited because the packaging of the embodiment of the machine element and the existing interacting interfaces must not be changed. If the bearing load measurement in the spur gear transmission could be taken by a dedicated conventional force sensor, the model used to deduce the force could be much simpler, and probably less uncertain. However, a dedicated force sensor close to the bearing would compromise the functional (stiffness) characteristics of the housing.

In contrast to the disturbances on the transmission path discussed in section 2.1, the influence of the disturbances acting within the sensor can be modelled without taking the application environment into account. For example, the temperature and speed compensation in the ball bearing, once implemented, works in all applications. The model used to calculate the measurand (e.g. bearing load) is developed as part of the development process of the sensor, not of the machine. The model can be used for all applications, and a complicated model is economically feasible due to economies of scale.

2.3 Transmission from sensor to controller: data transfer

The third transmission step depicted in Figure 4 is the transmission of the sensor signal from the integrated sensor to the controller, or in general the connection to the higher-level computing system. In many cases of in-situ measurement, it is very challenging to find a solution for this function, especially when the measurement is taken in a rotating system. One reason is that many disturbances act on the transmission elements, e.g. mechanical vibration that can lead to mechanical failure of electric connections, and electromagnetic fields. The effects of the transmission from sensor to controller will be discussed using the example of the output torque measurement in an electric drive described in Figure 3. The sensor output signal of the torque-sensing feather key is analog, but can be digitized by a microcontroller close to the sensor. An established solution to transfer the data from the rotating system to a stationary receiver is radio communication e.g. by Bluetooth, used for example in [8] for transmitting data from the tool holder of a milling machine. The electromagnetic field created by the electric machine can act as a disturbance on all electric signals (Sensor signal, radio transmission and received signal), as shown in Figure 8. It can induce noise in the sensor signal and the received signal, in the Bluetooth radio transmission it can lead to the loss of data packages or the complete breakdown of the connection.

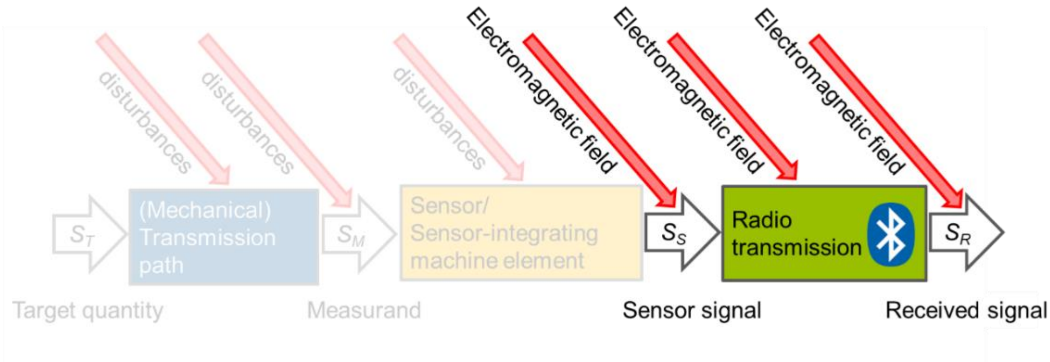


Figure 9: Schematic model of the signal transmission from the sensor to the receiver via radio communication, influenced by the electromagnetic field from a nearby electric motor

Established protocols such as *Bluetooth Low Energy* contain mechanisms to deal with the loss of data packages and thus make the transmission more robust, but nevertheless radio communication is not feasible in the presence of strong electromagnetic fields. For the torque measurement in the vicinity of an electric machine, this factor has to be taken into account. Robust data transmission protocols help to mitigate the effects of electromagnetic disturbances, but research is still necessary to find robust and easy-to-use solutions for data transfer between the in-situ location and the controller. It is possible to use the structure of the machine to conduct signals, but much research is still necessary to define design paradigms for electric signal conduction through machine structures. This is exemplified in [9]. It is possible to transfer electric signals through rolling bearings, but research the modification of the signal in the bearing and the damaging effect of electric current on rolling bearings are not well-understood enough for wide use.

3 Conclusion and Outlook: Mechatronic machine elements are enablers for usable, robust data acquisition

The presented examples and models show that sensor-integrating mechatronic machine elements have potential for reducing measurement uncertainty that originates in the transfer path between the point of interest and the sensor. A prerequisite for this is that the measurement uncertainty originating in the sensor-integrating machine element can be controlled, meaning that a determined model of the sensor behavior can be built. The important difference between these types of uncertainty is that the uncertainty in the machine element is less application-specific than the uncertainty in the transfer path, and can therefore be controlled by the developer of the machine element. Thus, the complexity of modeling can be concentrated in a module with large production quantities, which justify a costly modeling effort.

However, it is clear that sensor integration or even retrofitting of sensor-enriched machine elements requires the consequent application of new design principles. These principles originate from the basic design rule of clarity and require a novel way of thinking from the designer not only respecting aspects of mechanical clarity e.g. in force transfer, but also with regard to signal transfer, especially when trying to conduct electronic signals via mechanical structures. The journey has just begun…

4 References

[1] Anderl R, Eigner M, Sendler U et al. (2012) Smart Engineering. Springer Berlin Heidelberg, Berlin, Heidelberg

[2] Würtenberger J, Lotz J, Freund T et al. (2017) An Approach to Handle Uncertainty During the Process of Product Modelling. In: Proceedings of the 21st International Conference on Engineering Design (ICED17), 4: Design Methods and Tools

[3] Würtenberger J (2018) Ein Beitrag zur Identifikation und Beherrschung von Unsicherheit bei der Modellierung technischer Systeme. Dissertation, Technische Universität Darmstadt

[4] Martin G, Schork S, Vogel S et al. (2018) MME – Potentiale durch mechatronische Maschinenelemente: MME – Potentials of Mechatronic Machine Elements. Konstruktion 70(01-02): 71–75

[5] Vogel S, Martin G, Schirra T et al. (2018) Robust Design for Mechatronic Machine Elements - How Robust Design Enables the Application of Mechatronic Shaft-Hub-Connections. In: Proceedings of the DESIGN 2018 15th International Design Conference

[6] Martin G, Vogel S, Schirra T et al. (2018) Methodical Evaluation of Sensor Positions for Condition Monitoring of Gears. Accepted for NordDesign 2018

[7] Schirra T, Martin G, Vogel S et al. (2018) Ball Bearings as Sensors for Systematical Combination of Load and Failure Monitoring. In: Proceedings of the DESIGN 2018 15th International Design Conference, pp 3011–3022

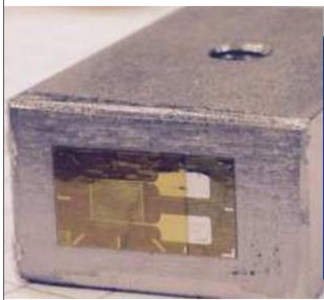
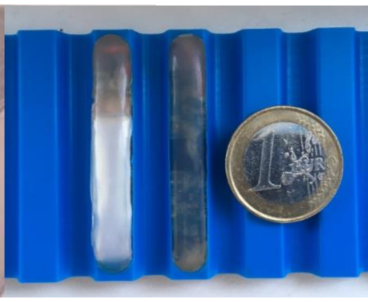
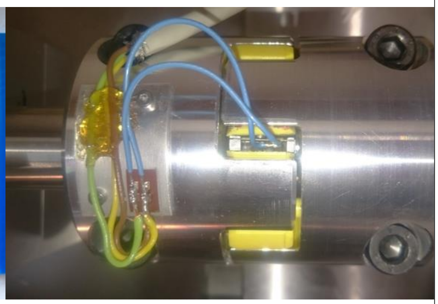
[8] Landfried K-C, Hofmann K (2015) So geht‘s dem Bohrer: Forschung zu drahtloser Datenübertragung im Projekt Smart Tool: Individualisierung und fertigungssynchrone Verschleißüberwachung revolutionieren das Werkzeugmanagement in der spanenden Fertigung. Mechatronik(12): 36–37

[9] Schirra T, Schork S, Kirchner E (2017) Konstruieren mit Mikroinvasiven Intelligenten Maschinenelemente - MI2ME - Wälzlager als Element der Energie- und Signalübertragung. In: Beiträge zum 28. DfX-Symposium, Oktober 2017, Hamburg, pp 153–163

Sensor Integrating Machine Elements
Key to in-situ measurements in mechanical engineering

TECHNISCHE UNIVERSITÄT DARMSTADT

Prof. Dr.-Ing. Eckhard Kirchner, Georg Martin, M.Sc., Sven Vogel, M.Sc.
TU Darmstadt, Institute for Product Development and Machine Elements

16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | Prof. Dr.-Ing. E. Kirchner | 1

Our history at a glance

TECHNISCHE UNIVERSITÄT DARMSTADT

Heads of the institute

- 1964 – 1990
  Prof. Dr.-Ing. Dr.-Ing. E.h. Dr. h.c. mult. Gerhard Pahl († 2015)

- 1990 – 2011
  Prof. Dr. h.c. Dr. h.c. Dr.-Ing. Herbert Birkhofer

- 2011 – 2012
  Prof. Dr.-Ing. Andrea Bohn

- 2012 – 2016 (acting)
  Prof. Dr.-Ing. Dipl.-Wirtsch.-Ing. Peter Groche

- Since 2016
  Prof. Dr.-Ing. Eckhard Kirchner


Until Q3 2017

Since Q3/2017

Gerhard-Pahl Zentrum

Selected research areas

- Methodic development and product design
- Machine elements such as curved teeth coupling, snap rings
- Rolling bearings with solid-phase lubricants
- Psychological influences on design of individuals and teams
- Holistic product and process development
- EcoDesign
- Management of uncertainty by development of robust systems
- Design for Additive Manufacturing
- Smart / intelligent machine elements

16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 2

pmd

Agenda

TECHNISCHE UNIVERSITÄT DARMSTADT

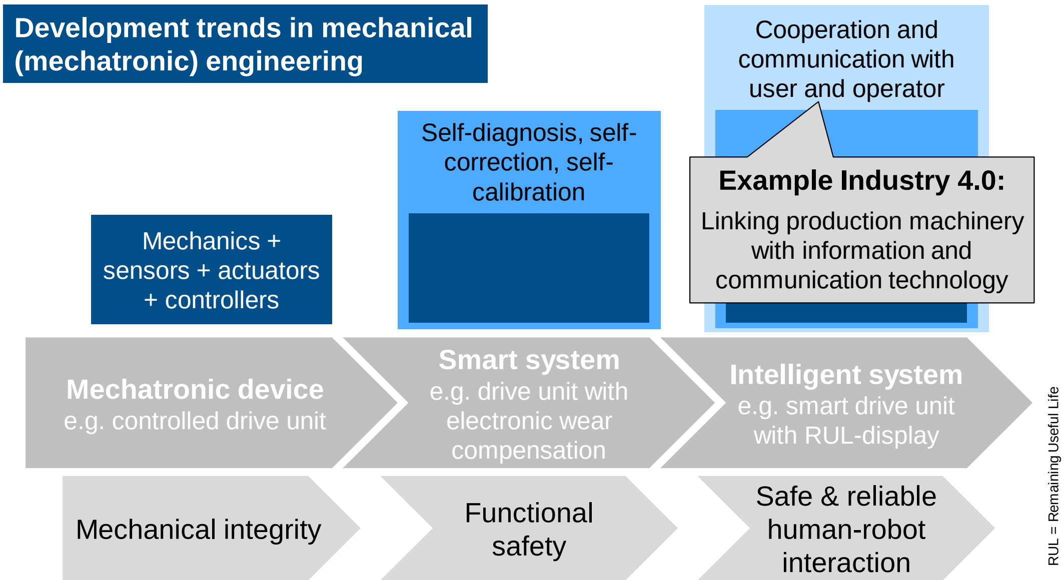
- **Scoping the talk: From mechanical components to intelligent Systems**
- **Potentials of in-situ measurement enabled by Sensor Integrating Machine Elements**
- **Sample prototypes of Sensor Integrating Machine Elements**
- **In-situ load data acquisition without physical sensors**
- **Need for Research in Product Development and outlook**

16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 3

pmd

From mechanical components to intelligent systems – Scoping of the talk

TECHNISCHE UNIVERSITÄT DARMSTADT



16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 4

pmd

From mechanical components to intelligent systems – Scoping of the talk

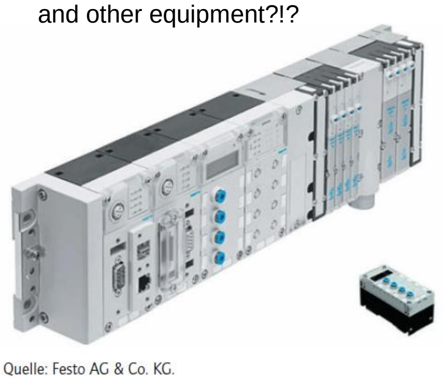
TECHNISCHE UNIVERSITÄT DARMSTADT

Product example: Valve block with integrated pressure sensor module

- Embedded pressure sensors arranged as integral part of the valve block
- Automated processing of data recorded at various positions as key to pneumatic control

? Large distance between piston and valve?!?

? Condition monitoring of production tools and other equipment?!?



Picture source: https://www.festo.com/net/bg_bg/SupportPortal/Press.aspx?cat=4192&tab=11&offset=480

16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 5

pmd

From mechanical components to intelligent systems – Scoping of the talk

TECHNISCHE UNIVERSITÄT DARMSTADT

Challenges of the digitalization process

- „As good as possible“ attitude of many engineers resulting in too much data
- Underestimation of data uncertainty
- Disregarding of disturbances impacting measurement and signal / data transfer

„Dr. Data“ [Süddeutsche Zeitung (18.3.2018)]

More data implies neither more information nor increased awareness

Research goal:

Acquisition of high quality data at the „skeleton“ of mechanical engineering products

Picture source: http://www.sueddeutsche.de/wissen/medizin-dr-data-1.3908072

16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 6

pmd

From mechanical components to intelligent systems – Scoping of the talk

TECHNISCHE UNIVERSITÄT DARMSTADT


Fachaufsatz Schwingungstechnik

MME – Potentiale durch mechatronische Maschinenelemente

MME – Potentials of Mechatronic Machine Elements

23.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 7

pmd

From mechanical components to intelligent systems – Scoping of the talk

TECHNISCHE UNIVERSITÄT DARMSTADT

Basic motivators:

- Potential to replace close-to-process sensors by in-situ located sensors
- Simplification of development of functional safety by direct in-situ measurement
- Control and monitoring of autonomous functions in transportation and industry sectors
- Predictive maintenance and condition monitoring at standard inter-element connections
- Integration of sensors in standardized machine elements facilitates application in low volume products even for small enterprises
- Machine elements upgraded to perform as sensor integration enablers: **Sensor Integrating Machine Elements (SIME)**
- …

***Abstract**: The digitalization in mechanical engineering requires the integration of additional sensors close to the process. The presented article addresses the approach of integrating sensors in standardized components, such as machine elements. It further discusses the need for a new thinking in machine design in order to enable sensor integration with few changes to assembly tools and processes. Finally, possible advantages of component-integrated sensors and a corresponding machine design are discussed and show the commercial potential of the approach, as well as the need for further research.*

16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 7

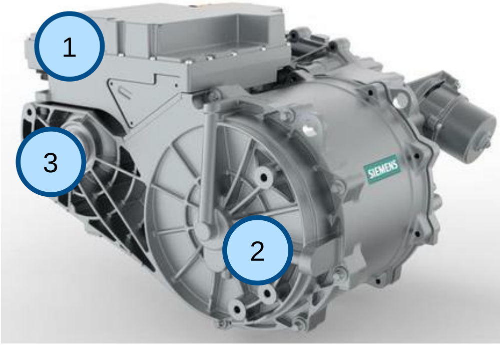
pmd

From mechanical components to intelligent systems – Scoping of the talk

TECHNISCHE UNIVERSITÄT DARMSTADT

Representative exercise:

Measuring the axle torque as an input quantity for vehicle longitudinal dynamics control



Picture source: https://twitter.com/siemensindustry/status/646746274276995072

Typical opportunities for locating the sensor

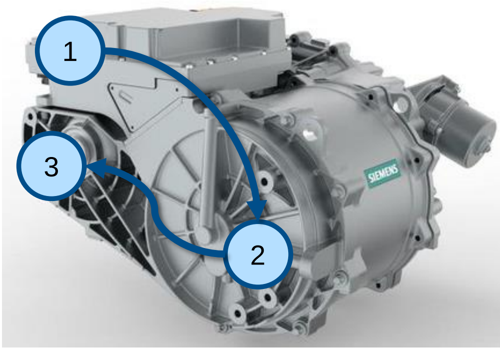
1. Distinct from the process at inverter power inlet – measuring energy pick up
2. Close to the process at the stator windings – measuring stator current
3. In-situ at the motor output or at the differential – measuring drive torque

16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 8

pmd

Potentials of in-situ measurement enabled by SIME – Uncertainty reduction

TECHNISCHE UNIVERSITÄT DARMSTADT



Picture source: https://twitter.com/siemensindustry/status/646746274276995072

Successive elimination of uncertainty from the signal transfer path relative to the process-distinct position:

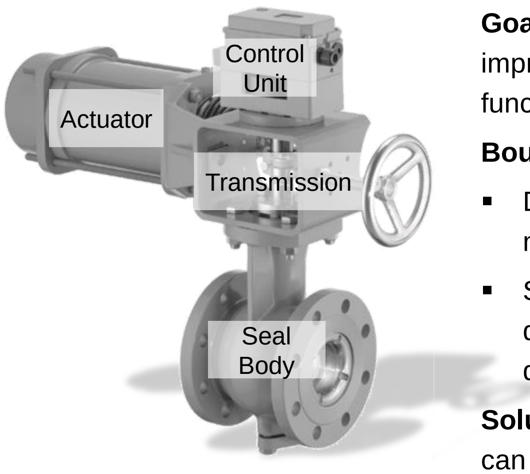
- ➢ Conversion, conduction and copper losses, tolerances of electronic components
- ➢ Magnetic circuit, copper losses, bearing friction, sealing friction at motor input shaft [Motor speed], tolerances of mechanical components
- ? (Gear mesh losses), sealing friction at side shafts [output shaft speed], few tolerances of mechanical components

16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 10

pmd

Potentials of in-situ measurement enabled by SIME – A motivating example

TECHNISCHE UNIVERSITÄT DARMSTADT



Conical valve for industrial plant applications

Goal: Measure torque in the seal shaft to improve sealing performance and functional reliability of the valve

Boundary Conditions:

- Disturbances cause uncertainty of measured data
- Small lot sizes and high variant diversity prevent dedicated sensor development

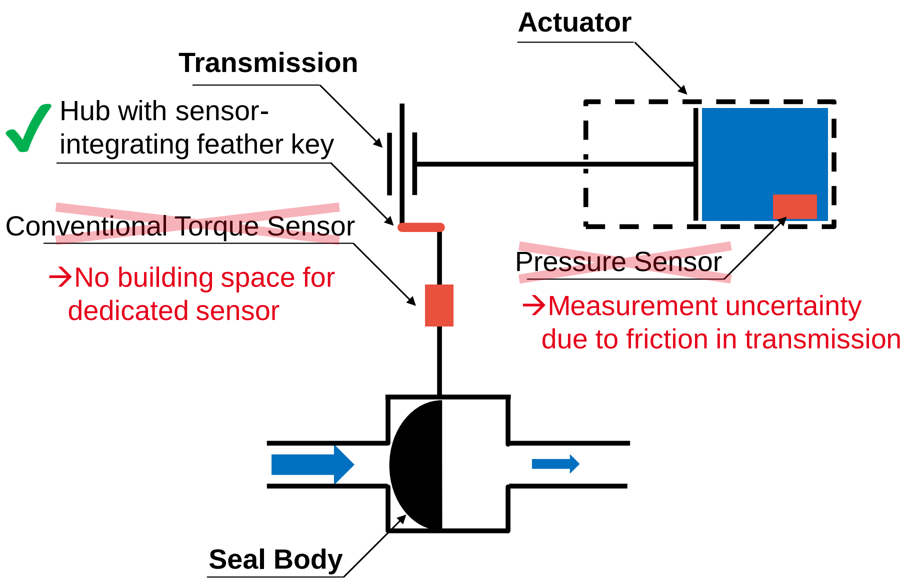
Solution: Sensor-integrating feather key can be used in all variants and decreases measurement uncertainty without significant changes to valve design

16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 11

pmd

Potentials of in-situ measurement enabled by SIME – A motivating example

TECHNISCHE UNIVERSITÄT DARMSTADT

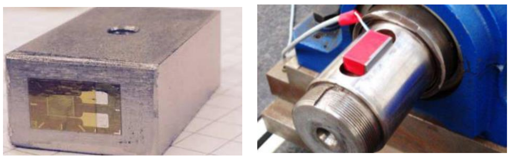


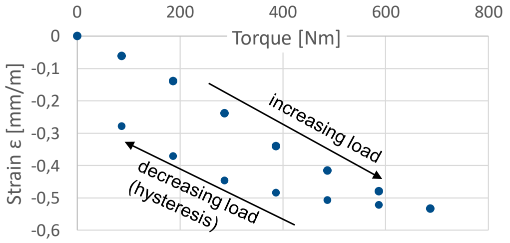
23.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 12

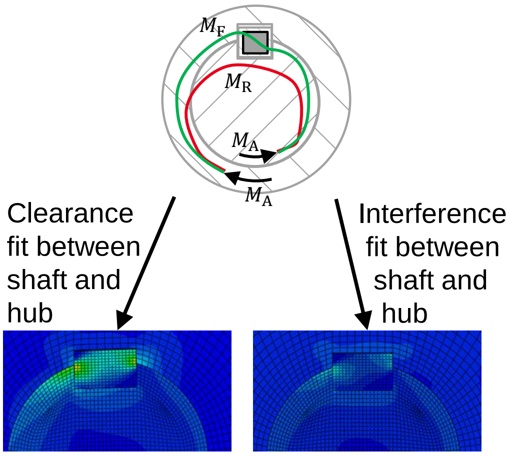
pmd

Sample prototypes of sensor integrating machine elements – Feather Key

TECHNISCHE UNIVERSITÄT DARMSTADT







Static torque measurement confirmed

Friction and fitting cause uncertainty
→ New guidelines are needed to design ***with*** mechatronic machine elements.

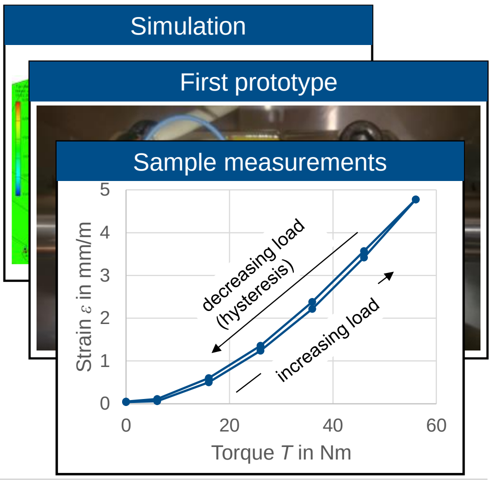
16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 14

Sample prototypes of sensor integrating machine elements – Claw coupling

TECHNISCHE UNIVERSITÄT DARMSTADT

Concept: Claw coupling

Determination of torque and radial misalignment enabled based in integrated strain gauges proven in non-rotating system. System Design lacks unambiguousness.



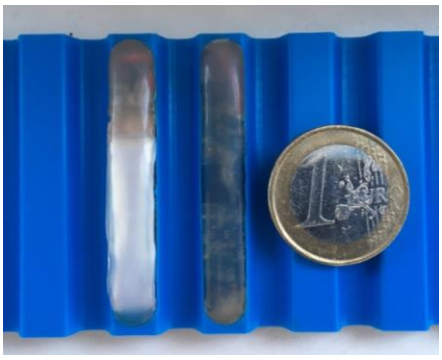
Slight hysteresis caused by viscoelastic properties of the polyurethane star and general non-linear system characteristic

16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 15

Sample prototypes of sensor integrating machine elements – Toothed belt

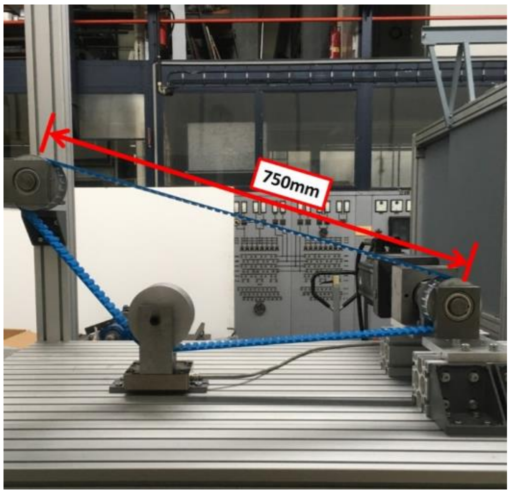
TECHNISCHE UNIVERSITÄT DARMSTADT

Concept: Smart Toothed Belt



Data processing in the toothed belt and radio data transfer for segment specific condition monitoring proven on lab scale with single sensor

Test Bench



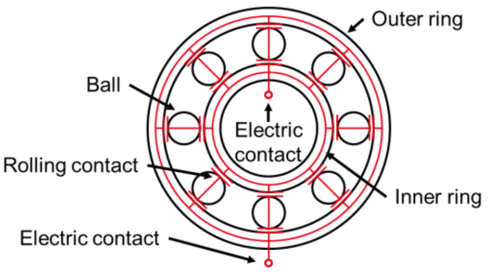
16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 16

pmd

In-situ load data acquisition without physical sensors – Rolling Bearings as sensors

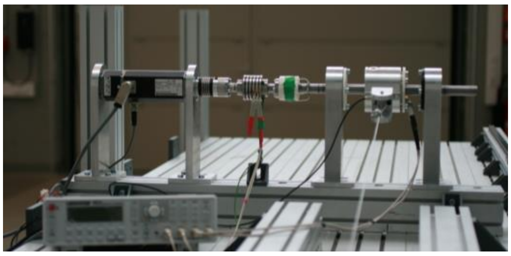
TECHNISCHE UNIVERSITÄT DARMSTADT

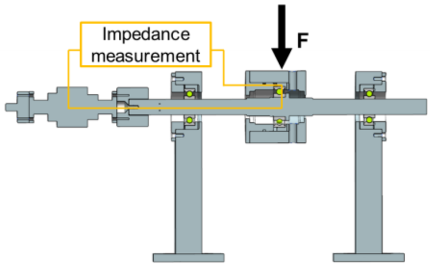
Concept: Sensor Bearing



Measurement of bearing impedance can be the key to better understanding component and system operating conditions and thus enable second order effects such as more energy efficient operation strategies

Test Bench

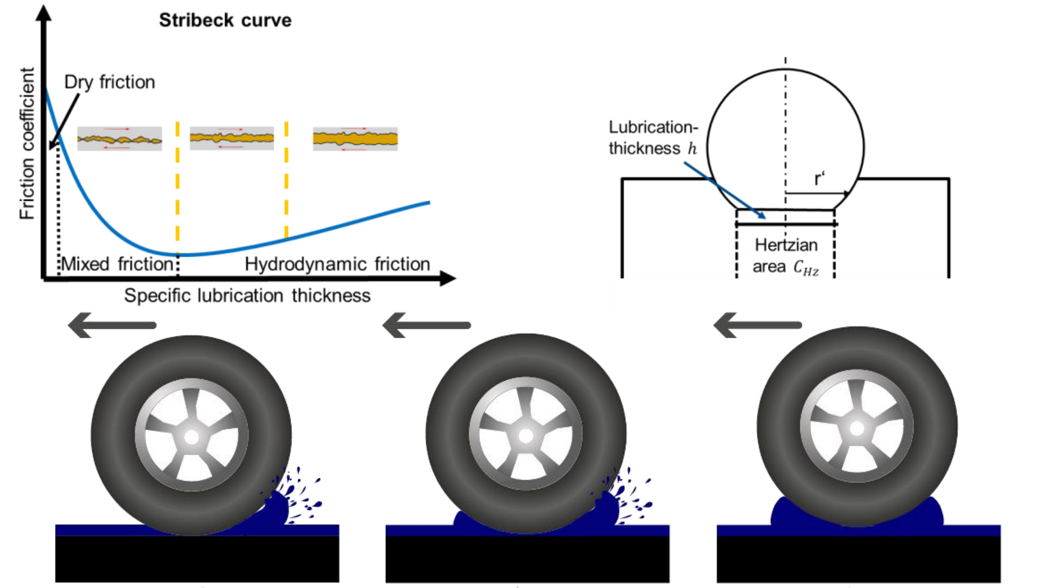




16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 18

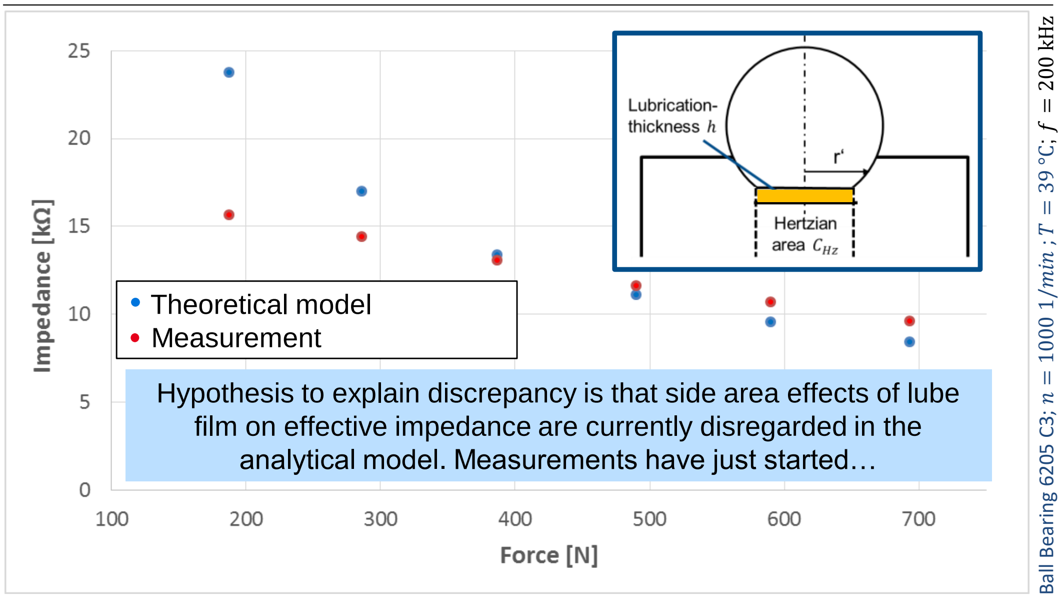
pmd

In-situ load data acquisition without physical sensors – Electric properties of rolling bearings



16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 19

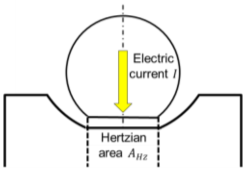
In-situ load data acquisition without physical sensors – Electric properties of rolling bearings



16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 20

In-situ load data acquisition without physical sensors – Damage risk of current transfer

TECHNISCHE UNIVERSITÄT DARMSTADT



Apparent current density $^{I}/_{A_{Hz}}$ is currently used as a threshold for avoiding bearing damage caused by electric current

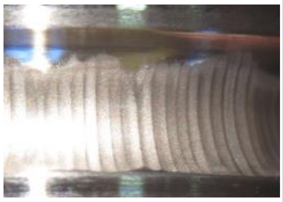
- Subcritical range < 0,3 A/mm²

Cratering

- Electric erosion caused by electric discharge
- Current density < 1 A/mm²

Auting

- Bearing lifetime < 500 h
- Current density > 1 A/mm²



Bearing failures caused by electric current restrict energy transmission. Load-dependent impedance has to be considered for energy o signal transmission.

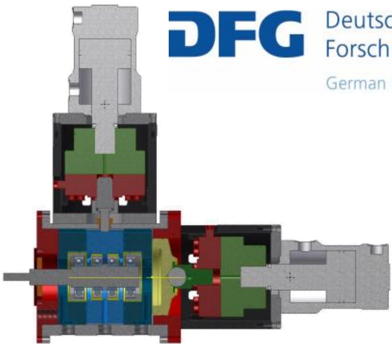
16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 21

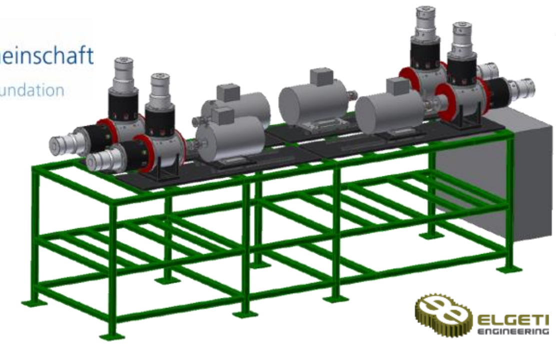
pmd

In-situ load data acquisition without physical sensors – Quantifying the damage risk

TECHNISCHE UNIVERSITÄT DARMSTADT

DFG Deutsche Forschungsgemeinschaft
German Research Foundation





Performance

- 4 test stations
- Axial load up to 40 kN
- Radial load up to 80kN
- Speed up to 8000 1/min
- Temperature 20-90 °C

Sensors

- Vibration up to 50 kHz
- Temperature
- Axial and radial load
- Rotation speed
- Voltage and current

Project details

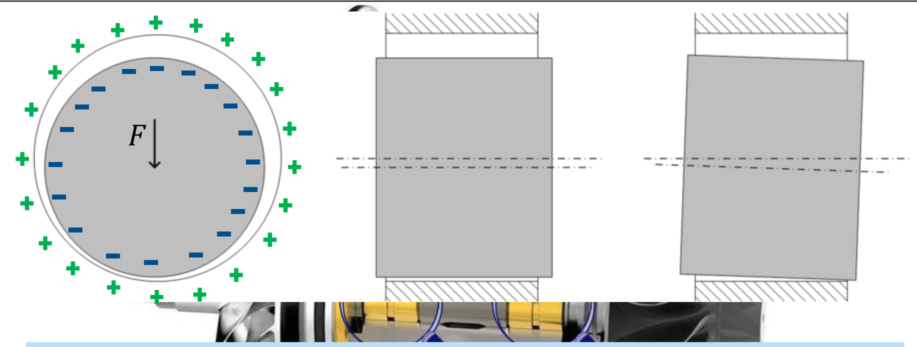
- Grant confirmed March 18
- Order placed April 2018
- Testing starts Nov 2018
- Dedicated research and industrial projects in 2019

16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 22

pmd

In-situ load data acquisition without physical sensors – Concept transfer to journal bearings

TECHNISCHE UNIVERSITÄT DARMSTADT



Research questions in the area of hydrodynamic journal bearings:

- Calculation of electric impedance under operating conditions and experimental verification
- Identification of failure mechanisms and tresholds for maximum permissible electric current
- Potentials and limits for sensoric application of journal bearings

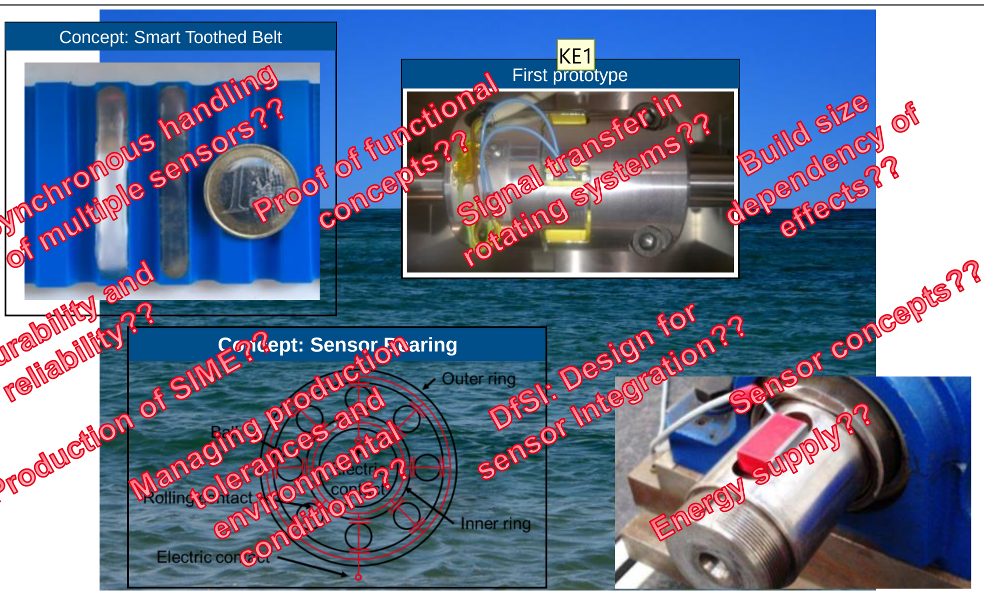
Bildquelle: https://www.springerprofessional.de/motorkomponenten/aufladung/turboladerlagerung-bietet-bis-zu-2-prozent-realverbrauchspotenzi/10059470

16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 24

pmd

Need for Research in Product Development – Unsolved questions discovered

TECHNISCHE UNIVERSITÄT DARMSTADT



https://www.ahoefler.de/images/maschinenbau/thermodynamik/temperatur/wasser/eisberg-01.jpg and eisberg-02.jpg

16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 25

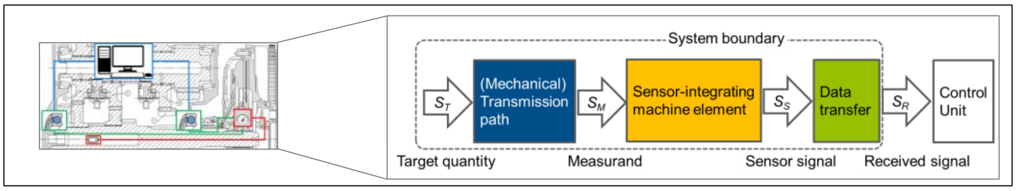
pmd

Need for Research in Product Development – Development of Systems using SIME

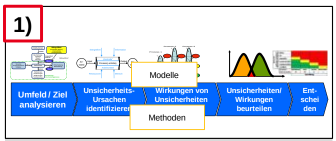
TECHNISCHE UNIVERSITÄT DARMSTADT

Open question for future Product Development Research

Research Project: Application of Uncertainty Mode and Effect Analysis (UMEA) and Robust Design (RD) for sensor-integrating machine elements in mechatronic systems

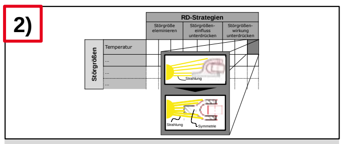


1)



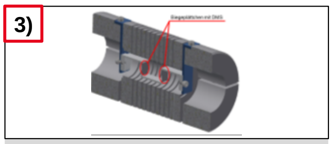
Identify disturbances

2)



Reduce impact of disturbances with RD

3)



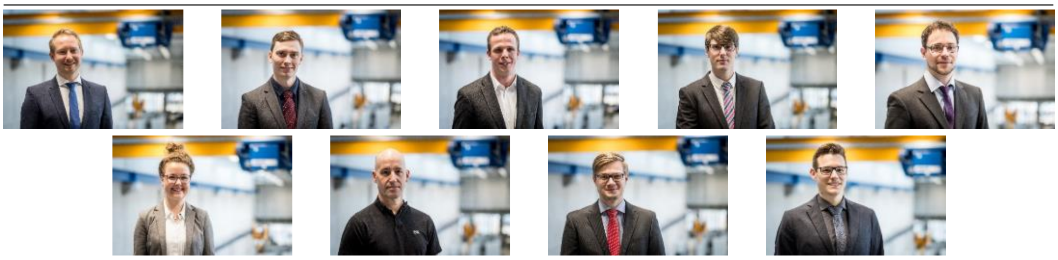
RD guidelines for design of SIME

16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 26

pmd

The team supporting this research – a big hand to all of them!

TECHNISCHE UNIVERSITÄT DARMSTADT



Thank you for your attention!

Pictures: F. Fernandes (8.2.2018)

16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | E. Kirchner | 27

pmd

Sensor Integrating Machine Elements
Key to in-situ measurements in mechanical engineering

TECHNISCHE UNIVERSITÄT DARMSTADT

Prof. Dr.-Ing. Eckhard Kirchner, Georg Martin, M.Sc., Sven Vogel, M.Sc.
TU Darmstadt, Institute for Product Development and Machine Elements

16.10.2018 | Fachbereich Maschinenbau | Produktentwicklung und Maschinenelemente | Prof. Dr.-Ing. E. Kirchner | 28

Prof. Dr.-Ing. Henrique Rozenfeld

Dr.-Ing. at WZL in RWTH-Aachen, Germany. Coordinator of the Advanced Manufacturing Nucleus (NUMA), Coordinator of the Research Group on Integrated Engineering (GEI). Faculty of the Industrial Engineering Department at the São Carlos Engineering School (EESC) of the São Paulo University (USP), Brazil. Visiting professor at WZL Aachen, Germany, research scholar at E-Business Competency Center of the University of Missouri, USA. Member of the design society. Advisor of 69 theses. More than 480 papers published. Consultant of many companies. His research interests include product development and innovation management, front-end of innovation (FEI), product-service system (PSS), servitization, business process innovation, product life-cycle management (PLM), design process modelling and business process management (BPM).

✉ roz@usp.br

Integrated Engineering Group

Integrated Engineering Group (GEI) of Nucleus of Advanced Manufacturing (NUMA). The Integrated Engineering Group (GEI) is located in the Production Engineering Department of São Carlos School of Engineering (EESC) at the University of São Paulo (USP), Brazil. The faculty members of GEI are Prof. Henrique Rozenfeld, Prof. Janaina Mascarenhas Hornos da Costa, and Prof. Daniel Capaldo Amaral, with 14 graduation and 8 undergraduation students. Currently, the research themes are in the following areas: servitization, business process management, agile innovation, and user centered design. Those research areas are interrelated, always keeping in mind the circular economy approach and the lifecycle management perspective. The goals of the GEI are to develop and validate new solutions in world applications, supporting companies to innovate their businesses. GEI has more than 112 finished research projects, resulting in about 690 publications, with over 92 finished Ph.D. and M.Sc. projects. The group website is http://www2.eesc.usp.br/grupoei/.

Integrated Engineering Group

Servitization methodology: PSS design, change management or business model innovation?

Abstract

Manufacturing companies are challenged to innovate their business in different aspects to add value to their offerings and sustain their competitive advantage. The need for fulfilling stakeholders' requirements and the higher demand for environmental responsibility lead companies to shift their traditional business models, based on product sales, to Product-Service System (PSS) – a new business model which encompasses integrated offerings of products and services. Servitization is the process to support companies on transforming themselves into PSS providers. This paper aims to discuss the experience of developing a servitization methodology that integrates concepts from different knowledge areas with a focus on PSS design, change process and business model innovation. Servitization is multidisciplinary. Therefore, knowledge from fields and communities with different mindsets and research methods were integrated: engineering design (lean, design thinking, product and service development, PSS design); sustainability (lifecycle management, circular economy); business administration (business process management, people change management, business model innovation, investment analysis, value chain); project management; and technology management.

Keywords

PSS; Development; Design; Servitization; Business Model Innovation.

Authors

Prof. Dr.-Ing. Henrique Rozenfeld
São Carlos School of Engineering, USP - GEI
roz@usp.br

Eng. Maiara Rosa, M.Sc.
São Carlos School of Engineering, USP - GEI
maiara.rosa@usp.br

Eng. Sânia da Costa Fernandes, M.Sc.
São Carlos School of Engineering, USP - GEI
saniafernandes@usp.br

1 Introduction

Circular economy (CE) is a regenerative system that aims to minimize the use of resources, waste, and emissions and can support the achievement of sustainability (GEISSDOERFER et al., 2017). Integrating design and business model in the context of the circular economy are necessary (BOCKEN et al., 2016). Indeed, it is based on multidisciplinary approaches with many business perspectives, including new technologies and policies. Change management to support a new mindset is important to the success of circular economy (LIEDER; RASHID, 2016). The implementation of product-service systems (PSS) can be seen as a central strategy to accomplish the circular economy (TUKKER, 2015).

Servitization is also multidisciplinary. Therefore, knowledge from fields and communities with different mindsets and research methods should be integrated: engineering design (lean, design thinking, product and service development); sustainability (lifecycle management, circular economy); business administration (business process management, people change management, business model innovation, investment analysis, value chain); project management; and technology management.

Some authors from the servitization community treat PSS as one of the researcher communities of servitization (BAINES et al., 2017; LIGHTFOOT; BAINES; SMART, 2013; RABETINO et al., 2018). Servitization is considered the transformation process followed by a product-oriented organization to become a PSS provider (BAINES et al., 2009, 2017; MARTINEZ et al., 2010; SMITH; MAULL; C.L. NG, 2014). It means that the system (PSS) is a result of servitization, which is a transformation process.

Business model innovation (BMI) is a subset of business model design for creating a new business and business model reconfiguration for existing companies when something new is created (MASSA; TUCCI, 2013). BMI should be distinguished from product, service or technology innovations (LINDGARDT et al., 2009). BMI occurs when some elements of business models are reinvented (LINDGARDT et al., 2009).

Since servitization is a process that creates new value propositions and the resulted system (PSS) typically presents novelties in value chain, organization, cost and revenue models, we consider that methods and tools of BMI are similar to those of servitization and that PSS design is included in the servitization.

Figure 1 illustrates the relationship among the approaches of change management, business model innovation, servitization, and PSS design. Servitization can be considered a business model innovation. Servitizing a manufacturing company demands organizational change management for preparing, orienting and supporting people throughout the transformation process. The scope of servitization is broader than the PSS design, because it is driven by more complex variables and comprises activities beyond the point-of-development of the integrated offering, such as change management for strategic alignment, business analysis, PSS launch, operation, end-of-life management activities, value chain definition, and other developments of business model elements.

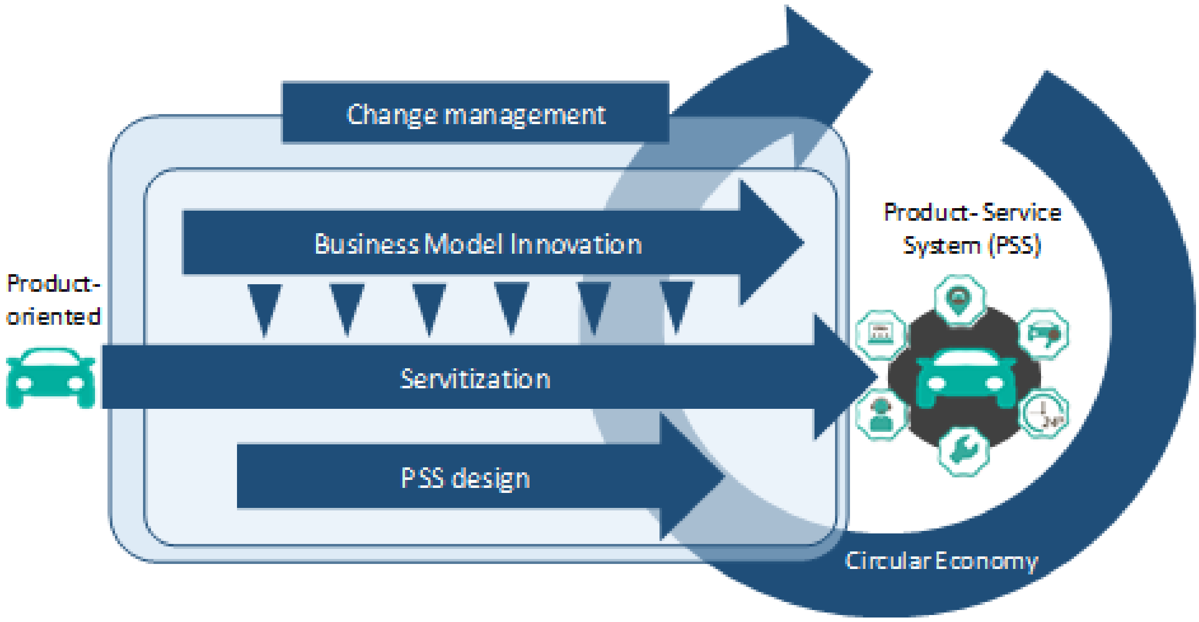


Figure 1: Conceptual vision of the relationships among circular economy, change management, business model innovation, servitization, and PSS design considered in the Servitization Methodology

Designing a PSS involves the integration of different elements that sustain the servitization in the early phases of development. If an organization is already a PSS provider, it should not follow the entire servitization process, but focus on the new PSS design as a development project. However, in any new PSS development, assessing the current business model is important to check whether changes are necessary or not.

New enabling technologies, such as the Internet of Things (IoT), can enhance the value of new business models (DIJKMAN et al., 2015). Therefore, they should be taken into consideration during the servitization process.

This publication intends to present an overview of a servitization methodology that considers the integration of the mentioned knowledge areas. This methodology resulted from a research project funded by FAPESP (process number 2015/23094-6) and is published as a guide in the web (under construction http://www.pdp.org.br/servmtd/) with the description of the methods, tools, and templates that anyone can download to support its application in real cases. This methodology was assessed by some case studies, but it is an ongoing development.

After presenting fundamental publications about PSS, servitization, PSS design, business model innovation, and change management, we show an overview of the methodology, and then we describe the main group of activities that complies with the methodology.

2 Product-Service System

The term product-service system was first formally introduced by Goedkoop et al. (1999, p. 18) (BAINES et al., 2007) as a "system of products, services, network of "players" and supporting infrastructure" capable of fulfilling customers' needs. Considering the disciplines of information system, business management, engineering, and design, Boehm; Thomas (2013, p. 252) formulated a core definition of PSS as an "integrated bundle of products and services which aims at creating customer utility and generating value."

PSS is presented as an alternative for companies to keep innovating in a market where the differentiation of products is no longer enough (VASANTHA; ROY; CORNEY, 2015). PSS typologies have been created to classify PSS based on core characteristics of the offerings (PARK; GEUM; LEE, 2012). The most applied typology for characterizing PSS was developed by Tukker (2004). The author proposed three main categories of PSS based on the ratio between product and service in the offering. According to Tukker (2004), a PSS is product-oriented when it involves the traditional sales of a product and additional services are offered to guarantee its functionality. A second type is use-oriented services, in which the PSS deliver the use or availability of a product. Last, the PSS can be result-oriented when the PSS provider and customer mutually agree on a result to be delivered (TUKKER, 2004).

The adoption of PSS strategies provides several benefits to the provider, customer, environment, and society (MONT, 2002). The PSS enhances strategic market opportunities and business differentiation when offering integrated solutions that meet the specific needs of customers (ANNARELLI; BATTISTELLA; NONINO, 2016; BAINES et al., 2007). A long-term relationship between provider and customer can be established and improved (BEUREN; FERREIRA; MIGUEL, 2013). Also, the PSS approach implies in competitive advantages while decoupling business and economic success from resource consumption (ANNARELLI; BATTISTELLA; NONINO, 2016; AURICH; MANNWEILER; SCHWEITZER, 2010). From the social perspective, a "sustainable pattern of consumption" can be promoted among customers (MONT, 2002).

However, some barriers challenge the PSS strategies implementation (ANNARELLI; BATTISTELLA; NONINO, 2016; BAINES et al., 2007). The provider still needs to deal with financial risks related to the net profit reduction (ANNARELLI; BATTISTELLA; NONINO, 2016; MONT, 2002; NEELY, 2008) and the cost generation for designing or changing the infrastructure for provisioning the PSS (MONT, 2002). The product-centered culture, the resistance to intra- and inter-organizational changes, and the risk absorbed by companies due to the full involvement with the product beyond its point-of-sale are also important barriers for the PSS approach (ANNARELLI; BATTISTELLA; NONINO, 2016; BAINES et al., 2007; MONT, 2002). Besides, customers can resist the new consumption pattern due to their ownership product-minded habits and schemes (MONT, 2002).

Relationships with stakeholders based on long-term cooperation are fundamental for PSS efficiency (ANNARELLI; BATTISTELLA; NONINO, 2016; MONT, 2002). Even if some problems may arise, such as the trade-off between cooperation management and internal requirements by each actor, information sharing, and different legislation or rules among countries (MONT, 2002), the involvement and acceptance from stakeholders play key conditions for implementing the PSS strategies.

3 Servitization and PSS Design

Servitization is the innovative process of creating additional value through the transition from traditional business to one that offers integrated products and services (BAINES et al., 2009, 2017; MARTINEZ et al., 2010; SMITH; MAULL; C.L. NG, 2014). This term was coined by Vandermerwe; Rada (1988). Servitization is long-lived, ensures competitive advantages for traditional manufacturers while creating new value-adding capabilities when moving from transaction-based to relationship-based (BAINES et al., 2009).

Among the drivers for the servitization, the financial, strategic and marketing factors should be highlighted (BAINES et al., 2009). According to Baines et al. (2009), companies are pursuing recurrent revenue stream, sustainable competitive advantages based on services that are difficult to imitate in commoditized markets, and customer-based relationships to influence their purchasing decision.

Some challenges impact the adoption of the servitization strategy. Service design is considerably different when compared to product design (BAINES et al., 2009; VELAMURI; NEYER; MÖSLEIN, 2011). Services are difficult to define (SLACK, 2005) by a conventional manufacturer since they are characterized by intangibility, heterogeneity, and simultaneity between production and consumption, being consumed as they are provided (AURICH; MANNWEILER; SCHWEITZER, 2010). Servitization also requires defining the organization strategy based on customer-centric competencies (MARTINEZ et al., 2010). Consequently, a long-standing organization transformation is expected, encompassing changes in the cultural environment, corporate mindset and in its alignment towards service provision, and in the company's infrastructure (BAINES et al., 2009; MARTINEZ et al., 2010).

The PSS domain is included in the scope of the servitization research. As PSS integrates product-oriented and service-oriented views in the design space (VASANTHA; ROY; CORNEY, 2015), an important condition for defining the tangible and intangible results of PSS is to include the physical artifact as well as the services' concept, process and channels, customer activities, and the network among multiple stakeholders throughout the PSS life cycle phases (TAN, 2010). Marketing strategies for environmental and social promotion can also be developed when designing a PSS (MONT, 2002). From the perspective of the design process, strategic, tactical and operational activities should be coordinated internally in the company and externally with customers and other partners (TAN, 2010).

The PSS design is multidimensional, and it is predominantly human-centered. The rationale for designing PSS solutions is based on the interaction between designers and further people involved in the early phases of PSS rather than being mediated by product and technological artifacts (ERICSON; LARSSON, 2009; MORELLI, 2003). This appears as a challenge for designers, who must expand their degree of freedom in design and their engineering design mindset to cope with new dimensions related to customers, stakeholders' interaction, services, and the entire product lifecycle (MORELLI, 2003; TAN, 2010).

Whenever a PSS is designed, dimensions of the business model can be changed by adding value to the offerings through services incorporation (ERICSON; LARSSON, 2009; TAN, 2010). In such cases, the business model detailing is paramount to the success of the PSS design (BARQUET et al., 2013).

4 Business Model Innovation

A business model defines the company's mechanisms of creating, delivering and capturing value (OSTERWALDER; PIGNEUR, 2010). In general, business models articulate how the business is performed to convert resources and capabilities into solutions using economic and financial structures. Every company employs specific business models to fit their strategy, core competencies, and operations (REIM; PARIDA; ÖRTQVIST, 2015). Business models can represent several dimensions, such as value proposition, resources, activities, and revenue considerations (BARQUET et al., 2013), and may have different detail levels to reflect the business logic.

Business models are considered as vehicles for innovation that enable the configuration of organizational capabilities according to the business context (EVANS et al., 2017). Business Model Innovation embraces the ability of the company of creating and delivering value to capture superior economic results (LANGE; VELAMURI, 2014). This concept involves either creating an entirely new business model or redesigning an existing business logic due to the transition from one business model to another within well-established organizations (BALDASSARRE et al., 2017; BOCKEN et al., 2014).

Designing a new PSS may also lead to the innovation of a business model. When both product and service platforms are novelties for the company, a new business model is created and developed from the beginning of the PSS design. However, when the company is already servitized, or a PSS has been previously designed, only incremental improvements are necessary to the business model.

5 Change Management

The mindset gradually changes during the servitization process, as well as the path to develop new PSS solutions. To assure the most satisfactory results, the leadership should conduct a change process for guiding the transformation efforts among the team. The first stage of a change process is the creation of a motivation to change, suspending past patterns. The second stage consists in the change itself, contemplating solutions to a given situation, and learning new behaviors, concepts and standards. The last stage is institutionalizing the change and all the achievements related to it, i.e., embodying the change (BUONO; KERBER, 2010; SCHEIN, 2002).

Successful transformation programs require the comprehension of the company's market position and competitive realities concerning technological trends, potential crises and major internal and external opportunities. Changes require people cooperation and involvement, and the leadership should motivate and convince the collaborators to drive out of their comfort zone, i.e. leadership should establish a sense of urgency (KOTTER, 1995).

6 Servitization Methodology Overview

A methodology is a set of methods. Usually, a methodology is organized by a category of methods, and sometimes they can represent phases of a development project. We structured our methodology in groups of activities that share a common goal related to a set of deliverables, which are related to methods.

Since there is an overlap of the content of many knowledge areas and we have structured the methodology content based on existing approaches and new practices., we employed three perspectives to illustrate the servitization methodology.

Figure 2 presents the perspective of the servitization methodology content, showing how the activity groups overlap each other.

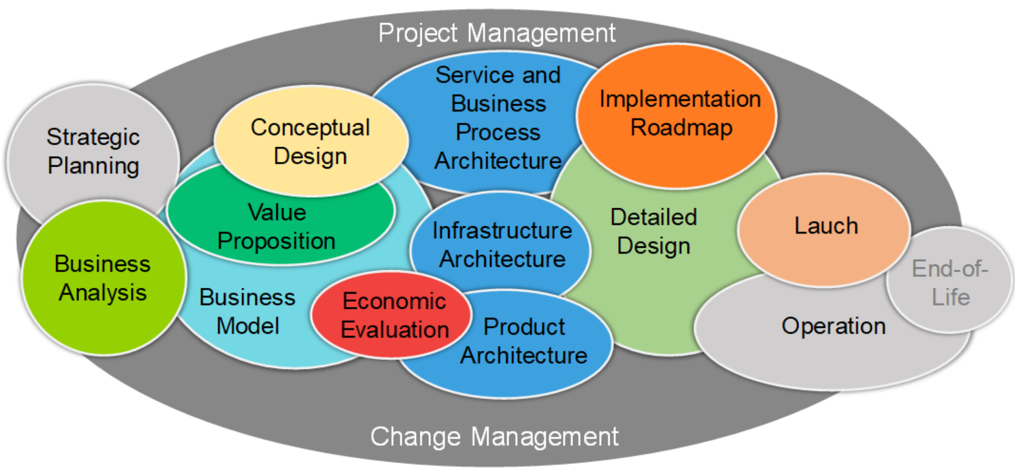


Figure 2: Content perspective of the servitization methodology

Business analysis should permanently run in any organization as parallel business processes (in the case of a startup, this is the beginning of entrepreneurship). It includes the analysis of the internal and external environment to learn the actual situation and trends of the company, value chain, market, competitors, technology, legislation, and stakeholders. We can observe in Figure 2 that business analysis may input information to strategic planning and both guide the value proposition, which is part of the business model.

Strategic planning sets the goals and actions for the organization. In this methodology, it includes the goals of the servitization.

Value proposition defines more precisely the market segment, who are the stakeholders, and which are their needs, expectations, desires, and problems. At the same time, it defines opportunities from market and technology, as well as limitations and requirements from legislation. We have to point out that part of this information comes from business analysis and strategic planning. Based on this information, we can outline the value proposition using creativity techniques so that we can explicitly define what benefits stakeholders may derive from the solution.

If we are developing a new business model, the beginning of the value proposition includes the initial activities from conceptual design. Indeed, *conceptual design* is more than value proposition. It consists of a representation of the solution with different models that go beyond “post its”: layout and mockup for the product, function diagram, a journey map for the service, a system map for the whole solution, etc. If the organization already offers PSS, we are not going to develop an entirely new business model anytime, but we can check whether the existing model copes with the new requirements.

Usually, a business model includes the cost and revenue models, which are the basis for *economic evaluation*, aka business case. Although at this moment we might not have enough data to precisely calculate the economic evaluation, we must make a decision. In the following activities, we can calculate the financial indicators again based on new information.

The *integrated architectures* are in the following level of detail, which fill up the gap between the conceptual and detailed design. It is the moment where the integration among the PSS elements come to reality. We map functions in elements of different natures. We can represent services with business processes (using for example service blueprint), infrastructure with system maps, and products with functional diagrams related to the product items. Moreover, we can connect the PSS elements among themselves and with the user. At the architectural level, we support the integrated development of product, service, infrastructure and value network. The lack of this level of abstraction hinders most PSS design methodologies on achieving an integrated solution.

The *implementation roadmap* indicates the development projects that we intend to carry out to achieve the proposed business model. It may be subdivided into categories and the development projects may range short, medium and long-term. The roadmap includes the individual development projects from detailed design until the launch of the PSS.

Detailed design is when we specify the solution (the system - PSS) at a level that allows us to create the whole system. This group of activities can vary depending on the technology we are going to apply. It executes what we have defined in the previous group of activities. It includes the test to validate and to homologate the whole solution.

Launch embraces the activities that allow the beginning of operation. It is the moment where we align all efforts and set the value chain running with the elements once designed in the business model. Most corrections and adjustments of the PSS occur during the launch. This can lead to updating the detailed design, architecture and, seldom, the business model.

Operation contains the activities of the PSS middle-of-life (MOL). This period requires PSS lifecycle management. This group of activities is similar to a phase (the usage phase). We can update the solutions applying configuration management practices, and in certain circumstances, we can apply *end-of-life* (EOL) strategies to some elements of the solution. Typically, we use those strategies to the physical artifact, i.e., the product. We can remanufacture it and bring it to a new usage phase, reuse in another context, or even recycle its main components. We can also treat the intangible elements of the PSS in EOL to define, for instance, a new business model.

On the methodology background, the company should run *project and change management* activities. It means that they overlap each other, i.e., they can occur before, concomitantly and after the other activities. People are involved in developing and operating the PSS as well as benefiting from it. Therefore, we consider *change management* as a crucial group of activities to motivate and support the collaborators' participation in this endeavor. The appropriate mindset should also be available to the success of the servitization. Imbricated with change management is *project management* since they share many practices. Servitization is a change process, but each instance of this process is a change project. Hence, we must manage it as a project based on hybrid techniques that use agile and traditional project management principles.

Observe that the content perspective of the servitization methodology does not point out phases of a servitization project. This will be better explained when we present the procedural perspective. Since those groups of activities result in the main deliverables of the servitization, Figure 3 illustrates their hierarchical perspective.

We can notice that business analysis is out of this hierarchical structure, as well as the implementation roadmap and launch. Economic evaluation is an ad hoc group of activities that we can apply at any moment. Conceptual design could be included in the value proposition of the business model and finalized at the PSS architecture. Nevertheless, as explained before, the abstraction level of conceptual design can be complementary to those two groups of activities. Change and project management are in another dimension of this hierarchical perspective.

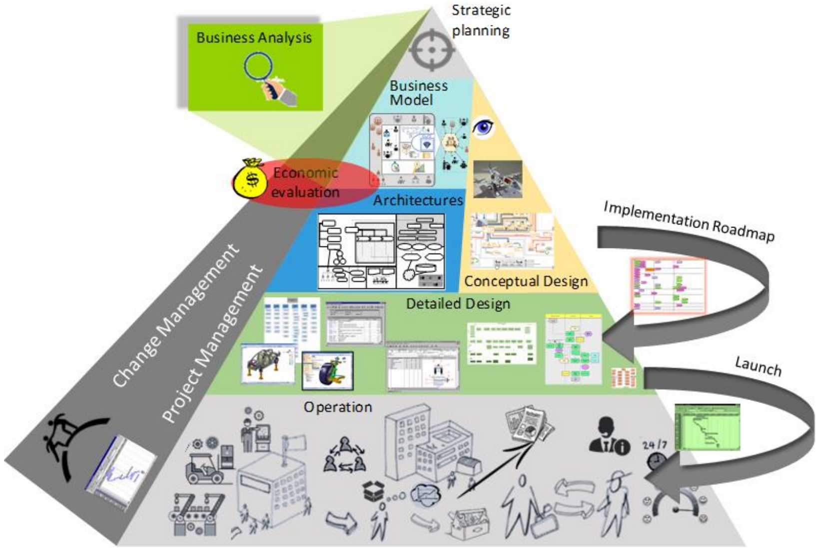


Figure 3: Hierarchical perspective of the servitization methodology

As servitization is a change process, the procedural perspective of the servitization methodology (Figure 4) can support the outline of a transformation project (the servitization project). We have related the groups of activities of Figure 2 to each stage of the procedural perspective to exhibit the possible content we can perform.

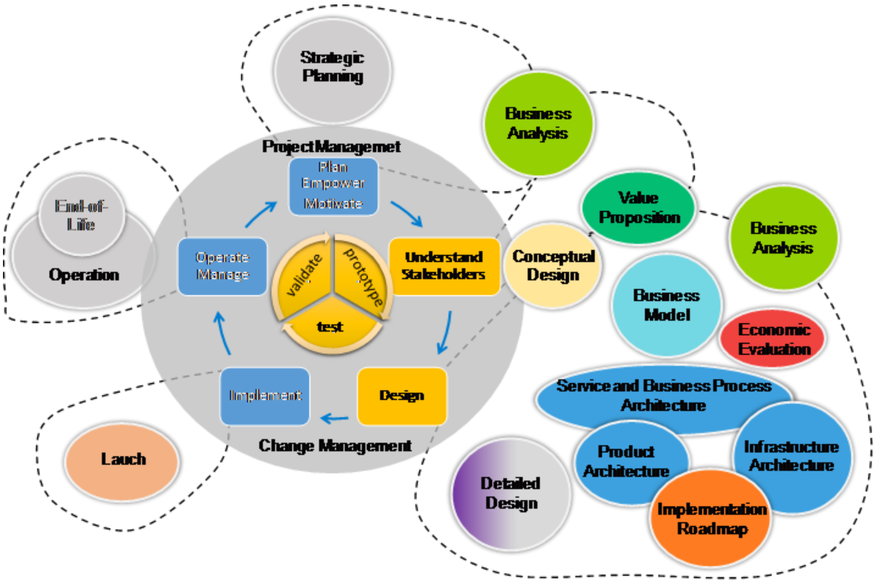


Figure 4: Procedural perspective of the servitization methodology

We begin a servitization project with the mobilization, empowerment, and motivation of the team together with the project planning. Then, we must deeply understand the stakeholders. The process covers the whole solution design (including business model and so on). The following stage is the implementation of what was designed. Finally, we can operate and manage the life-cycle, which includes the end-of-life. As background, the activities of change and project management may be performed in parallel.

Two characteristics of Figure 4 should be highlighted. Prototypes should be built steadily during the development, and not only in the design phase as it is usual in the actual practice (in the center of the figure). Those are low fidelity and virtual prototypes that we should create whenever necessary since the beginning of conceptual design. We test them to evaluate the progress of the solution according to the stakeholders' requirements (to verify if the solution may capture the proposed value).

The procedural perspective shows that this process is iterative. It means that we can define servitization projects considering that a partial solution can be delivered and that we can develop a next step with a more mature version. This fact justifies the stages of the procedural perspective. Phases are elements related to specific projects, defined according to the project life-cycle.

After observing the figures of the three perspectives, you might have a superficial vision of the methodology. In the next sections, we will point out some of the groups of activities to show novelties we have introduced in this methodology and how they are orchestrated with traditional and good practices.

6.1 Change Management and Project Management

Servitization implies in changes that are performed by people and involve people towards continuous improvement in business. It is necessary to ensure the alignment of capabilities, mindset, behaviors of people, their roles in the servitization, and the organizational culture.

People's mindset depends on their value and beliefs, education background, and life experience. They are influenced by the organizational profile of the company, which is a set of institutional, political, and managerial characteristics that define an organization considering both the formal structure and interpersonal relationships among people from different teams and with different roles. Those aspects strongly influence the development of the people's competences, which integrate their capabilities and attitudes. The knowledge of people sustains their capabilities when dealing with their qualification and skills (Figure 5).

The change management approach is the background of the Servitization Methodology, creating the conditions for preparing and motivating the organization towards servitization. That approach comprises processes, structures, and techniques to support people to adapt towards a new paradigm.

The change process throughout servitization requires creating a vision that provides a well-defined direction for the servitization, defining the preliminary organizational profile, communicating with stakeholders, motivating and empowering others to act on the vision, agile planning, consolidating partnerships, institutionalizing new approaches, launching and monitoring the servitization and the operations, and continually improving.

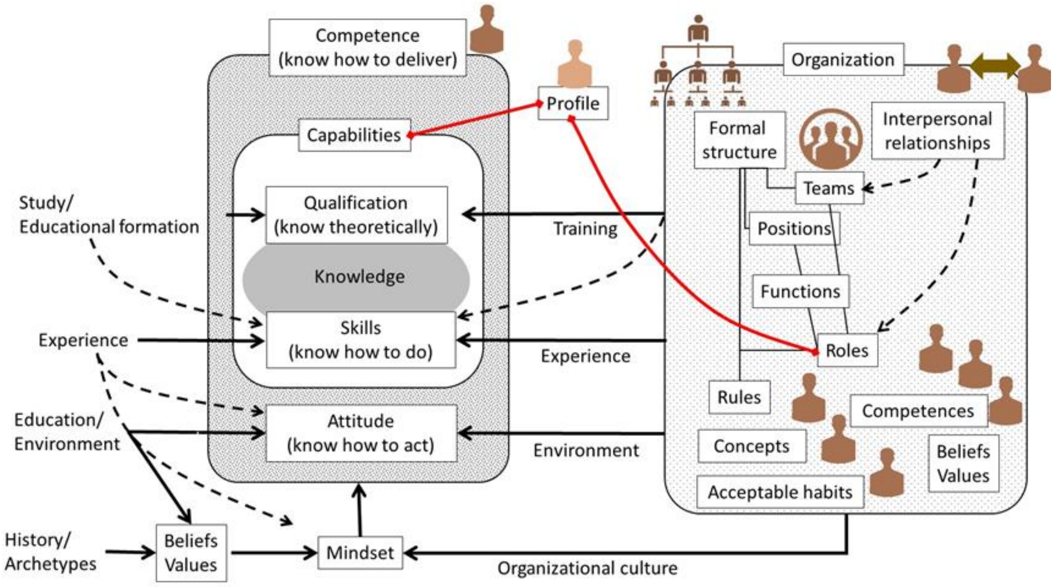


Figure 5: Relationship between individual profile and organization profile

As changes encompass temporary endeavors that have a defined beginning and end in time, change may be seen as a project. Project management provides knowledge, methods, and tools to accomplish the changes during the servitization journey. While the change management approach is centered on people and the organization, project management is focused on the results/deliverables to be achieved with the servitization. Both approaches are integrated and carried out collaboratively to meet the servitization objectives.

6.2 Strategic Planning and Business Analysis

Every organization must be aware of the business environment where it intends to act. The strategic planning and business analysis is the moment where the company understands and articulates what change and why the change is required. Independently of the company's context, it is essential to know the market, competitors, context, and the company itself, and to establish a strategic path towards the future. Strategic planning and business analysis provide this essential information during servitization.

Strategic planning and business analysis are related processes. While the first establishes the path that the company should follow (future), the latter aims at understanding the current situation, besides defining the market segment, learning about the competitive environment where the company intends to act, aligning the project to the company's strategy, and defining the servitization challenges. The deliverables that result from strategic planning and business analysis are illustrated in Figure 6.

The Servitization Methodology recommends that, if companies already perform this kind of analysis, it should be followed as it is. Otherwise, companies should define a strategic direction and try to acquire as much information as possible about the existing business ecosystem to reduce the risks of a servitization project.

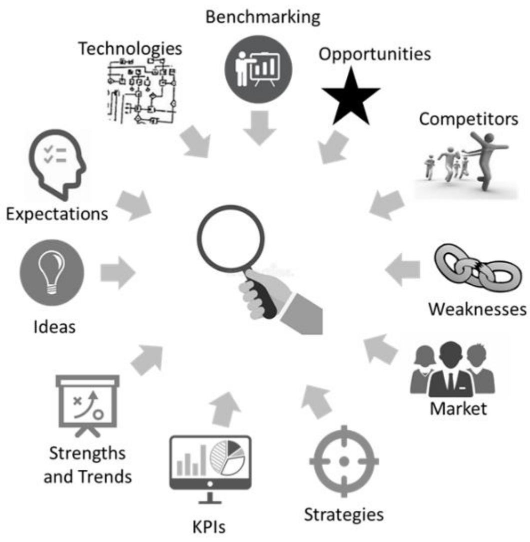


Figure 6: Deliverables resulting from strategic planning and business analysis

6.3 Value Proposition

During servitization, the value proposition is the moment where the team identifies a meaningful problem for a specific market segment and proposes an initial concept of how this problem might be solved. The value proposition stage provides information for two business model dimensions, as illustrated in Figure 7: to the value proposition itself, which is central to the business model; and to the market segment dimension as well.

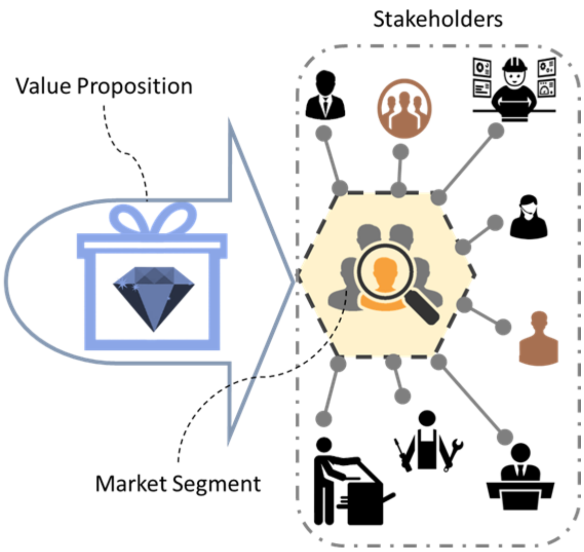


Figure 7: Business model dimensions filled by the value proposition stage

We highlight one core difference at this moment when comparing traditional product development and servitization. In the first, market segment usually focuses on the customer or the user. However, the latter requires regarding all important stakeholders, since PSS demands a strong partnership network and may provide value to multiple stakeholders.

The Servitization Methodology suggests that the value proposition should be developed in a double-diamond process, with succeeding moments of divergence and convergence, as illustrated in Figure 8. Readers who are familiar with design thinking (BROWN, 2008) will perceive that this process follows exactly this approach.

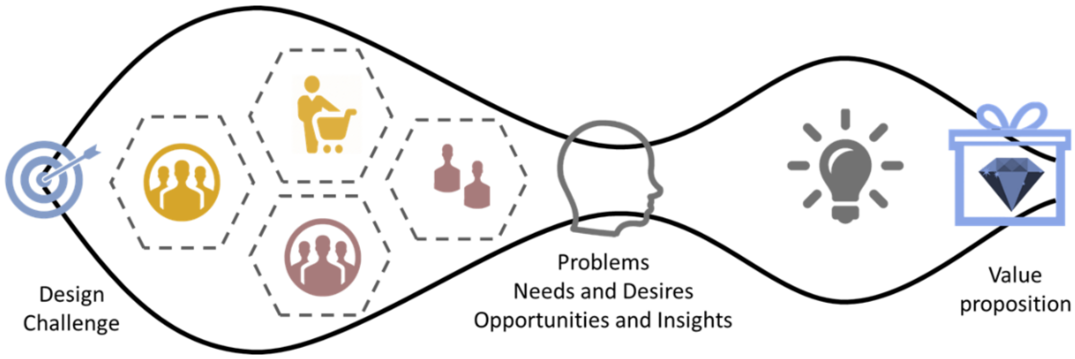


Figure 8: Value proposition process

Figure 8 shows that the value proposition process starts by establishing a design challenge, which is usually the vision that directs the servitization process, being aligned with the organizational strategic goals. This design challenge will support the team in framing what stakeholders are the most important ones. Then, the first diamond begins to diverge. The team follows a process of thoroughly understanding the stakeholders through interviews, ethnographic techniques, among others. This is the moment of identifying problems, needs, desires, opportunities and insights from the stakeholders. Some problems may seem more meaningful than others and they may require further understanding. This is the moment where the first diamond starts to converge: interviews and ethnographic research may still be performed but in a more focused way. The design team begins to focus on what problems, needs, desires, opportunities, and insights are more relevant to the design challenge.

The second diamond from Figure 8 covers ideation. The design team starts to generate ideas that shall solve or fulfill the problems, needs, desires, opportunities, and insights. The divergence of the second diamond covers an “uncontrolled” creation of ideas - all ideas are welcome, and judging is not allowed. Ideas will only be evaluated and selected when the second diamond starts to converge. Specifically, for the servitization process, we suggest analyzing what ideas may be combined before selecting them, assembling initial concepts. Servitization provides several product and service ideas. Some of them may even be solution principles or details for a given product or service. Therefore, those ideas may be combined to compose solutions. Then, the team selects the most promising ideas to test them with stakeholders. This testing should be done using low-resolution prototypes, i.e., physical representations of solution hypotheses that should be tested. The prototype should not imitate the solution, but be able to validate hypotheses. Testing ideas is essential to reduce the servitization risk, since poor solutions will be cut off from the beginning. Finally, the best solutions and their benefits are explicitly stated, composing the value proposition.

Two final remarks should be highlighted. First, the value proposition process may (and should) result in more than one solution. In this case, the team may follow a concurrent engineering process, proceeding with all promising solutions until they have enough information to justify canceling its development. Second, the value proposition process, as well as the entire servitization process, is iterative and may be performed again or iterated whenever necessary, as showed in the procedural perspective.

6.4 Business Model

The business model CANVAS (OSTERWALDER; PIGNEUR, 2010) is the most popular template - most methodologies employ this template. However, it contains some flaws. It is ambiguous for many users to precisely determine what a customer relationship is and, in practical application, users intermingle customer relationship with the definition of channels (COES, 2014). The servitization methodology deals with this issue including the category “channels” into the category “resources” since a channel is a type of resource. The category “relationship with customer” we consider an attribute of the resource “channel”. Thus, with this change we can add any channel and type of relationship we want to any stakeholder. Furthermore, we do not consider people as a resource, defining a specific category for them.

Nevertheless, if an organization is used to employ the CANVAS template, Table 1 provides an equivalence map to identify what categories are equivalent between both templates.

Table 1: Equivalence of the CANVAS categories and the servitization methodology categories for business models

<table>
<tr><th>CANVAS business model categories</th><th>Business model categories of the servitization methodology</th></tr>
<tr><td>Customer segments</td><td>Stakeholders (including customers)</td></tr>
<tr><td>Value proposition</td><td>Value proposition</td></tr>
<tr><td>Channels</td><td rowspan="3">Resources (*)</td></tr>
<tr><td>Customer relationship</td></tr>
<tr><td rowspan="2">Key resources</td></tr>
<tr><td>People and organization</td></tr>
<tr><td>Key activities</td><td>Business Processes</td></tr>
<tr><td>Key partnerships</td><td>Partners</td></tr>
<tr><td>Revenue streams</td><td rowspan="2">Revenue and Cost (base for economic evaluation)</td></tr>
<tr><td>Cost structure</td></tr>
</table>

(*) channels can be related to any stakeholders (different channels with customers, partners, shareholders, agencies, etc.) and we consider channel as one type of resource. The relationship is an attribute of a channel.

Therefore, we have simplified and generalized the CANVAS categories in our template for business model innovation (see Figure 9).

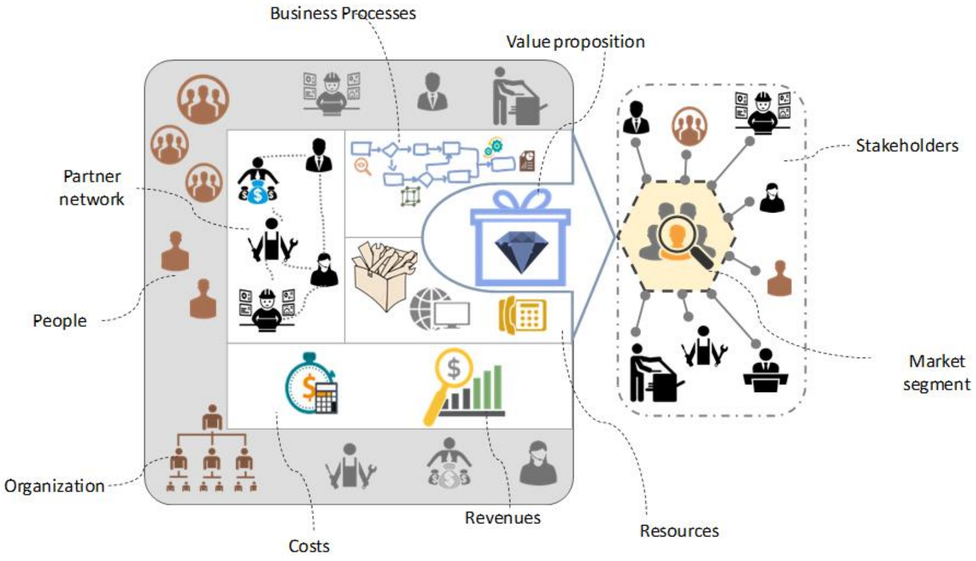


Figure 9: Template for business model design of the servitization methodology

The beginning of the business model is the value proposition defined in the previous section, which must be evaluated and reviewed during the whole process. There is an interdependence among process, resource, and partner. Thus, the business model design is an iterative process (see Figure 10).

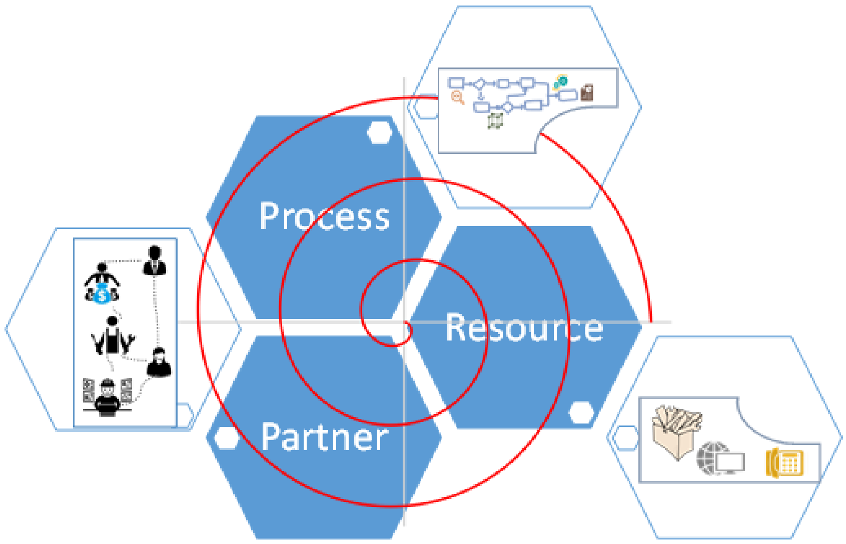


Figure 10: Interactive way for defining process, resource and partner

The novelty of the servitization methodology are the patterns of business models and catalog of business model elements that could support the definition of new solutions. However, we must avoid only reusing those patterns and elements. We should support creativity and continuously update those “standards” as a living methodology so that always-new business models can serve as an inspiration to new endeavors.

A business model representation should be at a high level. Nevertheless, the servitization methodology offers the possibility of detailing a next level, where the relationships among the elements are explicit as illustrated in Figure 11. This abstraction level is already the first step in describing the integrated architectures. We consider the traditional abstraction level of the business model as the “tip of the iceberg.” This level is important at a first iteration, but it misses the connection among the elements that we could represent in complementary documents, such as tables and cross references. We also propose the checklists with the elements catalogue of business models as complementary documents.

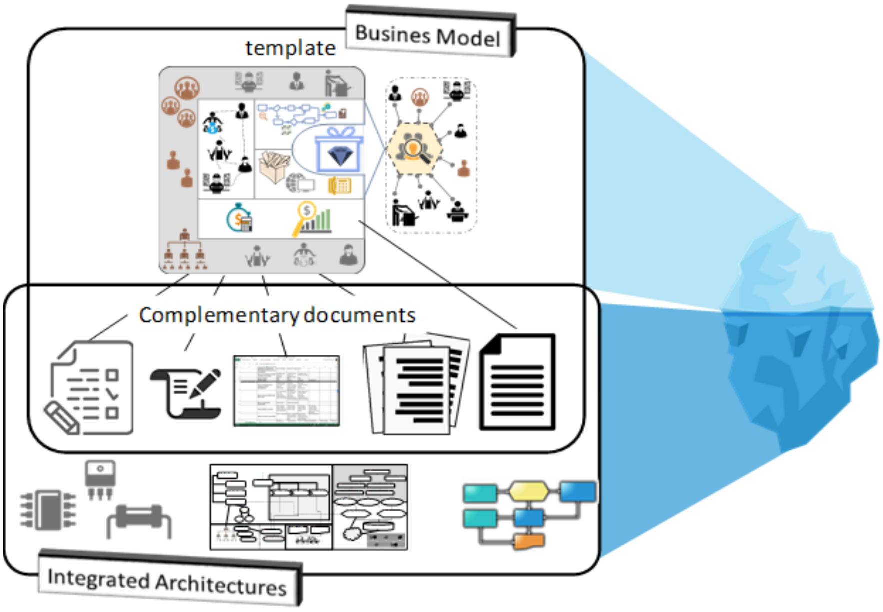


Figure 11: Illustration of the complementary level of description of the business model

6.5 Economic Evaluation

One of the barriers to adopt a PSS business model is the lack of effective economic evaluation considering the associated risks. Another barrier is the mindset of decision makers who focus on short payback and low investments (OLIVEIRA et al., 2018). Servitized organizations usually have higher revenues but generate lower net profit if compared with manufacturing pure product-oriented organizations (NEELY, 2008). These issues are considered some of the causes to cancel a servitization project.

One of the inspirations for the economic evaluation logic of this servitization methodology were the 12 categories of servitization approaches presented by Neely (2008).

In this methodology, during the business model generation, we have introduced a list of possible revenue streams that make the user aware of the available possibilities. As mentioned, this goes beyond the actual way of describing a business model. However, the servitization methodology proposes a level of detail that can support the calculation of the economic evaluation just after obtaining the business model, as illustrated in Figure 12.

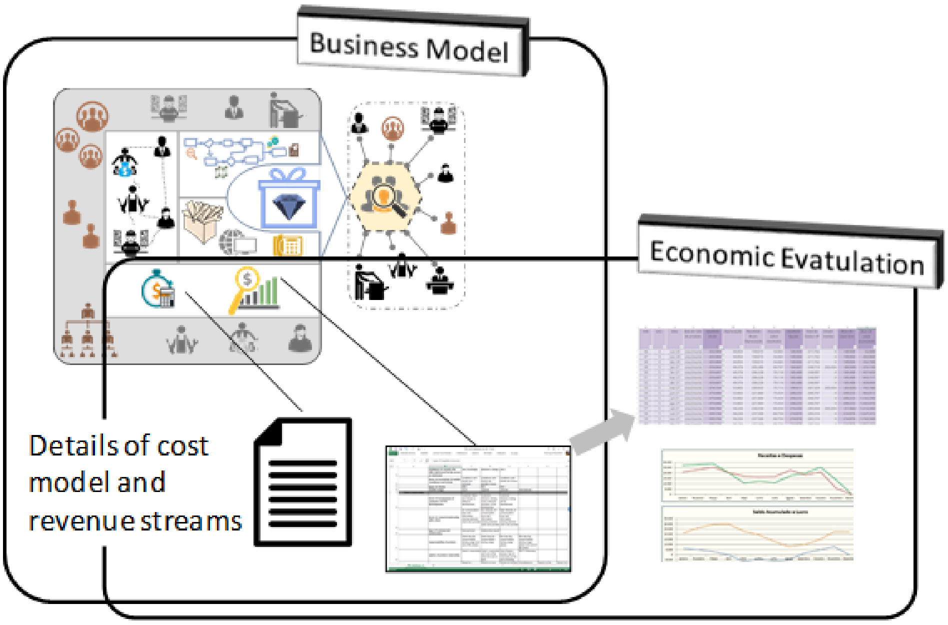


Figure 12: Detailed information of cost model and revenue stream from business model as input for the economic evaluation

The revenue stream is one of the inputs for the economic evaluation. Based on the combination of offerings related to the options of revenue streams, we can define a bundle of offerings to perform the economic evaluation. The methodology defines a set of offerings considered as building blocks to compound the streams, which must be related to the value proposition. Together with the cost model, we can define a cash flow of the whole life-cycle to determine the financial indexes.

There are many particularities that we should take into consideration when evaluating the financial results of a PSS during the development. We carry out the economic evaluation just after designing the business model, but we should repeat this calculation at any moment where we have more detailed information. Thus, we can validate the premises defined in the first economic evaluation, as well as the assumed indexes.

6.6 PSS Architecture

As the name suggests, PSS is a system and should be designed as such. During the development of a system, the architecture is an essential deliverable. Taking an electronic system as an example, an architecture states how all subsystems and components are intercorrelated to assure that, during detailed design, the electrical engineers will design components and subsystems that allow the final system integration. However, a PSS development highly differentiates from a traditional system, since it is composed of elements of different natures - products, services, processes, organization, and infrastructure (ICT and resources). During detailed design, there will be engineers, service designers, product designers, programmers, among many other professionals detailing the same solution. Therefore, a well-defined architecture during servitization plays even a more important role than during product development.

A PSS architecture consolidates the solution, structures the main elements of a PSS, and establishes relationships and interfaces among the PSS elements. Due to the multiple natures of the PSS elements, we may subdivide the PSS architecture into process, service, product, ICT, organizational, and resource architectures, as illustrated in Figure 13.

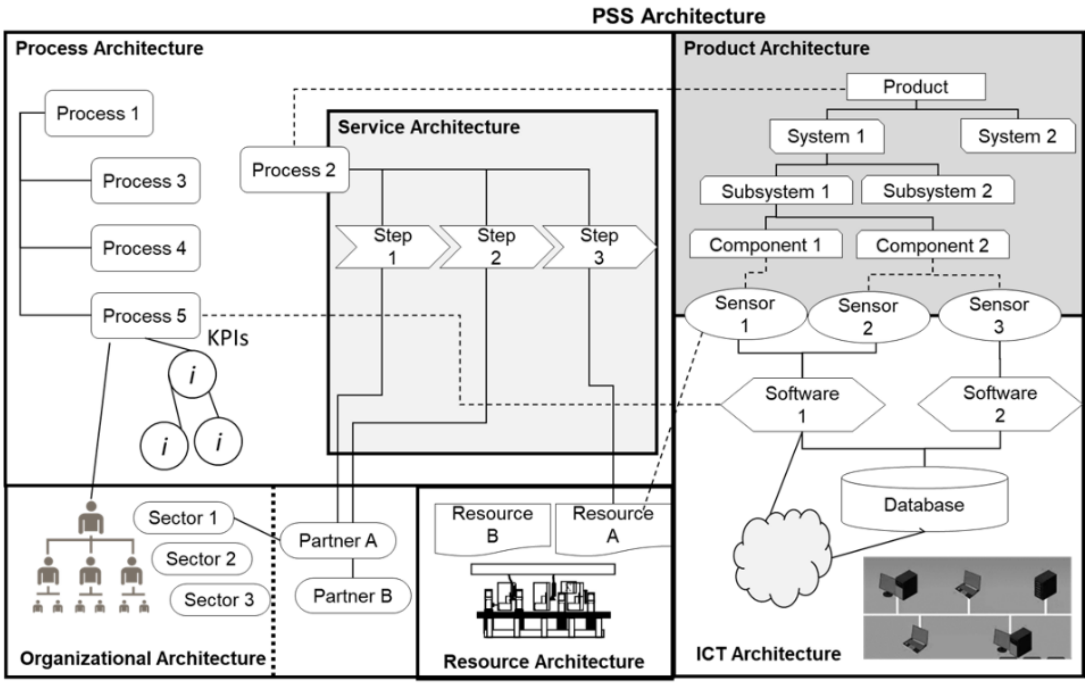


Figure 13: Structure of a PSS Architecture

The process architecture structures the interfaces and main parts of the business processes that support the company in providing PSS, as well as their key performance indicators (KPIs). As a subdivision of the process architecture, the service architecture follows the same format, however structuring all processes that provide value with direct interface with the customers, i.e., services. The product architecture structures what are the systems, subsystems, and components (SSCs) that compose the product, as well as how are their interfaces. The ICT architecture represents the computational solutions that support the PSS services and may interface the product, such as IoT solutions. Another important representation is the organizational architecture, which structures the responsibilities of the company sectors and the partnerships influences in the architecture. Finally, to represent the infrastructure required to provide the PSS, a resource architecture should be structured.

When developing a PSS architecture, the team may design each architecture separately, interconnecting the architectures later through their interfaces and relationships. Due to its complexity, a systems engineer would be helpful to structure the PSS architecture and to make the integration requirements explicit.

6.7 Implementation Roadmap 0,5 san

From the Business Analysis, the company being servitized can initiate the development of an implementation roadmap, which represents the main results or advancements to be achieved over time during the servitization. It is highlighted that a roadmap is not a schedule neither the result of the project planning for the servitization. The roadmap indicates the main results expected for the detailed design towards the implementation of the PSS. Those results should be aligned to the Business Model categories for delivering value to the stakeholders. They can be represented in a roadmap such as that illustrated in Figure 14. Short-term results must be developed and implemented in the current servitization project. Mid-term and long-term results establish future trends or challenges in the servitization context.

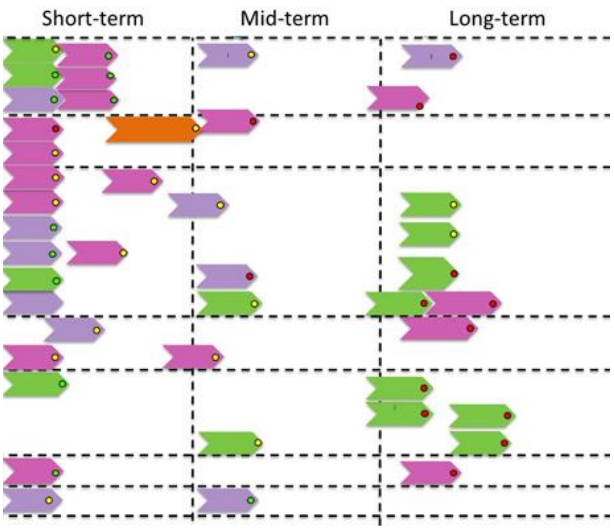


Figure 14: Example of implementation roadmap

6.8 Detailed Design

The main goal of the detailed design is to specify the PSS in detail, testing solutions using virtual and high-fidelity prototypes, evaluating and certifying all solution aspects, and releasing information for launch and operations.

At this moment, the architecture and the integrations requirements follow their path for detailing. Engineers will specify the products' components and subsystems, service designers will specify the service details, programmers and software engineers will detail the ICT devices, among others. The detailed design will be restricted to the short-term implementation, according to the roadmap.

The detailed design in the servitization methodology follows the "V-Model", as illustrated in Figure 15. The left side of the model illustrates how the items (i.e., the SSCs) are defined, specified, and drawn, from architecture up to the detailed item being built, prototyped and codified. The right side illustrates the inverse path, illustrating that such items shall be tested, integrated and validated until achieving the system level again.

One core criticism of servitization and PSS design is regarding little integration between product and service design as a single solution. The servitization methodology highlights that integrated architectures assure this consistency, allowing each artifact to be developed separately if following the integration requirements.

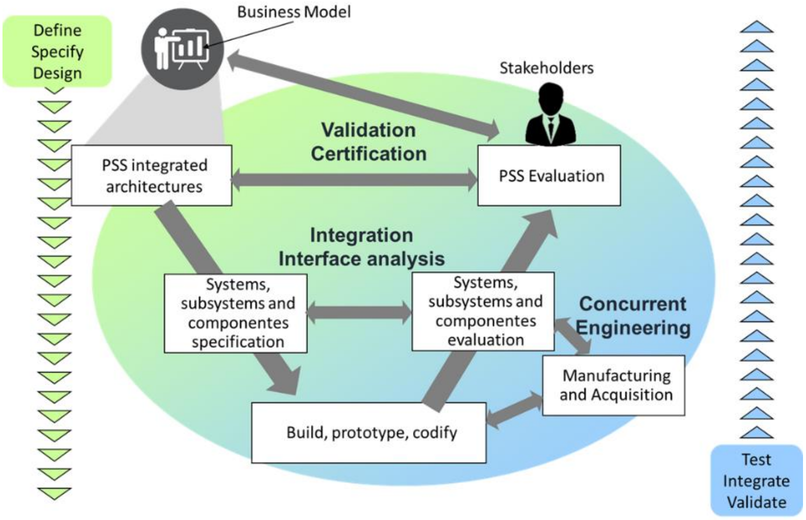


Figure 15: Schematic of the detailed design activities

6.9 Launch and Operation

In the servitization methodology, the launch is the moment where the value chain starts running. Following the roadmap and the detailed design specifications, the final preparations for offering the PSS are finally done. This is the moment where the company makes the final acquisitions, installs machinery, train people, establishes the last partnerships, homologates processes, the PSS, and the value chain, and emits all necessary certifications. Operation starts with the launch, and unexpected initial problems should be solved at this moment.

When the operation starts, the middle of life (MOL) of the PSS finally starts. Everything that was specified is running. The solution may be submitted for improvement regarding what was planned in the implementation roadmap for mid-term and long-term. This period also requires constant monitoring of the business for continuous improvement until the solution’s end of life (EOL).

6.10 End-of-Life

The end of life occurs when the PSS is not able to fulfill its intended purpose for the customers. The PSS can be upgraded by adapting the product or service, or it can be dismissed. The services considered in the PSS end of life are related to the practices of circular economy, such as upgrading, reuse, take-back systems, remanufacturing, refurbishment, recycling, or cancellation and return to the beginning of the cycle.

As a new concept, the circularity of the tangible components of PSS depends on restructuring the product and service design throughout their life cycle, the manufacturing process and operation, as well as the entire supply chain.

7 How to apply the servitization methodology

As mentioned before, the servitization methodology is a collection of methods organized in groups of activities. The activity and corresponding deliverable are the building blocks that we can use to structure a servitization project.

The steps to apply this servitization methodology are:

- Simplified diagnostic of the as-is situation of your organization: We verify whether the organization fulfills the requirements to apply the methodology. It is a questionnaire to acquire information to support the following steps, such as verifying the strategic planning, existing offerings, competitors, market conditions, among others (please, see the servitization methodology guide to access all questions).
- Selection of the groups of activities and complementary approaches: Based on the knowledge acquired in the previous step, we can select the groups and define other approaches and activities required for successfully applying the servitization methodology.
- Selection of the activities and corresponding deliverables: We extract from the methodology what we need to configure a specific servitization project based on the results of the previous step.
- Project planning: Depending on the characteristics of the project, we define a planning approach (normally hybrid, mixing agile and traditional project management techniques). The procedural perspective of the methodology may be employed to support this step.
- Execution: This step covers performing what was planned.

8 Final Remarks

The servitization methodology proposed in this paper may be followed by companies willing to innovate their business models toward integrated solutions composed by products and services. The methodology reinforces that servitization encompasses the scope of PSS design, change management, and business model innovation. More than that, servitization is a complex process that should take into consideration several knowledge fields to succeed -

especially when the company aims to achieve circular economy business models, requiring a systemic perspective permeating the entire solution. We propose the combination of engineering design (lean, design thinking, product and service development, PSS design); sustainability (lifecycle management, circular economy); business administration (business process management, people change management, business model innovation, investment analysis, value chain); project management; and technology management.

The servitization methodology was created based on action research cycles and case studies that have been performed during the past years, leading to the proposal described in this paper. The methodology is registered in a guide, which should be seen as a living document that will be updated according to new insights and findings that may derive from application cases. This guide was elaborated in the context of open knowledge, with free access in the Internet. It contains all templates, checklists, patterns, and other building blocks around the activities and their deliverables.

Finally, the servitization methodology should be seen as an iterative and adaptable process. In the guide, we provide methods, good practices, and other guidelines that may support the activities that should be performed during servitization. However, we highlight that the sequence of activities and the methods that will support them should be selected according to the section “How to apply the servitization methodology” for each project context and respecting the collaborators’ repertoire of knowledge.

In the near future, life-cycle assessment techniques and methods for supporting the integration of smart objects capabilities in PSS solutions shall be included in the servitization methodology.

9 Acknowledgment

This work was supported by São Paulo Research Foundation (FAPESP) under the process 2015/23094-6, 2017/12520-0 and 2017/27144-3. The opinions, hypotheses and conclusions or recommendations expressed in this material are responsibility of the authors and do not necessarily reflect the views of FAPESP. The authors would like to extend sincere thanks to São Paulo Research Foundation (FAPESP), Brazilian Council for Scientific and Technological Development (CNPq) and the Higher Education Personnel Improvement Coordination (Capes) for supporting this research.

10 References

ANNARELLI, A.; BATTISTELLA, C.; NONINO, F. Product service system: A conceptual framework from a systematic review. Journal of Cleaner Production, v. 139, p. 1011–1032, 2016

AURICH, J. C.; MANNWEILER, C.; SCHWEITZER, E. How to design and offer services successfully. CIRP Journal of Manufacturing Science and Technology, v. 2, n. 3, p. 136–143, 2010

BAINES, T. et al. The servitization of manufacturing: a review of literature and reflection on future challenges. Journal of Manufacturing Technology Management, v. 20, n. 5, p. 547–567, 2009

BAINES, T. S. et al. State-of-the-art in product service-systems. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, v. 221, n. 10, p. 1543–1552, 2007

BAINES, T. S. et al. Servitization: Revisiting the State-of-the-art and Research Priorities. International Journal of Operations & Production Management, v. 37, n. 2, p. 256–278, 2017

BALDASSARRE, B. et al. Bridging sustainable business model innovation and user-driven innovation: A process for sustainable value proposition design. Journal of Cleaner Production, v. 147, p. 175–186, 2017

BARQUET, A. P. B. et al. Employing the business model concept to support the adoption of product-service systems (PSS). Industrial Marketing Management, v. 42, n. 5, p. 693–704, 2013

BEUREN, F. H.; FERREIRA, M. G. G.; MIGUEL, P. A. C. Product-service systems: A literature review on integrated products and services. Journal of Cleaner Production, v. 47, p. 222–231, 2013

BOCKEN, et al. A literature and practice review to identify Sustainable Business Model Element Archetypes. Journal of Cleaner Production, v. 65, p. 42–56, 2014

BOCKEN, N. M. P. et al. Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering, v. 33, n. 5, p. 308–320, 2016

BOEHM, M.; THOMAS, O. Looking beyond the rim of one’s teacup: A multidisciplinary literature review of Product-Service Systems in Information Systems, Business Management, and Engineering & Design. Journal of Cleaner Production, v. 51, p. 245–260, 2013

BROWN, T. Design Thinking. Harvard Business Review, n. 06, p. 1–10, 2008

COES, B. Critically assessing the strengths and limitations of the business model canvas. Master Dissertation. University of Twente, 2014

DIJKMAN, R. M. et al. Business models for the Internet of Things. International Journal of Information Management, v. 35, n. 6, p. 672–678, 2015

ERICSON, Å. M.; LARSSON, T. C. People , Product and Process Perspectives on Product / Service-System Development. Development, p. 219–236, 2009

EVANS, S. et al. Business Model Innovation for Sustainability: Towards a Unified Perspective for Creation of Sustainable Business Models. Business Strategy and the Environment, v. 608, n. April, p. 597–608, 2017

GEISSDOERFER, M. et al. The Circular Economy – A new sustainability paradigm? Journal of Cleaner Production, v. 143, p. 757–768, 2017

GOEDKOOP, M. J. et al. Product Service systems, Ecological and Economic Basics. Economic Affairs. 1999, 132 p

KOTTER, J. Leading change: why transformation efforts fail. Harvard Business Review, p. 59–67, 1995

LANGE, V. G.; VELAMURI, V. K. Business model innovation in the retail industry: growth by serving the silver generation Veit Gregor Lange. International Journal Entrepreneurship and Innovation Management, v. 18, n. 4, p. 310–329, 2014

LIEDER, M.; RASHID, A. Towards circular economy implementation: A comprehensive review in context of manufacturing industry. Journal of Cleaner Production, v. 115, p. 36–51, 2016

LIGHTFOOT, H.; BAINES, T.; SMART, P. The servitization of manufacturing: a systematic literature review of interdependent trends. International Journal of Operations & Production Management, v. 33, n. 11/12, p. 1408–1434, 2013

LINDGARDT, Zhenya et al. Business model innovation: When the Game Gets Tough, Change the Game, The Boston Consulting Group, Boston, MA, 2009

MARTINEZ, V. et al. Challenges in transforming manufacturing organisations into product-service providers. Journal of Manufacturing Technology Management, v. 21, n. 4, p. 449–469, 2010

MASSA, L.; TUCCI, L. C. Business Model Innovation. In: The Oxford Handbook of Innovation Management. Chapter 21, p. 420–441, 2013

MONT, O. Clarifying the concept of product – service system. Journal of Cleaner Production, v. 10, p. 237–245, 2002

MORELLI, N. Product-service systems , a perspective shift for designers: A case study - The design of a telecentre. Design Studies, v. 24, n. 1, p. 73–99, 2003

NEELY, A. Exploring the financial consequences of the servitization of manufacturing. Operations Management Research, v. 1, p. 103–118, 2008

OLIVEIRA, M. et al. Lessons learned from a successful industrial Product Service System business model: emphasis on financial aspects. Journal of Business & Industrial Marketing, v. 33, n. 3, p. 365–376, 2018

OSTERWALDER, A.; PIGNEUR, Y. Business Model Generation. John Wiley & Sons, 2010

PARK, Y.; GEUM, Y.; LEE, H. Toward integration of products and services: Taxonomy and typology. Journal of Engineering and Technology Management - JET-M, v. 29, n. 4, p. 528–545, 2012

RABETINO, R. et al. Structuring servitization-related research. International Journal of Operations & Production Management, v. 38, n. 2, p. 350–371, 2018

REIM, W.; PARIDA, V.; ÖRTQVIST, D. Product-Service Systems (PSS) business models and tactics - A systematic literature review. Journal of Cleaner Production, v. 97, p. 61–75, 2015

SLACK, N. Operations strategy: will it ever realize its potential? Gestão & Produção, v. 12, n. 3, p. 323–332, 2005

SMITH, L.; MAULL, R.; C.L. NG, I. Servitization and operations management: a service dominant-logic approach. International Journal of Operations & Production Management, v. 34, n. 2, p. 242–269, 2014

TAN, A. R. Service-oriented product development strategies. Thesis. Technical University of Denmark, 2010

TUKKER, A. Eight Types of Product-service systems. Business Strategy and the Environment, v. 13, p. 246–260, 2004

TUKKER, A. Product services for a resource-efficient and circular economy - A review. Journal of Cleaner Production, v. 97, p. 76–91, 2015

VANDERMERWE, S.; RADA, J. Servitization of Business: Adding Value by Adding Services. European Management Journal, v. 6, n. 4, p. 314–324, 1988

VASANTHA, G. V. A.; ROY, R.; CORNEY, J. R. Advances in Designing Product-Service Systems. Journal of the Indian Institute of Science, v. 95, n. 4, p. 429–447, 2015

VELAMURI, V. K.; NEYER, A. K.; MÖSLEIN, K. M. Hybrid value creation: A systematic review of an evolving research area. Journal fur Betriebswirtschaft, v. 61, n. 1, p. 3–35, 2011

Grupo de Engenharia Integrada

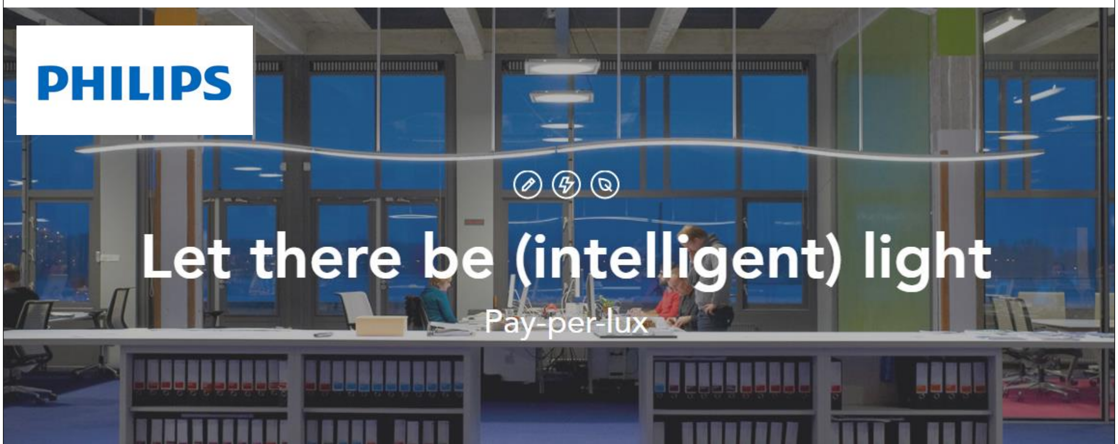
Servitization methodology: PSS design, change management or business model innovation?

Henrique Rozenfeld
Maiara Rosa
Sânia da Costa Fernandes

Engenharia de Produção
Escola de Engenharia de São Carlos
Universidade de São Paulo


PHILIPS
STEREO
RCA
Victor
ESTEREO
S U N
RADIATION LEVEL
Instrumental
B

Spotify®



Pay-per-lux **- Philips, Holanda, Amsterdã**

Clientes pagam uma taxa pela iluminação de um local, e não mais pela aquisição de lâmpadas. A Philips é responsável por todo o serviço de iluminação – design, equipamentos, instalação, manutenção e atualizações. No final do contrato, as lâmpadas podem retornar para o processo produtivo novamente, com o reuso de materiais, otimizando a reciclagem e reduzindo desperdícios.

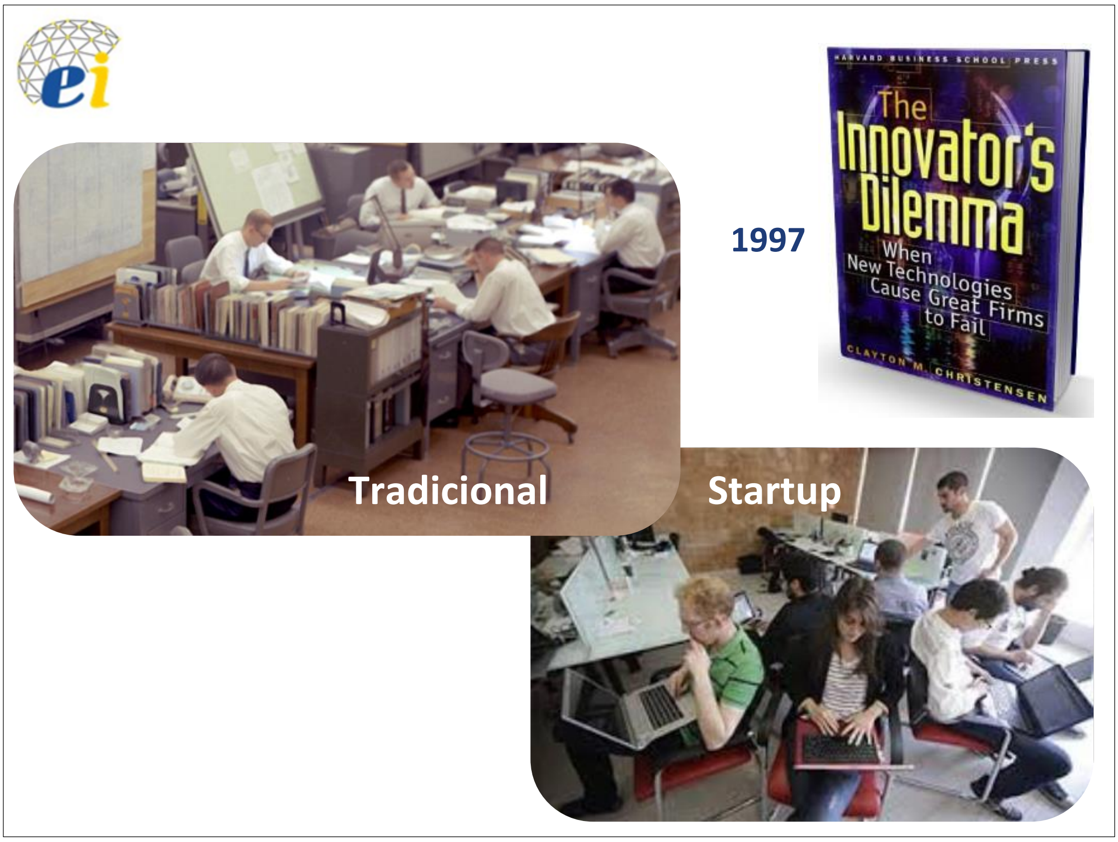
Água Pura – Brastemp, Brasil

É um programa de relacionamento exclusivo com assinantes dos Purificadores Brastemp. Não oferece apenas um purificador de água com classificações de filtragem. Oferece comodidade e segurança através do fornecimento de água limpa. Inclui serviços online, agendamento de manutenção e assistência técnica.

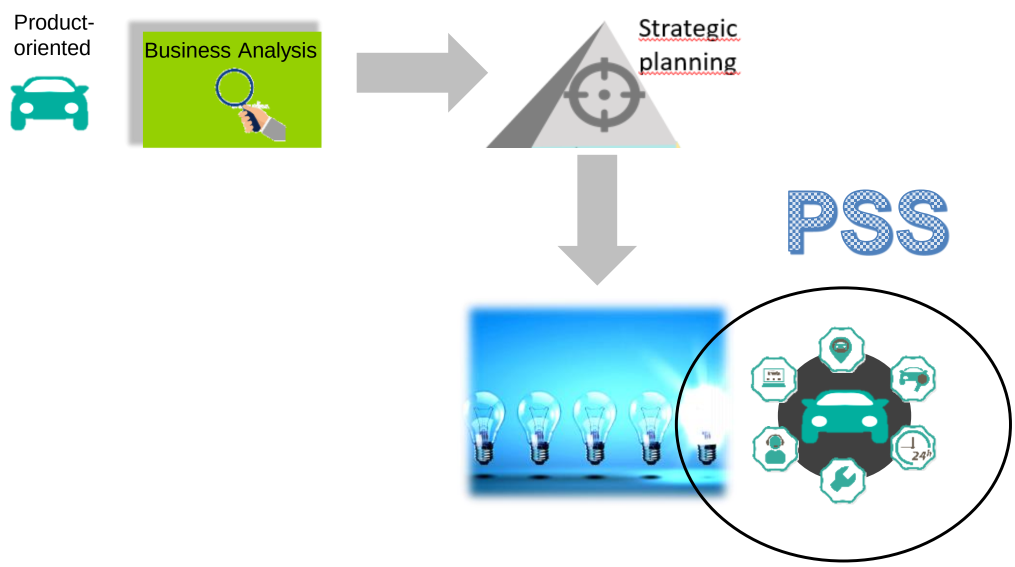
JBT, São Paulo, Brasil

É fornecedora de produtos e serviços no segmento da indústria de frutas e vegetais. No setor de cítricos, a empresa produz o Citrus Extractor, o coração de qualquer sistema de processamento de cítricos. O modelo de negócio centra-se no fornecimento de soluções, que incluem aluguel de equipamentos, manutenção e suporte técnico. Atualmente, a empresa possui 2.500 equipamentos alugados.

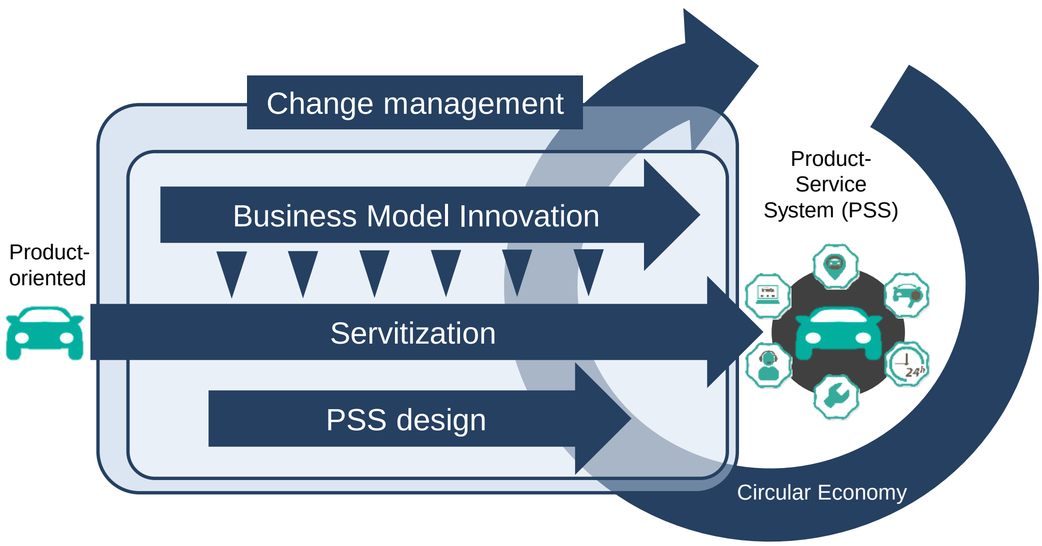

Current situation

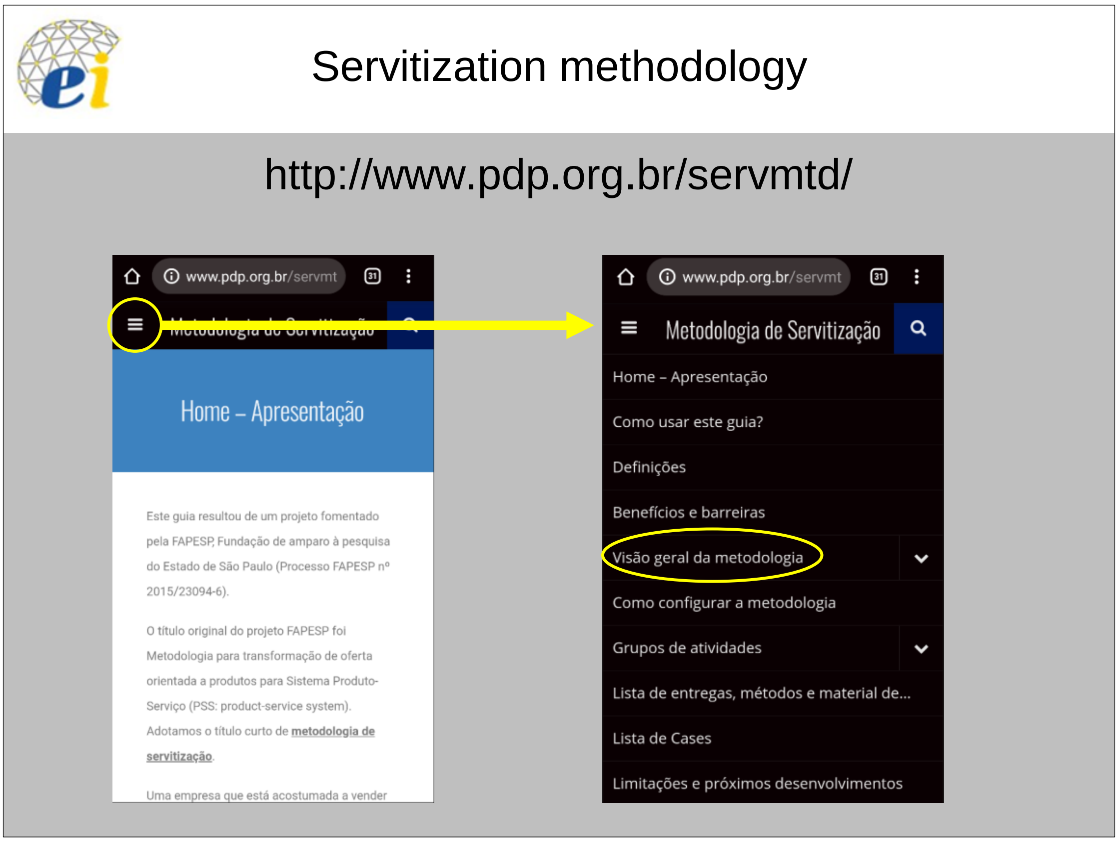

ei
1997
HARVARD BUSINESS SCHOOL PRESS
The Innovator's Dilemma
When New Technologies Cause Great Firms to Fail
CLAYTON M. CHRISTENSEN
Tradicional
Startup

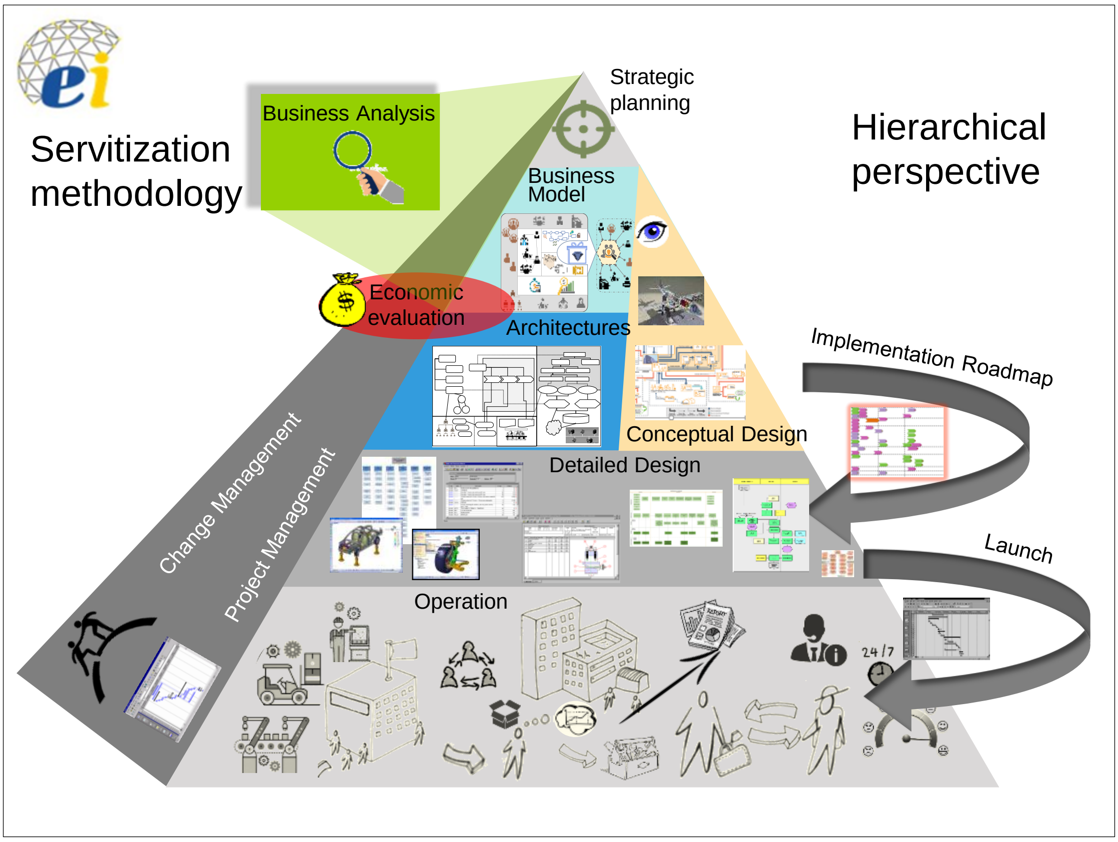
Start point: strategic planning

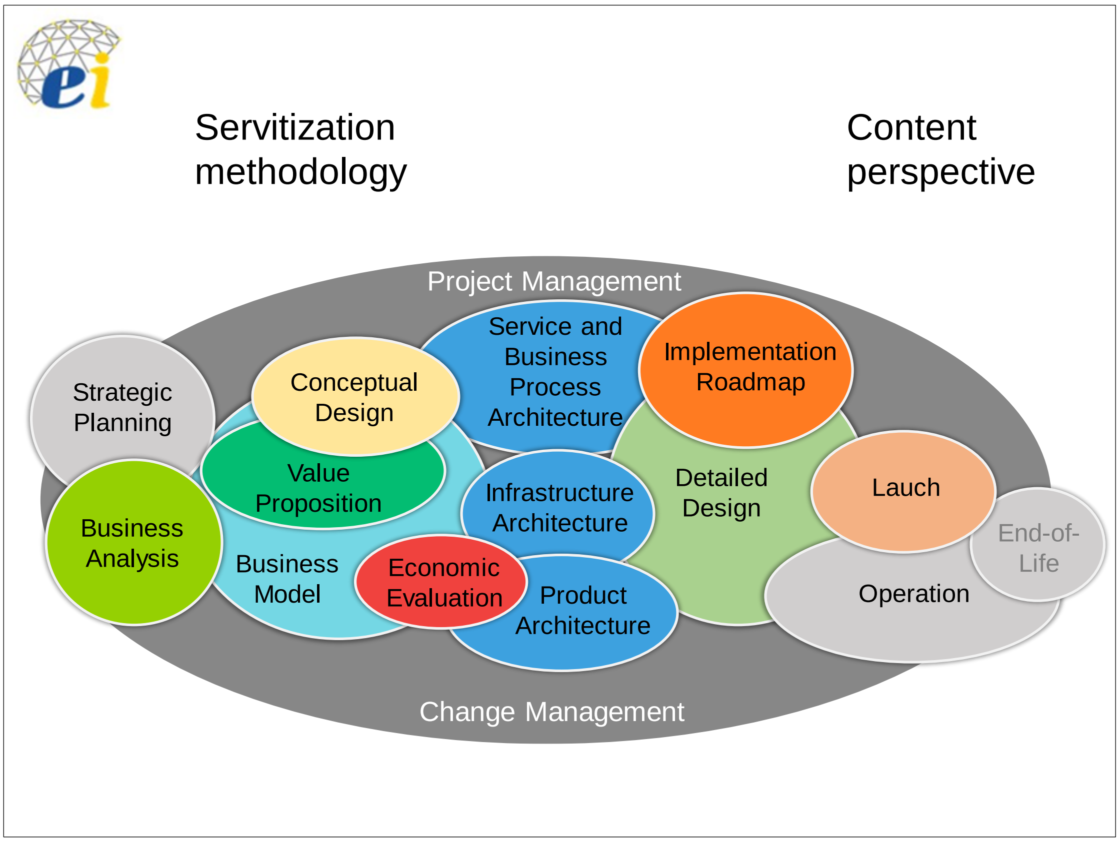


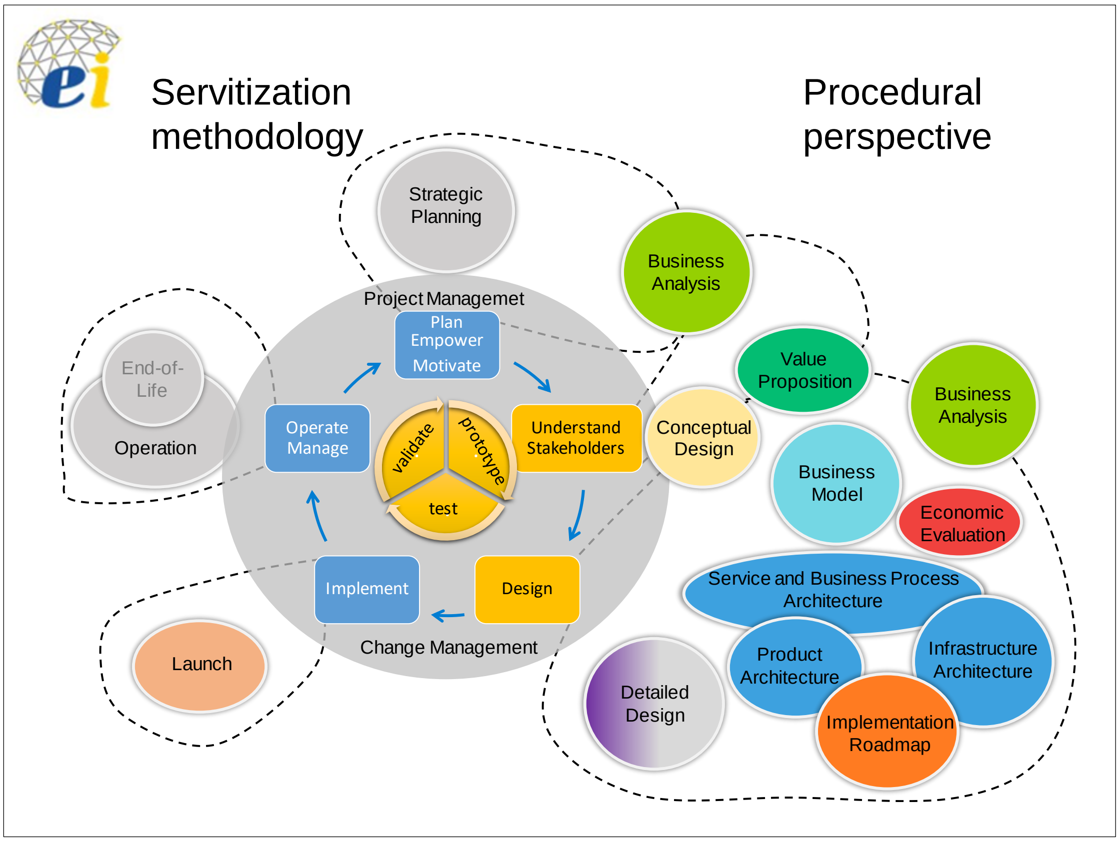
PSS design, change management or business model innovation?

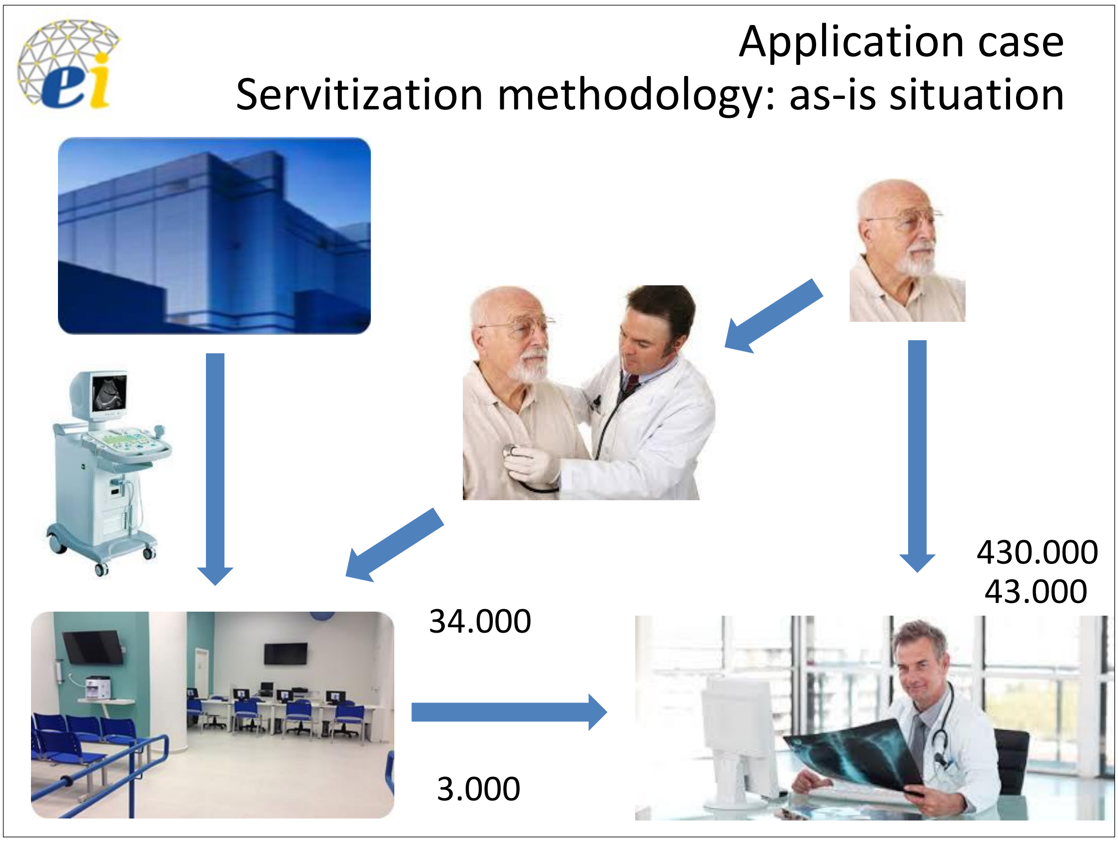


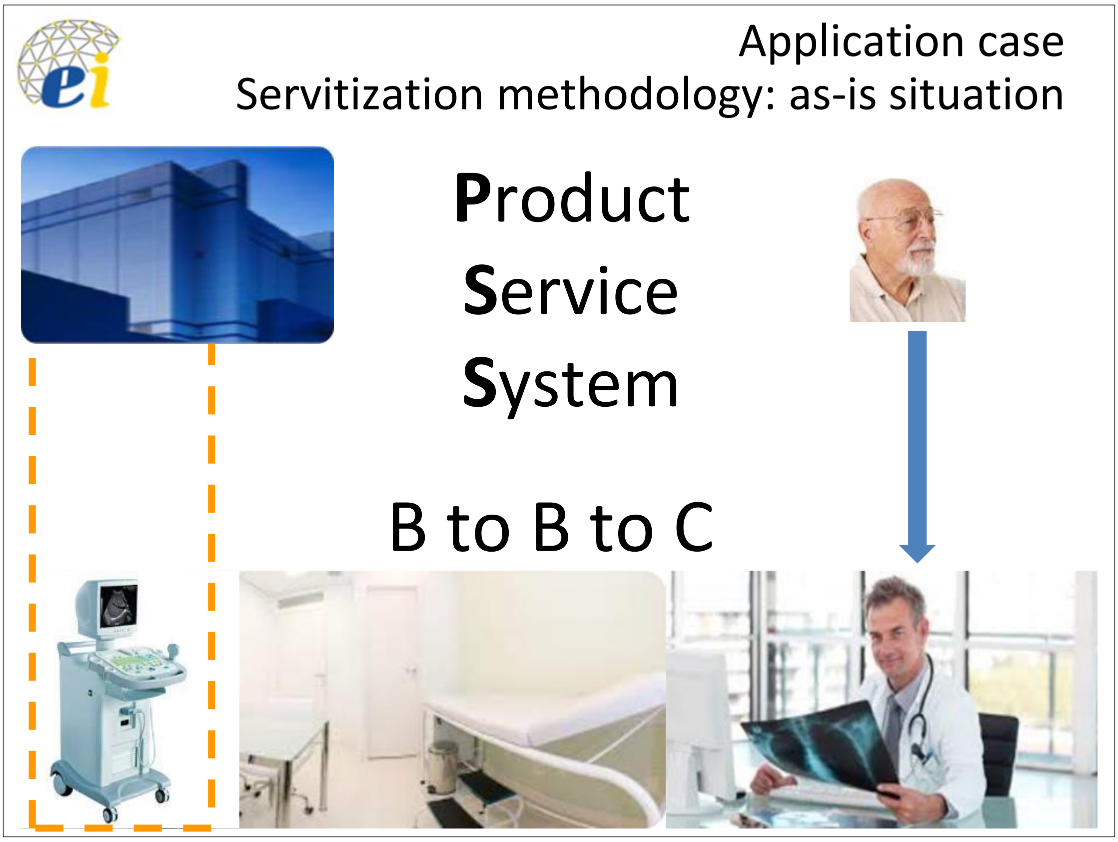

Servitization methodology
http://www.pdp.org.br/servmtd/
www.pdp.org.br/servmt
Home – Apresentação
Este guia resultou de um projeto fomentado pela FAPESP, Fundação de amparo à pesquisa do Estado de São Paulo (Processo FAPESP nº 2015/23094-6).
O título original do projeto FAPESP foi Metodologia para transformação de oferta orientada a produtos para Sistema Produto-Serviço (PSS: product-service system).
Adotamos o título curto de metodologia de servitização.
Uma empresa que está acostumada a vender
www.pdp.org.br/servmt
Metodologia de Servitização
Home – Apresentação
Como usar este guia?
Definições
Benefícios e barreiras
Visão geral da metodologia
Como configurar a metodologia
Grupos de atividades
Lista de entregas, métodos e material de...
Lista de Cases
Limitações e próximos desenvolvimentos

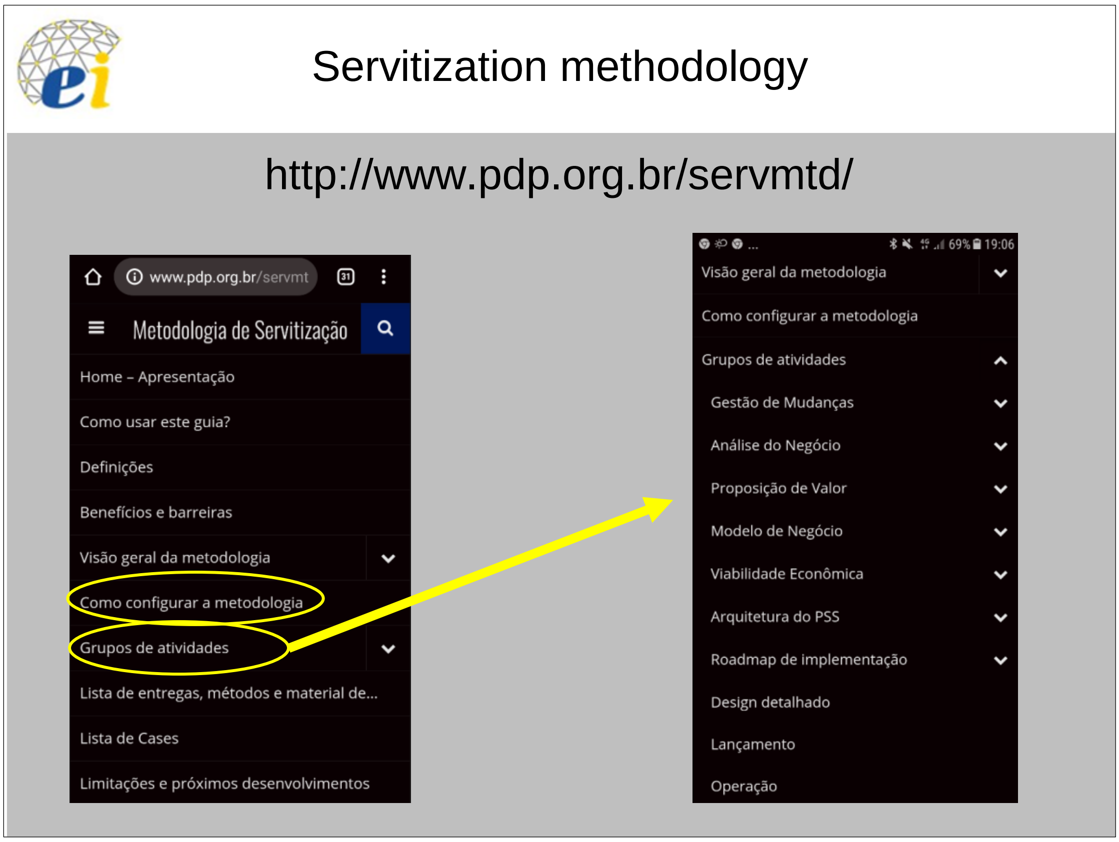

Servitization methodology
Hierarchical perspective
Strategic planning
Business Analysis
Business Model
Economic evaluation
Architectures
Conceptual Design
Detailed Design
Operation
Implementation Roadmap
Launch
Change Management
Project Management
24/7

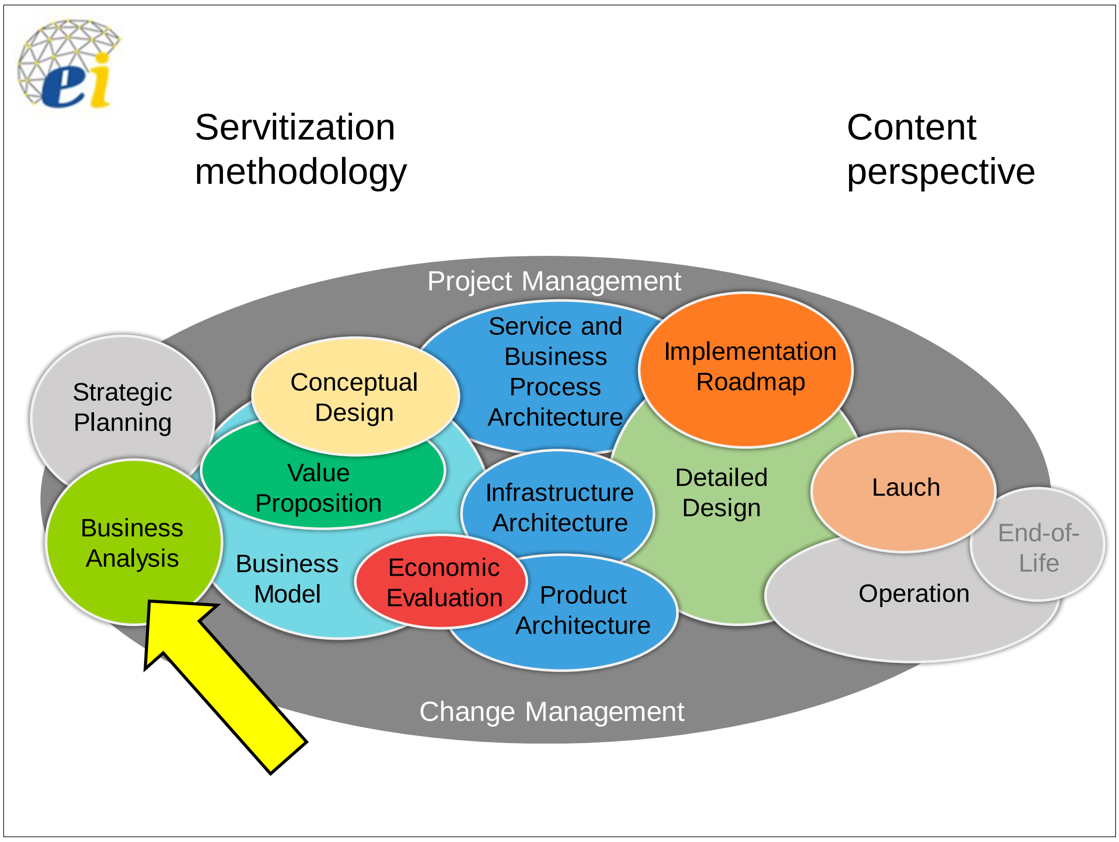

Servitization
methodology
Content
perspective
Project Management
Strategic
Planning
Conceptual
Design
Service and
Business
Process
Architecture
Implementation
Roadmap
Value
Proposition
Infrastructure
Architecture
Detailed
Design
Lauch
Business
Analysis
End-of-
Life
Business
Model
Economic
Evaluation
Product
Architecture
Operation
Change Management

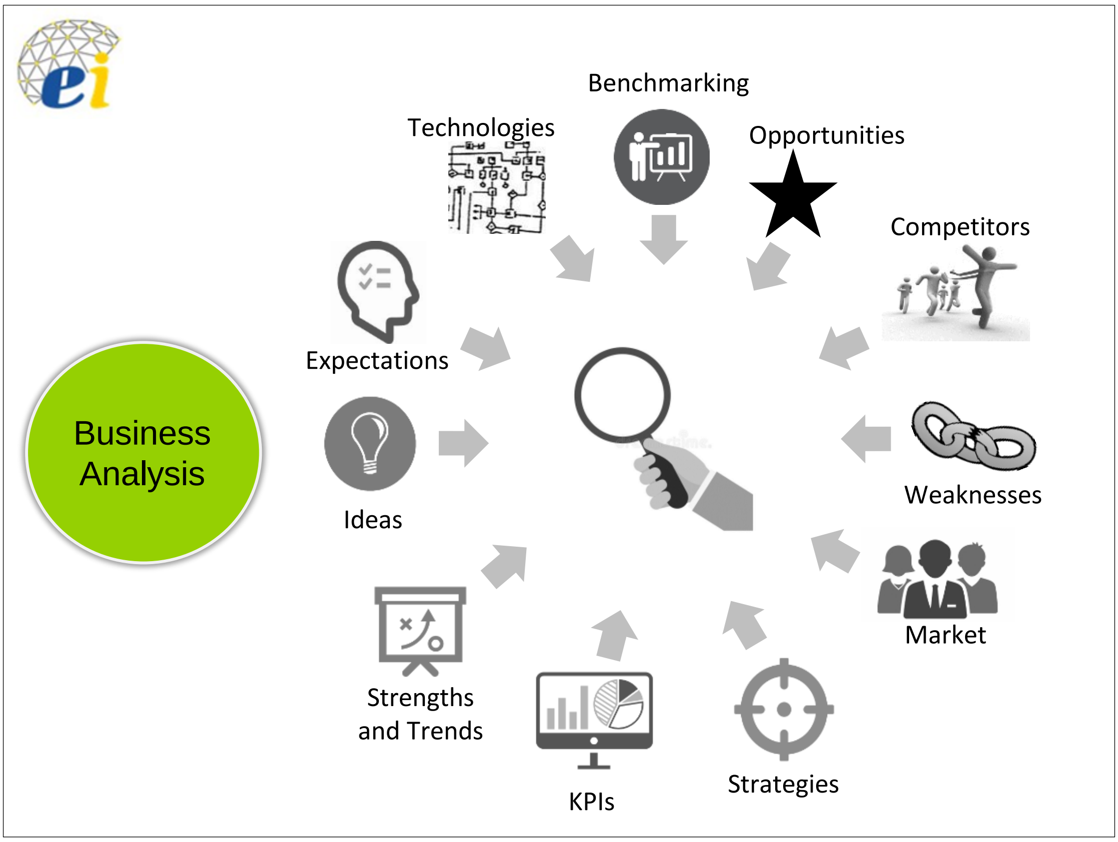

Servitization
methodology
Procedural
perspective
Strategic
Planning
Business
Analysis
Project Managemet
Plan
Empower
Motivate
End-of-
Life
Operation
Operate
Manage
validate
prototype
test
Understand
Stakeholders
Value
Proposition
Business
Analysis
Conceptual
Design
Business
Model
Economic
Evaluation
Implement
Design
Change Management
Service and Business Process
Architecture
Launch
Product
Architecture
Infrastructure
Architecture
Detailed
Design
Implementation
Roadmap

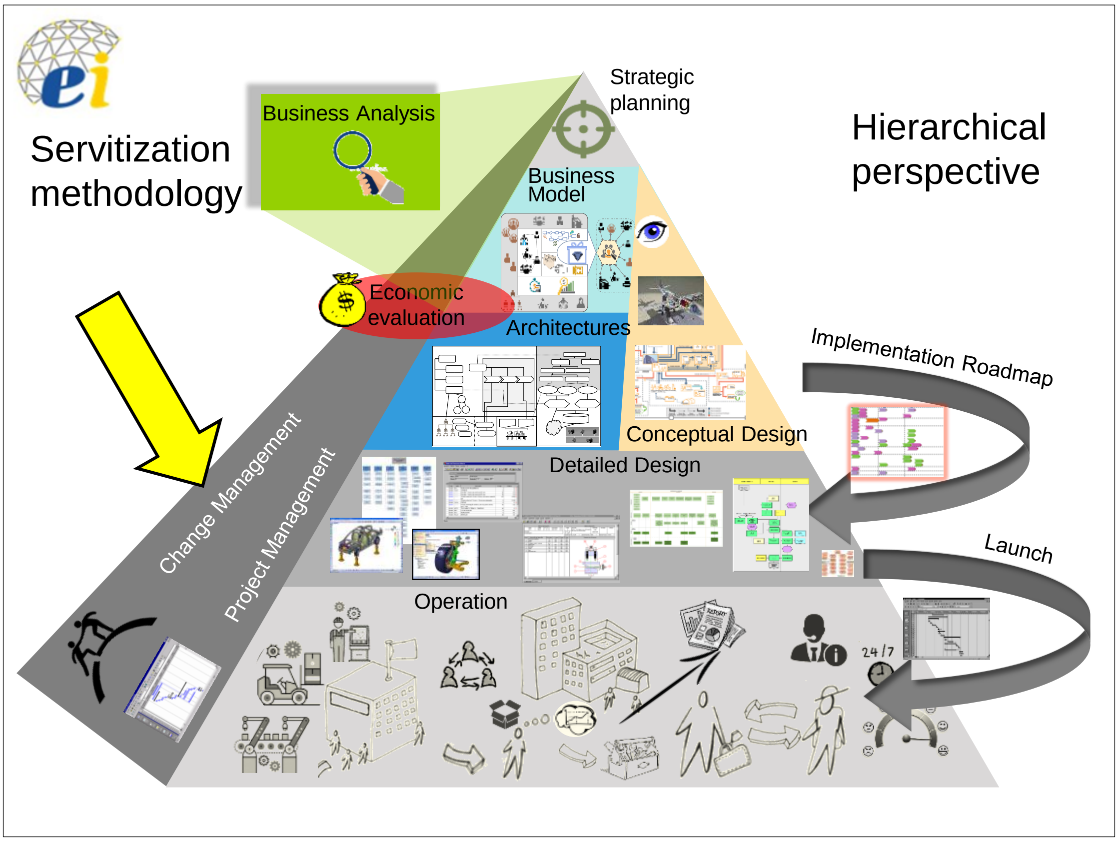

Application case
Servitization methodology: as-is situation
430.000
43.000
34.000
3.000


Application case
Servitization methodology: as-is situation
Product
Service
System
B to B to C


Servitization methodology
http://www.pdp.org.br/servmtd/
www.pdp.org.br/servmt
Metodologia de Servitização
Home – Apresentação
Como usar este guia?
Definições
Benefícios e barreiras
Visão geral da metodologia
Como configurar a metodologia
Grupos de atividades
Lista de entregas, métodos e material de...
Lista de Cases
Limitações e próximos desenvolvimentos
Visão geral da metodologia
Como configurar a metodologia
Grupos de atividades
Gestão de Mudanças
Análise do Negócio
Proposição de Valor
Modelo de Negócio
Viabilidade Econômica
Arquitetura do PSS
Roadmap de implementação
Design detalhado
Lançamento
Operação


Servitization methodology
Content perspective
Project Management
Strategic Planning
Conceptual Design
Service and Business Process Architecture
Implementation Roadmap
Value Proposition
Business Analysis
Infrastructure Architecture
Detailed Design
Lauch
End-of-Life
Business Model
Economic Evaluation
Product Architecture
Operation
Change Management

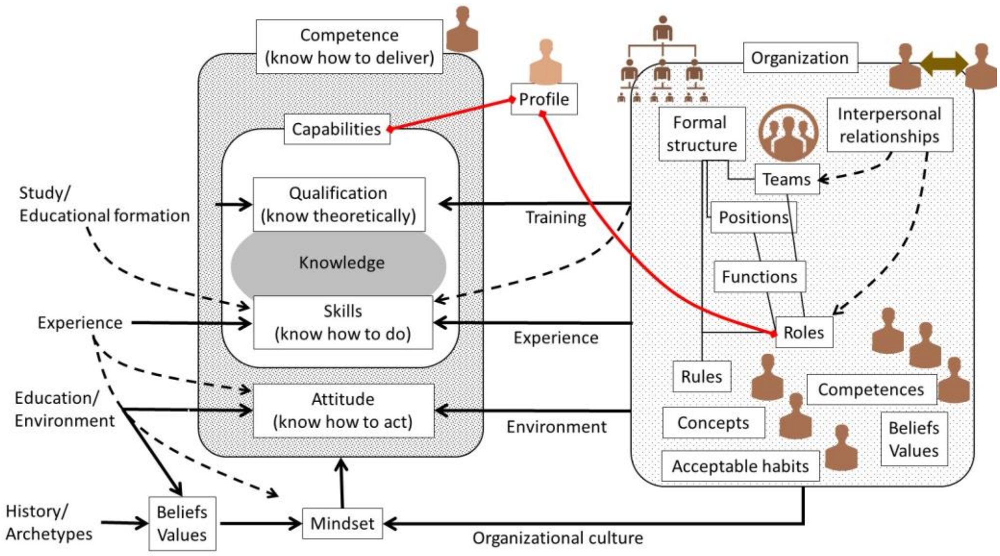

Business Analysis
Benchmarking
Technologies
Opportunities
Competitors
Expectations
Ideas
Weaknesses
Market
Strengths and Trends
KPIs
Strategies


Servitization methodology
Business Analysis
Strategic planning
Hierarchical perspective
Business Model
Economic evaluation
Architectures
Conceptual Design
Implementation Roadmap
Detailed Design
Change Management
Project Management
Launch
Operation
24/7

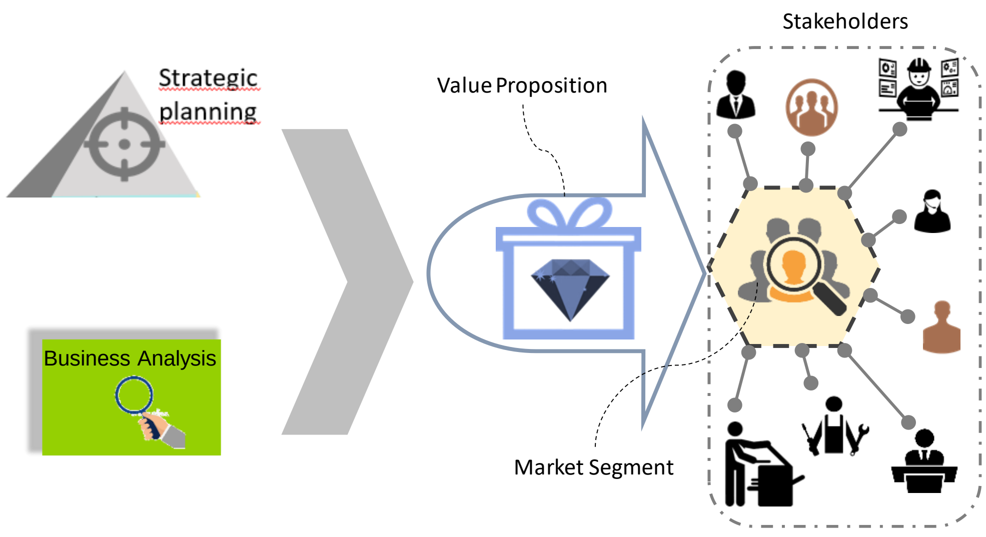
Change management goals

- Change mindset
- Align expectations, objectives and abilities of the organization and people
- Support the success of the new business model

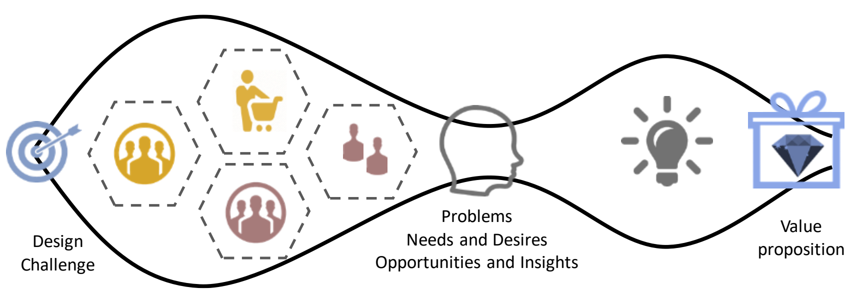
Change management reference



Value proposition



Process to identify value proposition



Case: Stakeholders map

Classificação

- Internos
- Externos
- Positivos
- Negativos
- Executores
- Consultores

Exemplos

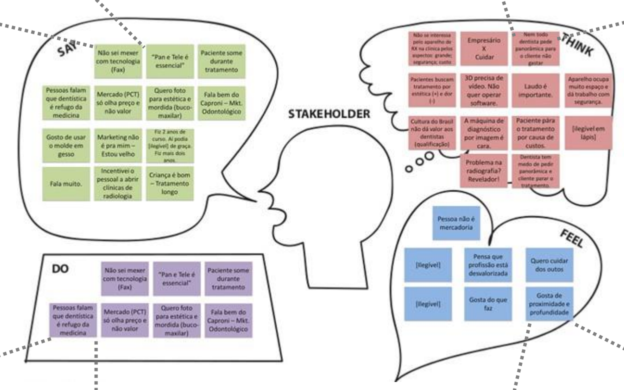
- Sponsor
- Clientes e Usuários
- Compradores
- Provedor do serviço
- Parceiros de negócio
- Governo
- Instituições financeiras

Case: Empathy map

Stakeholder: Médico

Diz — Quer se modernizar

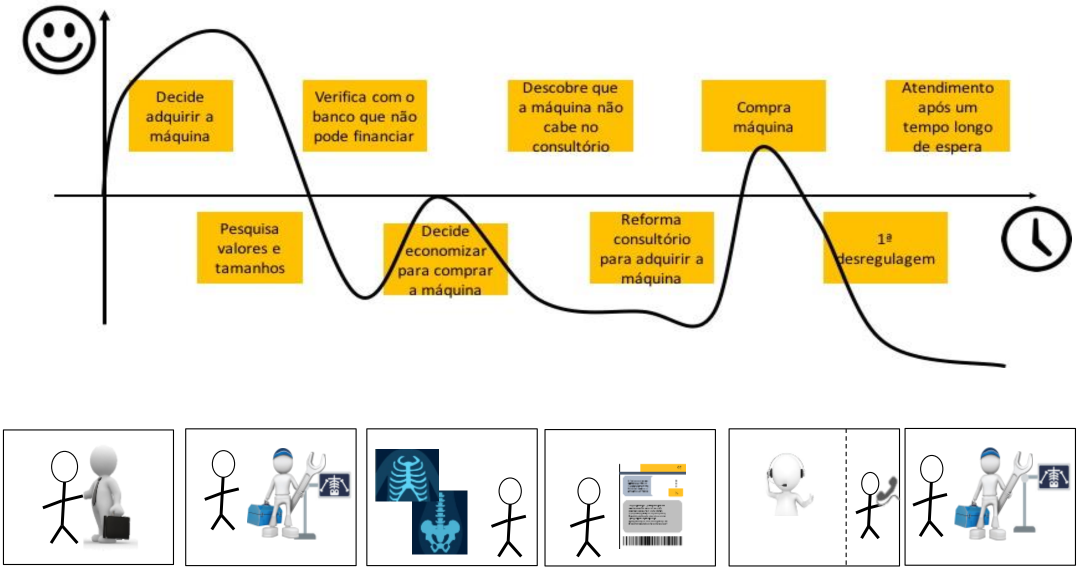
Pensa — Prefere atender no consultório



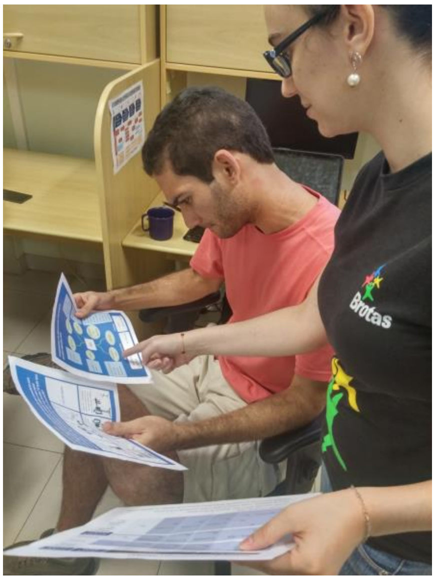
Faz — Analisa exames apenas no papel

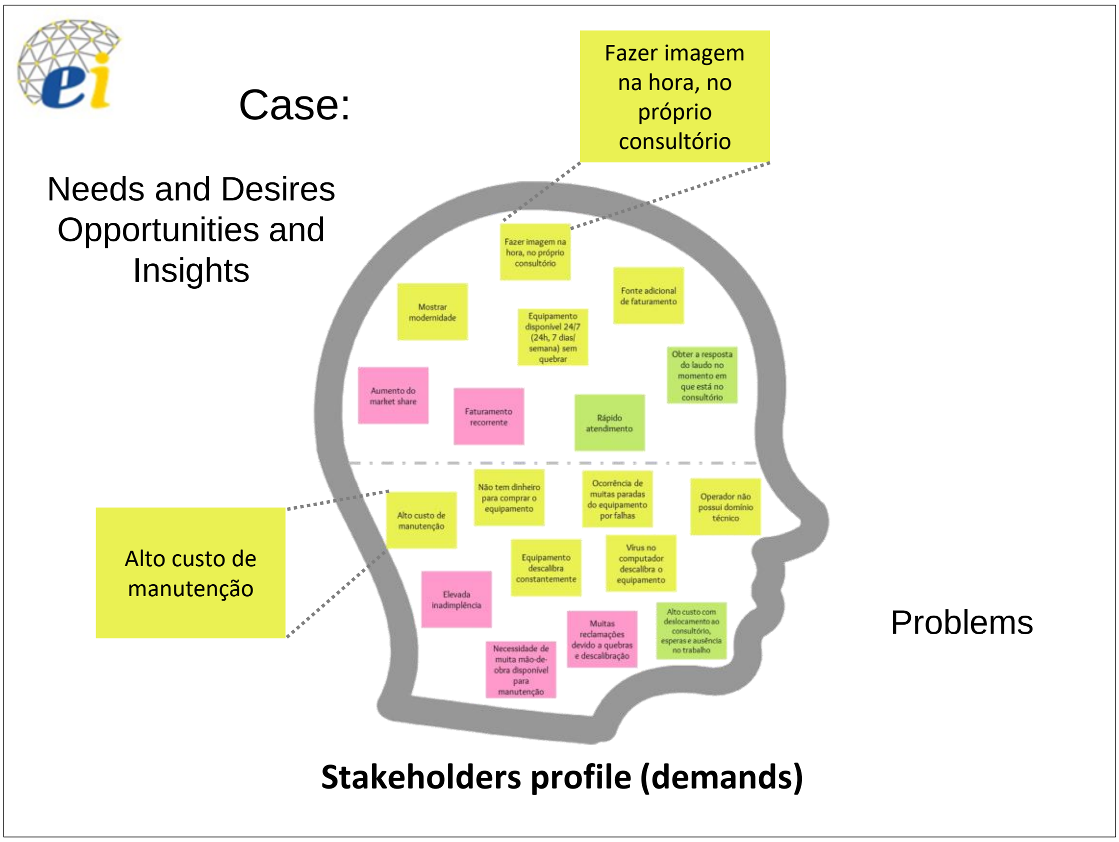
Sente — Medo que o paciente não volte

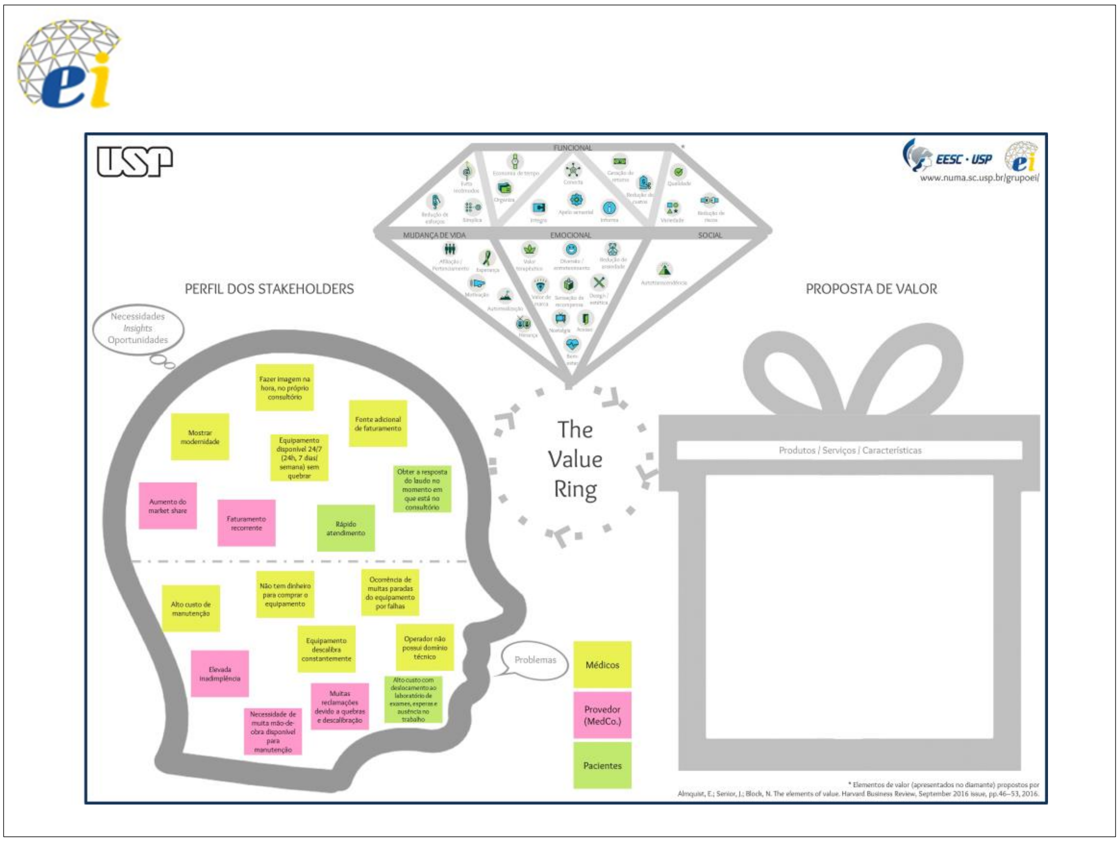
Case: Journey map

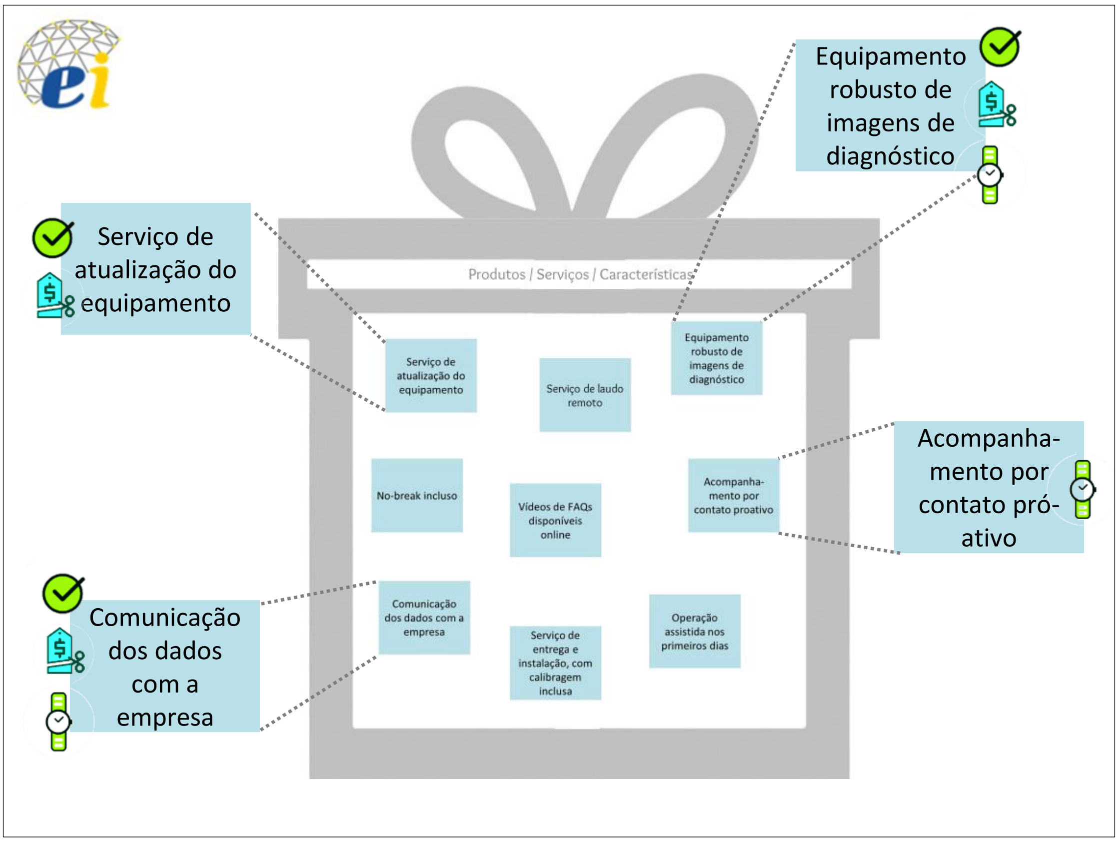


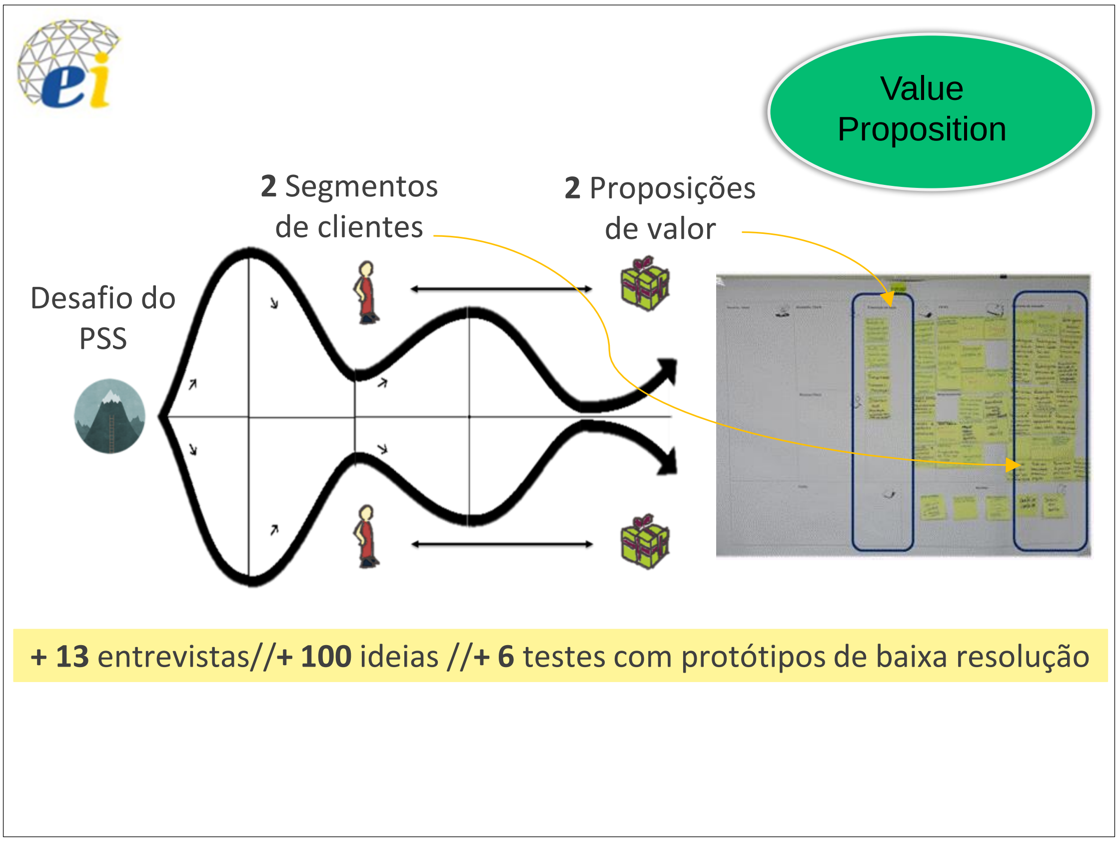
Case: Low fidelity prototypes

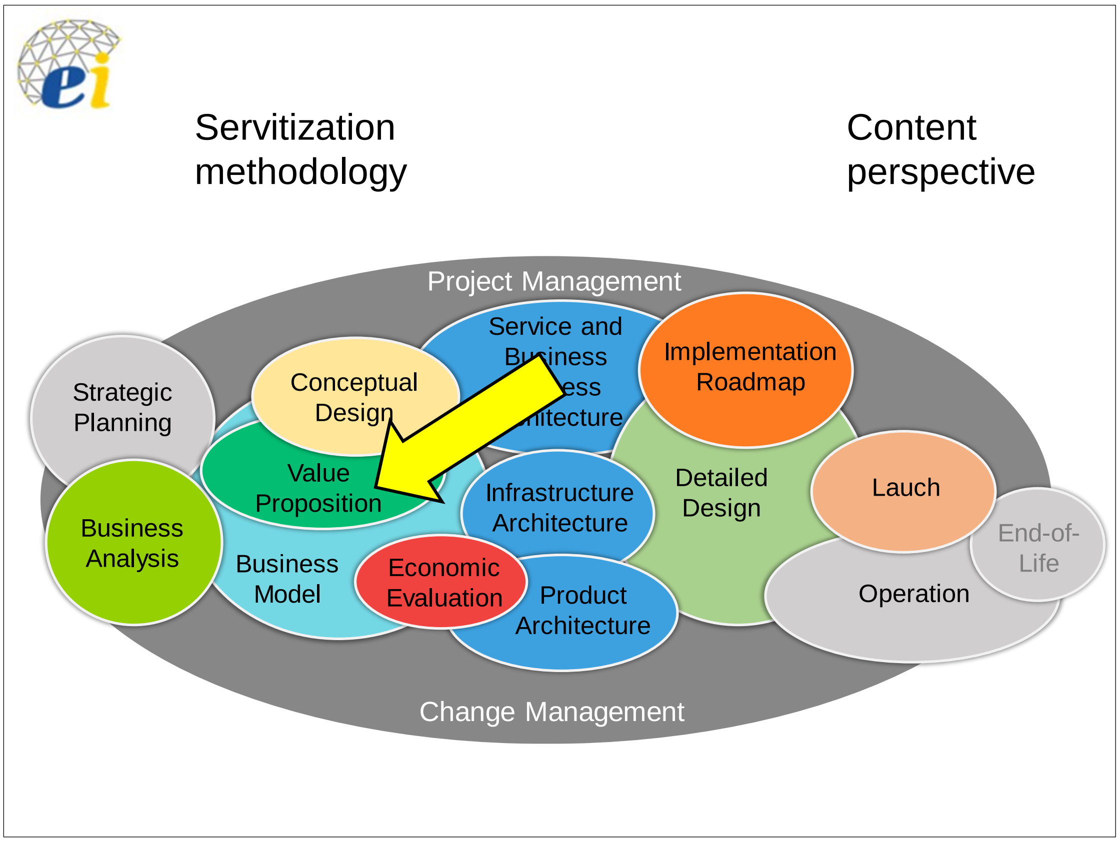


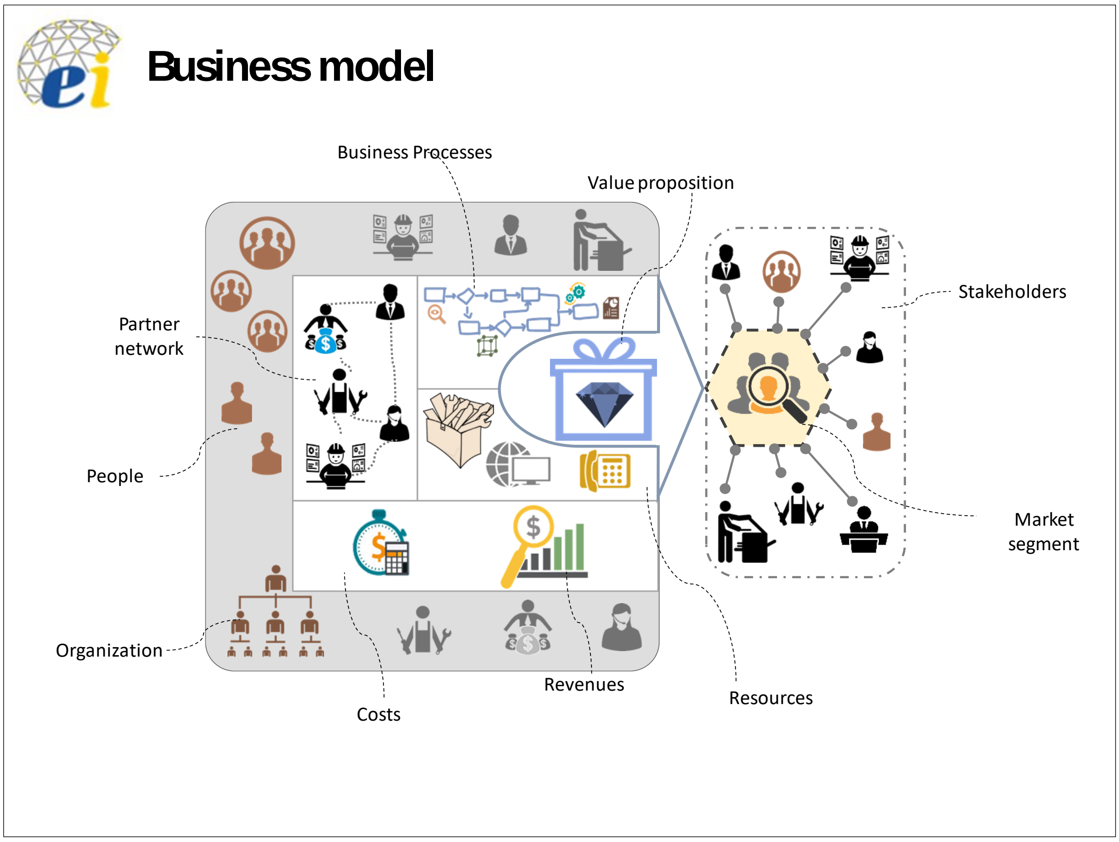

Case:
Needs and Desires
Opportunities and
Insights
Fazer imagem na hora, no próprio consultório
Fazer imagem na hora, no próprio consultório
Mostrar modernidade
Fonte adicional de faturamento
Equipamento disponível 24/7 (24h, 7 dias/ semana) sem quebrar
Obter a resposta do laudo no momento em que está no consultório
Aumento do market share
Faturamento recorrente
Rápido atendimento
Alto custo de manutenção
Não tem dinheiro para comprar o equipamento
Ocorrência de muitas paradas do equipamento por falhas
Operador não possui domínio técnico
Alto custo de manutenção
Equipamento descalibra constantemente
Vírus no computador descalibra o equipamento
Elevada inadimplência
Alto custo com deslocamento ao consultório, esperas e ausência no trabalho
Muitas reclamações devido a quebras e descalibração
Necessidade de muita mão-de-obra disponível para manutenção
Problems
Stakeholders profile (demands)

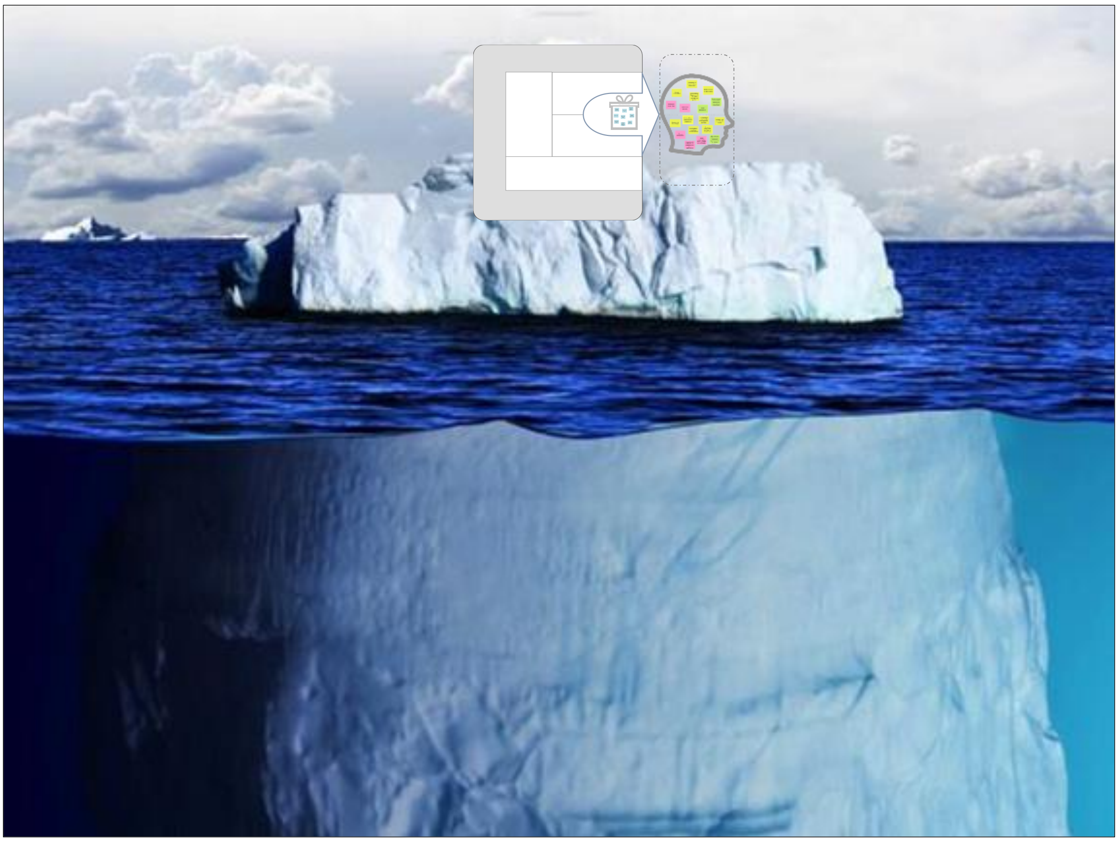

USP
EESC · USP
www.numa.sc.usp.br/grupoei/
FUNCIONAL
MUDANÇA DE VIDA
EMOCIONAL
SOCIAL
PERFIL DOS STAKEHOLDERS
PROPOSTA DE VALOR
Necessidades
Insights
Oportunidades
The
Value
Ring
Produtos / Serviços / Características
Problemas
Médicos
Provedor (MedCo.)
Pacientes

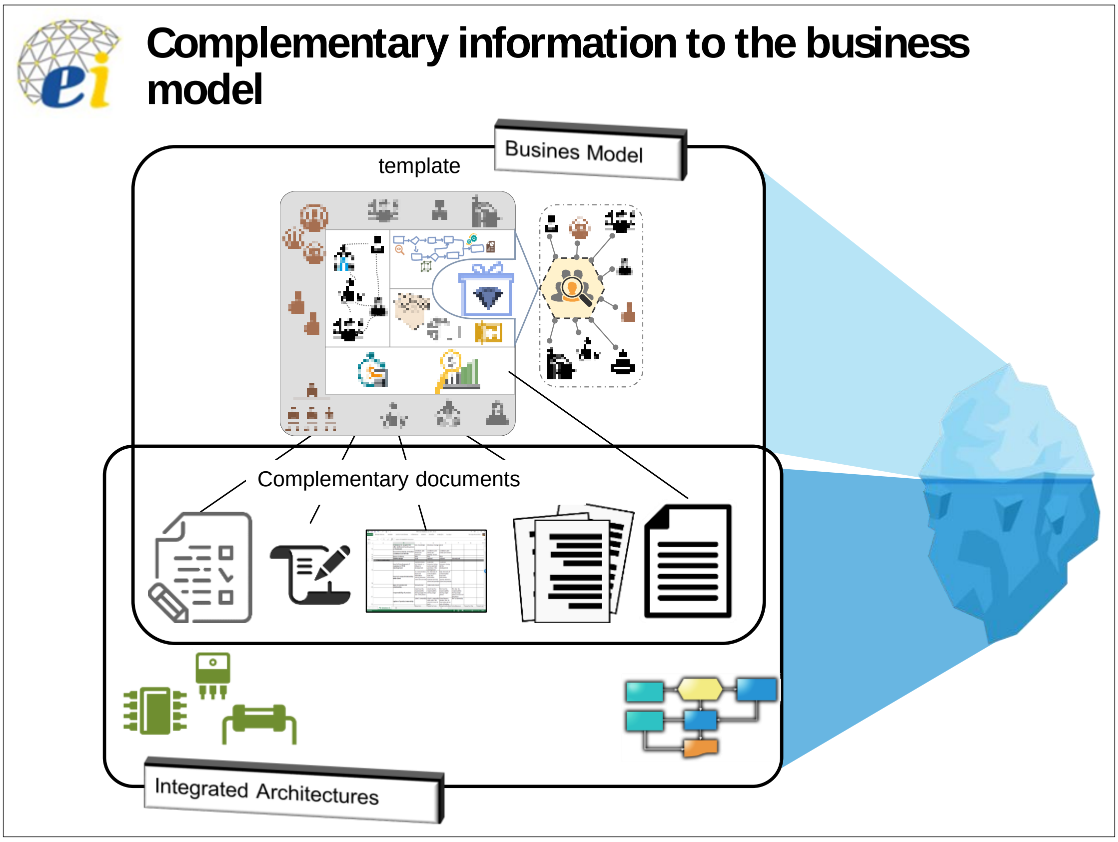

Equipamento robusto de imagens de diagnóstico
Serviço de atualização do equipamento
Produtos / Serviços / Características
Serviço de atualização do equipamento
Serviço de laudo remoto
Equipamento robusto de imagens de diagnóstico
No-break incluso
Vídeos de FAQs disponíveis online
Acompanha-mento por contato proativo
Acompanha-mento por contato pró-ativo
Comunicação dos dados com a empresa
Comunicação dos dados com a empresa
Serviço de entrega e instalação, com calibragem inclusa
Operação assistida nos primeiros dias

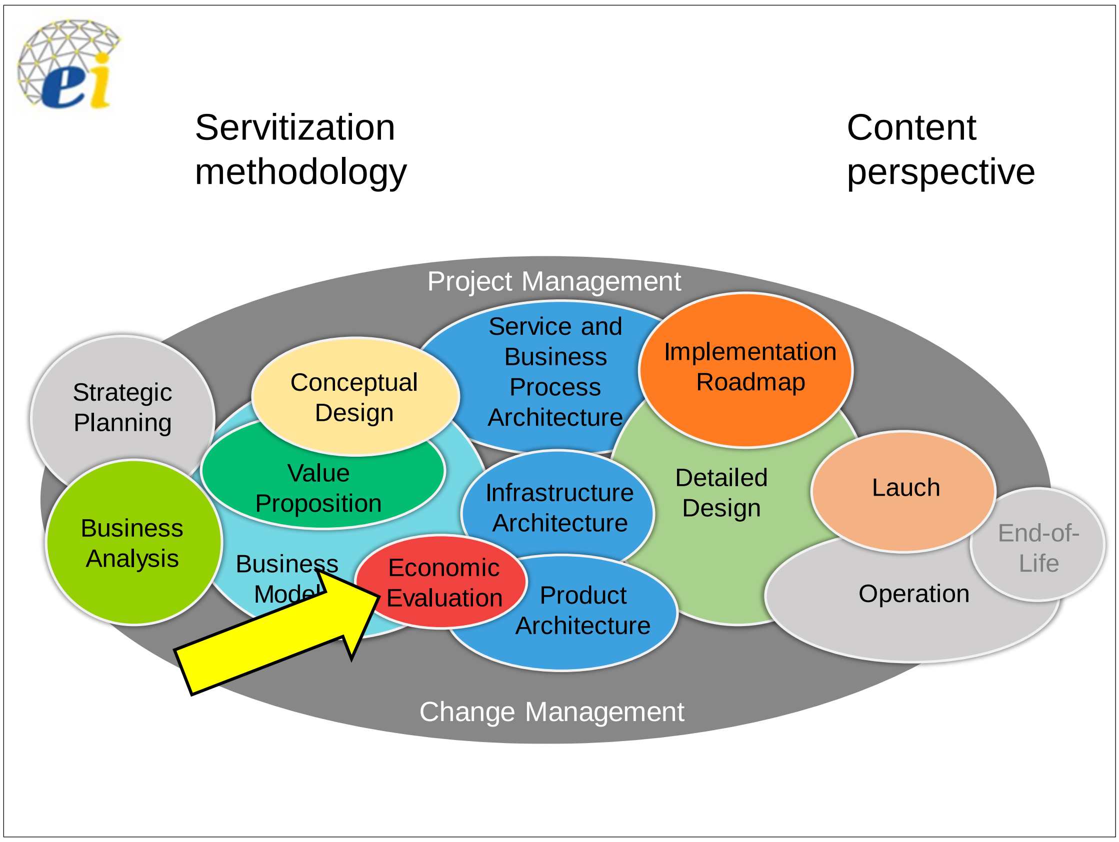

Value Proposition
2 Segmentos de clientes
2 Proposições de valor
Desafio do PSS
+ 13 entrevistas//**+ 100** ideias //**+ 6** testes com protótipos de baixa resolução

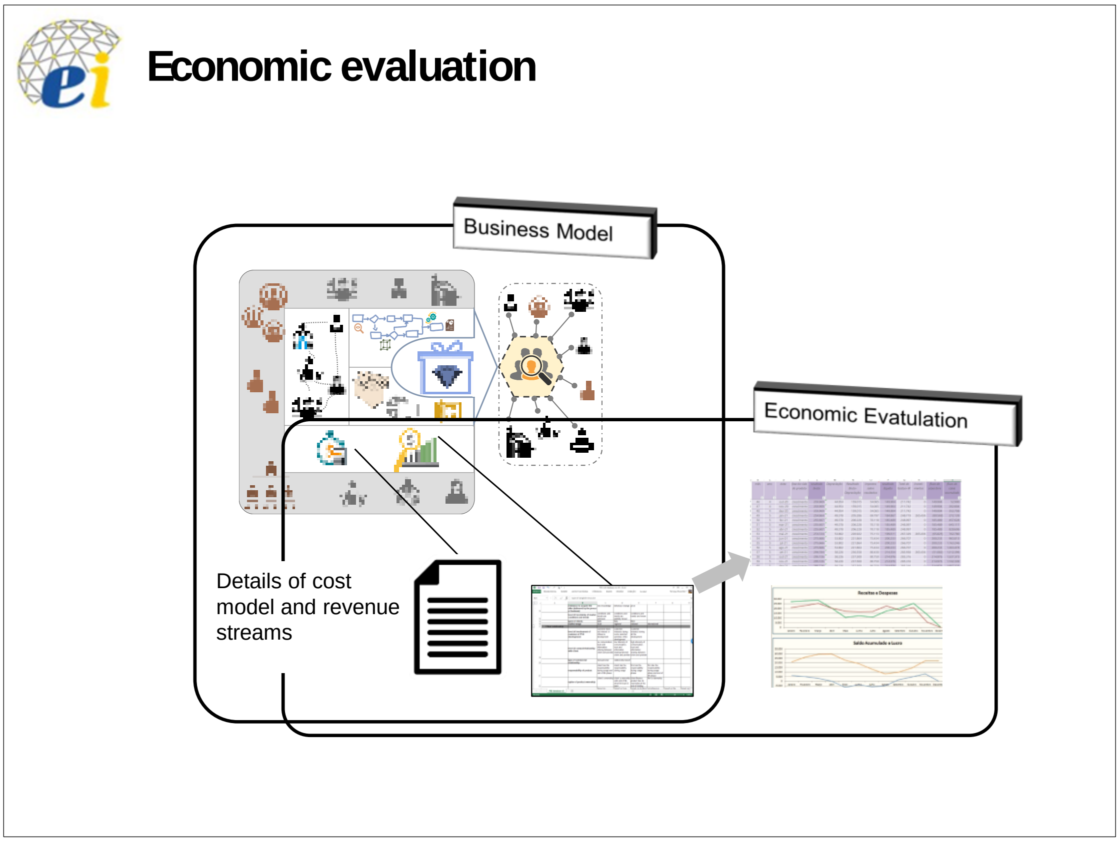

Servitization methodology
Content perspective
Project Management
Service and
Business
Implementation Roadmap
Strategic Planning
Conceptual Design
Value Proposition
Business Analysis
Infrastructure Architecture
Detailed Design
Lauch
End-of-Life
Business Model
Economic Evaluation
Product Architecture
Operation
Change Management

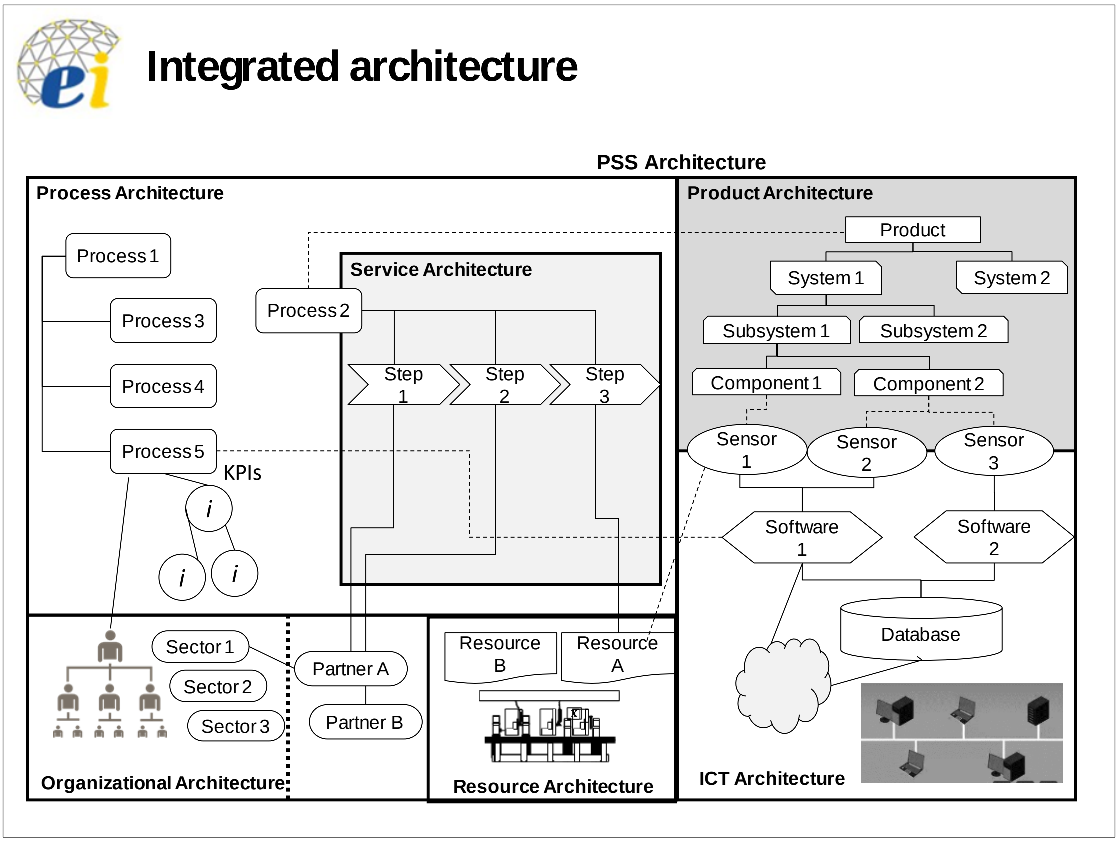

Business model
Business Processes
Value proposition
Stakeholders
Partner network
People
Market segment
Organization
Costs
Revenues
Resources

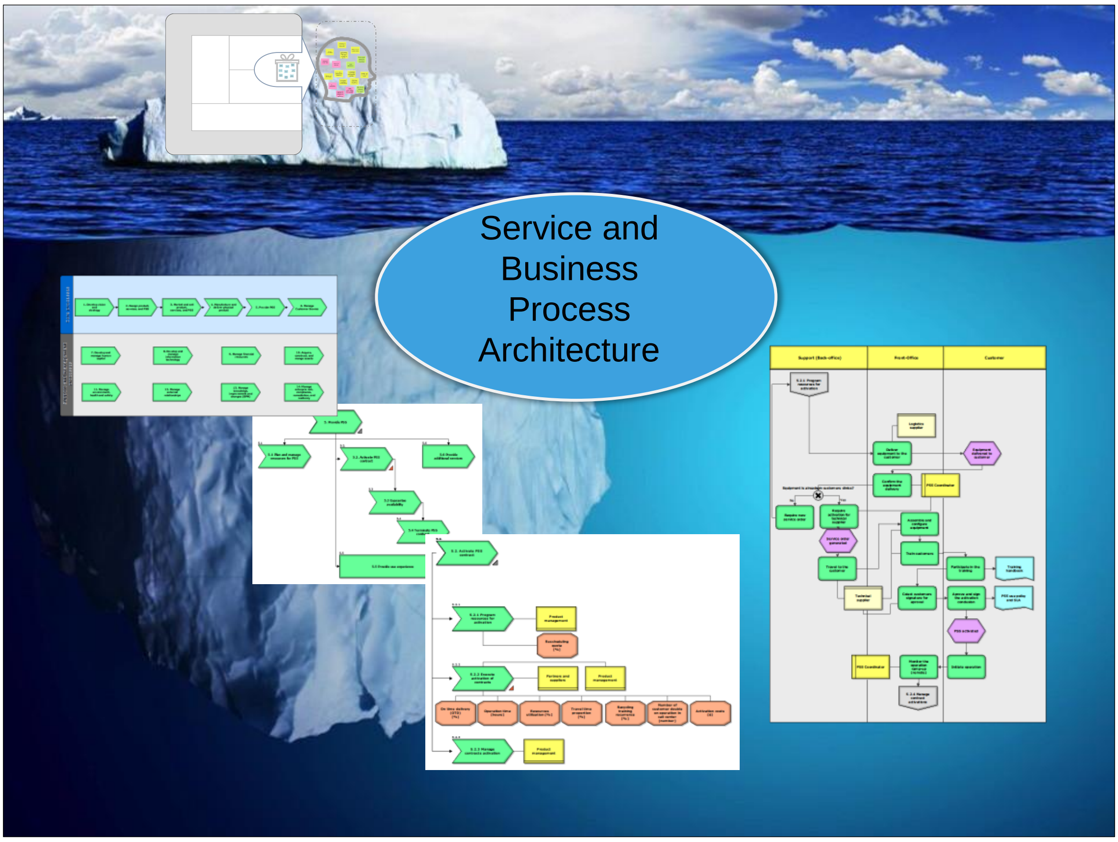


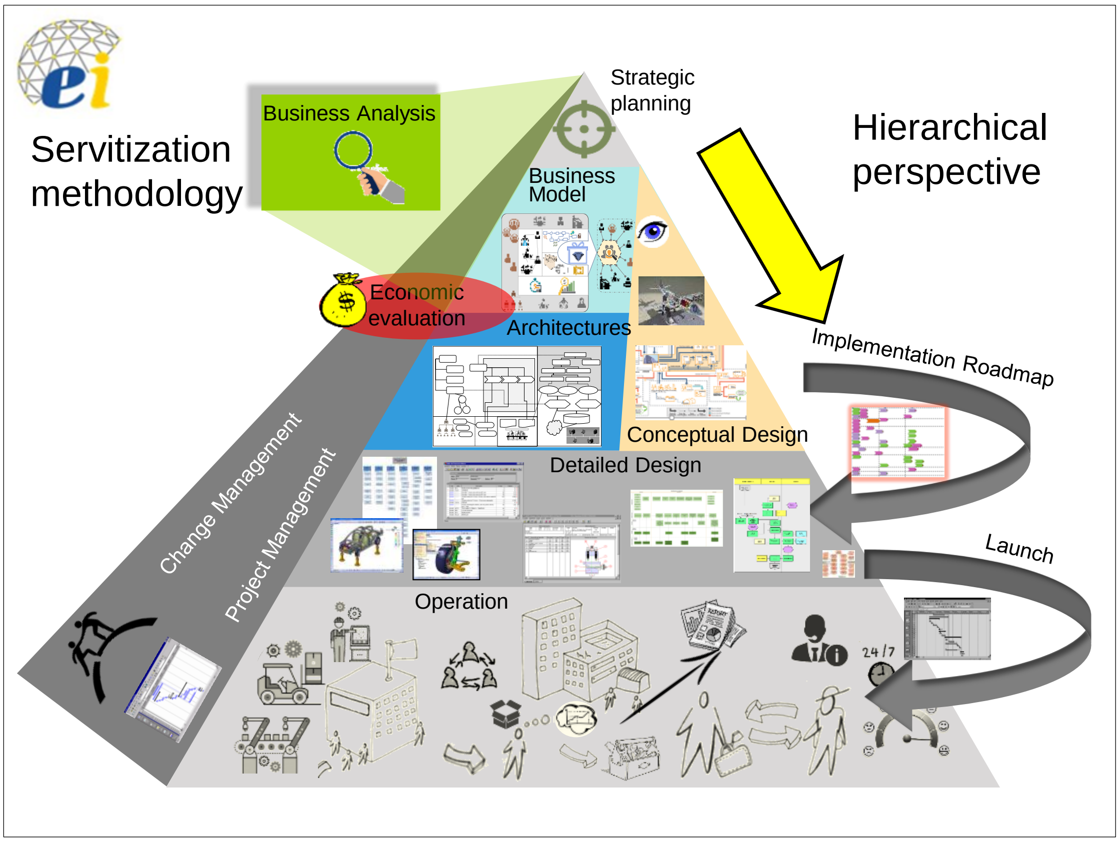

Complementary information to the business model
template
Busines Model
Complementary documents
Integrated Architectures

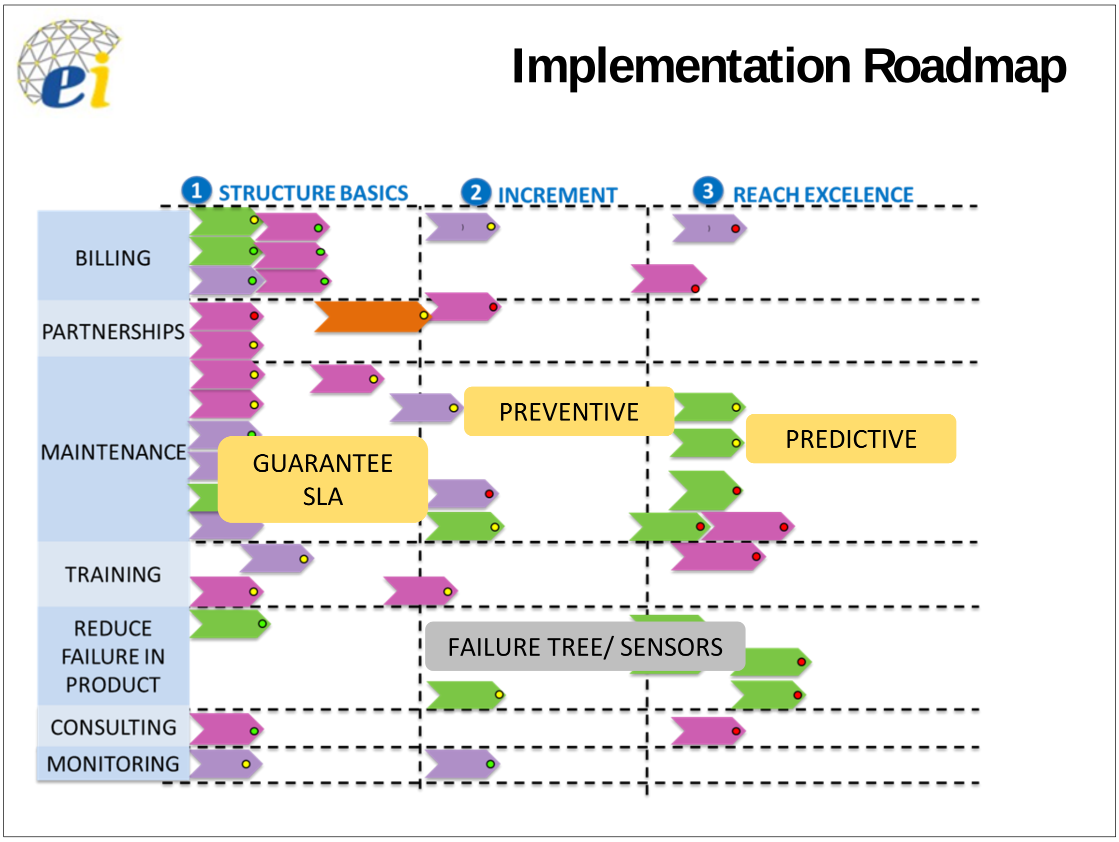

Servitization methodology
Content perspective
Project Management
Strategic Planning
Conceptual Design
Service and Business Process Architecture
Implementation Roadmap
Value Proposition
Business Analysis
Infrastructure Architecture
Detailed Design
Lauch
End-of-Life
Business Model
Economic Evaluation
Product Architecture
Operation
Change Management

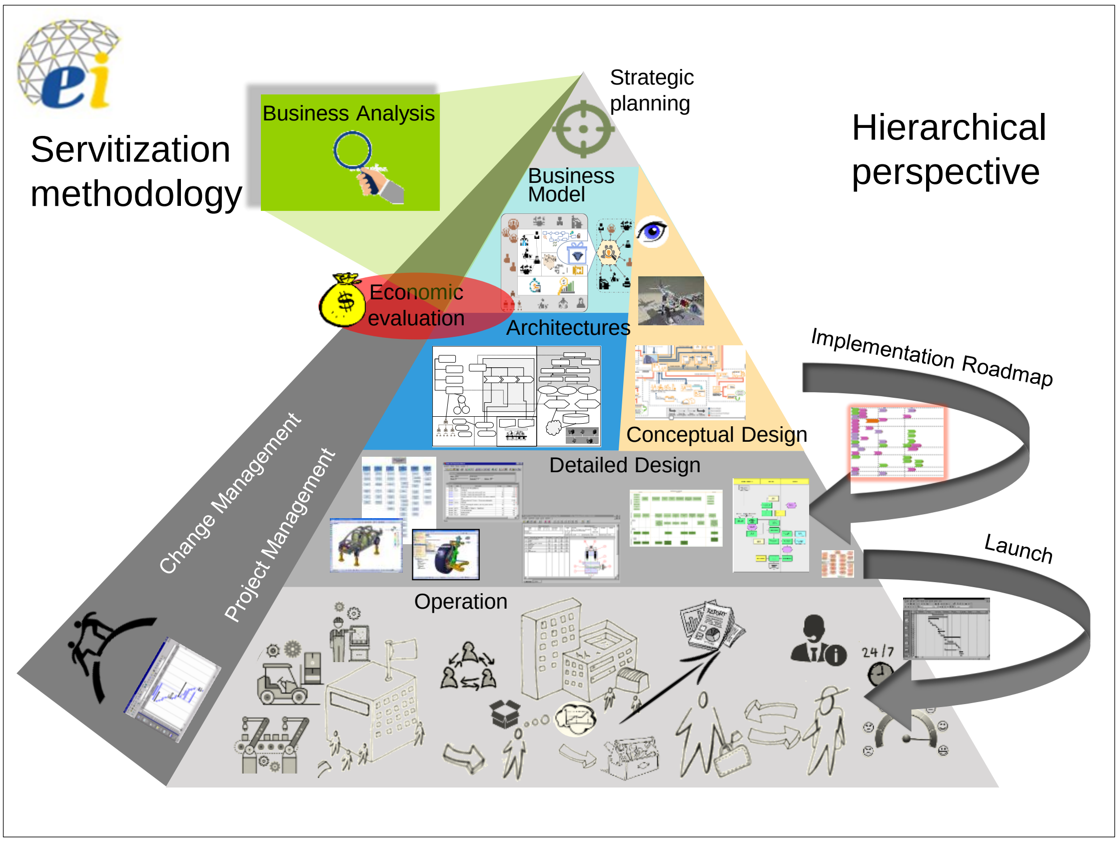

Economic evaluation
Business Model
Economic Evatulation
Details of cost model and revenue streams


Integrated architecture
PSS Architecture
Process Architecture
Process 1
Process 3
Process 4
Process 5
Process 2
KPIs
i
i
i
Service Architecture
Step 1
Step 2
Step 3
Product Architecture
Product
System 1
System 2
Subsystem 1
Subsystem 2
Component 1
Component 2
Sensor 1
Sensor 2
Sensor 3
Software 1
Software 2
Database
Sector 1
Sector 2
Sector 3
Partner A
Partner B
Resource B
Resource A
Organizational Architecture
Resource Architecture
ICT Architecture


Service and Business Process Architecture


Servitization methodology
Business Analysis
Strategic planning
Hierarchical perspective
Business Model
Economic evaluation
Architectures
Implementation Roadmap
Conceptual Design
Detailed Design
Change Management
Project Management
Launch
Operation
24/7


Implementation Roadmap
1 STRUCTURE BASICS
2 INCREMENT
3 REACH EXCELENCE
BILLING
PARTNERSHIPS
MAINTENANCE
TRAINING
REDUCE FAILURE IN PRODUCT
CONSULTING
MONITORING
PREVENTIVE
PREDICTIVE
GUARANTEE SLA
FAILURE TREE/ SENSORS


Servitization methodology
Hierarchical perspective
Strategic planning
Business Analysis
Business Model
Economic evaluation
Architectures
Conceptual Design
Detailed Design
Operation
Implementation Roadmap
Launch
Change Management
Project Management


Benefits

Benefits for the customer

- Access to solutions not posible before
- Offerings with more value agregation
- Shared solution;
- New vision of risks, reponsabilities and costs associated to property
- Better user experience along the life-cycle

Benefits for environment

- Lower environmental impact:
  - Production with less
  - Closing the material cycle;
  - Product last longer due to robust design (for example)
- Share with customer the sustentability culture

Benefits for companies

- New approach available for innovating
- Creation of recurrent revenue;
- Increase of market share and brand
- Services increase value proposition;
- Possibility of influencing user experience
- Less production needed
- Higher resource eficiency >> lower production costs

Benefits for job market

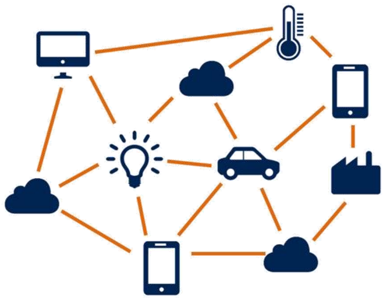
- Hiring and training people for providing service
- Creation of small companies (even start up) around the PSS offering

Challenges for servitization

- Mindset of focus on service
- How to design a new business model
- Economic evaluation
- Lower profits
- Longer payback
- Reliability – robustness
- Partner’s network and customer involvement
- Assets
- Vendor’s mindset
- Customers want to own the product
- Life-cycle assessment and management

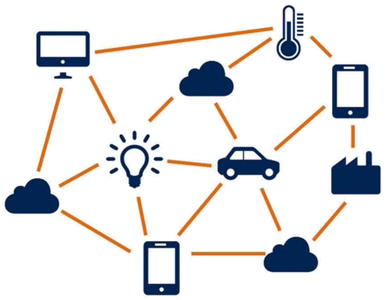
Challenges for servitization

- Sharing economy
- Internet of things (IoT)
- Industrie 4.0
- Big data
- Circular economy



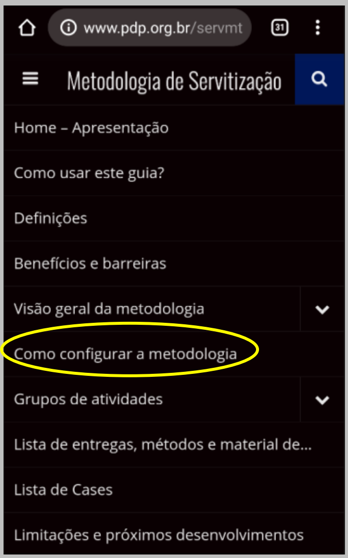
Tendências em PSS

- Transformação do negócio de montadoras de automóveis e caminhões para "empresas de mobilidade";
- *Car sharing*;
- Internet das Coisas (IoT – *Internet of Things*);
- *Big data*;
- Economia compartilhada;
- Economia circular.



Servitization methodology

http://www.pdp.org.br/servmtd/



USP

Grupo de Engenharia Integrada

Henrique Rozenfeld

www.numa.sc.usp.br/grupoei/

Comunidade sobre Sistema Produto-Serviço (PSS)

Engenharia de Produção
Escola de Engenharia de São Carlos
Universidade de São Paulo

M.Sc. Cordula Auth

Cordula Auth studied at Technische Universität Darmstadt until October 2016 and achieved the Master of Science degree. Since January 2017, she is working as a research assistant at the Department of Computer Integrated Design (DiK). The research focus of Ms. Auth is additive manufacturing. In the center of the research focus is the digital process chain with the creation of 3D-CAD geometry data, the pre-processing, the in-processing and the post-processing. This process chain is enlarged trough the phases of the material production, product distribution and use and the component recycling or disposal to realize a holistic implementation of the component lifecycle. These phases are represented in a real demonstrator, which serves the study of process monitoring and quality control through the collection and analysis of process data. Since January 2018, Mrs. Auth is managing and working on the transfer project “ArePron – agile resource efficient production network”. The aim until the end of the project in December 2020 is the increase of the resource efficiency with the help of an intelligent, cross-location linking of production systems. Technologies of digitalization improve the resource efficiency and, therefore, reduce costs while they reduce the ecological footprint of the company.

✉ auth@dik.tu-darmstadt.de

DiK, TU Darmstadt

The Department of Computer Integrated Design (DiK) is part of the Faculty of Mechanical Engineering of the Technische Universität Darmstadt. It is directed by Prof. Dr.-Ing. Reiner Anderl. The integration of information technology as integral part of modern mechanical engineering and the linkage of research and education to industrial needs are our fundamental targets. One core competence is the virtual product development. The principles and methods of processing product data are still quite challenging. To understand product data, product data flows and product data processing, the holistic approach of Virtual Product Development has been chosen for education and research. Besides the virtual product development, additive manufacturing, IT security and Industrie 4.0 are further core competences and research fields. The competences are represented with the help of different demonstrators in the DiK research lab, which was opened in 2017 and welcomes since then visitors of industry and other research institutes.

Additive Manufacturing Lifecycle – Data Collection and Analysis for Process and Component Optimization

Abstract

Based on the increasing digitalization, data collection and analysis for process optimization gets more important. New business models can be established through a proper database as for example tracking and tracing or predictive maintenance. In the field of additive manufacturing, a structured data collection and handling do not exist. The development of a data management concept to collect and analyze data over the entire lifecycle generates possibilities to optimize the AM product and process. The starting point for the optimization is the product development phase, because most decisions concerning the product are made in this phase. Besides, the additive manufacturing lifecycle features the phases material production, production process with pre-, in- and post-processing, use phase of the product and recycling or disposal. The different phases of the lifecycle can be monitored with the help of the data management concept. Furthermore, the influences between lifecycle phases need to be analyzed and the findings need to be returned to the appropriate lifecycle phase. Based on this possibility, a process and component optimization are possible.

Keywords

Additive Manufacturing (AM); Product Development; Data Management; Process and Product Optimization; Lifecycle; Fused Deposition Modeling; Data Collection; Data Analysis; Platform; Monitoring.

Authors

Cordula Auth, M.Sc.
TU Darmstadt - DiK
auth@dik.tu-darmstadt.de

Prof. Dr.-Ing. Reiner Anderl
TU Darmstadt - DiK
anderl@dik.tu-darmstadt.de

1 Motivation and Introduction

Additive Manufacturing (AM) technologies show growing importance not only in the rapid prototyping sector. Especially in the exclusive and sport automobile sector or the aerospace sector, additive instead of conventional manufacturing of components is interesting for serial production. For example, Airbus equips the A350 XWB aircraft with a titanium 3D-printed bracket. This bracket is built using the selective laser melting or additive-layer manufacturing [1]. In the automobile sector, BMW uses AM parts in the Rolls-Royce Phantom production. With the help of the multi jet fusion, over 10,000 parts made of plastics are manufactured and installed since 2012 [2]. For further serial use in different market segments and further developments of products, AM technologies need to be improved and the benefits of the AM technologies and the manufactured parts need to be exhausted.

The benefits are the economic individualization, the integration of functions and the constant cost level in spite of an increase in geometry complexity. Only if these benefits are savored, an economically efficient production with a suitable quality level can be achieved. Based on this, the advantages of AM need to be included in the product development phase of a component. To optimize the AM production process and AM products, information of the whole lifecycle of the product is collected and analyzed and benefits of AM are integrated into the AM lifecycle phases.

The increasing digitalization and the trend of *Industrie 4.0* enable new business models in the most fields of industry. In the field of AM, the advantages and possibilities are not used comprehensively. Process optimization is limited to the pre-processing and the in-processing, for example in the case of the machine producer EOS [3]. A holistic lifecycle optimization to increase product and process quality and to use the AM benefits comprehensively does not exist now. This is the starting point of the development of a concept for data collection and analysis for process and product optimization, which uses collected data of all AM lifecycle phases.

With the gained knowledge about correlations between the lifecycle phases and especially the influence factors on the product development phase, new requirements on the product development arise. The evaluation of lifecycle information enables a smarter product development process and in the end a process and product optimization. To develop a concept for data acquisition and analysis, the state of the art contains the AM process chain and AM lifecycle with the different phases. The following part deals with the concept that is targeted on process and especially component optimization in the AM lifecycle. Important information over the different phases is identified and the procedure to establish AM data management system is described. The implementation of the concept in a demonstrator shows a first approach to realize the concept for data collection and analysis in the AM lifecycle.

2 State of the Art

AM methods record high growth rates in various industrial sectors. The general growth of AM can be detected for example through the number of AM system manufacturer, which nearly tripled from 2013 to 2016 [4]. Accordingly to the trend of an increase of AM system manufacturer, AM patent applications show a 7.7 times growth from the year 2013 to 2016 [5]. The huge growth rates correspond to the increasing attention to AM. The interest in AM technologies is based on the advantages of AM in general and the positive impact, which comes along with the advantages.

Compared to conventional manufacturing methods, AM methods show high potentials concerning an enhancement of the sustainability in the production. This results of the AM benefits individualization, geometry complexity and function integration. The economic individualization of products enables not only new business models as for example the individualized production of consumer goods. Furthermore, it is a great possibility to revolute the maintenance sector.

Companies do not need to stock all necessary spare parts, if rarely used parts can be manufactured quickly with an AM method at their place of need. This scenario can increase the sustainability and optimize the supply chain [6, 7]. The second benefit of AM methods is the possibility to generate complex or even bionic structures at a reasonable cost level. This benefit enables a further lightweight construction and therefore, a redesign of the products. Through the geometry optimization, a weight reduction is possible, which supports for example further fuel savings in air traffic. Bionic structures help to improve especially individualized products in the health sector. The third advantage of AM is the function integration. This enables the aggregation of single parts to one component with constant functionalities. Therefore, assembling time can be reduced and an assembly optimization concerning weight and functionalities is possible. The product improvements might reduce environmental impacts indirectly through weight reduction and optimized design. The possible prospects of AM technologies generally explain the high growth in the field of AM [6, 7, 8, 9].

For an economic industrial use of AM technologies, the advantages of AM need to be utilized fully. Therefore, the advantages have to be integrated into the whole AM lifecycle. The AM process chain consists of three phases: the pre-, in- and post-processing. During the first phase the pre-processing, the machine is prepared. In the following data transformation, the native CAD data is converted into the STL (Standard Tessellation Language) format. The original geometry is approximated with the help of triangles. Today, STL is the common data format used with most of the printer software systems. After the transformation of data, the part orientation and positioning takes place. Depending on the AM technology and the capabilities of the printer, support structures are generated in the following step. The last step of the pre-processing is the slicing. During the slicing, the part is separated into the single layers virtually and the G-Code is generated. After the pre-processing, the in-processing follows with the manufacturing process of the part. Besides, the unloading and part removal take place in the in-processing. The post-processing includes, depending on AM method, the removal of additional powder or the removal of support structures. Besides, an improvement of the component characteristics can be accomplished in the post-processing [10, 11, 12].

The AM process chain can be integrated into the concept of the AM lifecycle. The AM lifecycle consists of six phases. The first phase is the new material extraction, where the new material gets into the lifecycle. This phase is followed by the material production. In this phase, the raw material is transferred into a suitable shape as for example powder or filament. The third phase is the product development, which can be separated into the product planning, product design, work preparation and product manufacturing.

During the product planning, the requirements on the product are generated. The resulting requirements influence the geometry, which is developed in the following product design phase. The work preparation follows the product design and includes the pre-processing as the first part of the AM process chain. The product manufacturing consists of the in- and post-processing. The fourth phase of the AM lifecycle is the product distribution. This phase comprises the transportation of the product to the end user. The distribution is followed by the product use phase. The AM lifecycle ends with the product end of life. The product can either be disposed or recycled. In case of the product recycling, chosen parts of the product or the material can be recycled [10].

Figure 1 shows the AM lifecycle with the integrated AM process chain.

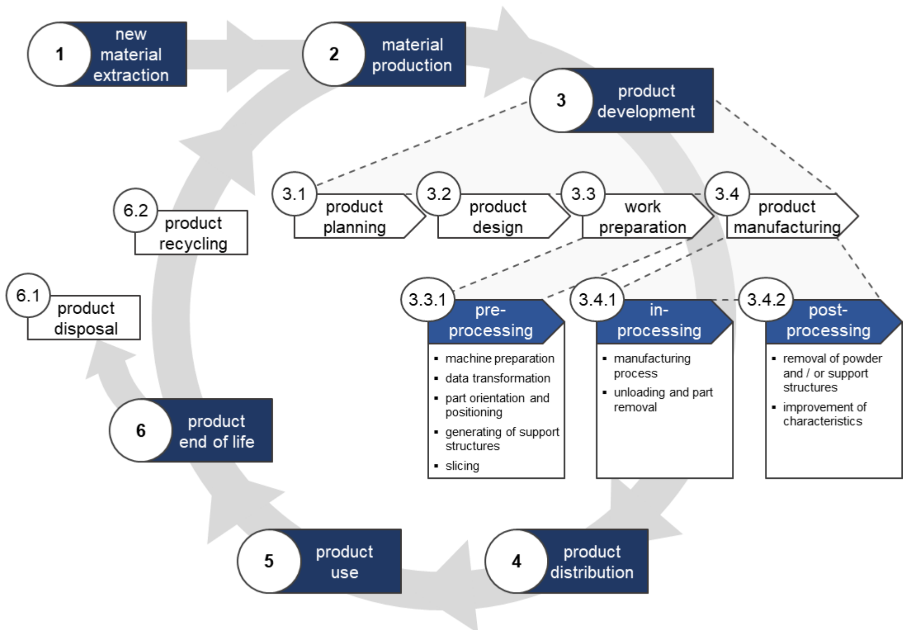


Figure 1: AM lifecycle with integrated AM process chain

Until now, there does not exist an approach to connect information of all lifecycle phases and to integrate AM characteristics into the holistic lifecycle. As mentioned in the motivation chapter, optimization of the AM methods takes place in the pre- and in-processing nowadays. An optimization of these phases is important, because the adjustments of the approximation of the geometry in the step of data transformation, the orientation and positioning of the part and the setting of machine parameters are essential to produce a certain quality. Negative consequences of a false parameter setting have been examined by for example Arndt et al (2015), Gurpal (2014) and Kirchner et al (2010) with the help of surface examination and experimental testing [13, 14, 15].

Machine producer as EOS include the findings in their printer software to minimize reject rate and to avoid mistakes in the pre- and in-processing [3]. These approaches are necessary, but they are not sufficient to control the whole AM lifecycle and the resulting quality of the products. Lifecycle phases can have an impact on each other, for example, the parameters and production information of the material production affect the product manufacturing and the resulting product quality. With the help of tensile strength testing of printed test geometries, negative influences of filament diameter changes on the tensile strength of the fused deposition modeling printed test geometries are detected [16].

3 Development of a concept for product optimization through data acquisition and usage in the AM lifecycle

After explaining the AM benefits, process chain, lifecycle and optimization approaches, this chapter deals with the development of the concept for data collection and analysis for process and component optimization. The main aim of this approach is the integration of new requirements on the AM product development through data acquisition and analysis in the AM lifecycle.

Decisions of the upstream phases influence the design possibilities as for example the choice of a manufacturing method and the depending material, which is used to manufacture the part. Based on the experiences of the downstream phases, the product design needs to be adapted to increase the benefits of the product. Besides, the benefits of the AM technologies need to be considered and integrated in the concept.

Figure 2 shows the approach for the concept. New capabilities of digitalization enable a further data collection, analysis and storage. With the help of the collection of sensor measurements and parameter settings over the different lifecycle phases the optimization of the AM process can be enlarged. Besides an improvement of the pre- and in-processing, the concept targets on the integration of the holistic AM lifecycle, the return of information from every phase to every phase in the lifecycle and the specific addition of AM benefits in the lifecycle phases. The most important phase is the product development. In this phase, the requirements on the product and its functionalities are assimilated and decisions concerning the product design and the production are made. Therefore, the concept needs to be established in the product development phase.

Figure 2 represents the idea, that information of the different phases is collected in a database. This database interacts with the product development phase and transfers the results of the data analysis into the phase. Besides, the AM characteristics are integrated into the database. The usage of the lifecycle data enables a further development of the product development phase through the integration of new requirements on the AM product development through the analysis.

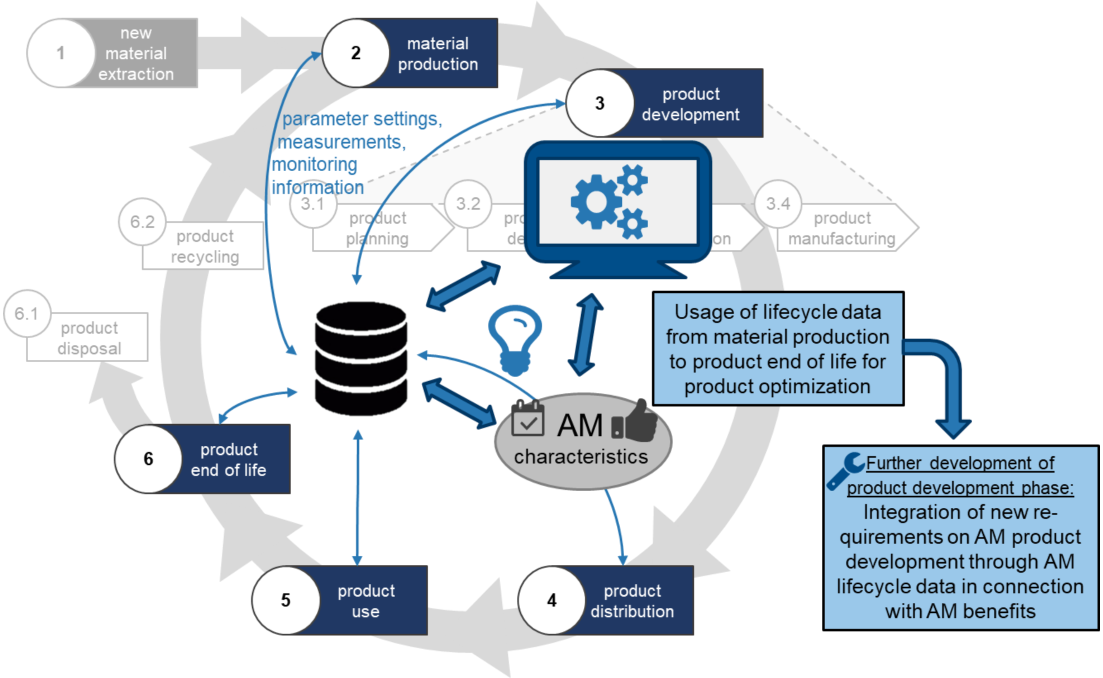


Figure 2: Concept idea in an overview

To realize the concept, important information over the entire AM lifecycle needs to be collected. Table 1 gives an overview of potential information. Besides, a short explanation of the phase is given. The correlations between the phases are essential for an overall increase of the product quality and process stability.

Therefore, phases, which have to face the consequences of the decisions and information, are recorded. Furthermore, phases that have an impact on the actual lifecycle phase are documented. Table 1 shows the approach to collect all the mentioned information.

Depending on the AM method, which is chosen, the important information needs to be adapted. Through the high variety of the AM technologies, a closer specification of the important information cannot be made generally. At department of computer integrated design, the implementation of the concept is realized in a demonstrator. An outlook on the implementation is given in the following chapter. Independently of the concrete information, a data exchange between the phase and the database is essential. In the database, all data, which are collected, are analyzed and the gained information is fed back to the phases.

Table 1: Important information of the lifecycle phases and their correlations

Lifecycle phase	Phase Content	Important Information	Consequences for	Influences by
new material extraction	new raw material gets into the holistic AM lifecycle	choice of material	material production	Choice of AM technology
		material characteristics	product development	
			recycling	
material production	raw material is transformed into a usable form, e. g. powder or filament	manufacturing information of the produced material	product development	Choice of AM technology
		environmental influences	product use phase	Requirements of the AM technology
		information concering recycling	recycling	
product development				
product planning	establishing of requirements on the product	planned process parameters as layer sizes or manufacturing speeds	product design	planned use phase
		planned manufacturing method	product manufacturing	Choice of AM technology
		product characteristics	product use	
		planned post-processing	product recycling	
		planned product functions		
product design	development of the design	product geometry	product manufacturing	Choice of AM technology
		product functions	product use	
		planned post-processing	product recycling	
work preparation	machine preparation and pre-processing	data transformation	product manufacturing	product planning
		nesting		product design
		support structures		
		slicing		
product manufacturing	in- and post-processing	manufacturing information as temperatures	product use	material production
				product planning
				product design
product distribution	the produced component becomes the property of the costumer	time of distribution	product development	product design
		place of distribution	product use	
		handling of the product during distribution process	product recycling	
product use	the new produced part is used by the costumer	time of usage	product development	
		way of usage	product recycling	
		environmental influences during usage		
		total lifetime		
product end of life				
product recycling	reuse of parts of the product or of the material	behaviour of material in recycling process	material production	
		evaluation of the component design	product use	
product disposal	disposal of the product	possibilities of disposal	sustainability of the product	Choice of AM technology
				material

The AM characteristics as design rules are integrated into the database as well and they are used during the analysis and evaluation of the collected data for a comprehensive AM process and product optimization. For data collection, several sensors need to be integrated into the AM lifecycle depending on the concrete information, which is identified in the first step of the method. To collect data of sensors and software systems, different possibilities exist. The sensors can be connected with the PLC of the machine. The PLC transfers the data to a database. Otherwise, additional microcontroller can be added.

For the data transportation a protocol is needed. In terms of *Industrie 4.0* this can be for example OPC UA, MQTT or DDS. To monitor the data a platform solution is used. This service is connected with the database. The platform offers an application for the user to process the data. With the help of the platform, data of the sensors can be visualized, it can be monitored, analyzed and stored for long term use. A specific explanation how the concept can be implemented is given in the following chapter.

Besides the identification of important information, the correlations of the information between the lifecycle phases and the data management, a connection between information and specific components needs to be made. The manufactured components need an identification that relevant production information can be connected to the certain part. This identification can be an optical identification as for example a QR code or an electrical identification as for example a RFID tag [17]. With the identification, the component can be identified clearly.

Depending on the identification and the final product, the identification helps in the following product distribution and product use phase to connect the appearing information with the product. For the proper choice of identification, correlations with other lifecycle phases need to be reconsidered and the requirements on the product have to be taken into account. The choice has an impact especially on the product recycling. For example, an integrated RFID tag contaminates the shredded material if it cannot be separated before the recycling process.

4 Implementation approaches for product optimization in the AM lifecycle for fused deposition modeling

After describing the concept for process and product optimization through data acquisition and usage, an outlook on a potential implementation follows. For the implementation, the phases of the lifecycle are installed physically or at least virtually. Figure 3 shows the actual state of the demonstrator at the DiK research laboratory.

For the material production, a material extruder has been developed. With the help of the extruder, granulate material is transferred into new filament. In the whole demonstrator PLA (polylactide) is used as material.

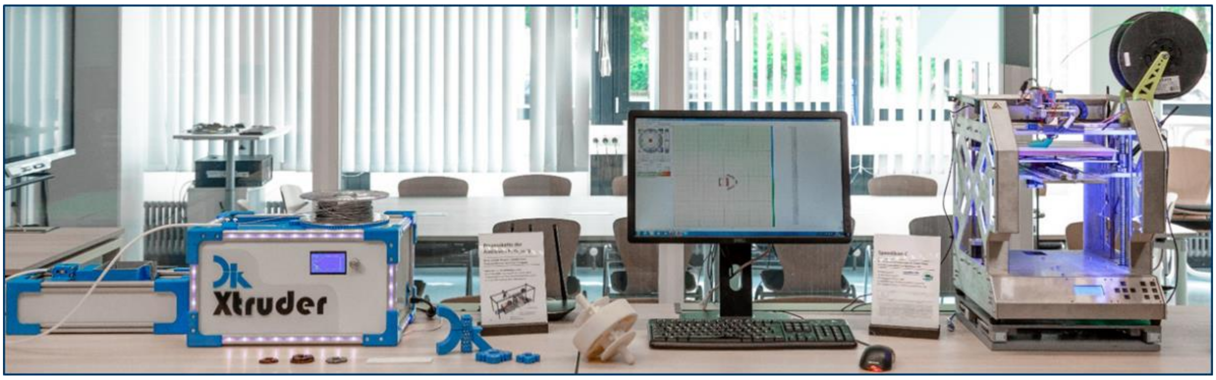


Figure 3: Actual state of the AM lifecycle demonstrator

The granulate material is inserted into a funnel, compacted with the help of a drill in a tube and heated up for extrusion. A sensor monitors the temperature of the nozzle, a light barrier controls the availability of the granulate material in the funnel. After the extrusion, the new filament passes another light barrier to control the sagging of the filament before it is cooled down in a water basin. To guarantee the cooling, the water temperature and the water level are monitored. The cooled down filament passes a sensor that measures the diameter of the filament before the filament is coiled up on a spool. The length of the produced filament can be calculated with the help of the steps of a stepping motor. The produced spool receives an identification to connect the spool with the manufacturing information, which are captured during the material production process.

The product development phase is represented through a work station and a FDM printer. The generated CAD model is transferred into the STL format and is sliced afterwards. The parameter settings as approximation accuracy and layer thickness are saved and connected with the produced products in the end. The planned nozzle speeds and ways, planned printer settings as temperature of the nozzle and the layer-on-layer building of the component can be extracted of the generated G-Code. The FDM printer represents the product manufacturing phase. Filament is conducted into a nozzle that heats up the filament and extrudes it on the building platform following the G-Code information. To control the feeder of the nozzle, the real inserted filament length is compared to the planned length to detect filament slippage.

A temperature sensor measures the nozzle temperature. The temperature of the heated building platform can be extracted from a sensor, which is implemented by the machine producer. The measurements are compared to the temperatures that a thermal image camera documents. With the help of the thermal image, the distribution of the temperature over the building platform and the printed layers is detected. Four piezo sensors measure the vibrations of the FDM printer. To exclude vibrations caused by platform moving, additional acceleration sensors are installed at the building platform. Figure 4 gives an overview of the implemented sensors at the material extruder and the FDM printer.

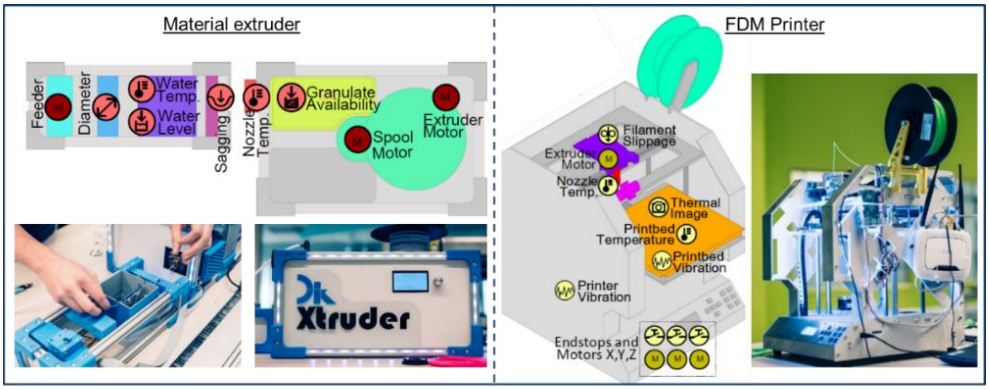


Figure 4: Sensor layout plans for the extruder and the printer

The product distribution and use phase are not implemented in the demonstrator now. For the product recycling phase, the concept for a material shredder is developed and the real installation is in implementation. With the help of this shredder, scrap components or no longer needed or used products made of PLA can be crushed. The resulting granulate material can be used again in the material production phase. One challenge is the sorting accuracy of the material concerning the color and especially concerning the plastic type. The sorting accuracy has to be maintained to conserve the quality of the new produced filament. To separate PLA from ABS, acetone is used. Coating a small part of the surface helps to identify the plastic type because of a different look of the surfaces after the treatment. The plastic type as well as the colors are separated by hand now. The sorted parts are inserted into a funnel that leads the parts into the shredder unit, where edgeless blends shear the parts. The resulting granulate is separated into three size categories. The first category is still too big for the material production that is why the material flakes are inserted into the shredder again. The second category collects the flakes, which are ready to use in the material production. The third category consists of really small flakes and powder, which cannot be used for material production. Different strainers separate the flakes in the collection vessel. Figure 5 shows the CAD model of the shredder in the overview (a), without covering (b) and reduced to the functional elements (c).

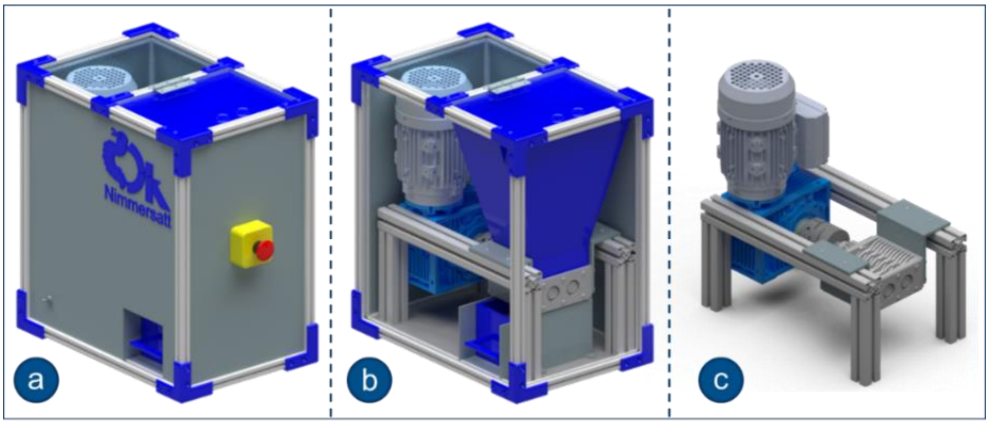


Figure 5: Concept for a shredder for recycling

For the occupational safety, the collection vessels cannot be missing or removed during the shredding process. Besides, the funnel is closed through a cap, which has to be closed to start the shredding process. An emergency stop enables the stopping of the shredding process at any moment immediately.

To realize the concept for data collection and analysis for process and component optimization a data management system has to be implemented. For the implementation, solutions for the data handling, data analysis and data storage need to be found. The solutions have to fit together to enable a proper data management system. The data handling serves to transfer the sensor measurements into a database. For the data handling or the communication between the participants, the MQTT protocol is used. This is one of the commonly used protocols in *Industrie 4.0* applications. Other possibilities to implement an *Industrie 4.0* communication are the OPC UA or the DDS protocol. The MQTT protocol has some advantages that justify the choice of the protocol. The MQTT protocol can be used effectively in a resource-restricted environment to establish a stable system. Another advantage is the decoupling of the protocol concerning three dimensions: The space decoupling means the clearing of the force for publisher and subscriber to know each other. Based on the time decoupling, a simultaneous operation of publisher and subscriber is not necessary. The last dimension is the synchronization decoupling with the asynchronous messaging, which prevents the blockade of sending and receiving messages at the same time [18, 19].

To realize a communication, the extruder and the FDM printer have a microcontroller that is connected with the sensors. The microcontroller possesses a Wi-Fi module, which enables a wireless communication between the extruder or FDM printer and the server. Every sensor acts as a MQTT client. The MQTT clients publish their messages with a certain topic in a defined data format. A MQTT broker subscribes the messages with the certain topic. The topics have to be determined, because the broker only subscribes known topics, that means, the topics that are defined by a user. The MQTT broker acts as a central agent in the communication system. Clients and broker are connected through the transmission control protocol (TCP) all the time. One advantage of the MQTT protocol is the independence of the clients. The single clients do not need to know each other, they are communicating through the broker. To enhance the safety of the communication, more than one broker can be used to prevent the failure of the communication with a broker failure.

The MQTT broker is connected with a database that serves for the data storage. This database corresponds with a platform. For this application, the Speedikon C platform of the German enterprise Speedikon FM is chosen [20]. With the help of Speedikon C, the measurements can be represented in charts. The process can be monitored through minima and maxima values. If the measurements exceed this range, a message is sent to the user. Furthermore, key performance indicators can be calculated and monitored. The monitoring can be simplified through the implementation of a dashboard in Speedikon C, which includes all significant performance indicators and measurements at one sight. With the monitoring, the actual process quality can be assured, this has a positive effect on the product quality as well. Constant monitoring enables a direct reaction and for example early cancellations of the printing process. This saves process time and material. Besides monitoring, the measurements are saved for long-term usage and analysis. Information of the product use phase can be compared with the manufacturing information of the component and the material. With the comparison, correlations between the product characteristics and the extreme values in the monitoring process might be found and the extreme values can be adapted afterwards for future production processes. Figure 6 gives an overview of the communication and the functionality of the chosen platform Speedikon C.

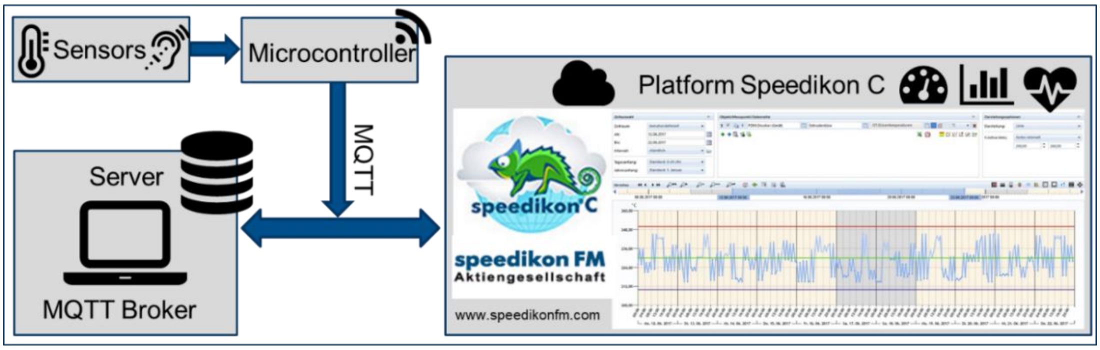


Figure 6: Communication concept and platform functionalities

The next steps for further implementation of the AM lifecycle and the concept for data collection and analysis for process and component optimization are the real installation of the shredder and an implementation of the lifecycle phases product distribution and product use.

5 Conclusion and outlook

Advantages of digitalization are not used comprehensively in the field of AM. Optimization approaches are limited on the pre- and in-processing of the AM process chain. Lots of decisions concerning the product are made in the whole product development phase. Therefore, the optimization approaches need to be enlarged to the holistic AM lifecycle with main focus on the product development phase. The consideration of the AM lifecycle phases tend to optimize the product and process through data collection and analysis combined with the integration of the AM characteristics in the lifecycle. In the first step of the concept important information of the lifecycle phases and their correlations are summarized in a table. The important information need to be concretized for the chosen AM technology, which is used.

The concept includes a description of the data collection, data analysis and the connection with the AM characteristics in the database and the platform. The platform can be used to monitor, analyze and process the data and can be seen as the interface to the user. The concept is implemented in the last chapter for the FDM technology. For the material production, a material extruder is developed. The product development phase is represented through a work station, where the CAD model is designed and the pre-processing takes place, and a FDM printer for the manufacturing of the part. A concept for a shredder represents the recycling phase. The data is collected with the help of additionally implemented sensors. The measurements are communicated with the MQTT protocol via microcontrollers to a database, which is connected with the Speedikon C platform. The collected data is monitored and visualized in a dashboard. The next steps are the evaluation of the collected data and the implementation of the shredder. Further research questions are the automatic extraction of information from the CAD program and the realization of the product distribution and use phase.

6 References

[1] Airbus (2017): First titanium 3D-printed part installed into serial production aircraft. Online: https://www.airbus.com/newsroom/press-releases/en/2017/09/first-titanium-3d-printed-part-installed-into-serial-production-.html

[2] BMW (2016) Serienbauteile aus dem 3D-Drucker: BMW Group baut den Einsatz additiver Fertigungsverfahren weiter aus. Online: https://www.press.bmwgroup.com/deutschland/article/detail/T0261924DE/serienbauteile-aus-dem-3d-drucker:-bmw-group-baut-den-einsatz-additiver-fertigungsverfahren-weiter-aus

[3] EOS (2018): Data Preparation & Process Software for Additive Manufacturing. Online: https://www.eos.info/systems_solutions/software_data-preparation

[4] Wohlers, Terry (2018): Wohlers Talk - AM System Manufacturer Growth. http://wohlersassociates.com/blog/ from January 27, 2018

[5] Wohlers, Terry T.(2017): Wohlers Report - 3D Printing and Additive Manufacturing - State of the Industry - Annual Worldwide Progress Report; ISBN 978-0-9913332-3-3

[6] Kellens, Karel; Baumers, Martin; Gutowski, Timothy G.; Flanagan, William; Lifset, Reid; Duflou, Joost R. (2017): Environmental Dimensions of Additive Manufacturing: Mapping Application Domains and Their Environmental Implications. In: Journal of Industrial Ecology. Online: http://onlinelibrary.wiley.com/doi/10.1111/jiec.12629/full

[7] VDI (2014): Statusreport – Additive Fertigungsverfahren. Online: https://www.vdi.de/fileadmin/vdi_de/redakteur_dateien/gpl_dateien/VDI_Statusreport_AM_2014_WEB.pdf

[8] Peng, Shitong; Li, Tao; Wang, Xinlin; Dong, Mengmeng; Liu, Zhichao; Shi, Junli; Zhang, Hongchao (2017): Toward a Sustainable Impeller Production: Environmental Impact Comparison of Different Impeller Manufacturing Methods. In: Journal of Industrial Ecology. Online: http://onlinelibrary.wiley.com/doi/10.1111/jiec.12628/full

[9] VDI (2016): Handlungsfelder – Additive Fertigungsverfahren. Online:https://www.vdi.de/fileadmin/vdi_de/redakteur_dateien/gpl_dateien/6242_PUB_GPL_Handlungsfelder_-_Additive_Fertigungsverfahren_Internet.pdf

[10] Auth, C.; Arndt, A.; Anderl, R. (2018): Development of a concept for a holistic knowledge-based additive manufacturing over the entire lifecycle. In: IFIP 15th International Conference on Product Lifecycle Management 01.07.-04.07.2018, Torino, Italy

[11] Gibson, I.; Rose, D. W.; Stucker, B. (2010): Additive Manufacturing Technologies – Rapid Prototyping to Direct Digital Manufacturing. 1. Edition. Springer, New York Heidelberg Dordrecht London. doi: 10.1007/978-1-4939-2113-3

[12] Verein Deutscher Ingenieure (2014): VDI 3405 – Additive Fertigungsverfahren – Grundlagen, Begriffe, Verfahrensbeschreibung

[13] Arndt, A.; Hackbusch, H.; Anderl, R. (2014): An algorithm-based method for process-specific three-dimensional nesting for additive manufacturing processes. In: 26th Solid Freeform Fabrication Symposium 2015, 10.08.-12.08.2015, Austin, Texas

[14] Gurpal, S. B., Parlad kumar (2014): Methods to Improve Surface Finish of Parts Produced by Fused Deposition Modeling. In: Manufacturing Science and Technology, 2014

[15] Kirchner, K.; Jäschke, H.; Franke, H.-J.; Vietor, T.; Grote, K.-H. (2010): Mechanischtechnologische Eigenschaften generativ gefertigter Bauteile in Abhängigkeit von der Bauteilorientierung. In: RTejournal - Forum für Rapid Technologie 1, 2010

[16] Auth, C.; Borstell, D.; Anderl, R. (2018): Knowledge-based material production in the additive manufacturing lifecycle of fused deposition modeling. In: 29th Solid Freeform Fabrication Symposium 2018, 13.08.-15.08.2018, Austin, Texas

[17] Arndt, Alexander (2018): Bauteilindividuelle und verfahrensspezifische Kennzeichnung und Identifikation für die Additive Fertigung. Dissertation

[18] Jaffey, Tobi: MQTT and CoAP, IoT Protocols. Online: http://www.eclipse.org/community/eclipse_newsletter/2014/february/article2.php. Version: 2014

[19] HIVEMQ: MQTT Essentials. Online: https://www.hivemq.com/blog/mqtt-essentials-part-1-introducing-mqtt. Version: 2015

[20] Speedikon FM (2017): Die webbasierte IT-Plattform. Online: https://www.speedikonfm.com/index.php?speedikon-fm-ag_und_speedikon-c

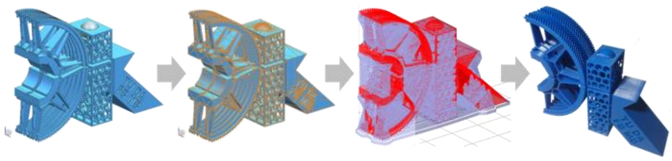
Additive Manufacturing Lifecycle – Data Collection and Analysis for Process and Component Optimization

TECHNISCHE UNIVERSITÄT DARMSTADT

Department of Computer Integrated Design (DiK)

Prof. Dr.-Ing. Reiner Anderl
Cordula Auth, M.Sc.

auth@dik.tu-darmstadt.de
www.dik.tu-darmstadt.de



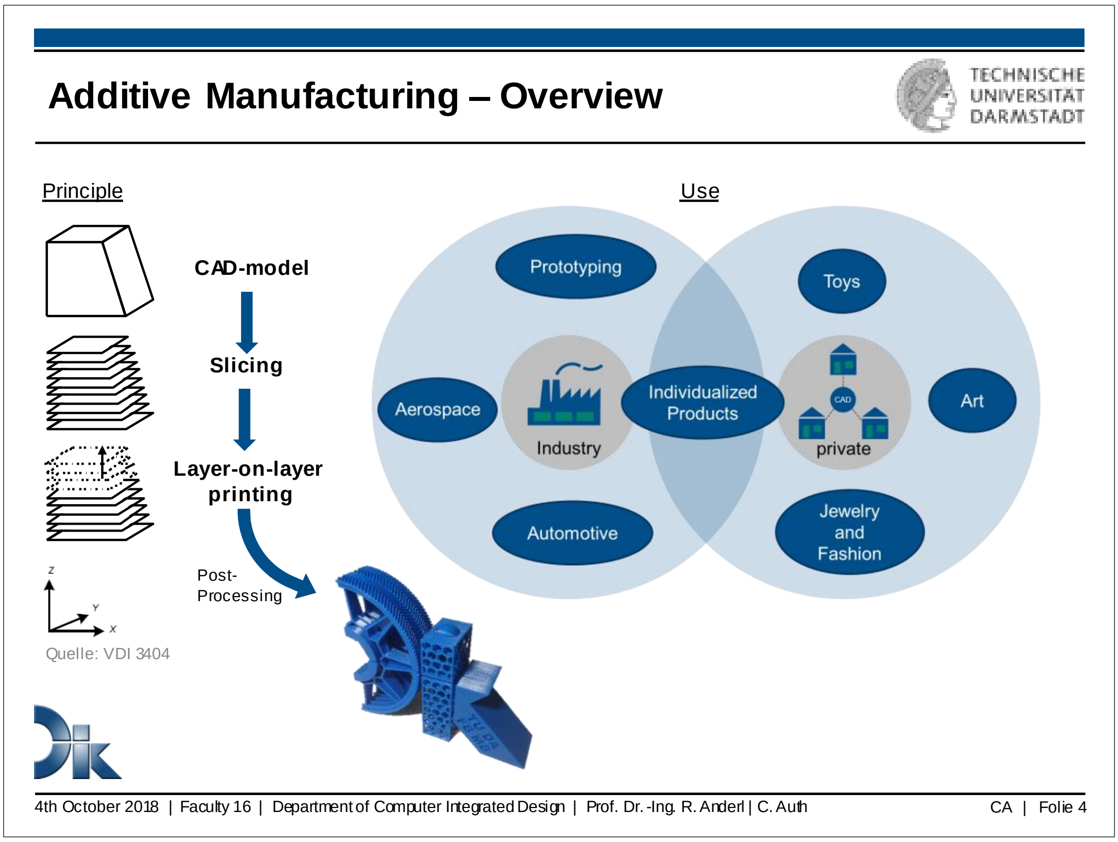
4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth   CA | Folie 1

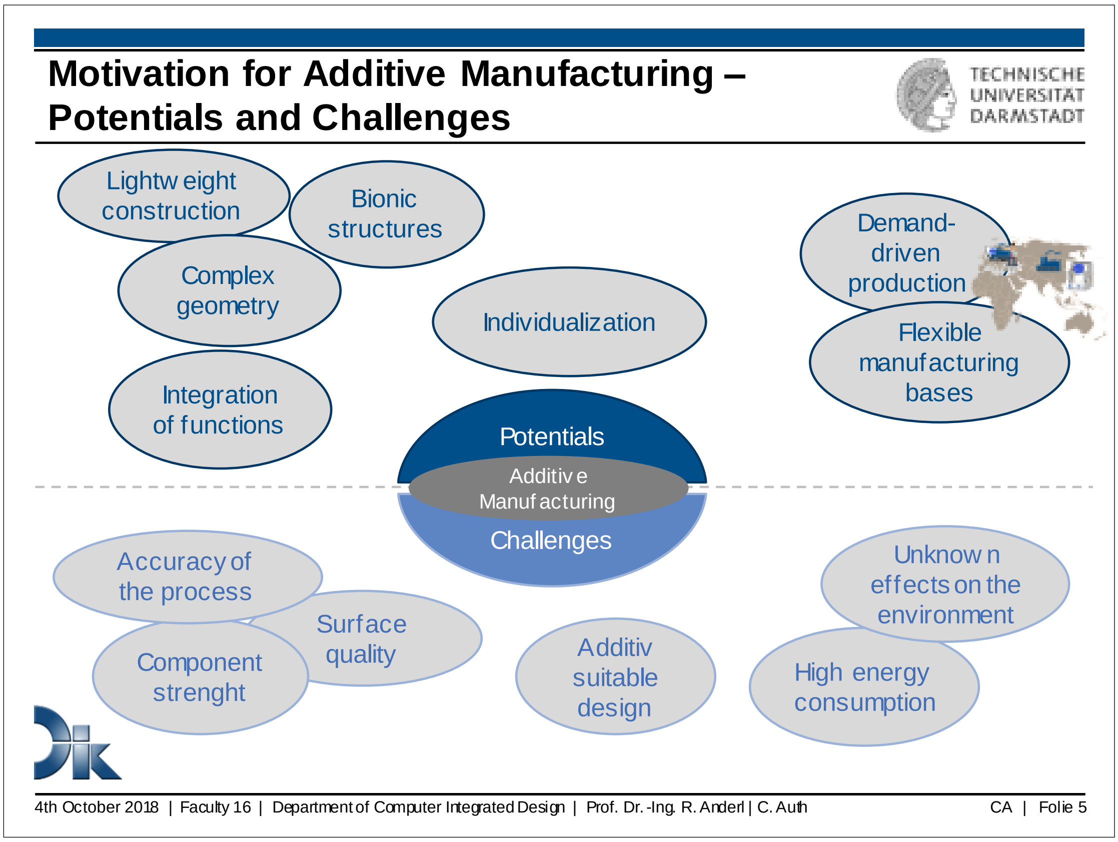
Structure

TECHNISCHE UNIVERSITÄT DARMSTADT

1. **Motivation**
2. **Definition of the AM lifecycle**
3. **Method for Data Collection and Analysis for Process and Component Optimization**
4. **Prototype Implementation**
5. **Outlook and Conclusion**

4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth   CA | Folie 2


Additive Manufacturing – Overview
TECHNISCHE UNIVERSITÄT DARMSTADT
Principle
Use
CAD-model
Slicing
Layer-on-layer printing
Post-Processing
Quelle: VDI 3404
Prototyping
Toys
Aerospace
Industry
Individualized Products
private
Art
Automotive
Jewelry and Fashion
4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth
CA | Folie 4


Motivation for Additive Manufacturing – Potentials and Challenges
TECHNISCHE UNIVERSITÄT DARMSTADT
Lightweight construction
Bionic structures
Complex geometry
Individualization
Demand-driven production
Flexible manufacturing bases
Integration of functions
Potentials
Additive Manufacturing
Challenges
Accuracy of the process
Surface quality
Component strenght
Additiv suitable design
Unknown effects on the environment
High energy consumption
4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth
CA | Folie 5

Motivation for Data Collection and Analysis in the Field of Additive Manufacturing

TECHNISCHE UNIVERSITÄT DARMSTADT

<u>Growing importance of AM:</u>

- First approaches in serial production for example in the aerospace sector
- Increasing number of AM system manufacturer and AM patent applications (Wohlers Report)

<u>Limitied approaches for optimization in the field of AM:</u>

- In most cases, optimization only takes place in pre- and in-processing
- Know ledge of process parameters and machine settings depend on the company and the employees
- There do not exist standards for achieving good quality of the product and a reliable process

4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth   CA | Folie 6

Example for Actual AM Process Optimization

TECHNISCHE UNIVERSITÄT DARMSTADT

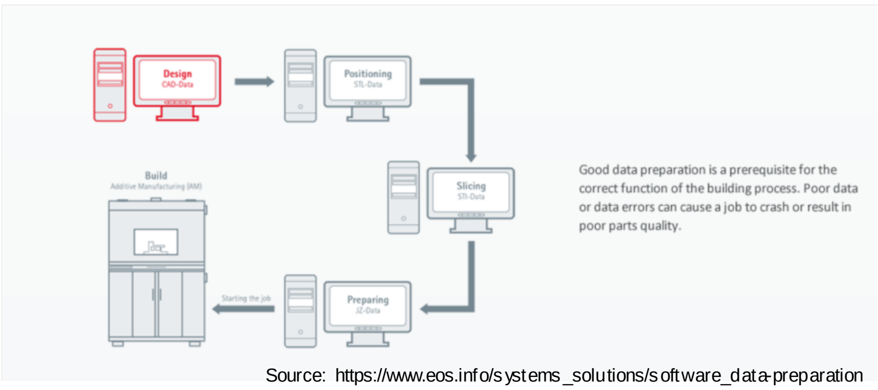
<u>Machine producer EOS optimizes the pre-processing</u>:

Data Preparation & Process Software for Additive Manufacturing

EOSPRINT 2: New generation of job and process management software

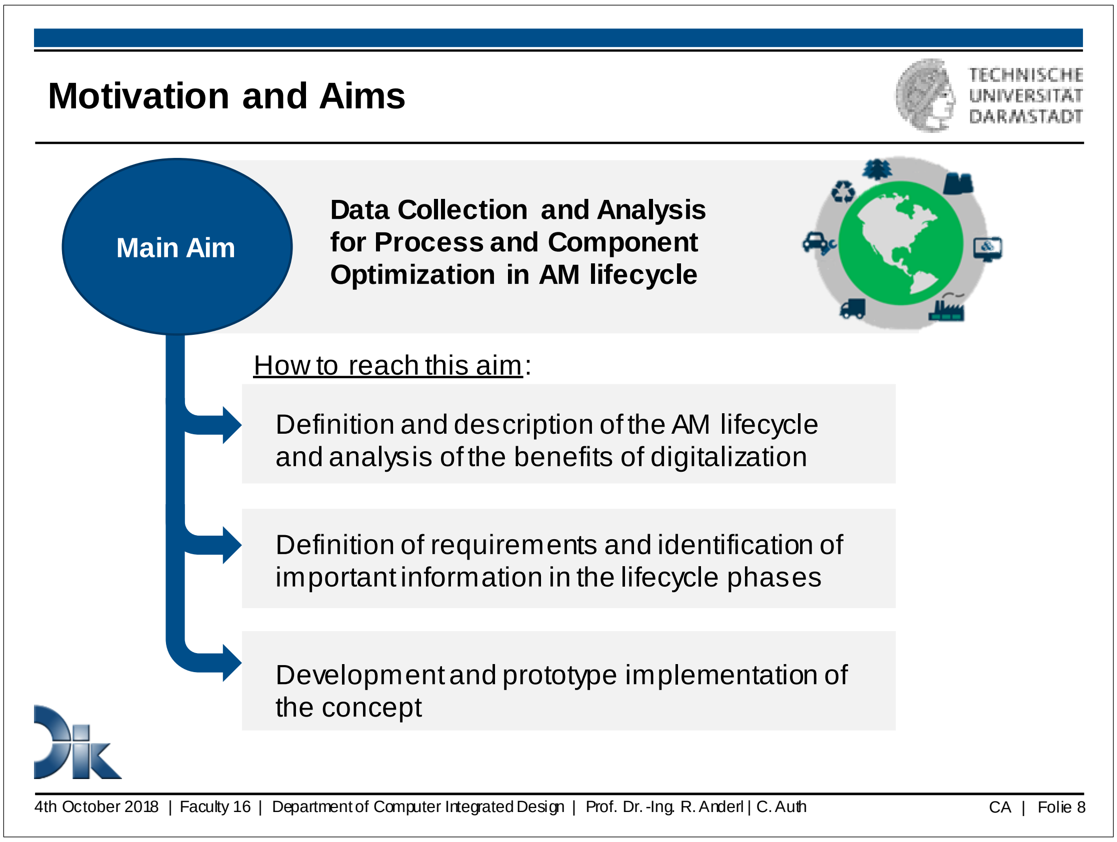
It is an intuitive, open and productive CAM tool for EOS systems that enables to assign and to optimize build parameters for your CAD data. Now available for EOS M 290, EOS M 400 and EOS M 400-4. Source: https://www.eos.info/systems_solutions/software_data-preparation

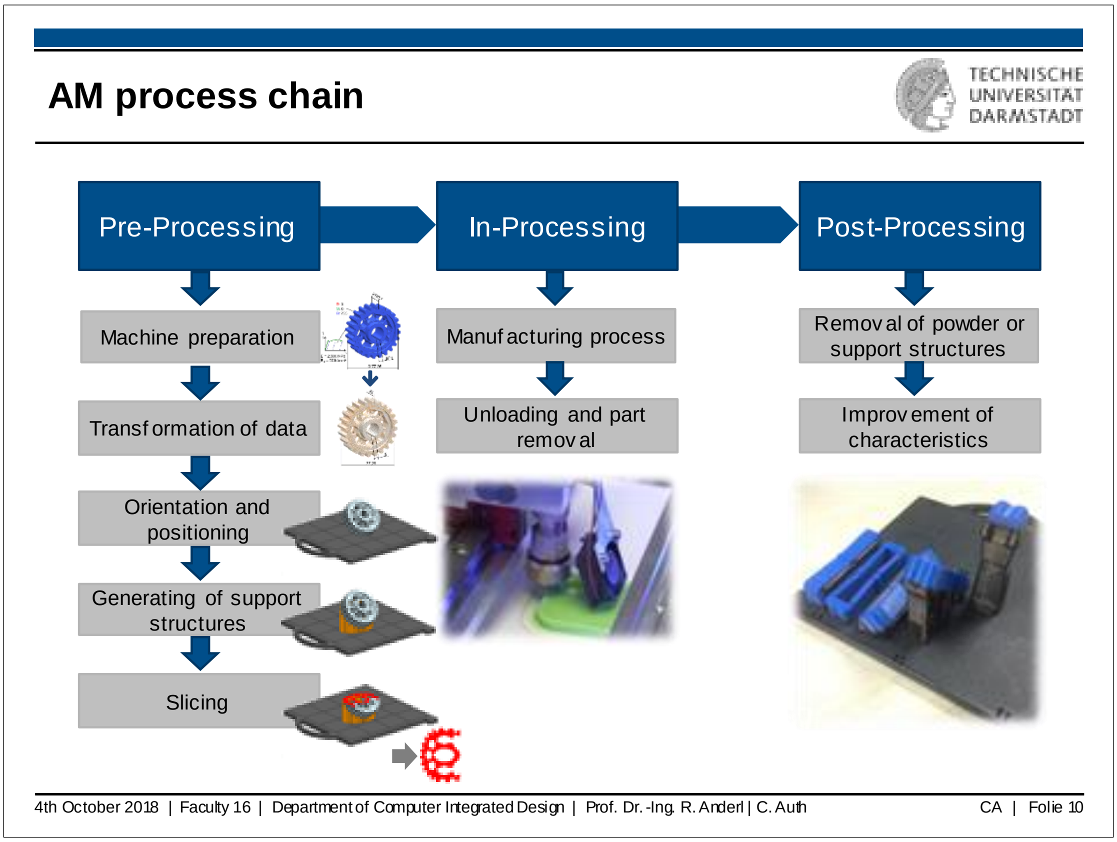
Procedure for data preparation

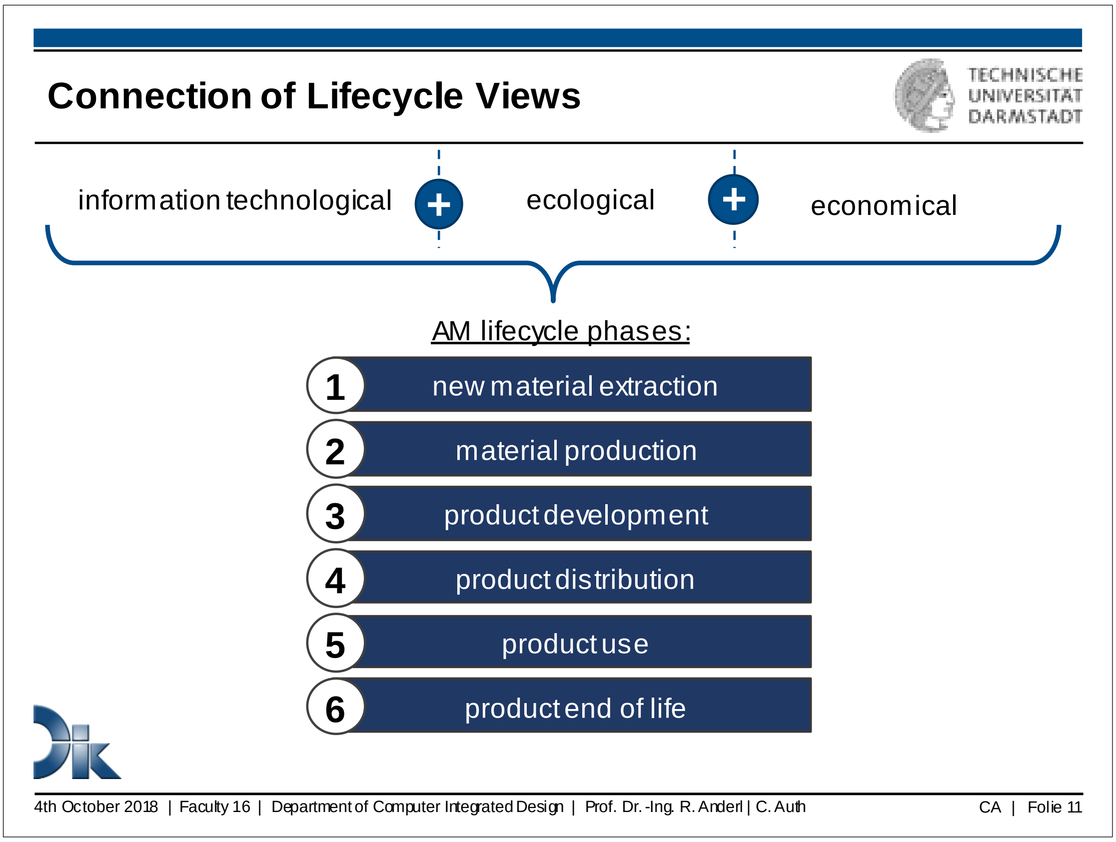


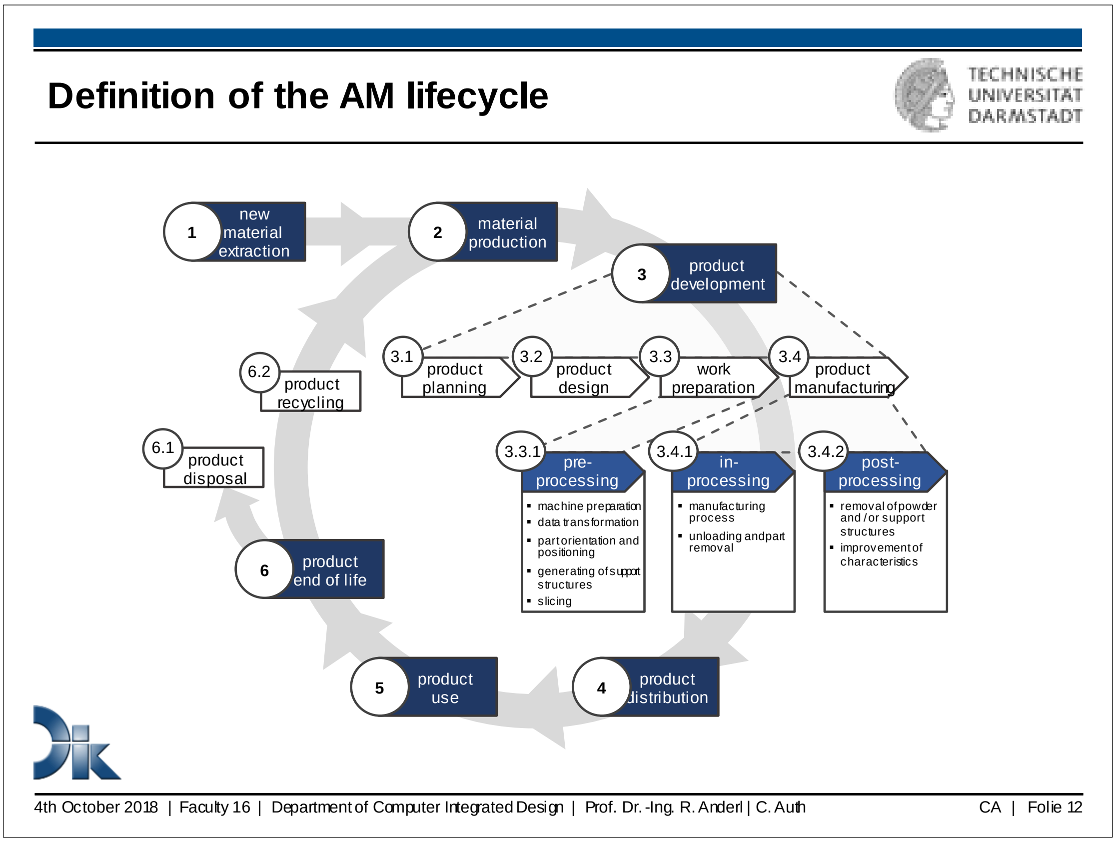
Source: https://www.eos.info/systems_solutions/software_data-preparation

4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth   CA | Folie 7


Motivation and Aims
TECHNISCHE UNIVERSITÄT DARMSTADT
Main Aim
Data Collection and Analysis for Process and Component Optimization in AM lifecycle
How to reach this aim:
Definition and description of the AM lifecycle and analysis of the benefits of digitalization
Definition of requirements and identification of important information in the lifecycle phases
Development and prototype implementation of the concept
4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth
CA | Folie 8


AM process chain
TECHNISCHE UNIVERSITÄT DARMSTADT
Pre-Processing
In-Processing
Post-Processing
Machine preparation
Transformation of data
Orientation and positioning
Generating of support structures
Slicing
Manufacturing process
Unloading and part removal
Removal of powder or support structures
Improvement of characteristics
4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth
CA | Folie 10

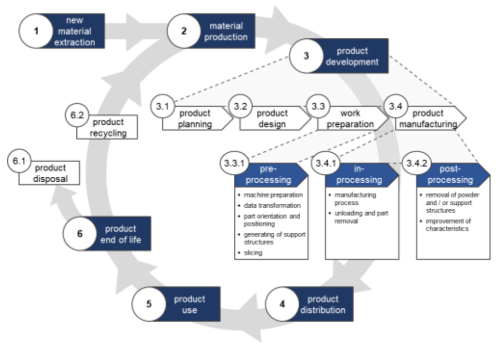

Connection of Lifecycle Views
TECHNISCHE UNIVERSITÄT DARMSTADT
information technological
+
ecological
+
economical
AM lifecycle phases:
1 new material extraction
2 material production
3 product development
4 product distribution
5 product use
6 product end of life
4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth
CA | Folie 11


Definition of the AM lifecycle
TECHNISCHE UNIVERSITÄT DARMSTADT
1 new material extraction
2 material production
3 product development
3.1 product planning
3.2 product design
3.3 work preparation
3.4 product manufacturing
3.3.1 pre-processing
machine preparation
data transformation
part orientation and positioning
generating of support structures
slicing
3.4.1 in-processing
manufacturing process
unloading and part removal
3.4.2 post-processing
removal of powder and / or support structures
improvement of characteristics
4 product distribution
5 product use
6 product end of life
6.1 product disposal
6.2 product recycling
4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth
CA | Folie 12

Development of a Concept for Product Optimization through Data Collection and Usage

TECHNISCHE UNIVERSITÄT DARMSTADT

1. Definition of the lifecycle phases



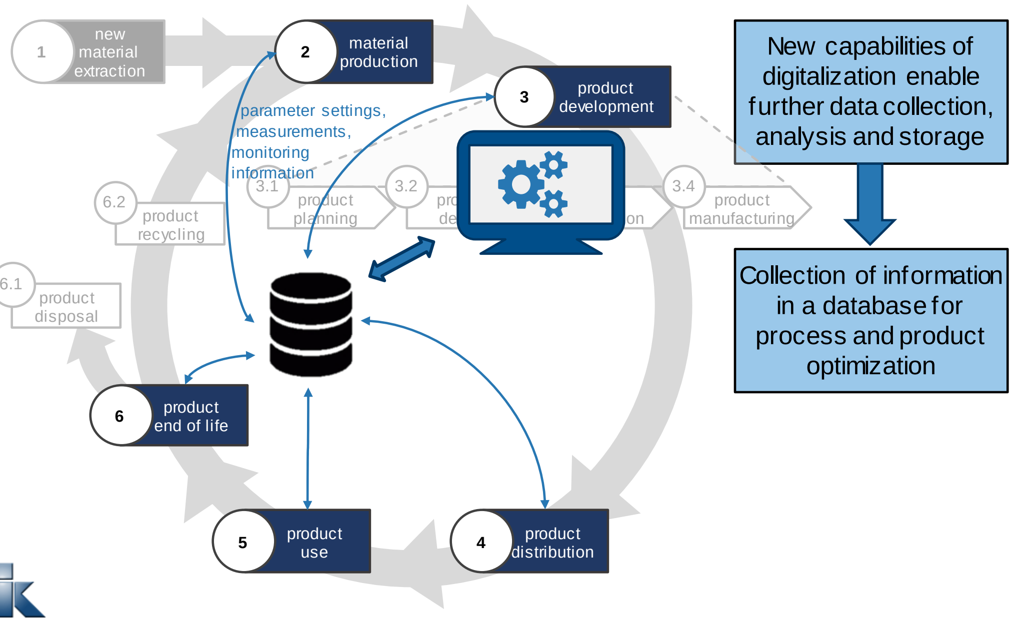
2. Definition of requirements

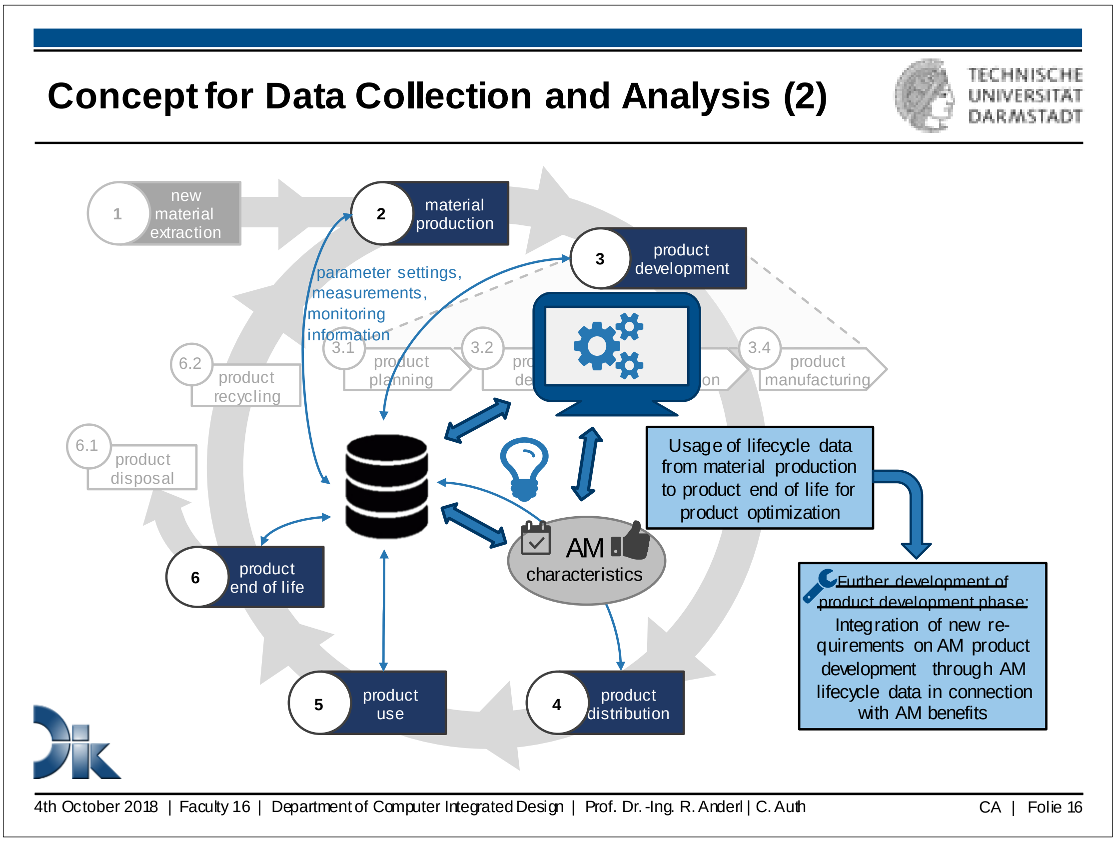
- Important process and lifecycle parameters need to be identified
- Data need to be collected for every important process parameter
- Collected data need to be analyzed and stored
- There has to be an additional benefit besides the storage of the data

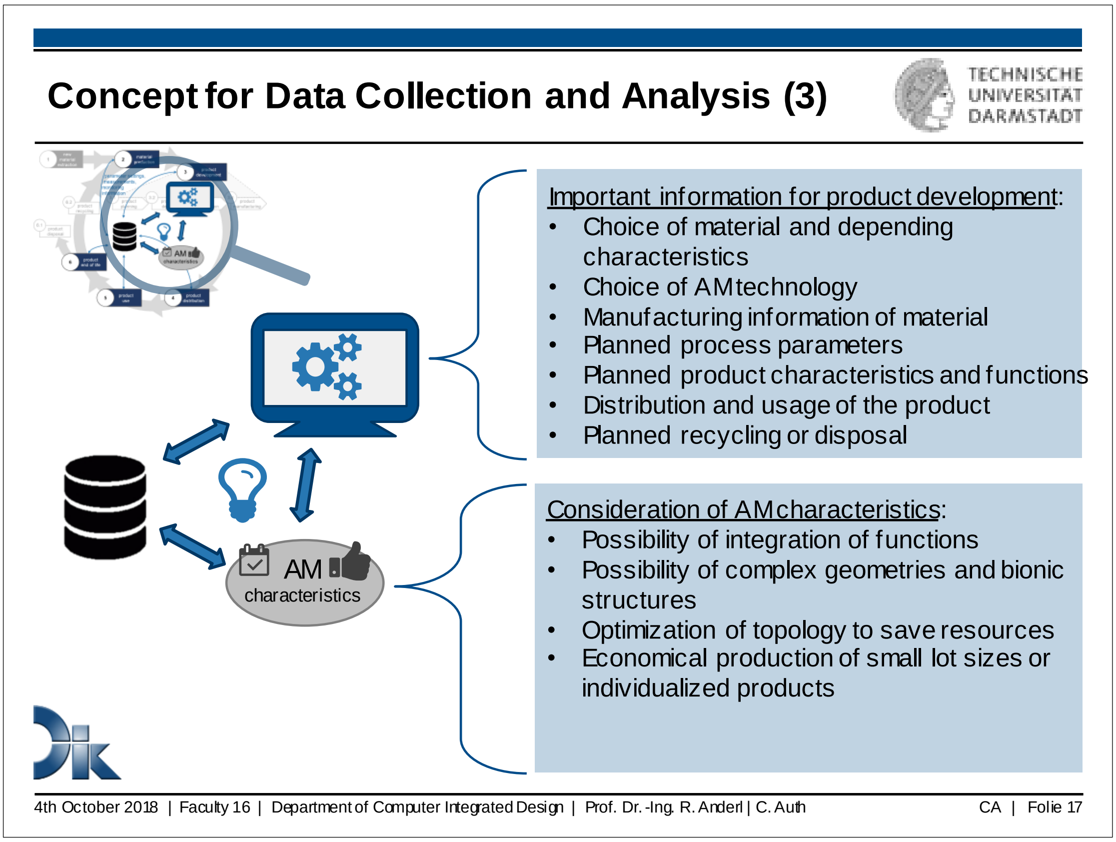
3. Explanation of information which is collected in the lifecycle phases and the correlation with other lifecycle phases, especially with the product development

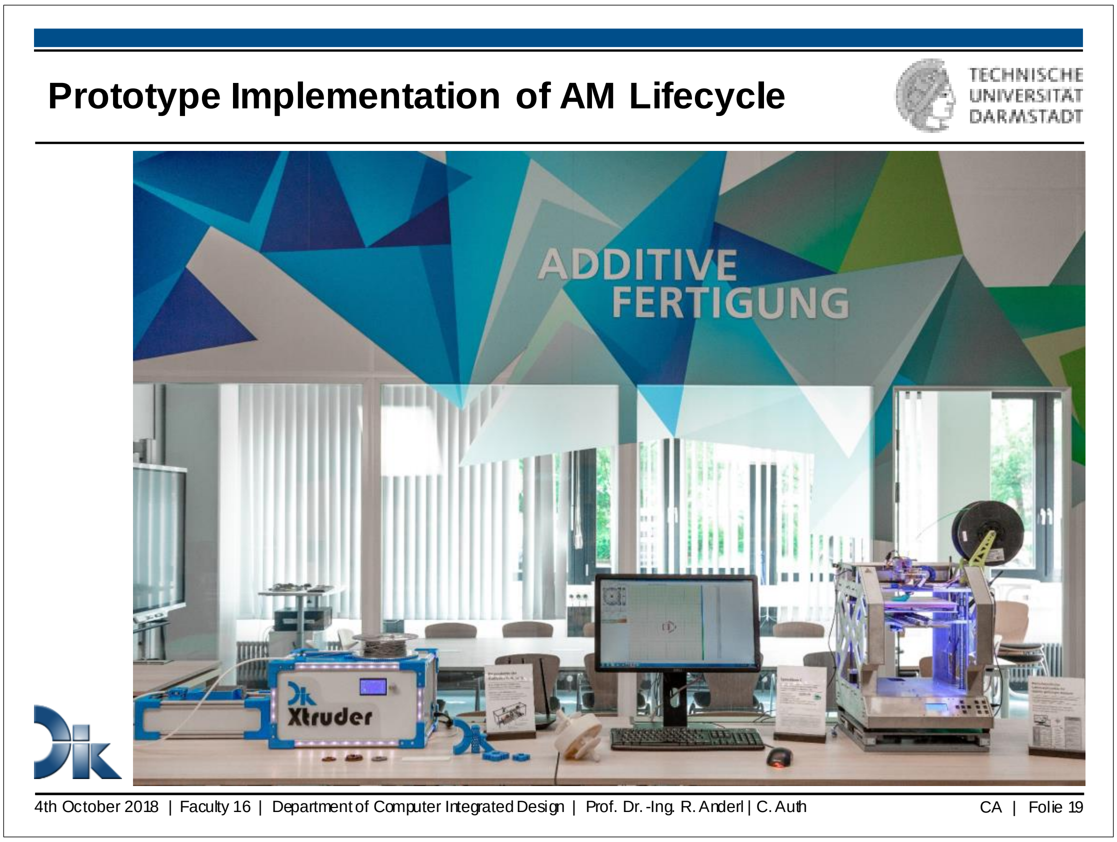
Concept for Data Collection and Analysis (1)

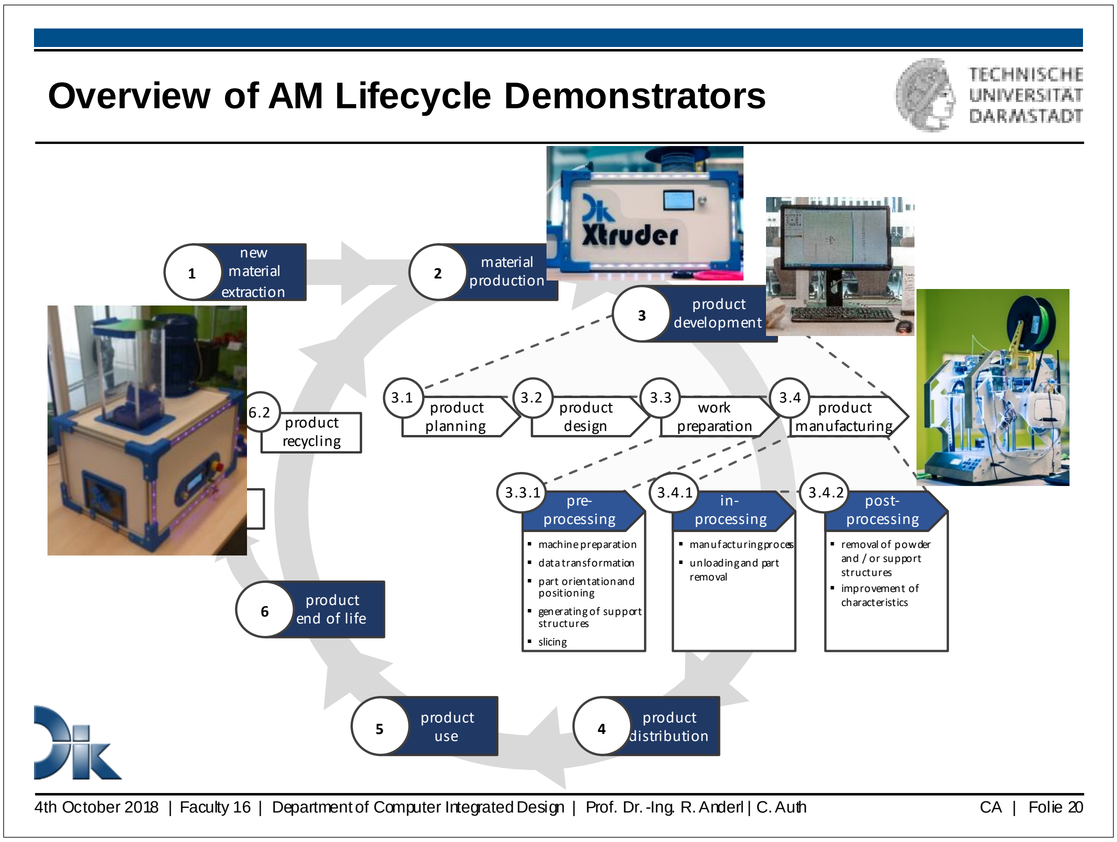
TECHNISCHE UNIVERSITÄT DARMSTADT




Concept for Data Collection and Analysis (2)
TECHNISCHE UNIVERSITÄT DARMSTADT
1 new material extraction
2 material production
3 product development
parameter settings, measurements, monitoring information
3.1 product planning
3.2
3.4 product manufacturing
6.2 product recycling
6.1 product disposal
Usage of lifecycle data from material production to product end of life for product optimization
AM characteristics
6 product end of life
5 product use
4 product distribution
Further development of product development phase:
Integration of new requirements on AM product development through AM lifecycle data in connection with AM benefits
4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth
CA | Folie 16


Concept for Data Collection and Analysis (3)
TECHNISCHE UNIVERSITÄT DARMSTADT
Important information for product development:
Choice of material and depending characteristics
Choice of AM technology
Manufacturing information of material
Planned process parameters
Planned product characteristics and functions
Distribution and usage of the product
Planned recycling or disposal
AM characteristics
Consideration of AM characteristics:
Possibility of integration of functions
Possibility of complex geometries and bionic structures
Optimization of topology to save resources
Economical production of small lot sizes or individualized products
4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth
CA | Folie 17

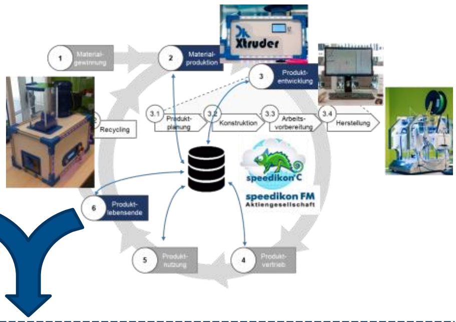

Prototype Implementation of AM Lifecycle
TECHNISCHE UNIVERSITÄT DARMSTADT
ADDITIVE FERTIGUNG
Xtruder
4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth
CA | Folie 19


Overview of AM Lifecycle Demonstrators
TECHNISCHE UNIVERSITÄT DARMSTADT
Xtruder
1 new material extraction
2 material production
3 product development
3.1 product planning
3.2 product design
3.3 work preparation
3.4 product manufacturing
3.3.1 pre-processing
machine preparation
data transformation
part orientation and positioning
generating of support structures
slicing
3.4.1 in-processing
manufacturing process
unloading and part removal
3.4.2 post-processing
removal of powder and / or support structures
improvement of characteristics
4 product distribution
5 product use
6 product end of life
6.2 product recycling
4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth
CA | Folie 20

Demonstrator: Lifecycle of Fused Deposition Modeling – actual State

TECHNISCHE UNIVERSITÄT DARMSTADT

Aim:
Data Collection and Analysis for Process and Component Optimization in AM lifecycle



Steps:

- Definition of the lifecycle
- Identification of useful data
- Integration of sensors
- Development of the communication concept
- Preparation of the concept for data aquisition, handling, analysis and storage
- Implementation in a demonstrator

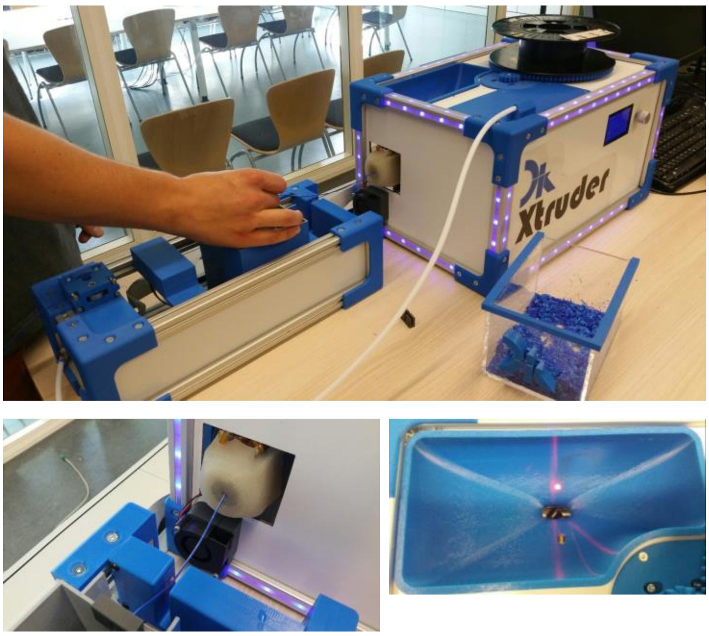
Actual State:

- Definition of the lifecycle for the fused deposition modeling and implementation of the phases
- Integration of sensors in the extruder and printer
- Implementation of the platform speed*ikon C* and the communication concept

4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth CA | Folie 21

Material Extruder for Material Production

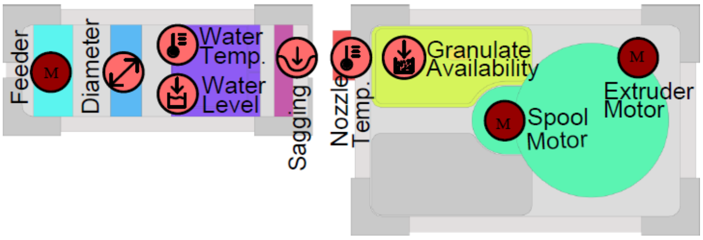
TECHNISCHE UNIVERSITÄT DARMSTADT



4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth CA | Folie 22

Material Extruder for Material Production

TECHNISCHE UNIVERSITÄT DARMSTADT

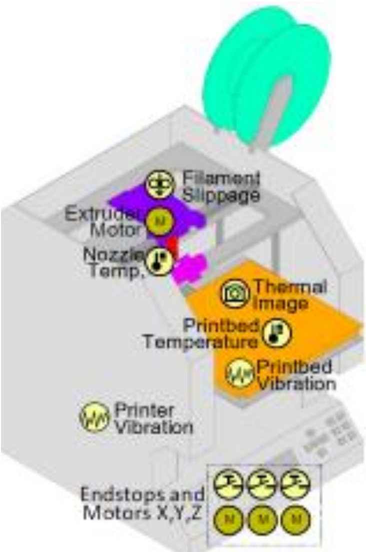


- Monitoring of process parameters in material production
- Nozzle temperature, diameter and length of filament are important measurements
- Collection, analysis and storage of measurements connected with the produced spool of filament

4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth   CA | Folie 23

FDM Printer for Product Manufacturing

TECHNISCHE UNIVERSITÄT DARMSTADT



- Monitoring of process parameters in product manufacturing
- Nozzle temperature, filament slippage, printbed temperature, vibrations are important measurements
- Collection, analysis and storage of measurements connected with the produced part

4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth   CA | Folie 24

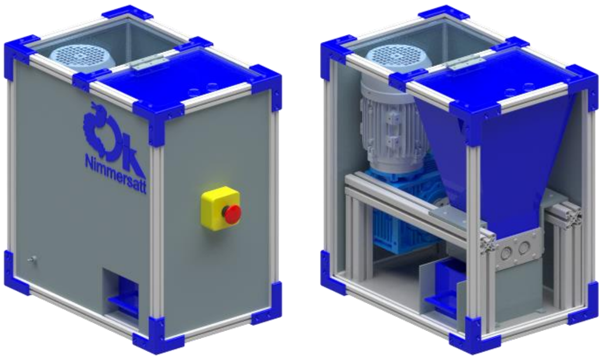
Improvements and Implementation of the Concept for the Shredder

TECHNISCHE UNIVERSITÄT DARMSTADT

4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth   CA | Folie 25

Concept of Material Shredder for Product Recycling (2)

TECHNISCHE UNIVERSITÄT DARMSTADT



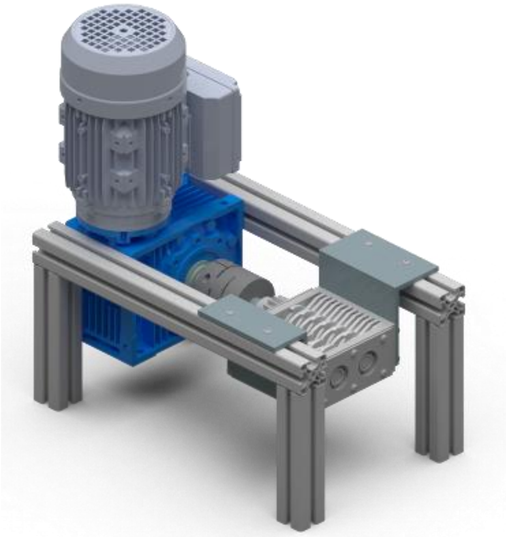
Requirements on the Concept for the Shredder:

- **Function**: shredding of printed parts (maximum 120mm*120mm*120mm) with adequate speed
- **Granulate size:** the resulting particles are between 1mm and 5mm
- **Safety at work:** protection against manual contact with the shredding modul and limitation of noise

4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth   CA | Folie 26

Concept of Material Shredder for Product Recycling (1)

TECHNISCHE UNIVERSITÄT DARMSTADT

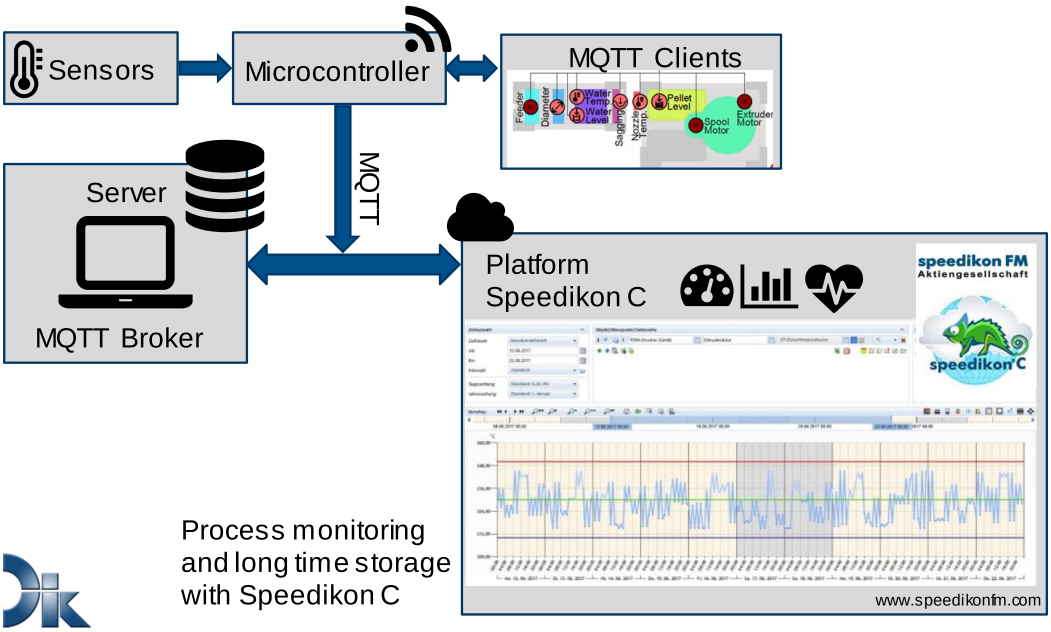


- Monitoring of the recycling process and the suitability of the products for recycling
- Correlations of the product geometry with the recycling results
- Documentation of the recycled products and the size of the new produced granulate and feedback of recycling suitability to product development

4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth CA | Folie 27

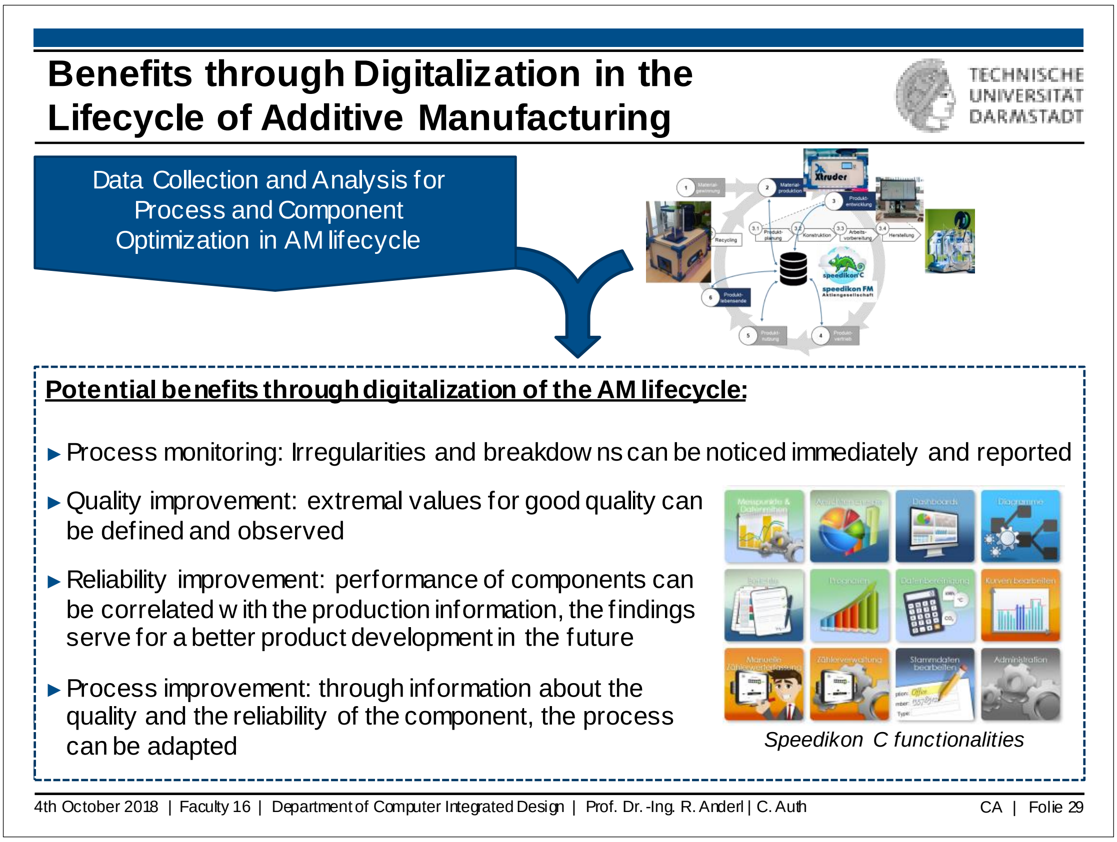
Communication Concept in Demonstrator

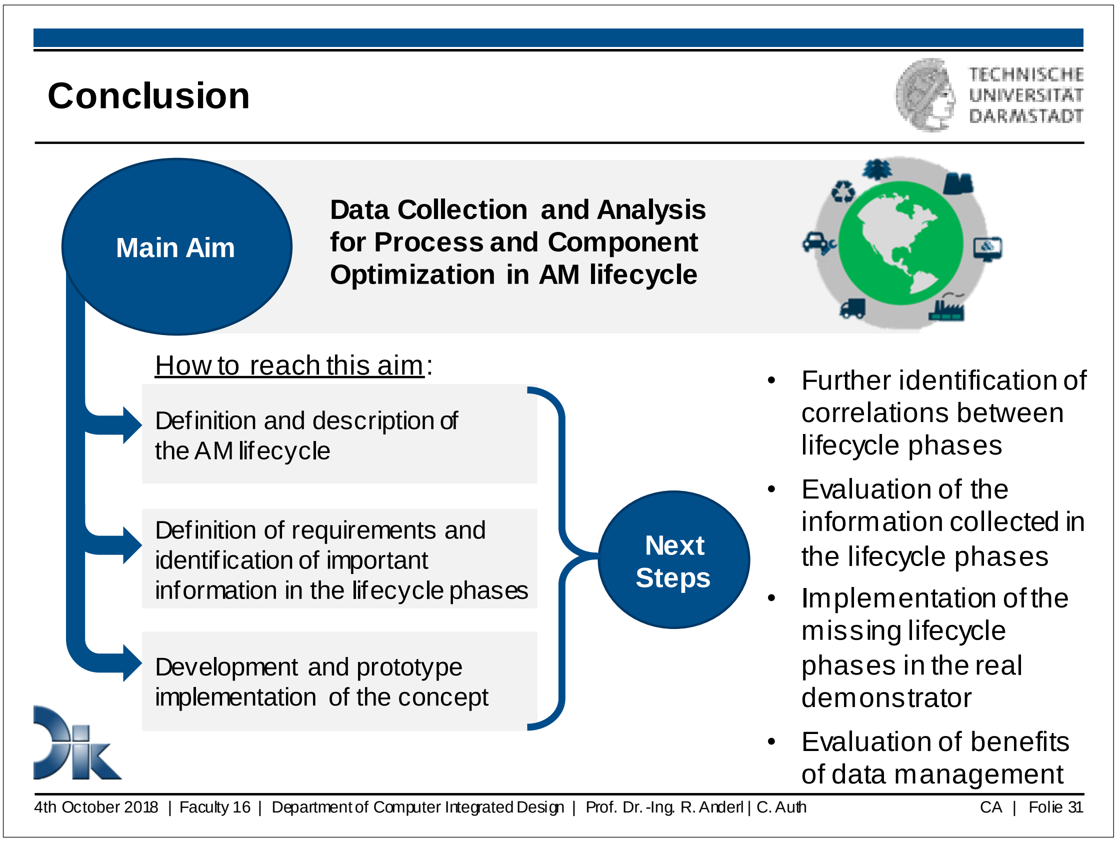
TECHNISCHE UNIVERSITÄT DARMSTADT

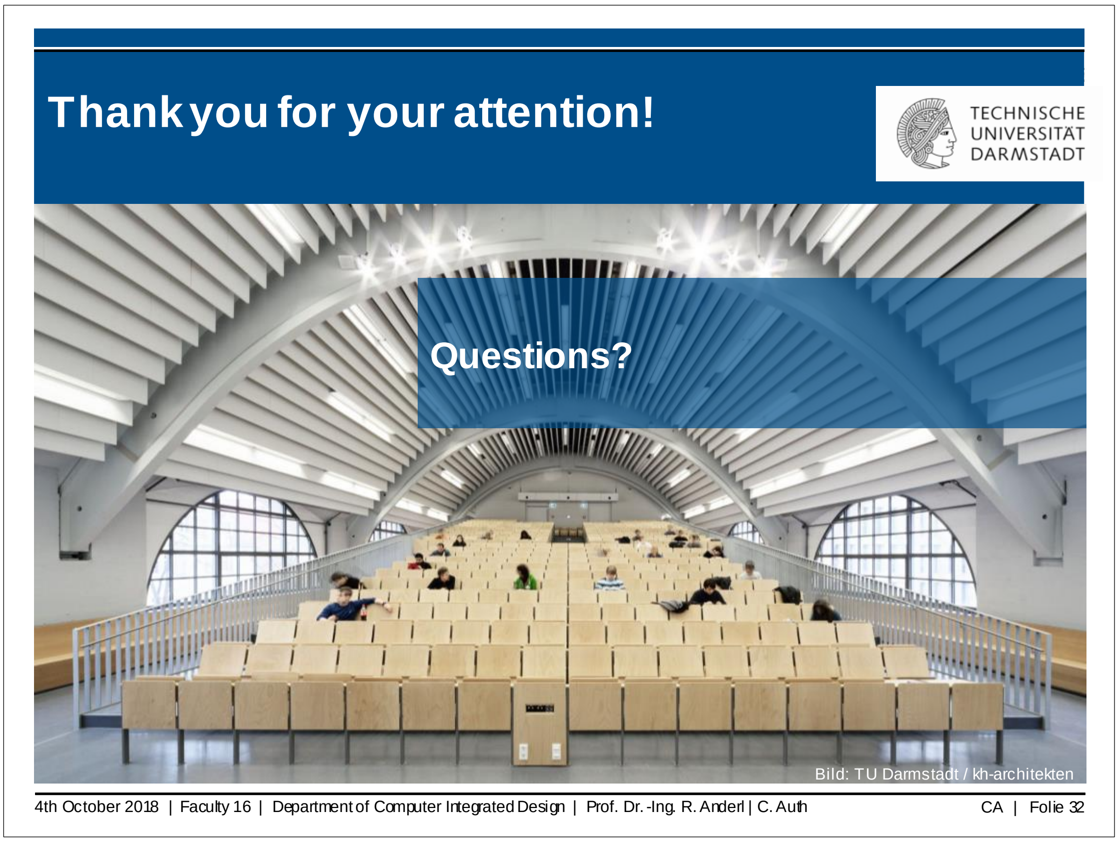


Process monitoring and long time storage with Speedikon C

4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth CA | Folie 28


Benefits through Digitalization in the Lifecycle of Additive Manufacturing
TECHNISCHE UNIVERSITÄT DARMSTADT
Data Collection and Analysis for Process and Component Optimization in AM lifecycle
Xtruder
speedikon C
speedikon FM
Potential benefits through digitalization of the AM lifecycle:
▸ Process monitoring: Irregularities and breakdowns can be noticed immediately and reported
▸ Quality improvement: extremal values for good quality can be defined and observed
▸ Reliability improvement: performance of components can be correlated with the production information, the findings serve for a better product development in the future
▸ Process improvement: through information about the quality and the reliability of the component, the process can be adapted
Speedikon C functionalities
4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth
CA | Folie 29


Conclusion
TECHNISCHE UNIVERSITÄT DARMSTADT
Main Aim
Data Collection and Analysis for Process and Component Optimization in AM lifecycle
How to reach this aim:
Definition and description of the AM lifecycle
Definition of requirements and identification of important information in the lifecycle phases
Development and prototype implementation of the concept
Next Steps
• Further identification of correlations between lifecycle phases
• Evaluation of the information collected in the lifecycle phases
• Implementation of the missing lifecycle phases in the real demonstrator
• Evaluation of benefits of data management
4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth
CA | Folie 31


Thank you for your attention!
TECHNISCHE UNIVERSITÄT DARMSTADT
Questions?
Bild: TU Darmstadt / kh-architekten
4th October 2018 | Faculty 16 | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | C. Auth
CA | Folie 32

Dr.-Ing. Andreas Hintz

Andreas Hintz studied Mechanical Engineering at the Technical University of Darmstadt in the mid-1980s. Later he became a research assistant of Prof. Dr.-Ing H. Schulz at the Institute for Production Management, Technology and Machine Tools (PTW). In 1995, he finished his PhD based on nonlinear process planning of feature based designs. In his first industry position he spent one year leading a software development team at Delcam, a CAD/CAM company in Birmingham, England. In 1996 Andreas Hintz joint AMP Incorporated as a manager for Engineering and Manufacturing Systems in Europe. He moved through various internal positions into a department manager for Engineering Systems and Continuous Improvements for the Automotive Business in EMEA. From 2004 to 2007 he worked for Porsche AG where he was responsible for the Engineering Systems at the car development center at Weissach where, amongst others, he migrated Porsche's car design from Catia V4 to V5. Late in 2007 he started to work again for AMP Incorporated which by then became Tyco Electronics and later TE Connectivity (TE). Amongst other roles Andreas Hintz is responsible for all design and simulation software at TE and Director of Digital Design which is embedded into the Digital strategy of TE.

✉ ahintz@te.com

TE Connectivity

TE Connectivity Ltd. is a $13 billion global technology and manufacturing leader creating a safer, sustainable, productive, and connected future. For more than 75 years, our connectivity and sensor solutions, proven in the harshest environments, have enabled advancements in transportation, industrial applications, medical technology, energy, data communications, and the home. With 78,000 employees, including more than 7,000 engineers, working alongside customers in nearly 150 countries, TE ensures that EVERY CONNECTION COUNTS.

Feeding the Digital Thread – Moving from drawing centric to model centric engineering

Abstract

For decades, the product engineering processes focused on creating a 2D drawing as the result of the product development process. Even with the widespread introduction of 3D CAD systems in the 1980s the 3D model's main purpose was to create a 2D drawing. While for the definition of complex shaped surfaces of products engineers started to adopt 3D design and manufacturing methods the design of industrial products like connectors is still drawing centric. TE Connectivity has started a journey to move towards a model based enterprise approach for the design and manufacturing of products in the terminal and connector business. The creation of the 3D model is a process that is wide spread in industry, however, providing a 3D model into all functions of the downstream process contains many cultural as well as technological challenges. Feeding the digital thread requires the product designer to follow a more stringent process on how to model and annotate the 3D model. The Product Manufacturing Information (PMI) that used to be an unintelligent text in a 2D drawing needs to be converted into data that is semantically connected with pieces of the geometry such as features or surfaces. Downstream functions such as tooling, inspection and Quality Inspection Planning (QIP) can utilize the "digital" data. TE's Digital Manufacturing approach gathers manufacturing performance data that can be traced back into the 3D model. This way TE will implement an engineering feedback loop, which allows product engineers to understand the manufacturing performance. This information allows the product designer and engineer to understand what dimensions and tolerances bear particular challenges to the manufacturing process. With that knowledge, the designer can improve existing designs and create new products that will be optimized for the manufacturing process, which will lead to an improved operating equipment efficiency and quality of the product.

Keywords

Model Based Design/Engineering; Product Lifecycle Management; Digital Thread; 3D Accurate Modeling; CT Scanning; Digital Engineering and Manufacturing; Quality Inspection Planning; Engineering Feedback Loop.

1 Introduction

Until today most of product design activities end in the creation of a 2D drawing. Historically this is a continuation of the drafting activities when designers and engineers drew 2D views on drawings. Although 3D modeling systems such as Creo, Siemens NX, Catia, Inventor and other were already invented in the 80's and largely deployed in the 90's the result of a 3D modeling session was still a 2D drawing that was handed over to the tool making or manufacturing organizations.

The reason for providing a 2D drawing into the operations area of a company are simple:

1. The operations area needed a "design contract" that describes the part that was to be manufactured.
2. The 2D drawing conveyed all dimensions that needed to be checked in a "First Article Inspection" (FAI) report.
3. The 2D drawing was mainly made up of 2 point dimensions with tolerances.
4. The 2D drawing corresponded with the inspection technology that was available.
5. Globalization took off in the 90's and the 2D drawing was the smallest common denominator in the communication between engineering and operation that was located in different geographies.

When looking at the design process the drafting (2D drawing) process looks like a redundant piece of work to the preceding 3D modeling phase. The 3D model already contains a complete and precise definition of the 3D shape of a product. Then the designer arranges views of the product on a drawing adding dimensions and tolerances to it. At TE a complex production drawing could easily contain about 200 dimensions that needed to be added to the drawing manually. On top of that, most of the dimension needed to have a tolerance that is supporting the function of the part/product.

With the introduction of new FAI capabilities like Computer Tomography (CT) it became obvious that creating the inspection program for a product is like re-entering all Product Manufacturing Information (PMI) that was already entered into the 3D model and partially into the 2D drawing. The task at hand was to utilize the 3D model directly for the FAI process without having to reenter the 2D based dimensions. In an ideal world, that way the designer would be able to save time by not having to create a 2D drawing from a 3D model and the inspection engineer would be able to reuse the 3D model instead of having to reenter dimensions and tolerances from a 2D drawing.

The above can be described as Model Based Definition (MBD) where the 3D model becomes the single source of truth of the product development process. While this is advantageous to most companies, there are even larger advantages. If product definitions are provided as a 3D model data into the manufacturing process and all its PMI is provided as data then subsequent systems/processes Quality Inspection Planning (QIP) process would be able to collect manufacturing performance data that is related to dimensions of parts and even more would enable product designer to see the impact of their tolerancing schema on the manufacturing performance of a part.

This paper describes how the Automotive Business Unit of TE identified the benefits of using a MBD approach in product design and subsequently implemented a whole Model Based Enterprise (MBE) approach that is affecting simulation, tooling, First Article Inspection and manufacturing.

2 TE's Model Based Definition Approach

As TE designs and manufactures a large number of connector housings for our customer's applications, we started our MBD approach on these products. Housings are typically injection molded plastic components that may be reinforced with glass fiber. This adds another level of complexity, as the designed product needs to go through a process of tool design and the shape of the final physical product is impacted by manufacturability constraints like draft, shrinkage and warpage. In order to separate the artifacts and deliverables of each stage of the design process TE has defined a sequence of 3D model progressions that are necessary for our MBD approach and which typically built up on each other.

Figure 1: Example of an Automotive Heavy Duty Sealed Connector Housing

The **Basic Part Model** (BPM) represents the product geometry in an idealistic state with no manufacturing constraints. It shows straight walls with no draft on them and no determination of a split line at that phase of the modeling process.

The **Accurate Part Model** (APM) represents the BPM including the draft that is necessary to eject the part from the mold tool. The APM is what we call the digital twin in our environment it is the most accurate representation of what we want to manufacture and manufacturing results will be measured against the APM. That is the reason why TE decided that the APM needs to be the fully annotated 3D model that represents the design contract between product design and internal manufacturing facilities as well as outside suppliers.

The **Tool Instance Part Model** (TIPM) represents the APM on which compensation factors are applied that take shrinkage and warpage of the physical part into account. These factors can be applied by feature, by dimension, by direction, universally or a mixture of those. The creation of the TIPM requires much experience on how a plastic part shrinks and warps after the manufacturing process. Some of that can be simulated using molding simulation packages. The TIPM is the core model of the tool designer to design the molding tool.

The **Scan Model** represents the results of the scanning process in which the pre-production physical samples that have been manufactured are 3D scanned using Computer Tomography (CT). These scans can now be overlayed with the APM and the deviation of the real part from the designed part can be calculated at any point and direction. That helps the product designer to evaluate the part and to determine if the part can be released for production or if the TIPM needs to be adjusted to correctly produce the part within its geometric specification. The TIPM adjustment will be executed by a mold designer, which then leads to a physical change of the mold steel tool. This cycle is called tool conditioning.

In order to realize the benefits of MBD some very foundational changes had to be made in the way engineers and designers work.

2.1 Who adds manufacturability features to the 3D model?

The question of who is responsible to add a manufacturability features such as draft and shrinkage and warpage compensation into the 3D Models can become very philosophic. Typically, product designers want to be responsible for the function of the part, but not necessarily its manufacturability. To better manage the responsibility between product designers and tool designers we have separated the BPM, APM and the TIPM described above. The product designer is responsible for the BPM. The APM is a result of a collaboration between the product designer and mold tool designer. The TIPM is solely managed by the tool designer. This means that the product designer is forced into a collaborative session with the mold designer to determine the split line of the product as well as the amount of draft on non-functional surfaces. This helps to increase the project team’s accountability from the viewpoint of functionality and manufacturability.

2.2 The key is to reduce dimensions

Historically our connector designs used many point to point dimensions that were documented in drawings. We have examples of connector drawings with more than 200 dimensions many of them a simple point-to-point dimension with a plus/minus tolerance. Many if not all of these dimensions have to be measured in a First Article Inspection process to validate the physical part against the geometric specification. From looking at the ergonomics and productivity of adding annotation dimensions into a 3D model, we understood that designers would need more time to add those annotations than adding dimensions to a drawing.

We needed to find a way to reduce the amount of dimensional annotations on a 3D model to make it more attractive to the designers to accept MBD as the new design approach. Coincidently around the same time, we started first trials with CT scanning machines and found out that their inspection programming software was capable of understanding GD&T and GPS tolerances. On top of that, our customers mainly driven by Automotive demand asked for GPS based tolerancing schemas on drawings and models. In larger change project designers, product and manufacturing engineers were trained on GPS in order to create and read drawings with a reduced set of dimensions compensated by GPS tolerances. For the transition from traditional drawings to fully annotated 3D models GPS supports both 2D and 3D.

2.3 Replacing the production drawing

Not using a production drawing anymore and adding all information that used to be on a drawing into a 3D model is not trivial. The easiest portion are the dimensions, which simply become 3D annotations. Annotating a dimension or a tolerance in 3D adds a huge benefit to the comprehension. Annotations will no longer be only connected to a line or a point on a drawing, but now we can semantically connect the annotated tolerance with surfaces of the 3D model. This helps the inspection planner/programmer to unambiguously identify those surfaces of a model that need to be utilized to calculate a distance for example.

However, many of TE's drawings also contain:

1. Manufacturing notes
2. General information (title block)
3. Material information or plating instructions
4. Bill of material (BOM)
5. Configuration option tables of product assemblies
6. Pictures or 2D views of the product with different codings
7. Critical Function symbols that require frequent checks during the manufacturing process

Our aim was to initially look at those drawing elements that have potential for reuse in downstream processes and to make those machine-readable. We decided to go for the dimensions and tolerances, the BOM and the critical function symbols that are related to some of the dimensions. Being able to access those information from a 3D model would already help us enormously and will reduce reentering the same information over and over again.

For us humans, we selected a software that was able to transform the 3D model with all its different views into a 3D PDF. The idea was to provide downstream consumers of the production drawing an easy and secure access to a lightweight representation of the 3D model.

Plus, those information that are not directly connected to the model via a geometry such as manufacturing notes or the amount of regrind that is permitted for a part.

TE selected a PDF template approach where the first page(s) of the PDF is a standard text page containing mainly manufacturing and other notes and the last page contains a 3D PDF model that is converted from the APM. The creation of the 3D PDF file is automated in our PLM system and happens at the release of the product design, which is a particular gate in our phased product development process.

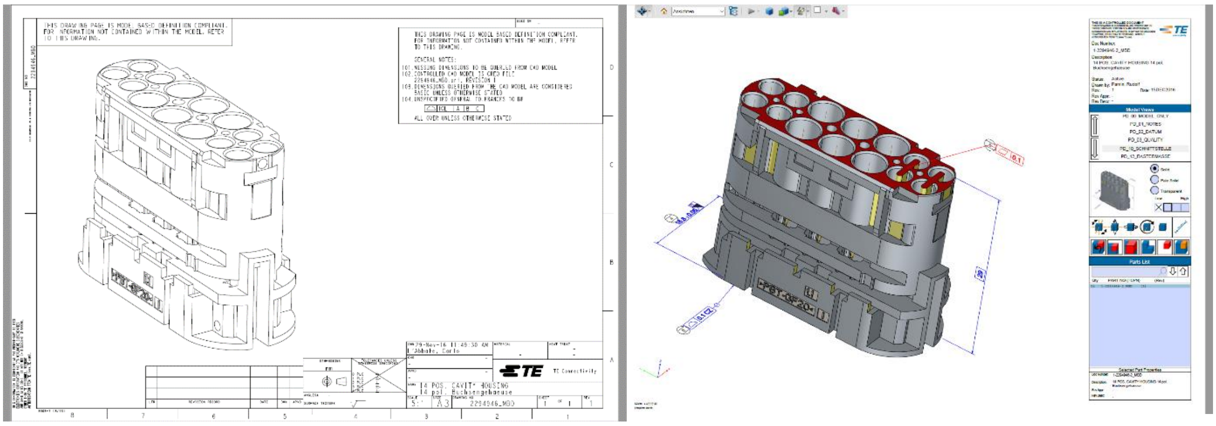


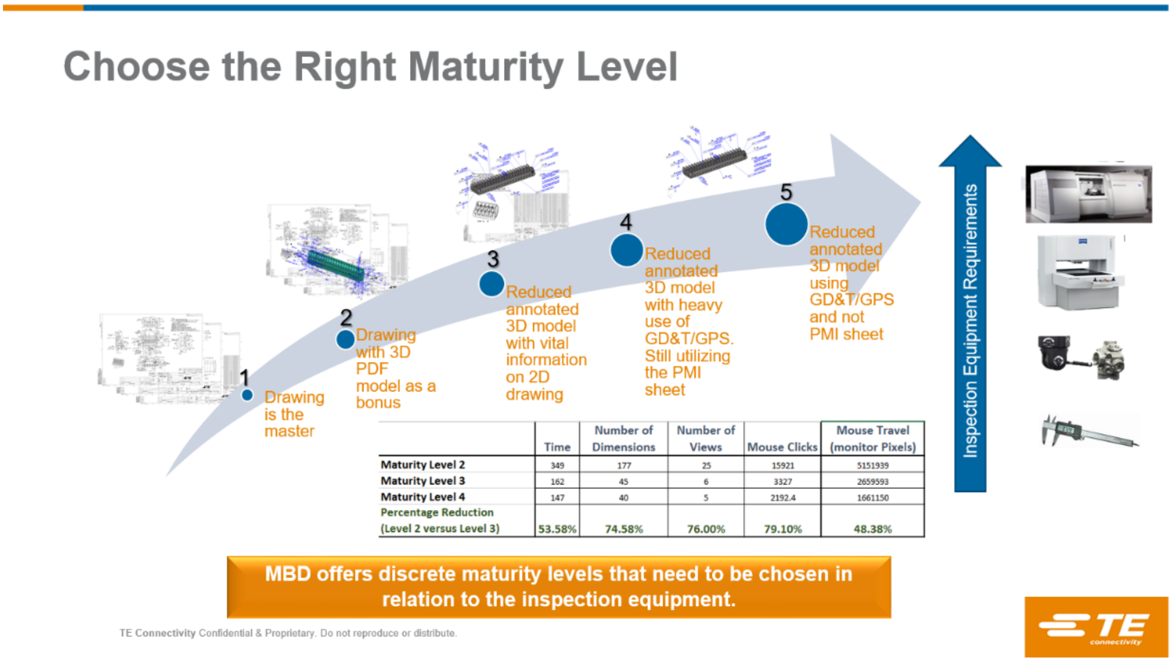
Figure 2: First and Second page of the 3D PDF file that replaces the production drawing

2.4 Finding the right MBD Maturity level

MBD is not a tool that can be installed and switched on. It is a process change that requires engineering and IT departments to work on solutions that cover tools, process but even more important skills of people. Developing products model centric instead of drawing centric requires very good CAD skills of the designers and engineers. The ability to read and design GPS tolerances even more so.

At TE we look at the different levels of MBD maturity as a continuum that allows departments with lower skills to start on a lower level and grow their capabilities.

Choosing the right level of MBD maturity is also a question of the inspection equipment. The major reason why TE is putting dimensions on drawings and 3D models is to inspect them after the part has been manufactured. Earlier in this paper, it was mentioned that GD&T and GPS had a very positive impact on the productivity of the designer. While that is true it also puts the burden on the manufacturing organizations as they now need to be able to measure and inspect a 3D based GD&T or GPS tolerance. Clearly, a profile tolerance cannot be measured with a caliper. Hence, there is a correlation between the MBD maturity level and what/how the organization can measure.



	Time	Number of Dimensions	Number of Views	Mouse Clicks	Mouse Travel (monitor Pixels)
Maturity Level 2	349	177	25	15921	5151939
Maturity Level 3	162	45	6	3327	2659593
Maturity Level 4	147	40	5	2192.4	1661150
Percentage Reduction (Level 2 versus Level 3)	53.58%	74.58%	76.00%	79.10%	48.38%

Figure 3: Maturity levels and achieved benefits related to inspection equipment

Another consideration is the path that an organization takes through the maturity levels. The two basic skills that need to be managed are “moving from point-to-point dimensions to GD&T/GPS” and “moving from a 2D drawing centric to a model centric approach”. Clearly, the top right section is the goal (see Figure 4), but how to get there and in what steps is something each engineering organization needs to determine for themselves.

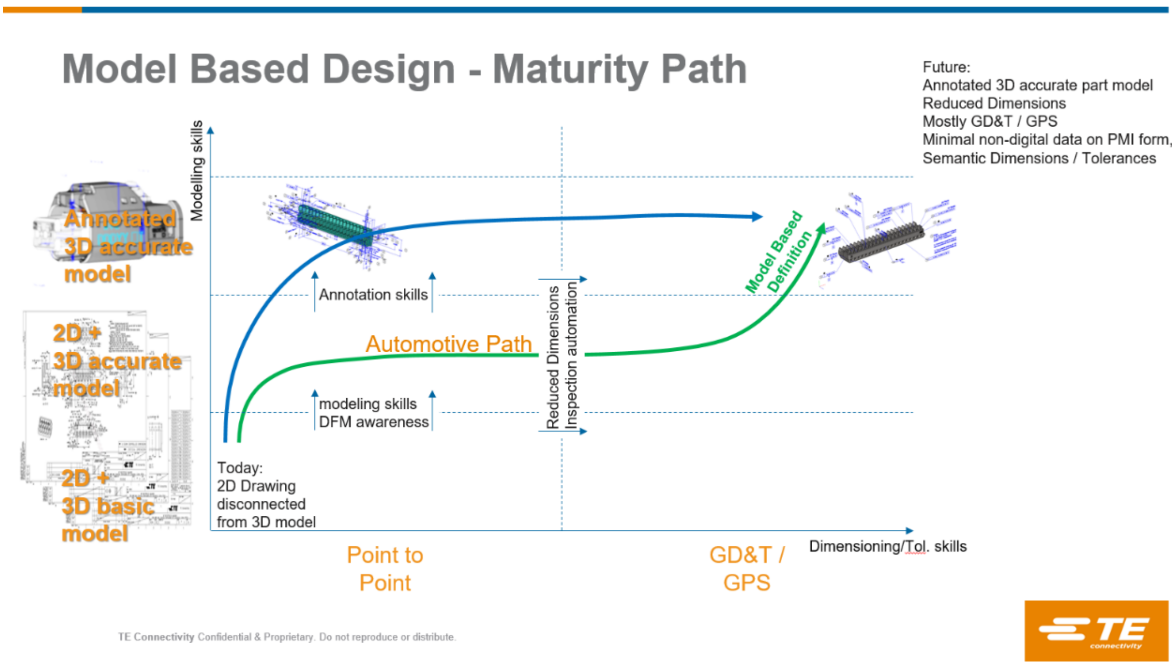


Figure 4: Maturity Path

2.5 Product Lifecycle Management (PLM) is the data backbone for MBD

On TE’s journey from drawing centric to model centric it became clear that PLM is the backbone for data and objects that are created in the engineering organizations, but are being consumed in many other functions throughout the enterprise. If engineers put BOM information on a drawing then this information is “lost” for others to be reused. Hence, TE started an initiative to put BOM and other information into structured databases that enables reuse of that information throughout the whole company and not just engineering.

TE believes that it is vital to have managed relationships between parts and documents as well as part to part relations that need to be maintained to allow all functions of TE to access the most up to date product and document information.

When comparing 3D models with each other, it is very essential to have the correct versions and revisions of the Basic Part Model, Accurate Part Model, Tool Instance Part Model, Scan Model, Simulation model, Requirements and Test Results available to the user. As the world is getting more complex around us PLM allows us to structure the information for us to make the right decisions.

3 Model Based Engineering Benefits

So far, this paper focused much on the product engineering organizations moving from drawing centric to Model Based Definition. Now we want to take a look into the benefits of utilizing the 3D model in downstream processes enabling Model Based Engineering (MBE).

Initially the MBD team at TE was very much obsessed of the idea of eliminating production drawings in the design process. In 2012/13 the team thought the major idea of MBD is to reduce the number of drawings and therefore to reduce the number of managed objects and the manual labor that goes into the creation of drawing. However, throughout the first pilot tests we found out that the productivity gains in the product development organizations are not huge. In fact, there might be none as we are frontloading product engineering with more responsibilities and duties such as Design for Inspection (adding GD&T and GPS based symbols to the 3D model).

In Figure 4 we have shown that the maturity level goes along with saving annotation time, mouse travel and number of views. However, creating the annotations on a 3D model is just a small portion of the daily routine of a designer/engineer at TE. Overall, the value stream of a 3D Accurate Part Model goes way beyond product engineering (Figure 5).

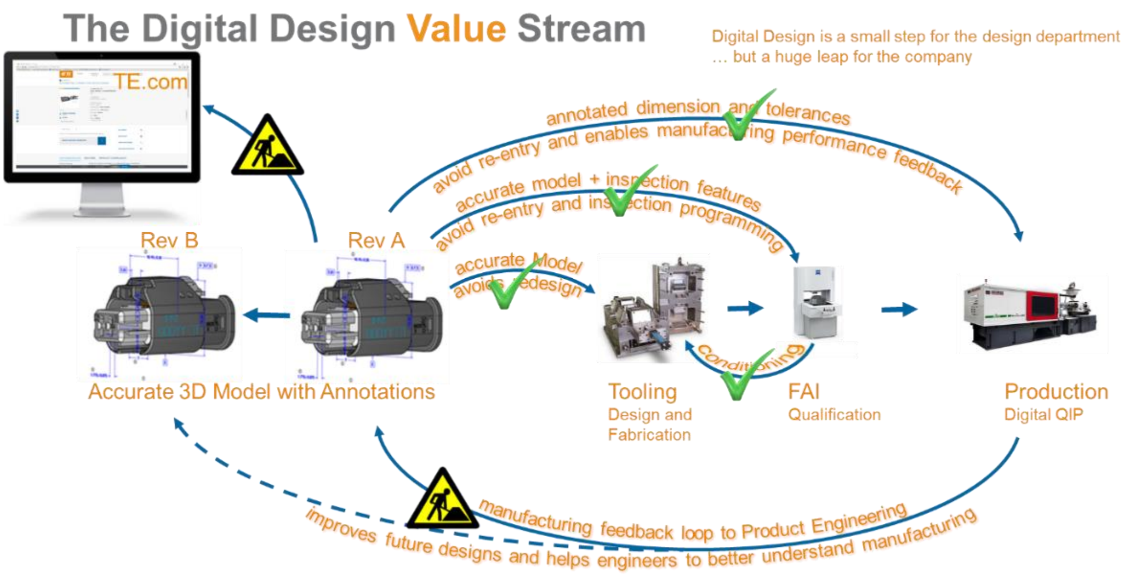


Figure 5: Value Stream of a Model Based Definition compliant 3D APM

TE has found value in various processes where 3D model information was provided to downstream processes:

a) Providing the 3D Accurate Part Model to the mold designer

As stated earlier it is almost a philosophical question as to who creates the manufacturability features into the 3D model, product engineering or manufacturing engineering (tooling). With the decision to provide Accurate Part Models to the mold tool designer the amount of redesign was reduced. At the last phase of the design adding the draft angles to the design becomes a common responsibility between the product designer and the experienced mold designer. The model is created in such a way that the mold designer "trusts" the product designer's model and reuses it rather than recreating it from scratch.

b) Providing the 3D Accurate Part Model to the inspection programmer for the FAI

One of the strongest value streams is in the use of the 3D Accurate Part Model for the First Article Inspection. Due to the nature of TE's products, tactile measuring machines are not able to reach into many of our contact cavities in a plastic housing. Thus, destroying measuring approaches had to be used in order to measure details inside a housing. Those are time consuming and not perfectly accurate. The utilization of CT scanning technology enabled us to scan a part in about 30 minutes. The inspection programming can be separated from the actual scan and today is centralized in a TE service center in India. What used to take days can now be done in hours; the inspection software can read the 3D model and even interpret the GD&T and GPS tolerances. There is almost no need for entering data that was already entered into the 3D model.

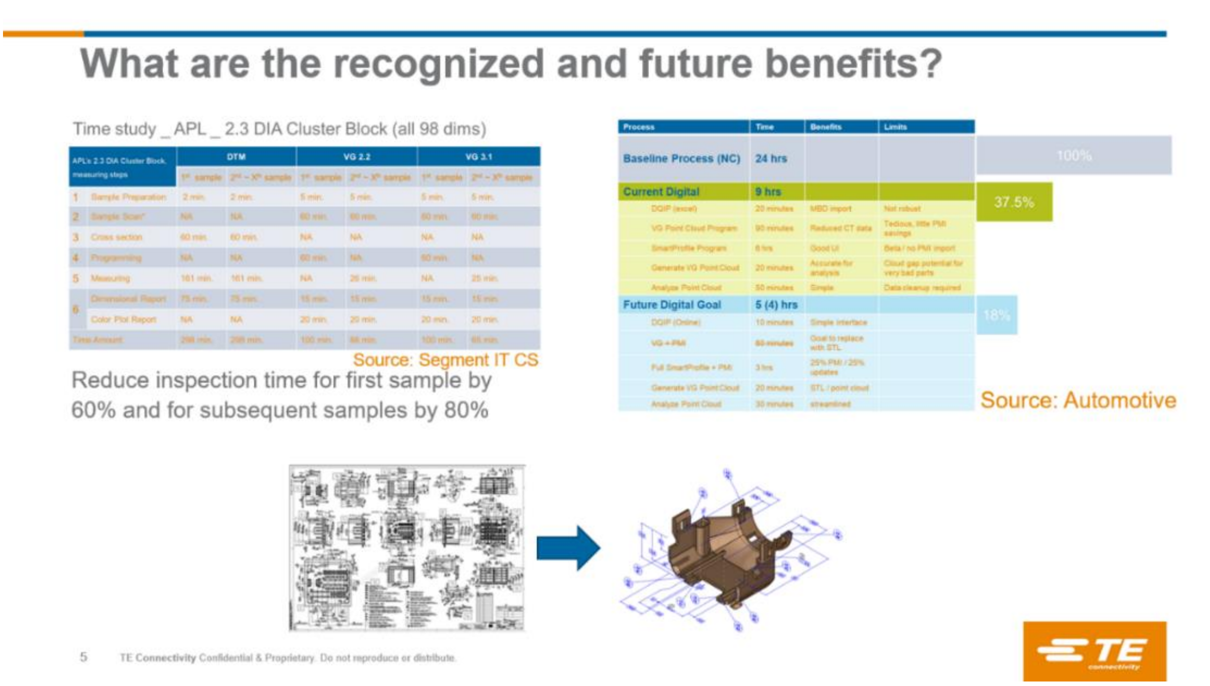


Figure 6: Benefits of First Article Inspection utilizing the 3D Accurate Part Model

c) Utilizing a model based approach for semi-automated TIPM compensation

Utilizing the APM, TIPM and the Scan Model allows us to reduce the conditioning loops for tool design. A conditioning loop is necessary if the result of the FAI process is not satisfying the product engineer and tool changes need to compensate shrinkage or warpage. In order to automate the correction or compensation of the Tool Instance Part Model we have worked with a CT scanning company to develop a compensation algorithm that takes into account the deviation between the APM and the scanned model as well as the TIPM and calculates a new version of a TIPM that compensates for those warpages and shrinkages recognized in the scanned model. The results are showing us that we can reduce the number of conditioning cycles.

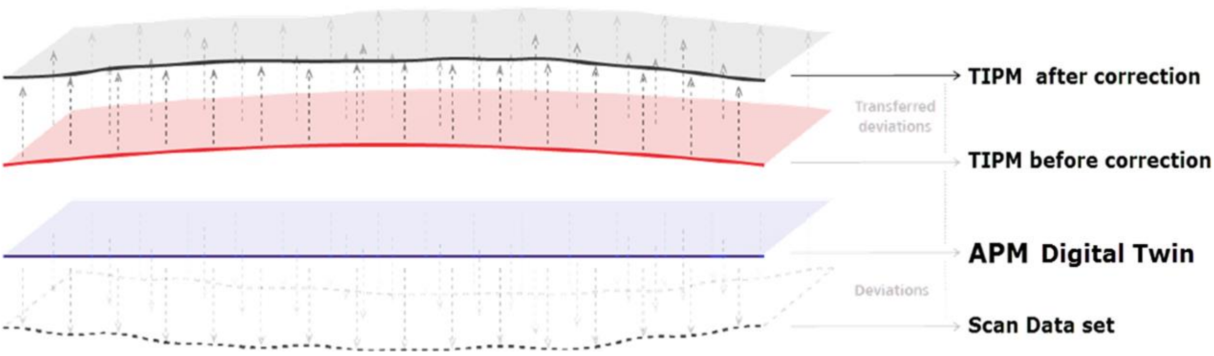


Figure 7: TIPM correction based on the Accurate Part Model and the Scan Model data

d) Providing an extract of 3D Accurate Part Model annotations to the Quality Inspection Plan (QIP)

TE creates Quality Inspection Plans that determine how a part production is being monitored and what dimensions need to be measured and how frequently.

The way we define annotations with dimensions and tolerances we can extract those from the CAD model and enter them into a XML structure. This XML structure can be read by our Manufacturing Execution System (MES) and the operation can enter measurement results directly into the MES system against those dimensions and characteristics that have been defined in the QIP.

This is saving time not having to reentering information and transferring the data without typos. More importantly though it allows the MES system to record the QIP measuring data back into a data base that keeps that information as data and not just on a piece of paper as in the past.

e) Future value streams that are not explored yet

There are some yet-to-come value streams that were identified but not yet developed.

- *Feedback loop from manufacturing to engineering*

Once we have a massive amount of data gathered on the manufacturing performance of a part TE believes that this data can be used to be feed back to the designer/engineer to better understand the implications of a very tight tolerance for example. As we all know tolerances drive the manufacturing cost and in our case also the operating equipment efficiency (OEE). We believe that the feedback of manufacturing performance information leads to a more robust designed part that also improves OEE and thus reduces manufacturing cost. A pilot of this will be started in 2018.

- *Providing information faster to TE.com*

Providing information faster to the customer is always worth striving for. In our current environment, we convert Accurate Part Models long after they have been released into Customer View Models (CVM). These are lightweight models that lack certain Intellectual Properties (IP) that TE wants to protect. CVMs are typically download collaterals from our TE.com web page. With the MBD approach, we would like to dedicate a view of the 3D Accurate Part Model to the Customer View Model. The idea is to create one additional view in the CAD system that suppresses certain features that represent IP. Since this is not a major task for the product designer we believe that this can accelerate the availability of CVMs and will make them available at the time the part is internally released for production.

4 Future Development

As mentioned previously the whole MBD approach was initially piloted for plastic housings only. We have just started to look into metal components as well as metal/plastic combined products. The reason for the delay was mainly that the CT scanning process was not providing the expected results for products that consisted of metal parts stitched into plastic housings. With technology progressing we will look into this and apply CT scanning to even more components and products of TE.

Currently we are actively working on the engineering feedback loop to provide manufacturing performance data back to the engineers and designers. Due to the large amount of data that is gathered from a one-year period of production, we believe that Artificial Intelligence can help us drawing the right conclusion from that data and improving our products and manufacturing processes.

Other areas where we still utilize unstructured data is the whole Requirements – Design – Virtual Validation – Physical Validation process. In an ideal world, requirements translate into design features, designs can be validated through simulation and later against physical tests. Today each of these domains create their own set of reports, but no data that can be compared with each other.

5 Acknowledgements

I would like to thank my manager Irina Novikova who supported me to write this paper and to present at the conference.

I also would like to thank the Model Based Definition team Mike McCaffrey, Holger Ostroske, Balazs Ludvig, Zach Miller and Ryan Gelotte for their great work and vision that they shared with me in countless sessions.

Feeding the Digital Thread

Moving from drawing centric to model centric engineering

Dr.-Ing. Andreas Hintz, Oct 2018

EVERY CONNECTION COUNTS

OUR PURPOSE

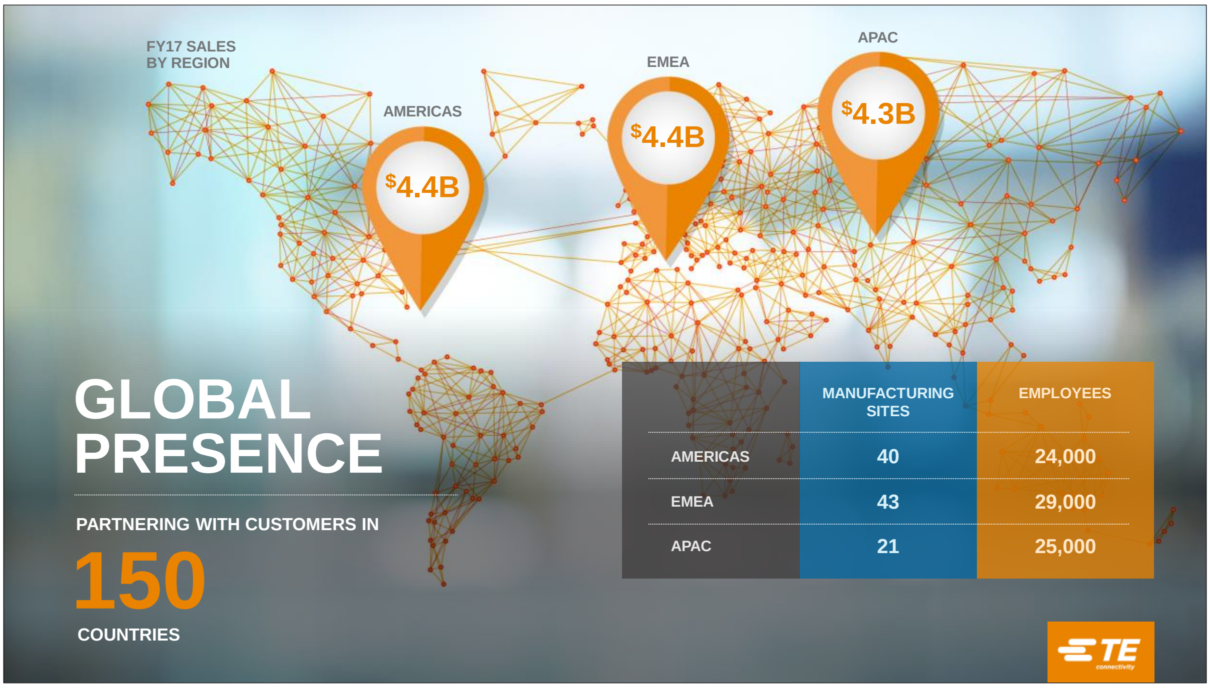
WE CREATE A SAFER, SUSTAINABLE, PRODUCTIVE AND CONNECTED FUTURE.

ADVANCING THE FUTURE OF TRANSPORTATION

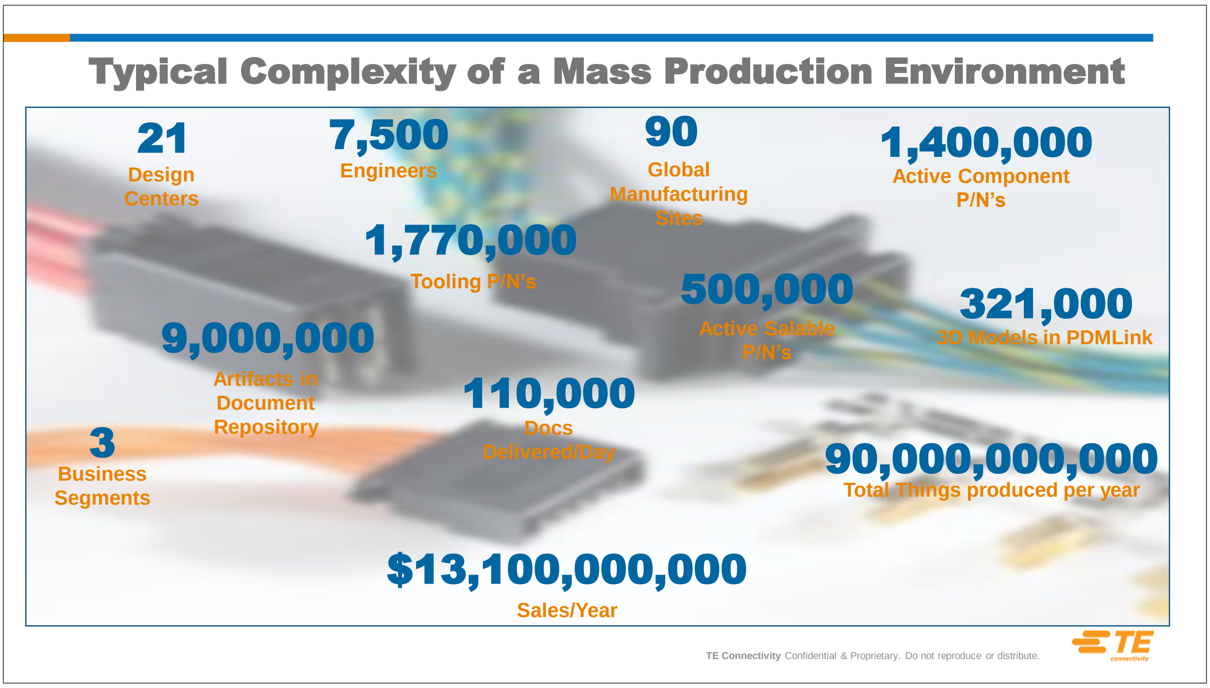
MAKING FACTORIES & HOMES SMARTER

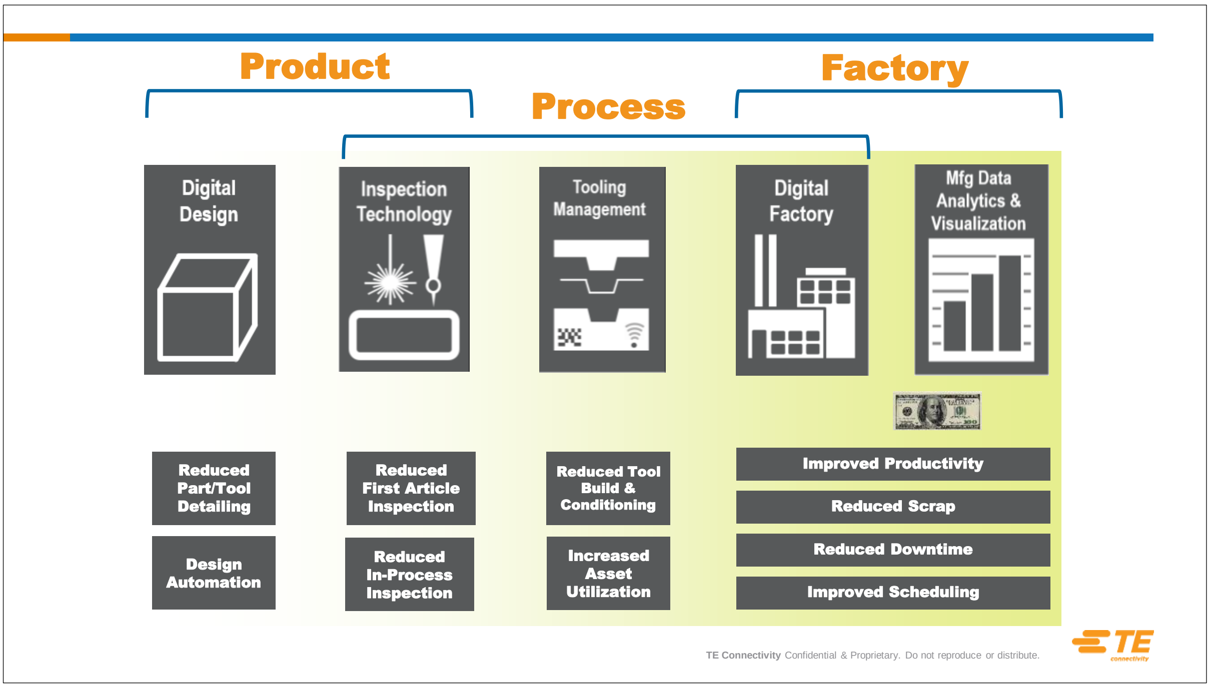
ENABLING GLOBAL COMMUNICATION NETWORKS

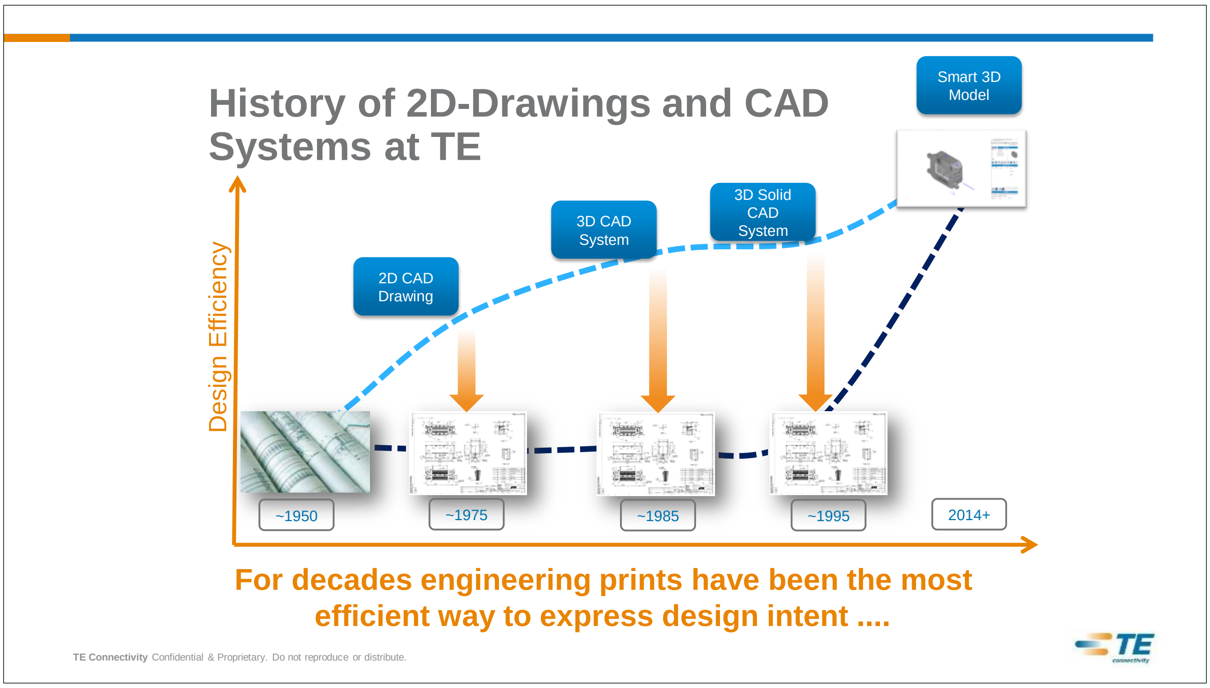
REVOLUTIONIZING MEDICAL TECHNOLOGY

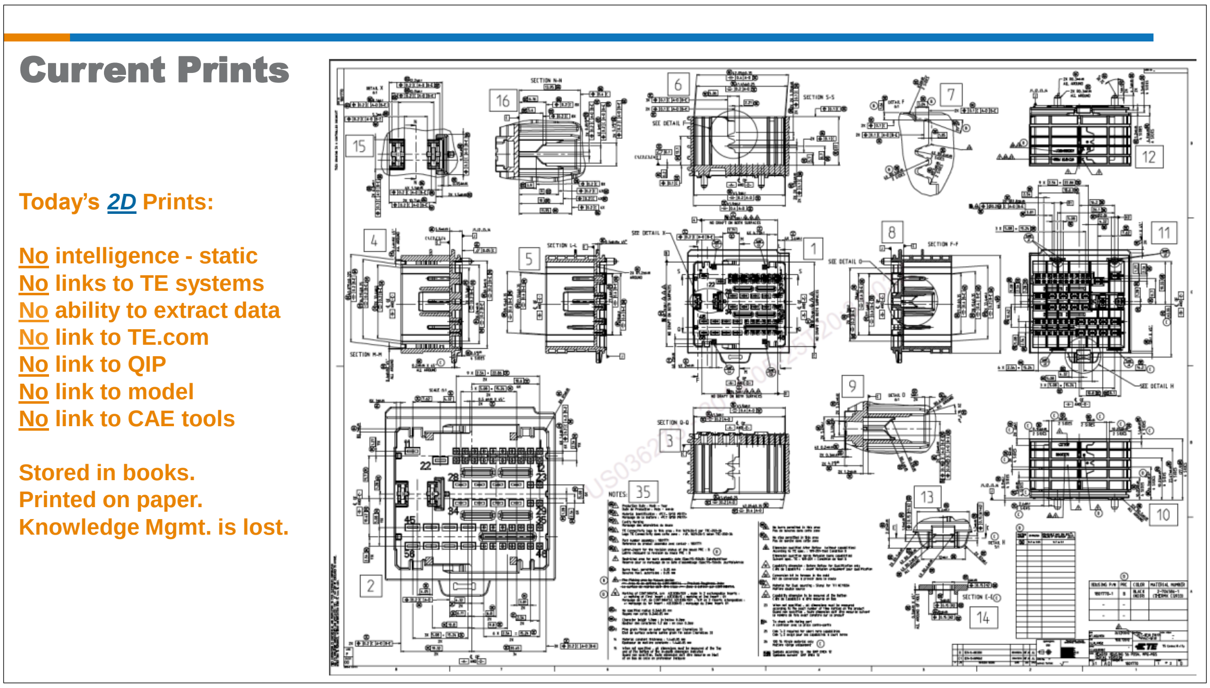


	MANUFACTURING SITES	EMPLOYEES
AMERICAS	40	24,000
EMEA	43	29,000
APAC	21	25,000

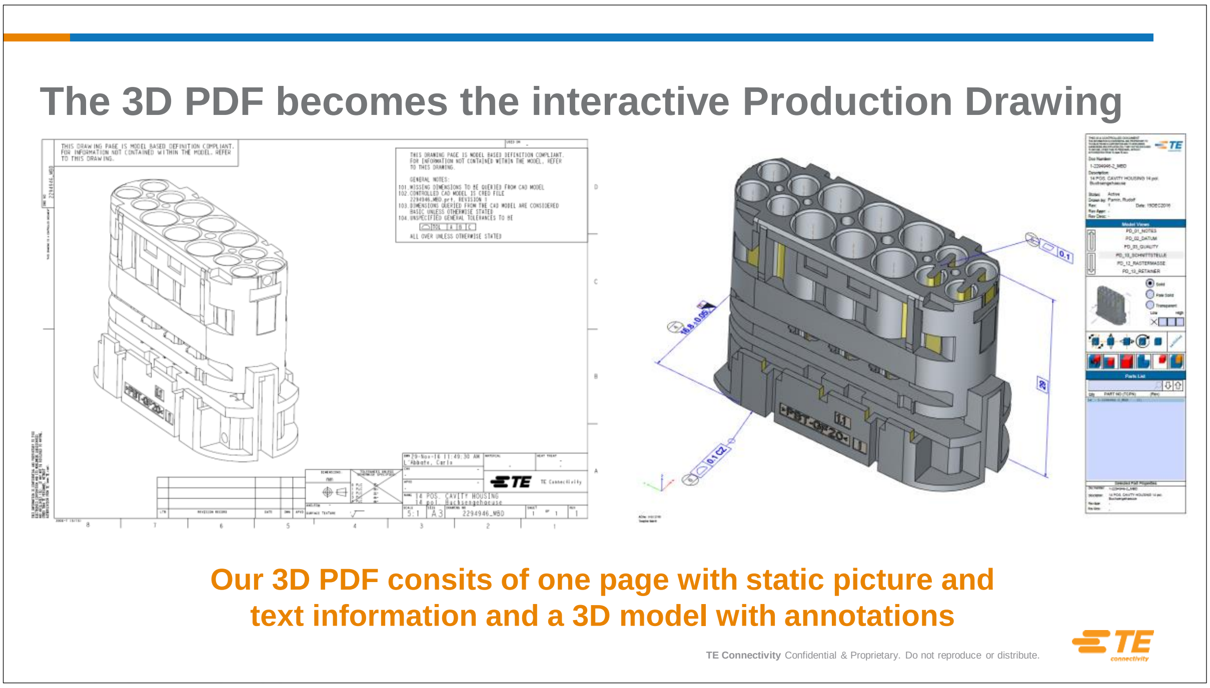

Typical Complexity of a Mass Production Environment
21
Design Centers
7,500
Engineers
90
Global Manufacturing Sites
1,400,000
Active Component P/N's
1,770,000
Tooling P/N's
500,000
Active Salable P/N's
321,000
3D Models in PDMLink
9,000,000
Artifacts in Document Repository
110,000
Docs Delivered/Day
3
Business Segments
90,000,000,000
Total Things produced per year
$13,100,000,000
Sales/Year
TE Connectivity Confidential & Proprietary. Do not reproduce or distribute.


Product
Process
Factory
Digital Design
Inspection Technology
Tooling Management
Digital Factory
Mfg Data Analytics & Visualization
Reduced Part/Tool Detailing
Reduced First Article Inspection
Reduced Tool Build & Conditioning
Improved Productivity
Reduced Scrap
Design Automation
Reduced In-Process Inspection
Increased Asset Utilization
Reduced Downtime
Improved Scheduling
TE Connectivity Confidential & Proprietary. Do not reproduce or distribute.

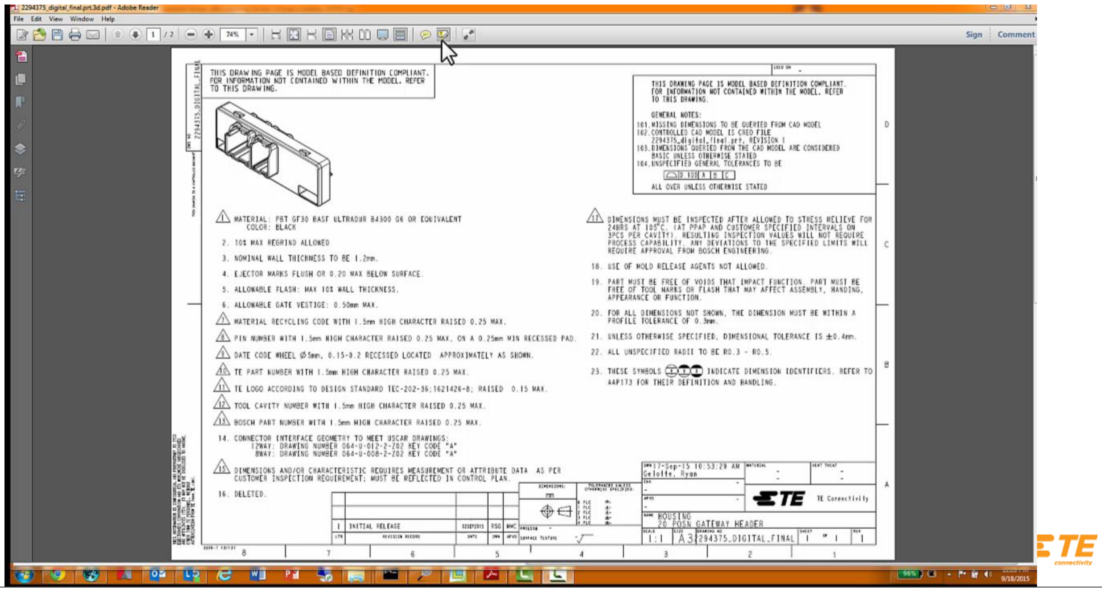

History of 2D-Drawings and CAD Systems at TE
Smart 3D Model
3D Solid CAD System
3D CAD System
2D CAD Drawing
Design Efficiency
~1950
~1975
~1985
~1995
2014+
For decades engineering prints have been the most efficient way to express design intent ....
TE Connectivity Confidential & Proprietary. Do not reproduce or distribute.
TE connectivity


Current Prints
Today's 2D Prints:
No intelligence - static
No links to TE systems
No ability to extract data
No link to TE.com
No link to QIP
No link to model
No link to CAE tools
Stored in books.
Printed on paper.
Knowledge Mgmt. is lost.

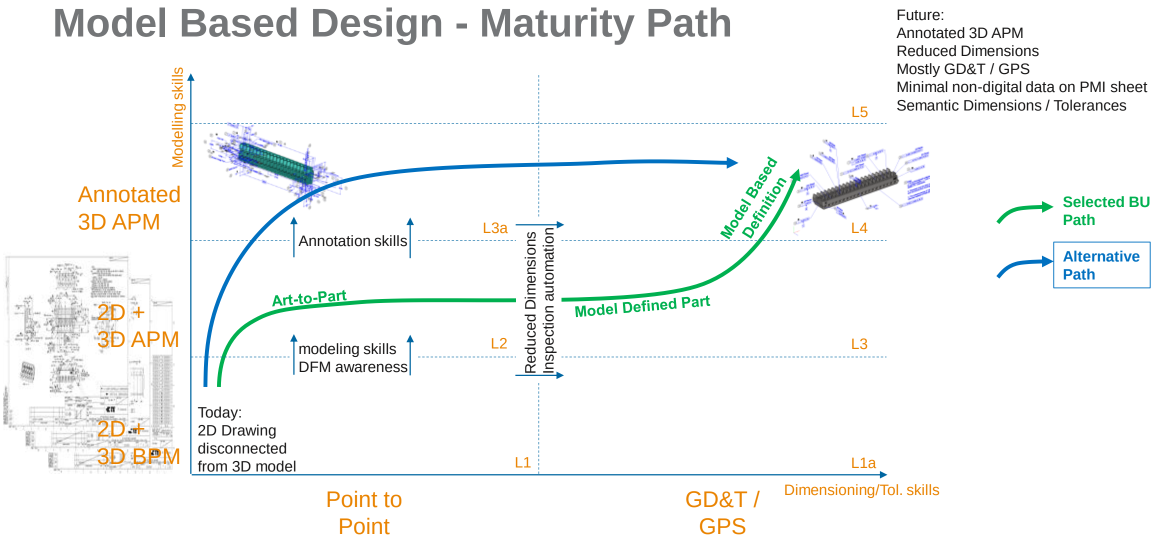

Product Design
Tooling
Inspection
Traditional
Current MdP
Future MBD
Tool Drawing
Paper
Digital OIP
8
TE


The 3D PDF becomes the interactive Production Drawing
Our 3D PDF consits of one page with static picture and
text information and a 3D model with annotations
TE Connectivity Confidential & Proprietary. Do not reproduce or distribute.
TE connectivity

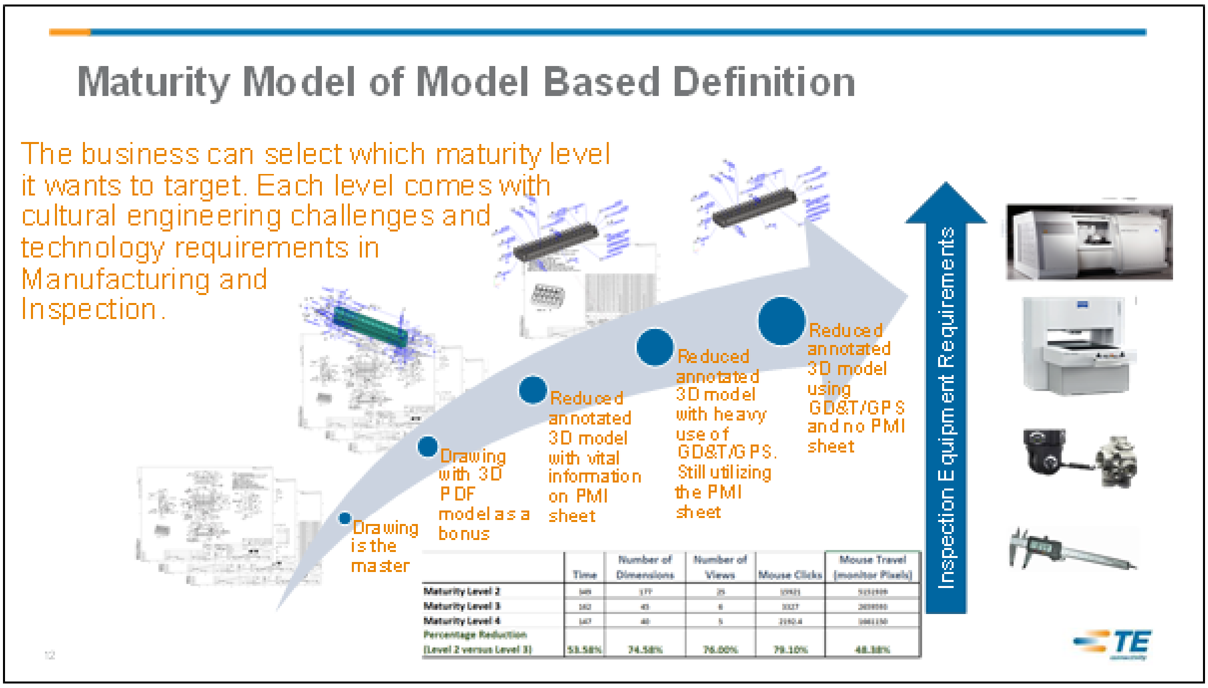
Embedded 3D PDF



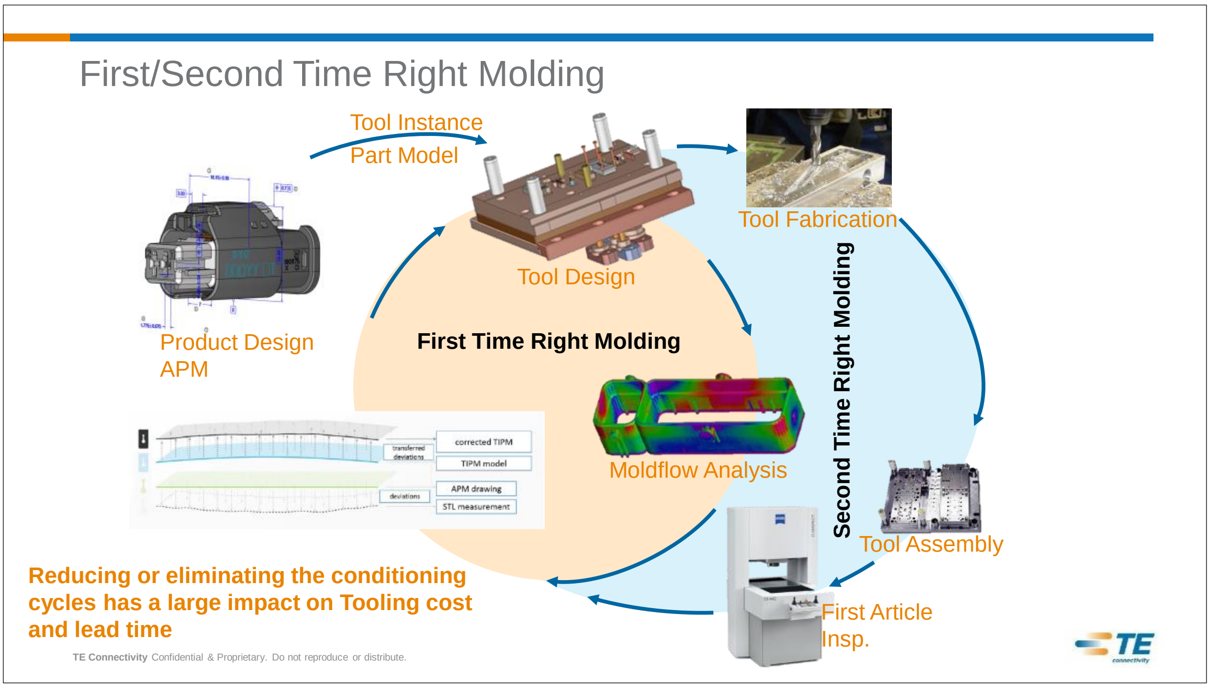
Model Based Design - Maturity Path



13



	Time	Number of Dimensions	Number of Views	Mouse Clicks	Mouse Travel (monitor Pixels)
Maturity Level 2	349	177	25	15921	[illegible]
Maturity Level 3	162	45	6	3327	[illegible]
Maturity Level 4	147	40	5	2192.4	[illegible]
Percentage Reduction (Level 2 versus Level 3)	53.58%	74.58%	76.00%	79.10%	48.38%



What are the recognized and future benefits?

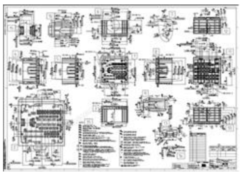
Time study _ APL _ 2.3 DIA Cluster Block (all 98 dims)

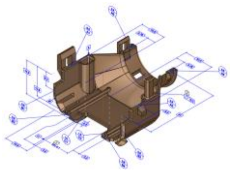
APL's 2.3 DIA Cluster Block, measuring steps		DTM		VG 2.2		VG 3.1	
		1st sample	2nd ~ Xth sample	1st sample	2nd ~ Xth sample	1st sample	2nd ~ Xth sample
1	Sample Preparation	2 min.	2 min.	5 min.	5 min.	5 min.	5 min.
2	Sample Scan*	NA	NA	60 min.	60 min.	60 min.	60 min.
3	Cross section	60 min.	60 min.	NA	NA	NA	NA
4	Programming	NA	NA	60 min.	NA	60 min.	NA
5	Measuring	161 min.	161 min.	NA	26 min.	NA	25 min.
6	Dimensional Report	75 min.	75 min.	15 min.	15 min.	15 min.	15 min.
	Color Plot Report	NA	NA	20 min.	20 min.	20 min.	20 min.
Time Amount		298 min.	298 min.	100 min.	66 min.	100 min.	65 min.

* No labor time

Reduce inspection time for first sample by 60% and for subsequent samples by 80%

Process	Time	Benefits	Limits	
Baseline Process (NC)	**24 hrs**			100%
Current Digital	**9 hrs**			37.5%
DQIP (excel)	20 minutes	MBD import	Not robust	
VG Point Cloud Program	90 minutes	Reduced CT data	Tedious, little PMI savings	
SmartProfile Program	6 hrs	Good UI	Beta / no PMI import	
Generate VG Point Cloud	20 minutes	Accurate for analysis	Cloud gap potential for very bad parts	
Analyze Point Cloud	50 minutes	Simple	Data cleanup required	
Future Digital Goal	**5 (4) hrs**			18%
DQIP (Online)	10 minutes	Simple interface		
~~VG + PMI~~	~~60 minutes~~	Goal to replace with STL		
Full SmartProfile + PMI	3 hrs	25% PMI / 25% updates		
Generate VG Point Cloud	20 minutes	STL / point cloud		
Analyze Point Cloud	30 minutes	streamlined		

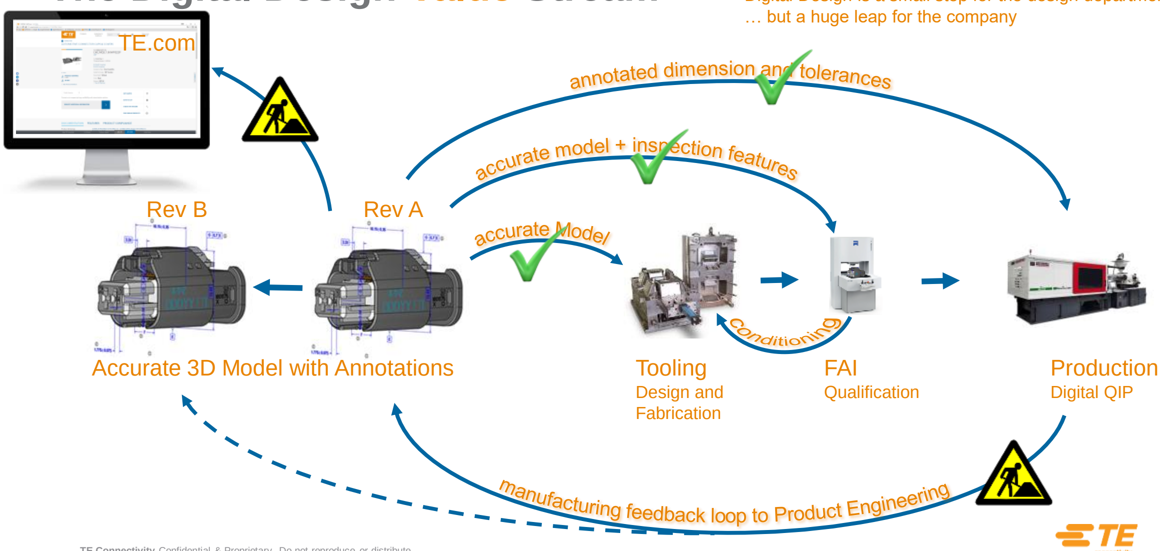




15 **TE Connectivity** Confidential & Proprietary. Do not reproduce or distribute.

The Digital Design **Value** Stream

Digital Design is a small step for the design department
… but a huge leap for the company



TE Connectivity Confidential & Proprietary. Do not reproduce or distribute.

Thank you for your attention!

Your questions please!

17 **TE Connectivity** Confidential & Proprietary. Do not reproduce or distribute.

Dipl.-Betriebsw. Marcus Goerke

Marcus Goerke studied business administration at the Beuth University of Applied Sciences (previously the Technische Fachhochschule Berlin), majoring in business informatics, finance and marketing. Simultaneously, he completed his traineeship at an international company. Marcus has been working for UNITY AG as the head of both the automotive business area and the Berlin office since 2012. He is responsible for projects in restructuring and logistics management to improve corporate performance. In addition, he gained many years of professional experience as the managing director of a management-consulting firm, in particular in the following areas: automotive, transport & logistics and commerce & services.

✉ marcus.goerke@unity.de

Unity AG

UNITY is a management consultancy with a focus on future-oriented corporate management. We elevate innovative strength and operational excellence of our clients. Since 1995 UNITY has successfully completed over 1.000 projects. Clients from the automotive, aerospace, manufacturing, health and medical technology, energy, pharmaceuticals, and chemical industries trust our expertise – from SMEs to Global Players. We are present at 14 locations worldwide, one in São Paulo, and implement projects around the globe. Our close link with the Heinz Nixdorf Institute guarantees consulting services based on the current state of research for our clients. We understand the topics and technologies of tomorrow. As a management consultancy for future-oriented corporate management, we make our clients fit for the markets of the future: Together we increase our clients' operational excellence and innovative power – always with the goal of ensuring long-term success. Using innovative processes and business models, we show that the increase of productivity and revenue is compatible with overriding goals such as creating a sustainable and viable environment and society.

UNITY
CONSULTING & INNOVATION

Challenges, strategies and practices in the automotive industry: Changing the product development to become a mobility service provider

Abstract

Megatrends like digitization, electrification, urbanization and shared economy have an enormous impact on the automotive industry. The future car will be electrified, autonomous, connected and regularly updated. This means that OEMs need to change their current product development, value chain and remodel their businesses into a mobility service offering company [VDE2016]. The automotive OEM have to change their business models to survive in new competitions as the automotive industry changes from producing cars to offering mobility services. As consequence OEM have to change their product development from "products to services", from "producing to managing ecosystems of network players" and from "hardware to software, data driven services and platforms". In a fast changing environment, it becomes crucial to be able to adapt to changes and develop services at rapid speed. This leads to a significant challenge for all network partners: trans-forming into an adaptive and agile organization. This presentation will display strategies and best practices in the automotive industry. OEM are changing their "Product Development Process" to be able to develop mobility service. Without new digital capabilities they will not be able to survive: How do they have to change their Product Life-Cycles, what does System Engineering add to that challenge and what does the digital twin offer with that respect– a virtual copy of every car that is being build? What does agile management mean and where is it recommended to meet new challenges? Why is managing "Data as the new oil" crucial to survive? The speech will tackle this questions with practical examples from the automotive industry. The talk will show best practices and challenges of the agile way of working. It will also show the way of digital transformation by implementing the idea of a "digital hub". Furthermore, the talk will reveal insight on current observations and lessons learned while transforming the organization of the OEMs. Finally, recommendations to cope with the changing conditions for different stakeholders will be displayed. Including in this, OEM and supplier industry, system partner like software companies, Start-ups and innovation partner companies as well as the individuals working within this environment are considered.

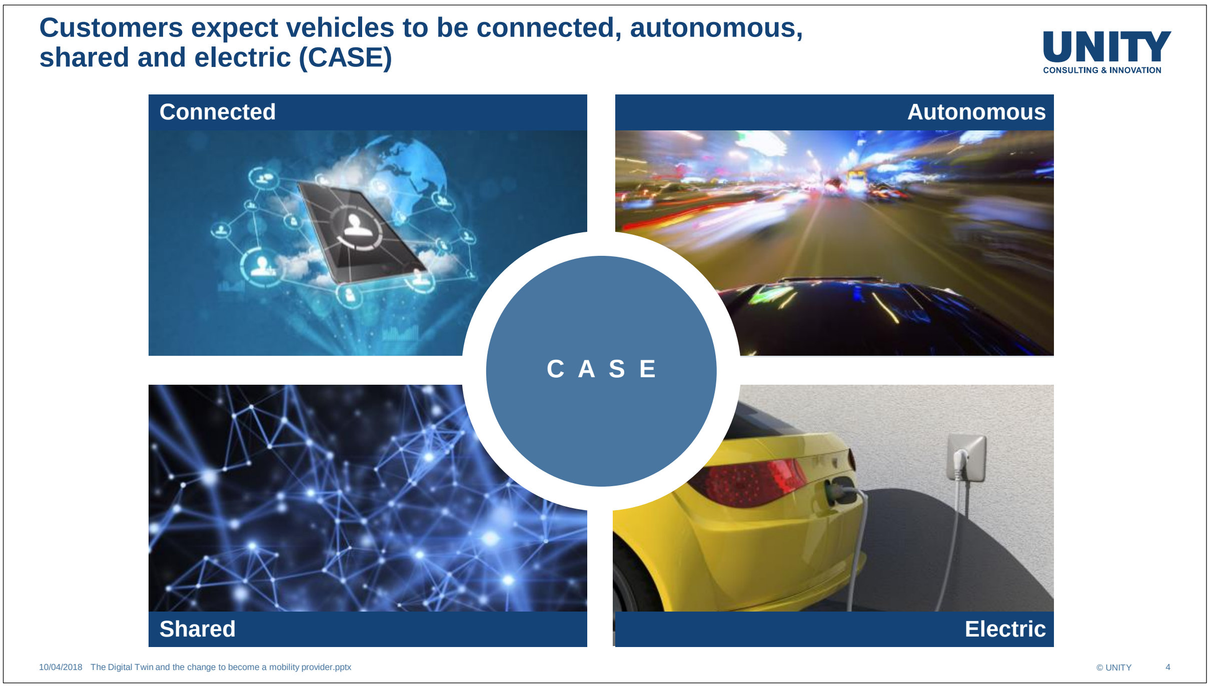
Keywords

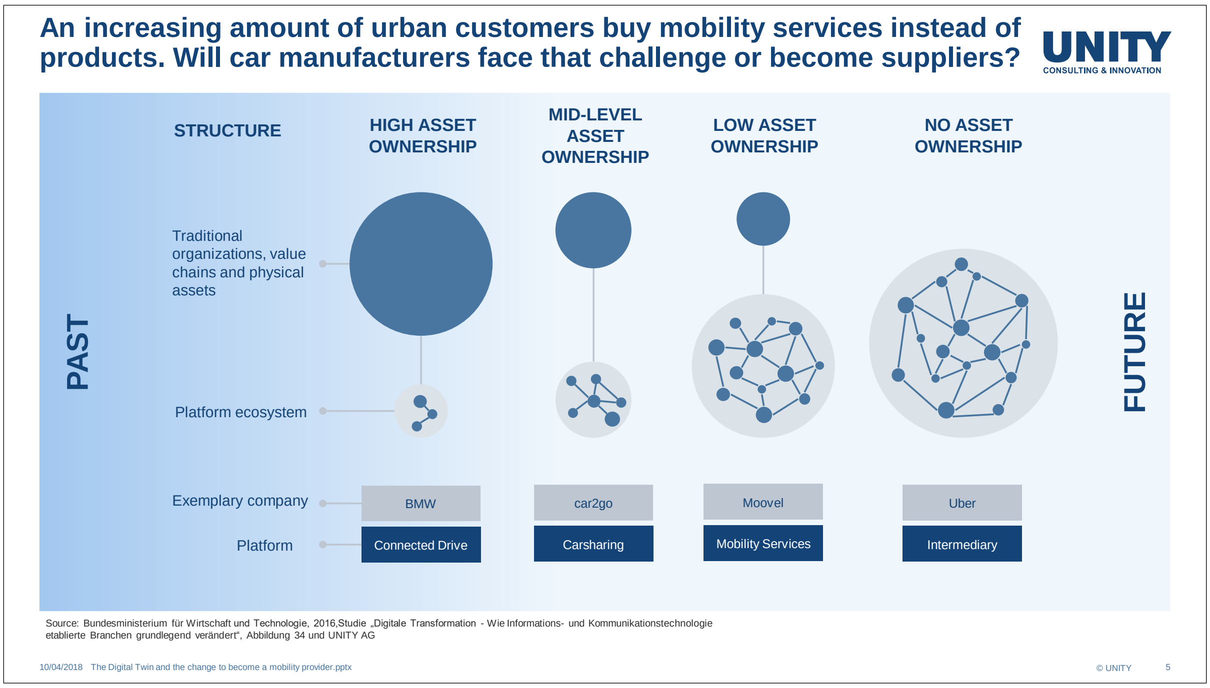
Digital Product Development; Digital Twin; Automotive Industry; Organizational Change; Mobility Services; Data Driven Services; Agile organization; Platform Economy; Digital Transformation; OEM.

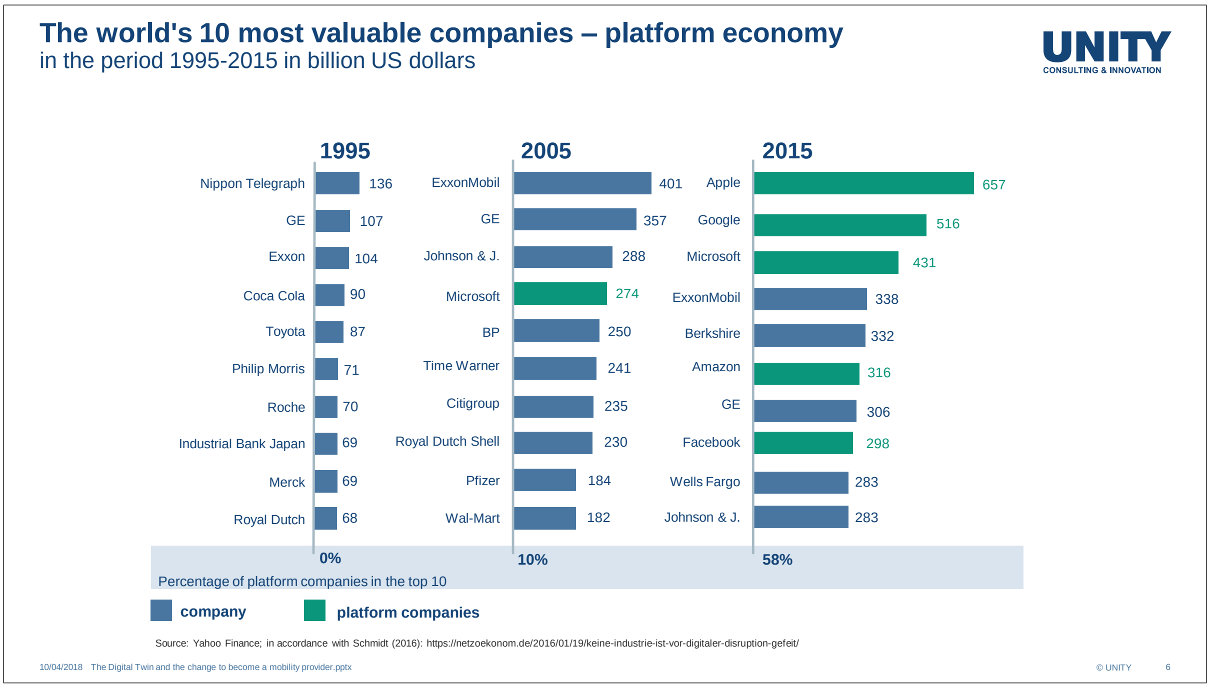
Global Trends & Challenges

What does that mean to the Automotive Industry?


Megatrends set the framework – and influence customer expectations'
UNITY
CONSULTING & INNOVATION
1 Digitalization
2 Connectivity
3 Urbanization
4 Social Dynamics
5 Sustainability
6 Platforms
10/04/2018 The Digital Twin and the change to become a mobility provider.pptx
© UNITY 3


Customers expect vehicles to be connected, autonomous, shared and electric (CASE)
UNITY
CONSULTING & INNOVATION
Connected
Autonomous
C A S E
Shared
Electric
10/04/2018 The Digital Twin and the change to become a mobility provider.pptx
© UNITY 4


An increasing amount of urban customers buy mobility services instead of products. Will car manufacturers face that challenge or become suppliers?
UNITY
CONSULTING & INNOVATION
STRUCTURE
HIGH ASSET OWNERSHIP
MID-LEVEL ASSET OWNERSHIP
LOW ASSET OWNERSHIP
NO ASSET OWNERSHIP
PAST
FUTURE
Traditional organizations, value chains and physical assets
Platform ecosystem
Exemplary company
Platform
BMW
Connected Drive
car2go
Carsharing
Moovel
Mobility Services
Uber
Intermediary
Source: Bundesministerium für Wirtschaft und Technologie, 2016,Studie „Digitale Transformation - Wie Informations- und Kommunikationstechnologie etablierte Branchen grundlegend verändert", Abbildung 34 und UNITY AG
10/04/2018 The Digital Twin and the change to become a mobility provider.pptx
© UNITY
5

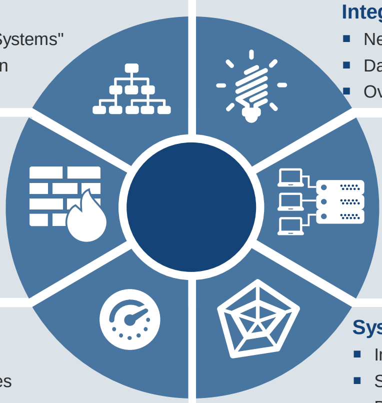

The world's 10 most valuable companies – platform economy
in the period 1995-2015 in billion US dollars
UNITY
CONSULTING & INNOVATION
1995
Nippon Telegraph 136
GE 107
Exxon 104
Coca Cola 90
Toyota 87
Philip Morris 71
Roche 70
Industrial Bank Japan 69
Merck 69
Royal Dutch 68
0%
2005
ExxonMobil 401
GE 357
Johnson & J. 288
Microsoft 274
BP 250
Time Warner 241
Citigroup 235
Royal Dutch Shell 230
Pfizer 184
Wal-Mart 182
10%
2015
Apple 657
Google 516
Microsoft 431
ExxonMobil 338
Berkshire 332
Amazon 316
GE 306
Facebook 298
Wells Fargo 283
Johnson & J. 283
58%
Percentage of platform companies in the top 10
company
platform companies
Source: Yahoo Finance; in accordance with Schmidt (2016): https://netzoekonom.de/2016/01/19/keine-industrie-ist-vor-digitaler-disruption-gefeit/
10/04/2018 The Digital Twin and the change to become a mobility provider.pptx
© UNITY
6

Therefor: OEMs and Suppliers product development (“Technische Entwicklung”) have to cope with massive increase of requirements

UNITY CONSULTING & INNOVATION

Complexity management
- Integration of the product into a "System of Systems"
- Steadily increasing degree of individualization
- Compatibilities must be ensured

Integrated data networking
- Networking within the development processes
- Data must be consistent and available
- Overcoming system breaks



Safety & Security
- Security of all involved users but also security against external system manipulation
- High development effort
- Integration of Safety & Security aspects into the process landscape

Data-driven innovation and development
- Collection, processing and use of system and user data
- Targeted product and service development based on concrete data

Speed & Time to Market
- Accelerated market
- Inclusion of electronics, software and services
- Technical up-to-date of the product is decisive

System architecture
- Increasing networking
- System boundaries are shifting
- Demand for sustainable architecture

How can OEMs transform their organization to meet this exponential growth in requirements?

10/04/2018 The Digital Twin and the change to become a mobility provider.pptx 7

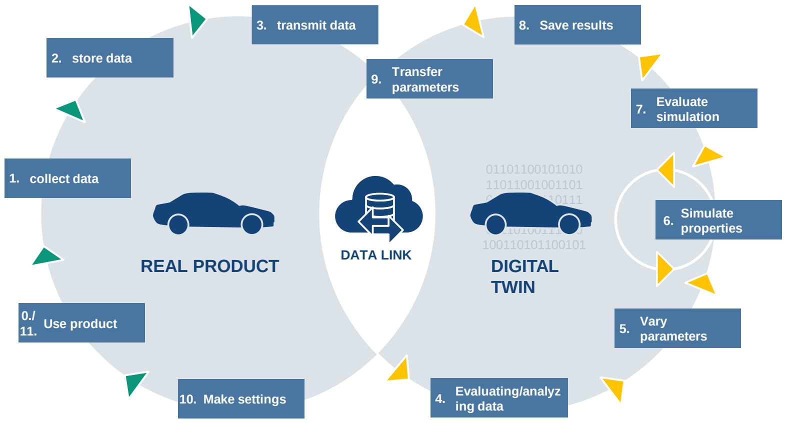
Strategies and Best Practices

How can OEMs meet the challenges?

1. **Combine real and digital world**
2. **Establish new architecture**
3. **Make use of data**
4. **Become agile and faster**
5. **Change organization**

Cars will be ONE part of a Digital Service: Consequently, a "Digital Twin" is a necessity

UNITY CONSULTING & INNOVATION

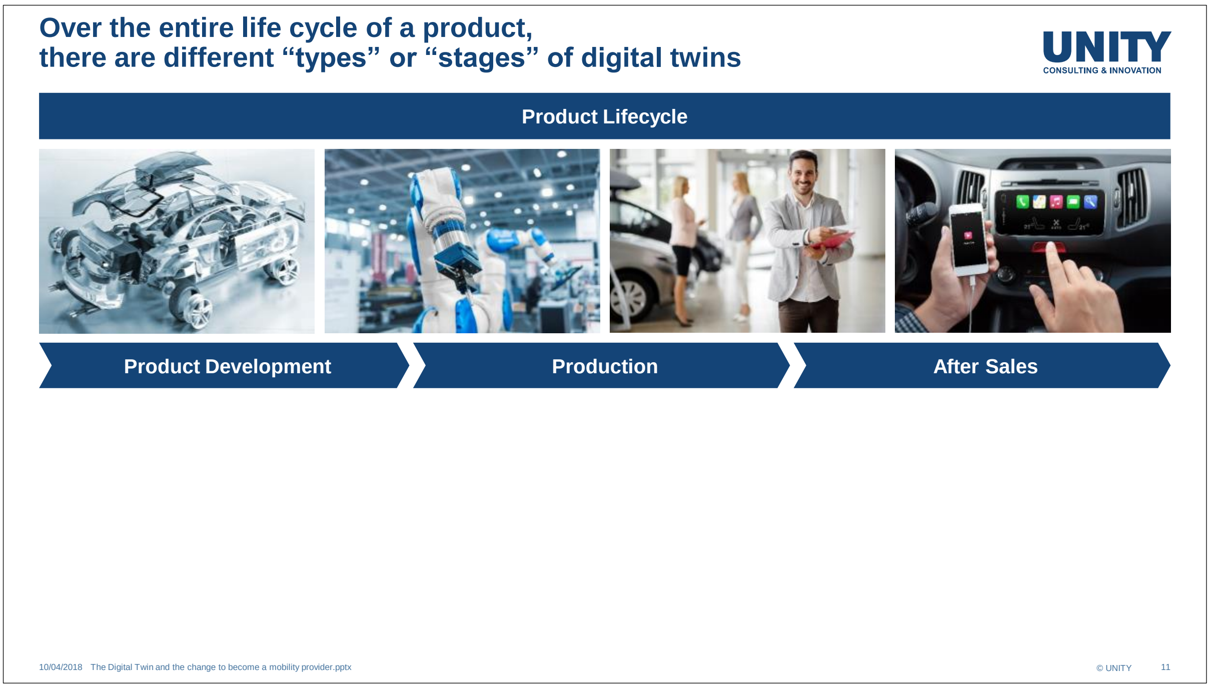


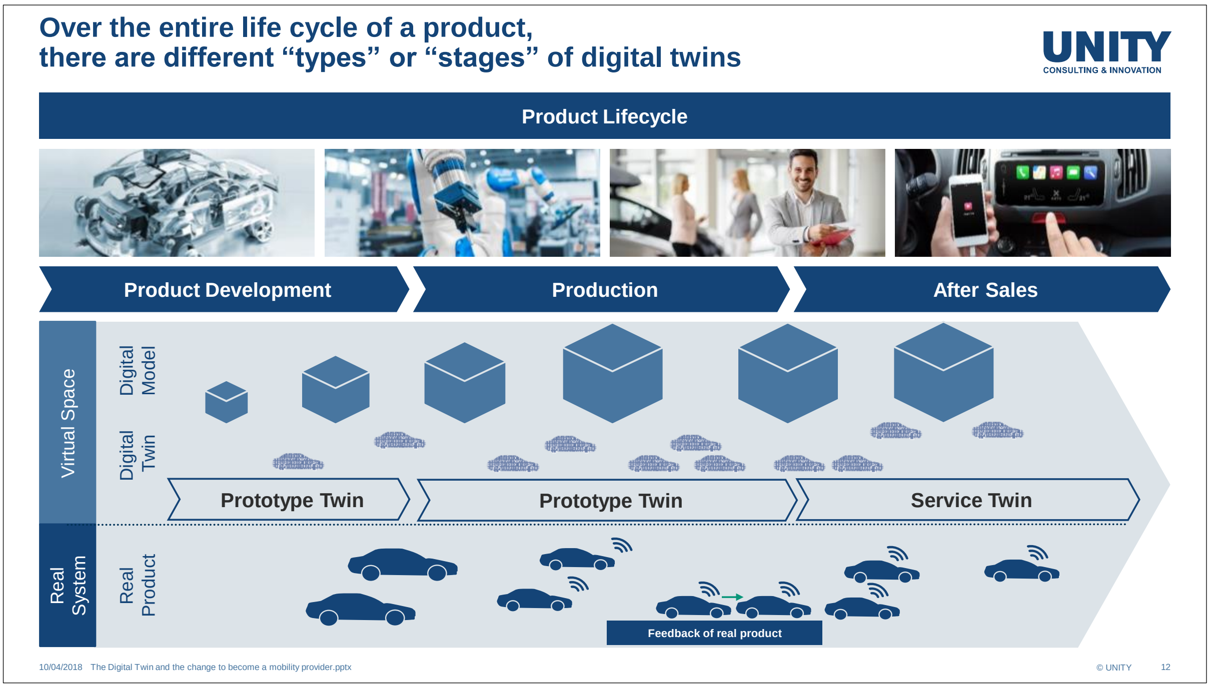
KEY SUCCESS FACTORS:

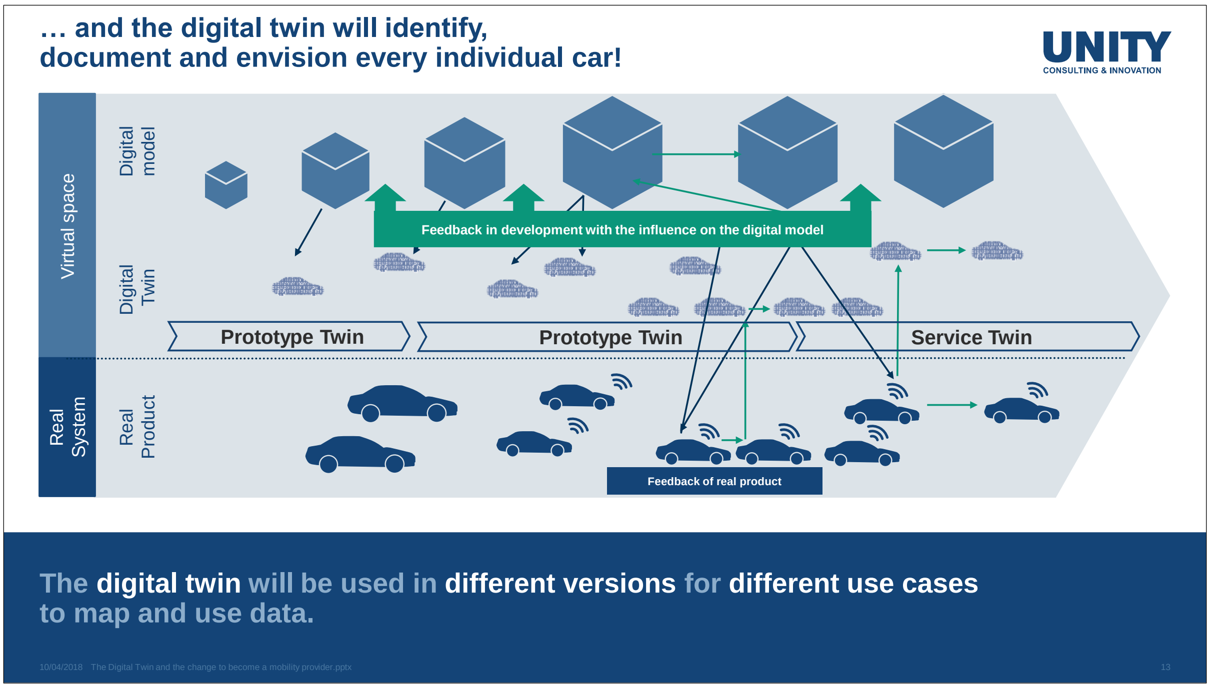
- Digital Factory/ Smart Factory
- Digital Factory-planning
- R&D and PLM
- Lean Management and Smart Production

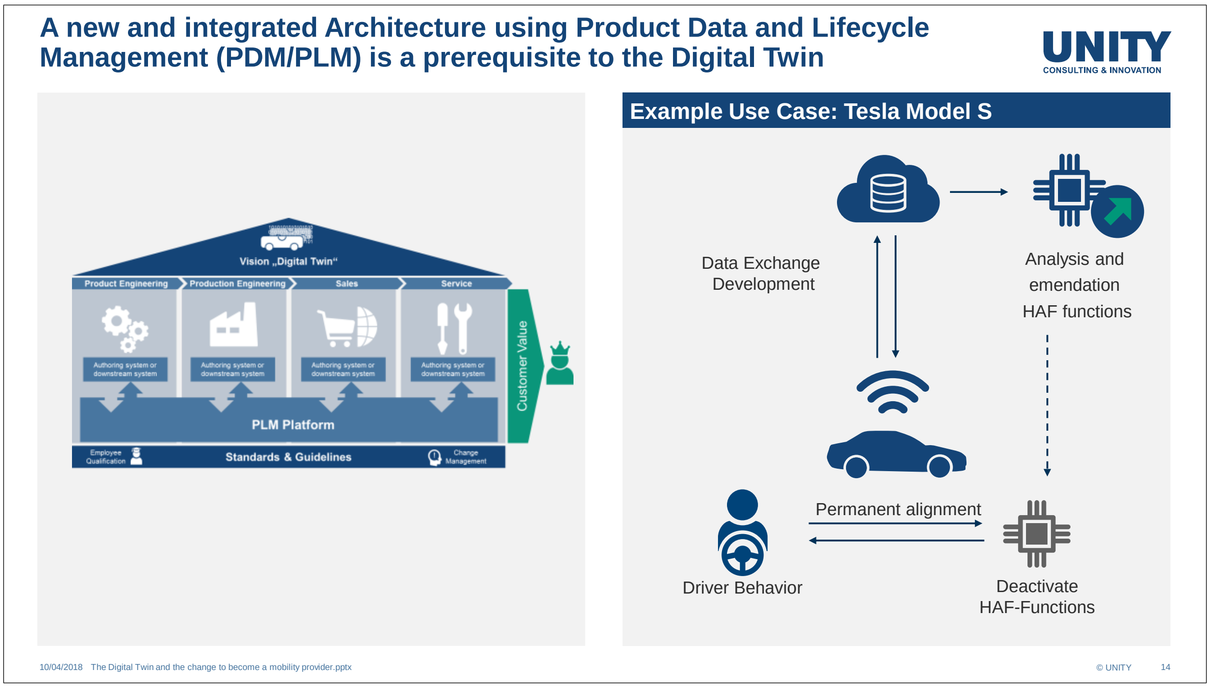
The **digital twin** is a **requirement for future success** of modern OEMs.

10/04/2018 The Digital Twin and the change to become a mobility provider.pptx 10


Over the entire life cycle of a product,
there are different “types” or “stages” of digital twins
UNITY
CONSULTING & INNOVATION
Product Lifecycle
Product Development
Production
After Sales
10/04/2018 The Digital Twin and the change to become a mobility provider.pptx
© UNITY
11


Over the entire life cycle of a product,
there are different “types” or “stages” of digital twins
UNITY
CONSULTING & INNOVATION
Product Lifecycle
Product Development
Production
After Sales
Virtual Space
Digital Model
Digital Twin
Prototype Twin
Prototype Twin
Service Twin
Real System
Real Product
Feedback of real product
10/04/2018 The Digital Twin and the change to become a mobility provider.pptx
© UNITY
12

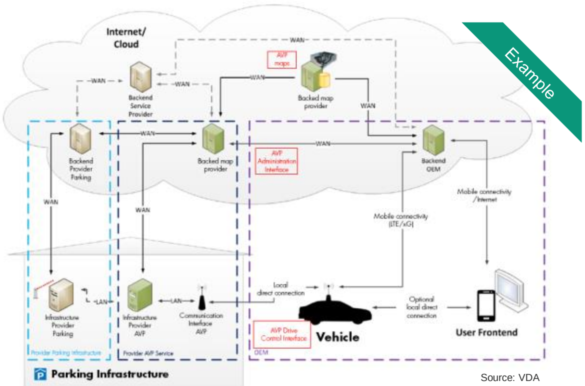

… and the digital twin will identify,
document and envision every individual car!
UNITY
CONSULTING & INNOVATION
Virtual space
Digital model
Digital Twin
Real System
Real Product
Feedback in development with the influence on the digital model
Prototype Twin
Prototype Twin
Service Twin
Feedback of real product
The digital twin will be used in different versions for different use cases
to map and use data.
10/04/2018 The Digital Twin and the change to become a mobility provider.pptx
13


A new and integrated Architecture using Product Data and Lifecycle
Management (PDM/PLM) is a prerequisite to the Digital Twin
UNITY
CONSULTING & INNOVATION
Vision „Digital Twin“
Product Engineering
Production Engineering
Sales
Service
Authoring system or downstream system
Authoring system or downstream system
Authoring system or downstream system
Authoring system or downstream system
PLM Platform
Customer Value
Employee Qualification
Standards & Guidelines
Change Management
Example Use Case: Tesla Model S
Data Exchange
Development
Analysis and
emendation
HAF functions
Permanent alignment
Driver Behavior
Deactivate
HAF-Functions
10/04/2018 The Digital Twin and the change to become a mobility provider.pptx
© UNITY
14

Complex systems require new and integrated architectures – from the systems of systems down to the technical detail

UNITY CONSULTING & INNOVATION

Example: Automated Valet Parking



Source: VDA

Architecture definition means to turn a high-level concept into a technical specification

- What kind of solutions do I need (system elements)?
- How do they interact (interfaces)?
- Which elements and interfaces could be stable across products and a certain period of time?
- What is the optimum amount of variants?
- Which models do I need for an early and plug & play simulation?

Realized Architecture

Architecture as Required

Develop new value networks, as suppliers aim for higher-value services

UNITY CONSULTING & INNOVATION

- Changing user behavior leads to networking of functions in the vehicle
- Suppliers are fighting for integrated solutions (interior, driver assistance, propulsion)

Example: Seats

Data is the new Oil: Reduce consumption with AI-prediction

UNITY CONSULTING & INNOVATION

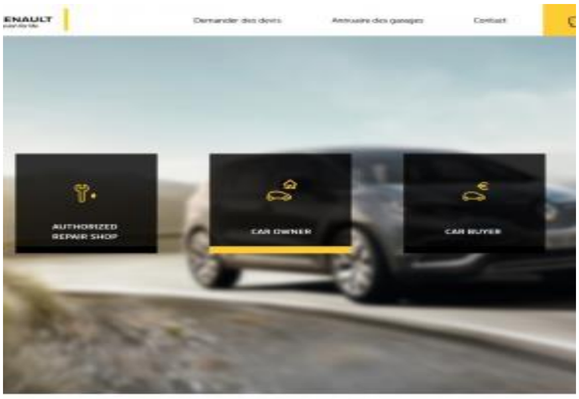
Deutsche Bahn has announced that it will equip 1000 diesel locomotives with telematics systems. The systems first measure how much diesel is consumed during a journey on the respective route sections. The data is evaluated using a big data analytics approach. A display then informs the drivers in the driver's cab on which steep sections of the track they can dispense with the internal combustion engine for acceleration. Deutsche Bahn's goal is to reduce diesel consumption by up to ten percent in this way.

Kann das bitte übersetzen!

10/04/2018 The Digital Twin and the change to become a mobility provider.pptx © UNITY 17

Data is the new Oil: Service Management with Blockchain technology

UNITY CONSULTING & INNOVATION



In cooperation with Microsoft and the blockchain specialist VISEO, French car manufacturer Renault plans to offer a blockchain-based maintenance book for car repairs in the future. A first prototype of the digital service booklet has already been completed. The primary goal is to create more transparency and to consolidate all vehicle data and maintenance information, whether from dealers or workshops, via the block chain. The digital maintenance booklet also enables Renault to offer its customers new services in collaboration with insurers and dealers.

Source: Renault S.A. & Microsoft Corp., France, 2017

10/04/2018 The Digital Twin and the change to become a mobility provider.pptx © UNITY 18

Data is the new Oil:
Use autonomous drive, give data, receive cheaper insurance

UNITY
CONSULTING & INNOVATION

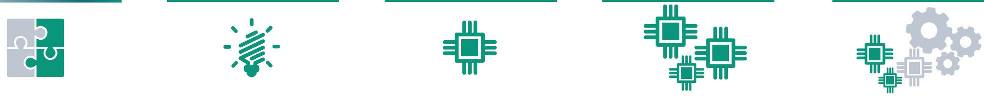
Direct Line, the official insurance provider of Tesla Motors, offers discounts to customers using their car's autopilot. The company hopes that the technology will be used more widely and wants to generate data for research purposes. The data will then be used to determine to what extent self-driving cars contribute to greater road safety and how insurance premiums would have to be adjusted in future. To create an incentive, participating customers receive a five percent discount if they activate the autopilot function.

Source: Direct Line Group, Great Britain, 2017

10/04/2018 The Digital Twin and the change to become a mobility provider.pptx © UNITY 19

Use Best Practices to turn existing data into value with an integrated approach working together with Process Owners, Data Specialists and agile Data Coaches!

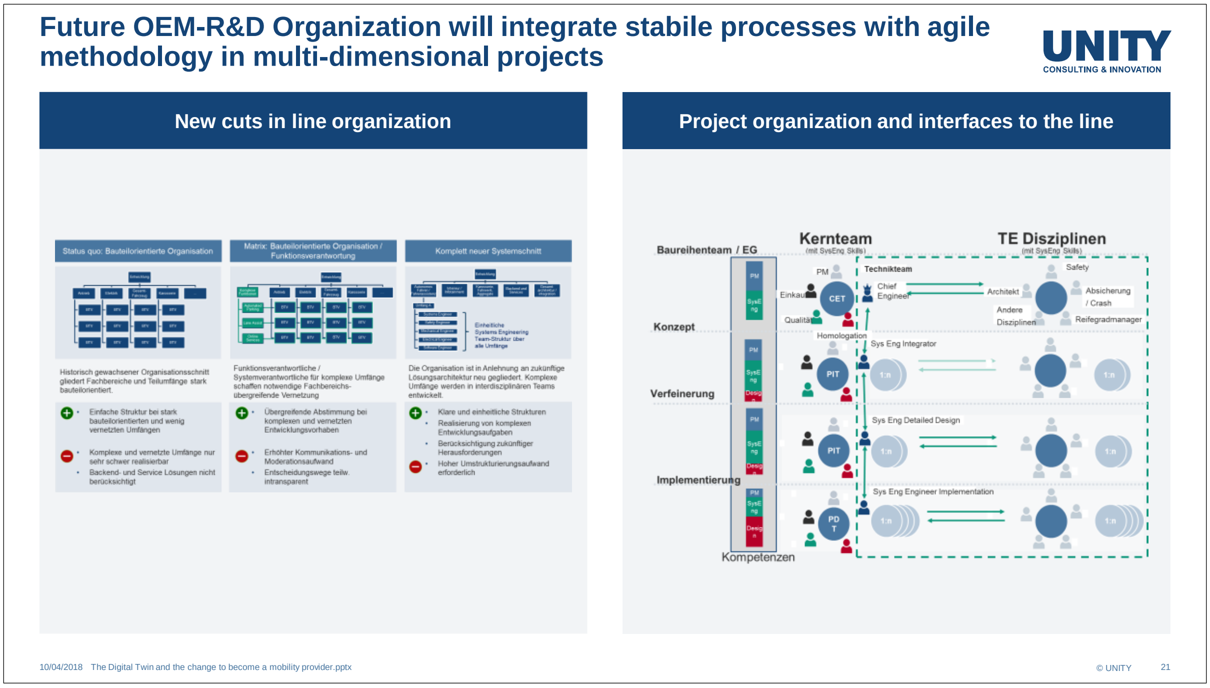
UNITY
CONSULTING & INNOVATION

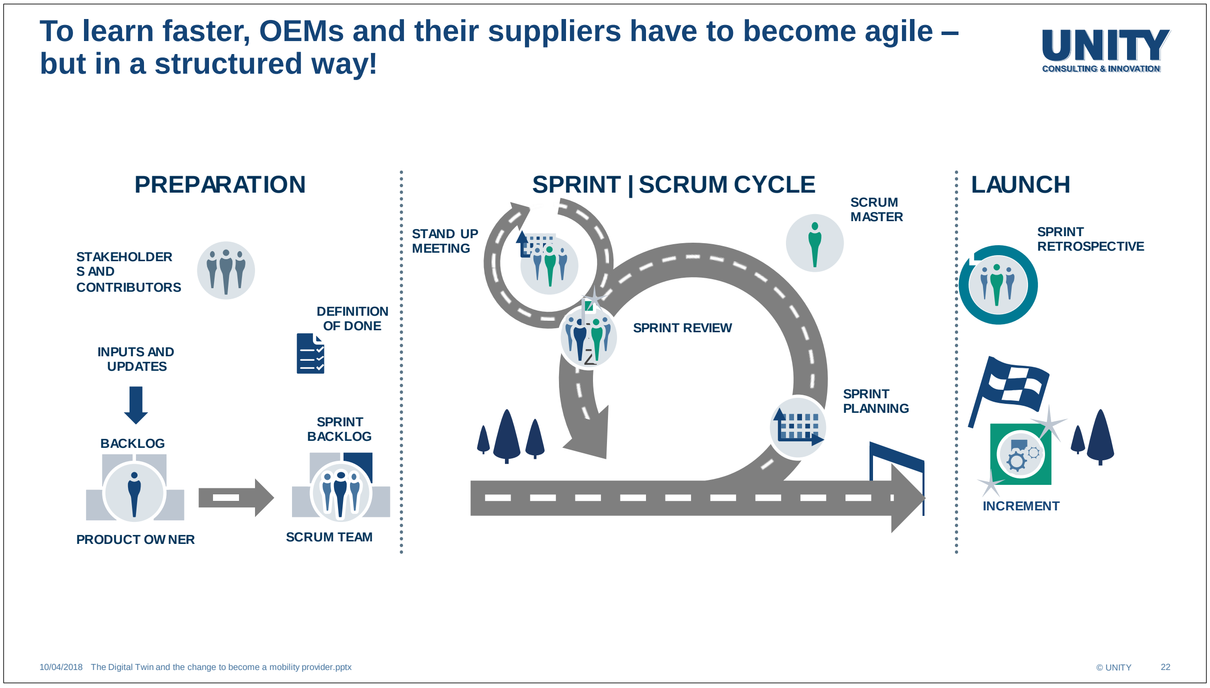


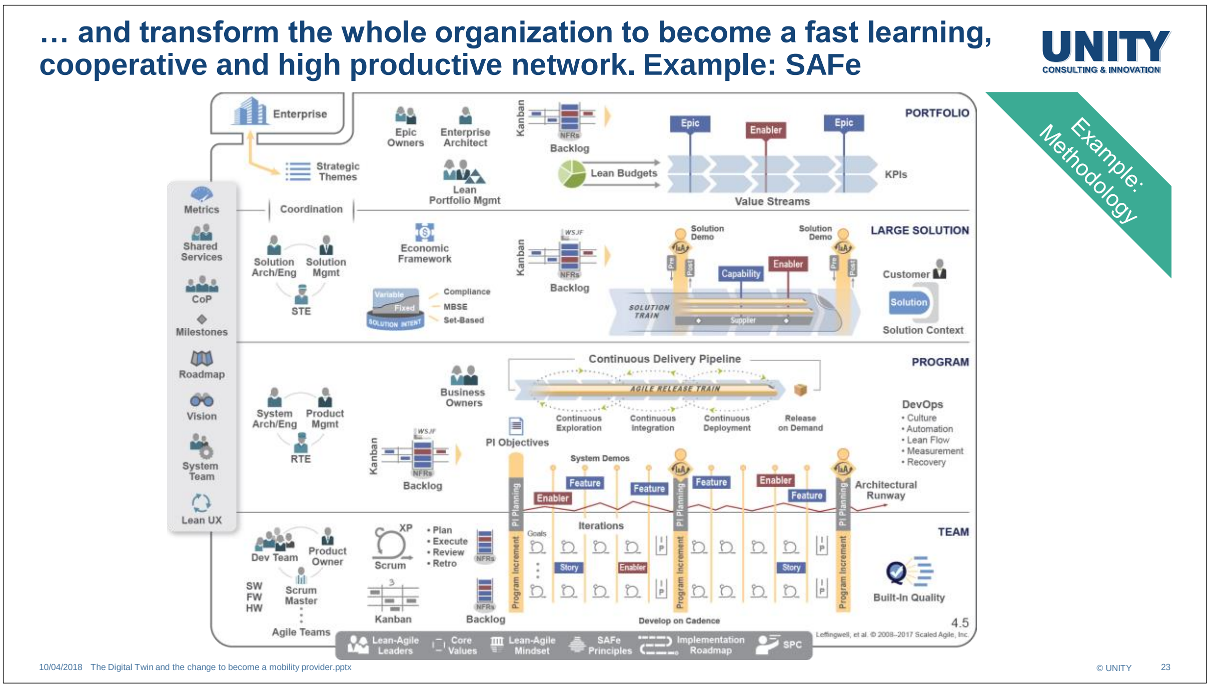
0	1	2	3	4
Data- & Service-Strategy	**Data Ideation Workshop**	**MVP Development** - Release 0.1 -	**Data-driven Service** - Release 1.0 -	**Service Business**
Develop Data- and Service-Strategy, Serviceportfolio and Implementation Roadmap	Implement Data Ideation Workshops to identify and evaluate Data Based Service Ideas	Define and develop minimal viable products (MVP) to test Service Ideas within 3 months each! (Release 0.1)	Develop and deliver fully integrated Data Service with all functions and features (Releases 1.0) to customer	Deliver ongoing Data Service to Customers. Learn, optimize and enhance the Service

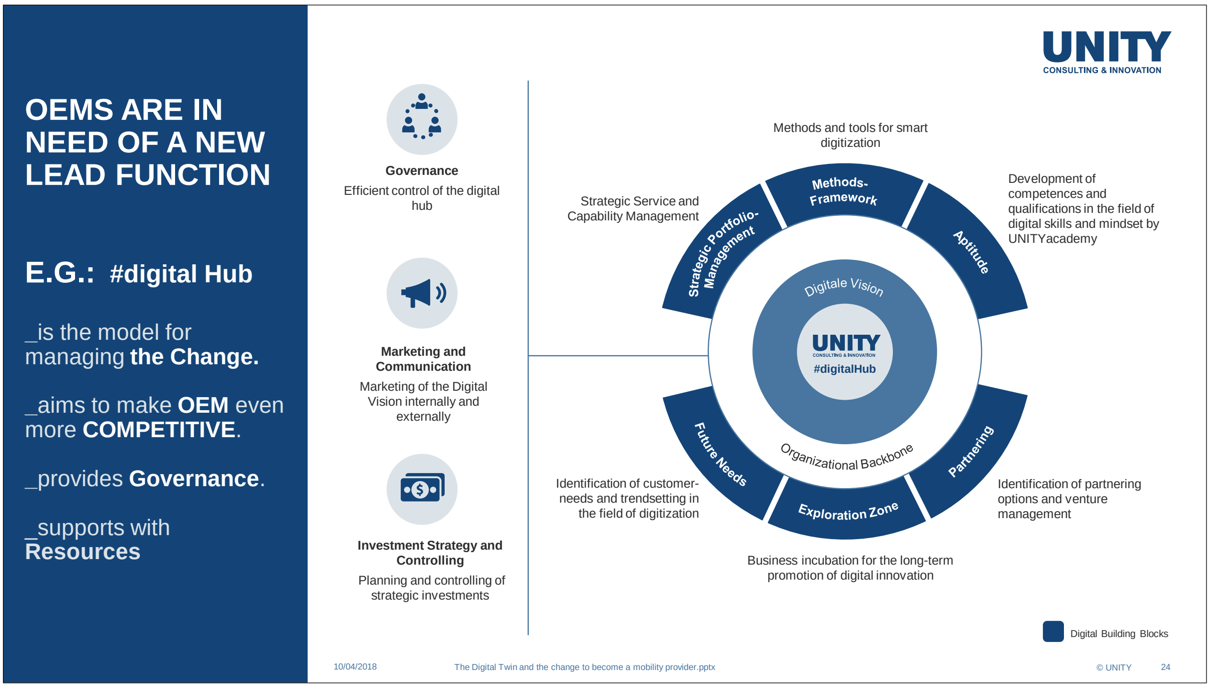
Source: www.next-data-service.com

10/04/2018 The Digital Twin and the change to become a mobility provider.pptx © UNITY 20


Future OEM-R&D Organization will integrate stabile processes with agile methodology in multi-dimensional projects
UNITY
CONSULTING & INNOVATION
New cuts in line organization
Project organization and interfaces to the line
Status quo: Bauteilorientierte Organisation
Matrix: Bauteilorientierte Organisation / Funktionsverantwortung
Komplett neuer Systemschnitt
Baureihenteam / EG
Kernteam
TE Disziplinen
Konzept
Verfeinerung
Implementierung
Kompetenzen
Technikteam
Sys Eng Integrator
Sys Eng Detailed Design
Sys Eng Engineer Implementation
10/04/2018 The Digital Twin and the change to become a mobility provider.pptx
© UNITY 21


To learn faster, OEMs and their suppliers have to become agile – but in a structured way!
UNITY
CONSULTING & INNOVATION
PREPARATION
STAKEHOLDERS AND CONTRIBUTORS
INPUTS AND UPDATES
BACKLOG
PRODUCT OWNER
DEFINITION OF DONE
SPRINT BACKLOG
SCRUM TEAM
SPRINT | SCRUM CYCLE
STAND UP MEETING
SCRUM MASTER
SPRINT REVIEW
SPRINT PLANNING
LAUNCH
SPRINT RETROSPECTIVE
INCREMENT
10/04/2018 The Digital Twin and the change to become a mobility provider.pptx
© UNITY 22


… and transform the whole organization to become a fast learning, cooperative and high productive network. Example: SAFe
UNITY
CONSULTING & INNOVATION
Example: Methodology
Enterprise
Epic Owners
Enterprise Architect
Kanban
Backlog
Strategic Themes
Lean Portfolio Mgmt
Lean Budgets
Epic
Enabler
Value Streams
KPIs
PORTFOLIO
Metrics
Shared Services
CoP
Milestones
Roadmap
Vision
System Team
Lean UX
Coordination
Solution Arch/Eng
Solution Mgmt
STE
Economic Framework
Compliance
MBSE
Set-Based
Solution Demo
Capability
LARGE SOLUTION
Customer
Solution
Solution Context
Continuous Delivery Pipeline
AGILE RELEASE TRAIN
Continuous Exploration
Continuous Integration
Continuous Deployment
Release on Demand
PROGRAM
DevOps
• Culture
• Automation
• Lean Flow
• Measurement
• Recovery
Business Owners
System Arch/Eng
Product Mgmt
RTE
PI Objectives
System Demos
Feature
Architectural Runway
TEAM
Dev Team
Product Owner
Scrum Master
XP
Scrum
• Plan
• Execute
• Review
• Retro
Iterations
Story
Built-In Quality
SW
FW
HW
Agile Teams
Develop on Cadence
4.5
Lean-Agile Leaders
Core Values
Lean-Agile Mindset
SAFe Principles
Implementation Roadmap
SPC
Leffingwell, et al. © 2008–2017 Scaled Agile, Inc.
10/04/2018 The Digital Twin and the change to become a mobility provider.pptx
© UNITY 23


OEMS ARE IN NEED OF A NEW LEAD FUNCTION
E.G.: #digital Hub
_is the model for managing the Change.
_aims to make OEM even more COMPETITIVE.
_provides Governance.
_supports with Resources
UNITY
CONSULTING & INNOVATION
Governance
Efficient control of the digital hub
Marketing and Communication
Marketing of the Digital Vision internally and externally
Investment Strategy and Controlling
Planning and controlling of strategic investments
Methods and tools for smart digitization
Strategic Service and Capability Management
Development of competences and qualifications in the field of digital skills and mindset by UNITYacademy
Methods-Framework
Strategic Portfolio-Management
Aptitude
Digitale Vision
UNITY
#digitalHub
Organizational Backbone
Future Needs
Exploration Zone
Partnering
Identification of customer-needs and trendsetting in the field of digitization
Identification of partnering options and venture management
Business incubation for the long-term promotion of digital innovation
Digital Building Blocks
10/04/2018
The Digital Twin and the change to become a mobility provider.pptx
© UNITY 24

Remarks, observations on the status quo

Some personal remarks and observations from the author

UNITY
CONSULTING & INNOVATION

- Vision is there
- Management-Power developing
- Technology available or under construction
- Organizational change on it's way (but too slow: Inside-out takes too much time)
- Future value creation still with open issues (battery, software-competence, network-management, data driven services,…)
- Speed is lacking
- Silos still exist! Break them, work integrated
- Complexity is still too high
- Systems Engineering not fully implemented yet

- The race is on. Exciting, challenging, open!

10/04/2018 The Digital Twin and the change to become a mobility provider.pptx © UNITY 26

Outlook

OEMs, Suppliers and Individuals …

Have to deliver new results
To realize completely new businesses
By making use of new technology
With new competencies they have to learn or integrate
With a completely new culture (learn fast)
Managing a higher complexity with obeying safety and security
accelerating exponentially!

10/04/2018 The Digital Twin and the change to become a mobility provider.pptx © UNITY 28


UNITY
CONSULTING & INNOVATION
Marcus Goerke
Global Account Management Automotive
+49 30 683202711
marcus.goerke@unity.de
www.unity.de | www.unityconsulting.com
BERLIN
BRAUNSCHWEIG
HAMBURG
KAIRO
KÖLN
MÜNCHEN
NÜRNBERG
PADERBORN
PEKING
SÃO PAULO
SHANGHAI
STUTTGART
WIEN
ZÜRICH

Eng. Fernando Lopes

Formado em Engenharia Mecatrônica pela Escola Politécnica da Universidade de São Paulo (Poli-USP) em 2015. Atuou no projeto mecânico de um sistema de transmissão para a equipe Poli Racing de Fórmula SAE, trabalhou na liga de mercado financeiro da Escola Politécnica e estagiou no HSBC Asset Management Group na área de Macro and Strategy Research (Quantitative Analysis), sendo finalista do Campeonato de Algoritmos para Mercado Financeiro, organizado pela Corretora Souza Barros. Realizou o curso Creativity, Innovation & New Businesses na Fondazione CUOA (Vicenza – Itália). Empreendedor desde 2014 abriu formalmente sua empresa com colegas da faculdade em 2016 com o objetivo de trazer tecnologia de ponta para o agronegócio brasileiro. Cuida das áreas financeira e contábil, além de ser o responsável pelo operacional interno da empresa (jurídico, recursos humanos, compras, relações externas e parcerias).

fernando.lopes@mvisia.com.br

MVISIA Desenvolvimentos Inovadores Ltda.

A MVISIA desenvolve câmeras inteligentes baseadas em visão computacional e inteligência artificial para determinação do índice de qualidade de produtos agrícolas e industriais. O princípio de nossas soluções é um sistema de visão que captura imagens de cada unidade de produto que deve ser analisado e as envia para um software de I.A. fazer a sua análise, levando em consideração os parâmetros importantes para a qualificação/seleção de cada produto. A empresa existe desde 2012, quando foi incubada no CIETEC-USP, e já desenvolveu soluções para os setores de hortifrúti, citricultura, avicultura, grãos, flores e mudas florestais. Tivemos três de nossos projetos financiados pela FAPESP e também mantemos estreitas relações com o ecos-sistema de inovação brasileiro, com diversos prêmios ganhos, como o Prêmio Santander de Empreendedorismo e o Prêmio Odebrecht de Sustentabilidade. Somos especialistas em desenvolvimento de softwares inteligentes para o reconhecimento de características visuais por meio de algoritmos próprios e exclusivos.

MVISIA
Máquinas de Visão e Inteligência Artificial

Desenvolvendo produtos inteligentes usando Visão Computacional e Inteligência Artificial

Resumo

Um dos principais campos de aplicação de algoritmos que utilizam técnicas de inteligência artificial é a área de análise de imagens, conhecida como visão computacional. Com o uso de um hardware dedicado para tal aplicação, composto por uma câmera integrada, um minicomputador de placa única e um invólucro mecânico de proteção e de um software de análise de imagens que utiliza conceitos de machine learning, é possível se controlar processos industriais que necessitam de algum tipo de inspeção visual com qualidade e agilidade. O conceito desta solução é conhecido no mercado como "câmeras inteligentes". Neste artigo são mostrados os princípios básicos de visão computacional e inteligência artificial, como reunir tais conceitos na forma de um produto inteligente e ao final é mostrado um case de sucesso da aplicação deste tipo de tecnologia.

Palavras-chave

Visão Computacional; Inteligência Artificial; Câmeras Inteligentes; Indústria 4.0.

Autores

Eng. Fernando Paes Lopes
MVISIA Desenvolvimentos Inovadores Ltda.
fernando.lopes@mvisia.com.br

Eng. Fernando Antonio Torres Velloso da Silva Neto
MVISIA Desenvolvimentos Inovadores Ltda.
fernando.velloso@mvisia.com.br

1 Introdução

Analisando o “simples” processo de se escolher uma fruta no supermercado: as opções são analisadas com cuidado, dando-se atenção especial a aspectos da aparência como tamanho, formato e cor. Entre uma banana verde e uma amarela, provavelmente é dada a preferência à segunda; uma maçã com manchas ou imperfeições na casca provavelmente será menos atraente aos olhos e não será escolhida.

Embora aconteça em questão de segundos e seja aparentemente simples, esse processo de escolha é extremamente complexo e elaborado. Ao se olhar as frutas com cuidado, o que se está fazendo de fato é retirando informações úteis das imagens. O amarelo da banana é interpretado como um sinal de fruta madura e apetitosa; as manchas, associadas com sujeira ou baixa qualidade. Simples traços ou padrões visuais obtidos pelos olhos são processados pelo cérebro e influenciam as tomadas de decisão.

Figura 1: Parâmetros visuais influenciam na decisão de compra de produtos agrícolas.
Fonte: banco público de imagens

A visão computacional é a área da ciência que visa justamente replicar essa complexidade dos nossos processos visuais e, quando possível, aprimorá-los e torná-los ainda mais sofisticados. O seu objetivo é desenvolver sistemas semelhantes à inteligência visual humana – ou seja, sistemas que possam retirar e analisar informações úteis a partir de imagens.

Atualmente, a tecnologia da visão computacional é aplicada em diversas áreas, como por exemplo, no raio-x em exames médicos, na identificação da placa de automóveis em radares e na análise de rótulos de garrafas. Até recentemente, a operação desse tipo de tecnologia era inviável por conta da imensa quantidade de poder de processamento que era exigida dos computadores. Com os avanços na computação, estamos vendo um grande aumento na utilização de sistemas que simulam a nossa visão.

O setor agrícola é uma das áreas que mais vêm sendo beneficiadas com esses avanços tecnológicos. Embora máquinas para agricultura tenham começado a utilizar câmeras e sensores já nos anos 80, o desenvolvimento recente de sistemas mais elaborados de visão computacional vêm aumentando ainda mais a eficiência do setor.

Ao capturar uma imagem, computadores podem analisá-la de acordo com diversos parâmetros. Dessa maneira, o sistema mecatrônico obtém dados de interesse sobre o material examinado, seja pela sua cor, formato ou por outros critérios pré-estabelecidos. O uso de visão computacional para qualificar e selecionar produtos agrícolas vem sendo usado amplamente no setor primário e secundário da economia para aumentar a produtividade da cadeia do agronegócio e quando combinada com o uso de técnicas de inteligência artificial também se torna uma poderosa ferramenta para se fazer o controle de qualidade das mercadorias analisadas.

Quando se ouve o termo “inteligência artificial”, normalmente se imagina civilizações avançadíssimas de robôs inteligentes, carros voadores e sociedades futuristas. Mas deixemos de lado por um instante as elaboradas ficções de filmes como “O exterminador do futuro”, “Star Wars” e “Eu, Robô” e pense nos dispositivos e plataformas que você já usa no dia-a-dia.

Ao se abrir o Netflix®, os filmes e séries que aparecem em destaque não são os mesmos que aparecem para os outros usuários. Ao se usar o Facebook®, o conteúdo que aparece na página inicial é baseado nos cliques e *likes* que o usuário deu em notícias ou publicações de amigos. Quanto mais se usam essas plataformas, mais estas aprendem sobre as preferências dos consumidores e sobre as tendências de diferentes usuários. E é exatamente isso o que caracteriza a inteligência artificial (I.A.): a capacidade de aprender com base em novas e antigas informações, justamente como os humanos fazem. Basicamente, um sistema inteligente é capaz de ensinar a si mesmo e aprender com as próprias experiências.

Assim como pessoas, máquinas e computadores dotados de I.A. retêm informações e ficam cada vez mais inteligentes à medida que o tempo passa. Este processo de aprendizado é conhecido como *machine learning*. É possível programar uma máquina para que ela aprenda com suas tentativas e erros: após analisar milhares de exemplos e elaborar diversos algoritmos, o programa entende qual é o algoritmo mais efetivo para cada usuário ou situação. No caso do Netflix® e do Facebook®, por exemplo, esse tipo de tecnologia permite que a experiência nessas plataformas seja cada vez mais personalizada e agradável.

Apesar de muito semelhante a alguns dos nossos processos cerebrais, a I.A. apresenta algumas vantagens inegáveis em relação à inteligência humana: diferentemente do que acontece com os seres humanos, a inteligência artificial não sofre com perda de memórias, cansaço mental, excesso de informação, falta de sono e distrações. Ou seja, uma vez desenvolvida, ela pode executar tarefas de alto grau de complexidade e sofisticação (como, por exemplo, dirigir um carro) praticamente de forma ininterrupta. Além disso, usando processos conhecidos como *deep learning* e “redes neurais” – que imitam a forma como o cérebro humano identifica padrões – máquinas com I.A. podem acessar bancos de dados gigantescos e encontrar e interpretar informações com muito mais rapidez e eficiência.

Como resultado do desenvolvimento da I.A., diversas áreas da ciência vêm apresentando grandes avanços e setores produtivos vêm obtendo ganhos em eficiência e produtividade. É o caso, por exemplo, do setor agrícola.

2 Desenvolvendo uma câmera inteligente

Uma câmera inteligente se trata de um equipamento que imita a capacidade humana de visualizar o ambiente ao seu redor e processar as imagens recebidas, buscando por padrões e eventos pré-definidos e possibilitando o controle de processos sem a subjetividade e os erros humanos.

E como essa tecnologia funciona? Analogamente ao ser humano, a solução é composta por uma câmera (olho), um minicomputador (cérebro) e uma rede neural embarcada (inteligência humana), sendo que todo este sistema é encapsulado em um invólucro de proteção para resistir às mais diversas condições de aplicação.

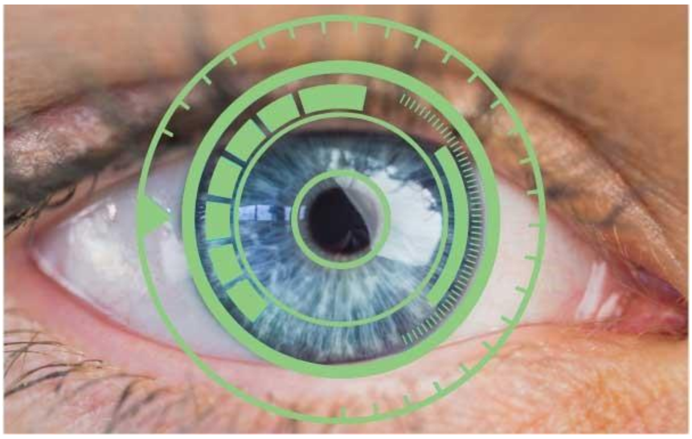


Figura 2: Uma câmera inteligente é um dispositivo mecatrônico que funciona como um olho robótico. Fonte: banco público de imagens

A Figura 3 abaixo explica o funcionamento do equipamento:

1. Invólucro de proteção: Encapsulamento de proteção para operar nos mais diversos tipos de ambiente de trabalho.

2. Câmera integrada: Uma câmera compacta e de máximo desempenho compõe o equipamento para realizar a captura das imagens a serem analisadas pelo software embarcado de inteligência artificial.

3. Unidade de processamento: Um microcomputador de alta performance é embarcado no equipamento para realizar o controle do processo que está sendo monitorado.

4. Software de Inteligência Artificial: Com algoritmos de *machine learning*, se faz o processamento das imagens capturadas.

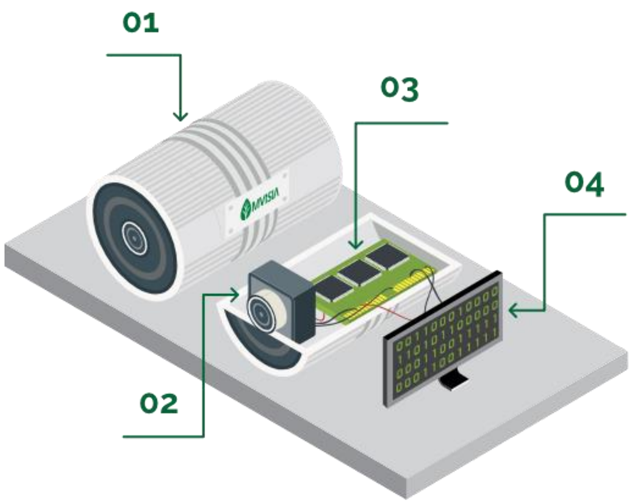


Figura 3: Funcionamento de uma câmera inteligente. Fonte: Elaborado pelo autor (2018).

Câmeras inteligentes já vem sendo usados nas mais diversas aplicações nos setores do agronegócio, industrial, segurança, varejo entre outros. Seja para analisar a qualidade de um fruto ou para fazer a contagem de pessoas que entram e saem de um estabelecimento comercial, esses dispositivos possibilitam a análise e tomada de ação em tempo real com precisão e confiabilidade.

3 Exemplo de aplicação: Seletora automática de mudas de eucalipto

A problemática abordada neste projeto é relacionada à análise da variação fenotípica de mudas florestais utilizando-se câmera inteligentes. A variação fenotípica dentro de uma espécie de muda florestal pode ser determinada pelas características genéticas (genótipo) ou por diferenças ambientais, ou por uma soma da combinação destes fatores [1]. O grupo de mudas florestais analisadas foram de mudas de eucalipto criadas em viveiros florestais.

A produção de mudas de eucalipto começa nos viveiros. Conforme se observa na Figura 4, grande parte das tarefas manuais de um viveiro de mudas de eucalipto são destinadas ao controle do crescimento das mudas, com etapas de seleção e raleio (etapas de 8 a 13). Assim a inspeção e classificação pré-plantio de mudas florestais é etapa importante da cadeia produtiva dessa indústria, pois garante que apenas mudas de boa qualidade e sem doenças sejam levadas ao campo, evitando perda de produtividade nos investimentos de longo prazo, o que torna mais competitiva a produção florestal. Contudo o excesso de tarefas realizadas de forma manual faz com que o resultado não seja consistente e que se torne custoso.

Dada a natureza visual da inspeção, um sistema de visão computacional pode ser empregado para automatizar essa tarefa. No sistema desenvolvido neste trabalho técnico, diversos parâmetros das mudas são extraídos através de técnicas de processamento de imagens, que servem de entrada para um software classificador. A construção deste classificador é feita com algoritmos de aprendizado de máquina, a partir de exemplos previamente classificados por especialistas.

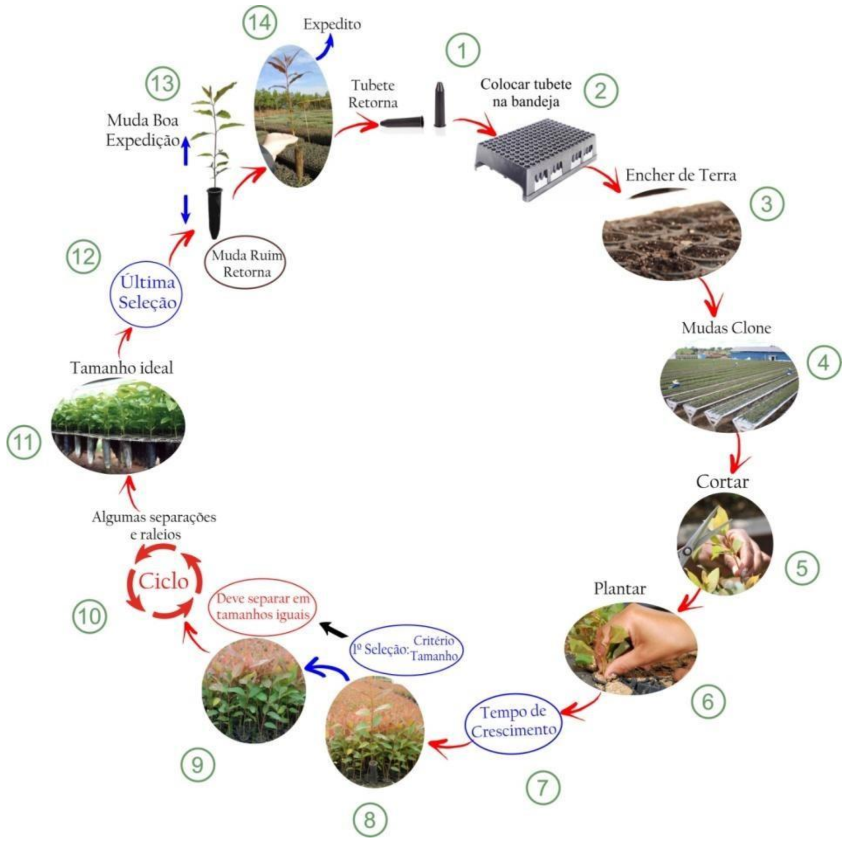


Figura 4: Diagrama de atividades num viveiro de mudas de eucalipto.
Fonte: Elaborado pelo autor (2017).

O objetivo do presente projeto é, portanto, criar uma solução (máquina) capaz de realizar a inspeção, classificação e separação das mudas de eucalipto automaticamente e em escala comercial. Ao final da realização deste projeto de pesquisa, espera-se obter um protótipo funcionando corretamente e validado por uso em campo. Futuramente, novas versões poderão ser fabricadas, efetivando a criação de um produto que possibilitará o aumento da produtividade, qualidade e rentabilidade dos produtores da cadeia florestal brasileira.

3.1 Material e métodos

Para o desenvolvimento de um sistema capaz de capturar imagens de mudas de eucalipto e realizar a separação destas mudas em classes diferenciadas, foi concebido um projeto de máquina utilizando-se de câmeras inteligentes, cujos conjuntos de componentes foram divididos em quatro grandes sistemas:

- Sistema mecânico
- Sistema elétrico/eletrônico

- Sistema pneumático
- Sistema computacional – Câmera Inteligente

O sistema mecânico condiz às estruturas mais básicas da máquina, como as esteiras, acoplamentos mecânicos com os motores e a própria estrutura física. Uma breve descrição se encontra na Figura 5 e na Tabela 1.

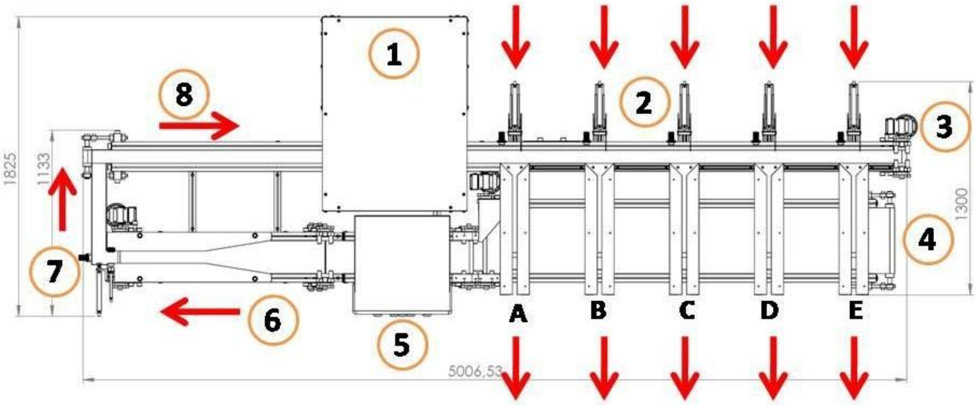


Figura 5: Vista de topo do layout de máquina proposto com destaque aos principais componentes funcionais do equipamento. Fonte: Elaborado pelo autor (2018)

Na Figura 5 destaca-se, com setas, o caminho realizado pela muda no equipamento. Na Tabela 1, é possível observar uma breve descrição sobre as partes enumeradas do equipamento ilustrado anteriormente.

Tabela 1: Componentes funcionais da máquina

Nº	ITEM	FUNCIONALIDADE
1	Cabine de visão computacional	Cabine com câmera inteligente e iluminação controlada.
2	Saídas de seleções	Separação das mudas, por acionamento de pistão, em 5 diferentes saídas físicas (A, B, C, D e E).
3	Descarte de mudas	Destino das mudas para descarte (doenças, fora das especificações mínimas).
4	Esteira de retorno	Esteira que faz o retorno dos suportes das mudas
5	Painel de comando	Interface de comando e energização, com monitor para acesso ao software de análise de imagem.
6	Esteira de deposição	Local para o operador depositar as mudas (entrada da máquina).
7	Pistão de retorno	Faz a integração entre as esteiras de deposição e seleção.
8	Esteira de seleção	Esteira que conduz as mudas para a cabine de inspeção e transporta até as saídas de seleção.

O sistema elétrico/eletrônico tem um papel fundamental na automação da máquina, sendo que dele fazem parte os motores, sensores de movimento, o Controlador Lógico Programável (CLP) e o painel elétrico, que energiza toda a máquina, assim como os elementos de proteção, como o acionamento de emergência.

Tem-se na máquina um sistema pneumático típico, com um compressor, válvulas e atuadores, o qual é responsável por realizar fisicamente a separação das mudas, e suas válvulas de acionamento são controladas por comandos vindos do CLP.

Por fim tem-se o sistema computacional, que cuida da interpretação das informações obtidas de cada muda selecionada e também gere todas as funções da máquina, como a partida dos motores, a autorização para o acionamento das válvulas pneumáticas e também a detecção de falhas na máquina. Fazem parte desse sistema a câmera inteligente que é instalada na máquina e o sistema de iluminação correspondente.

Na Figura 6 pode-se ver um diagrama que representa a hierarquia presente na interação entre os sistemas. O sistema computacional é responsável por enviar todas as ordens e demandas ao sistema elétrico/eletrônico (aqui representado pelo CLP) por meio de uma comunicação do tipo mestre-escravo. Então este sistema despacha aos elementos necessários os comandos condizentes com a ordem dada pela câmera inteligente, seja o acionamento de uma válvula no sistema pneumático ou o aumento de velocidade de uma das esteiras.

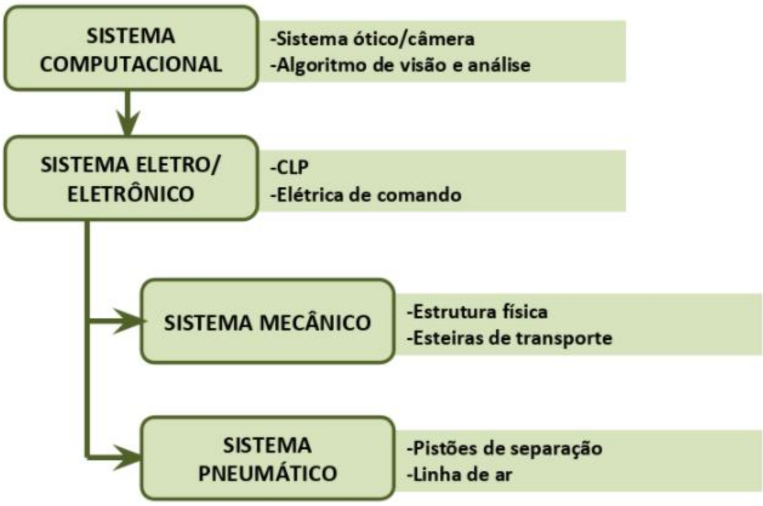


Figura 6: Relação hierárquica entre sistemas. Fonte: Elaborado pelo autor (2018)

3.2 Resultados e discussão

Instalou-se a máquina em um viveiro de mudas de eucalipto de uma grande empresa do setor florestal, com o intuito de avaliar a performance da solução e, assim, propor melhorias para uma nova versão da tecnologia. Na Figura 7 tem-se o layout final do produto. Nesta configuração, durante os primeiros ensaios, obteve-se uma produtividade da ordem de 2.200 mudas/hora.

Figura 7: Layout da solução final. Fonte: Elaborado pelo autor (2018)

A Figura 8 mostra a tela inicial do software desenvolvido, no qual está embarcado o algoritmo de extração de *features* das imagens. Mediu-se a assertividade desta classificação automática, tendo como base de comparação o input de um especialista, e chegou-se em uma assertividade de 85%.

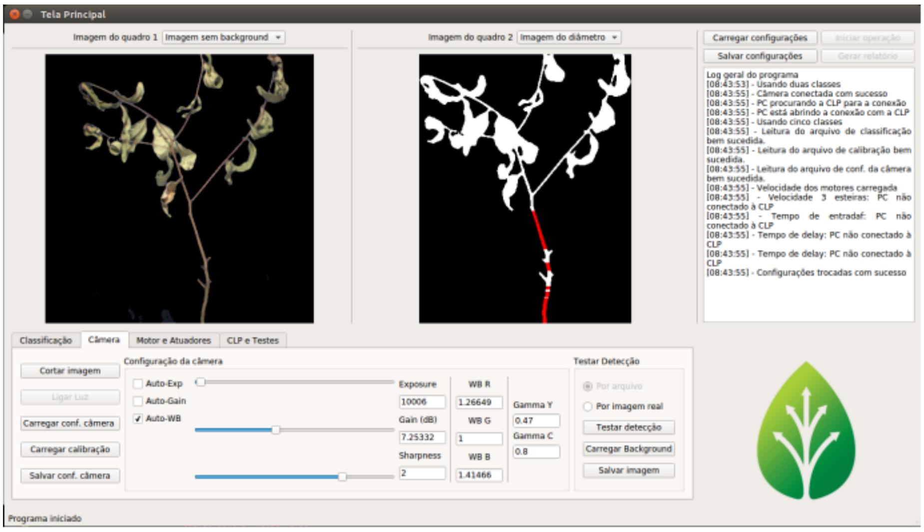


Figura 8: Tela de operação do software com um exemplo de classificação.
Fonte: Elaborado pelo autor (2018)

4 Conclusão

Os resultados obtidos, considerando-se as métricas de produtividade e assertividade, validaram que a tecnologia é viável tecnicamente. São necessárias, entretanto, melhorias para aumentar a atratividade comercial do produto, principalmente sob a perspectiva da capacidade de mecanização e substituição de mão-de-obra.

O software possui alguns pontos de melhorias a serem realizados além da necessidade de aumento de performance na assertividade dos parâmetros, que será obtido através de um maior banco de dados realizados in loco. Ao software de visão computacional também é capaz de se adicionar qualquer variável desejada para análise, assim sendo a análise poderia incluir novos tipos de doenças, readaptação para outras variedades de mudas ou qualquer outra característica fenotípica desejada.

Outro ponto de mudança que ocorre entre um viveiro e outro é o padrão de tubetes utilizado, ou o tamanho da variedade de mudas, tanto para o caso de Eucalipto ou Pinus. Mesmo com essas grandes variedades disponíveis no mercado, a máquina concebida é capaz de ser calibrada para estes ajustes dimensionais, sendo assim possível utilizar a mesma tecnologia para adequação a outras culturas de mudas, em que se necessita obter ganhos no controle de crescimento de mudas criadas em tubetes, como café, açaí, cana de açúcar, pimenta do reino, palmeiras entre outras [2, 3].

5 Referências

[1] Peruquetti, Rui Carlos. Genética básica - Variação fenotípica: Introdução. Em: Genética básica. Disponível em: <http://www.ufac.br/ccbn/genetica>. Acessado em: 10 fev. 2018

[2] INSTITUTO BRASILEIRO DE FLORESTAS, Tubetes. Londrina, [2015?]. Disponível em: <http://www.ibflorestas.org.br/news/tubetes-plasticos-290-cm-3.pdf>. Acessado em: 20 nov. 2017

[3] Matos, Marcos Antonio. Modelo informatizado para o planejamento operacional e econômico de sistemas mecanizados com a consideração da pontualidade. 2007. Dissertação (Mestrado em Máquinas Agrícolas) - Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo, Piracicaba, 2007

MVISIA
Máquinas de Visão e Inteligência Artificial

Sistema ESOS

Câmeras Inteligentes para Controle de Processos

Fernando Velloso
CEO, MVisia

São Paulo / SP – Outubro de 2018

MVISIA
Máquinas de Visão e Inteligência Artificial

Problemática Atual

Como Controlar Processos Visualmente?

- **Manualmente**
  Ex: pessoas analisando qualidade de embalagem
  - Custo com mão-de-obra
  - Baixa produtividade
  - Subjetividade dos Critérios humanos
  - Altas taxas de erro
- **Câmeras Tradicionais**
  Ex: câmera para fazer leitura de posição de código de barras
  - Alto Custo
  - Assertividade baixa para problemas complexos

MVISIA
Máquinas de Visão e Inteligência Artificial

Solução Proposta - Conceito

Unidade de Processamento + Câmera Integrada + Inteligência Artificial

Sistema ESOS - Câmeras Inteligentes

MVISIA
Máquinas de Visão e Inteligência Artificial

Solução Proposta - Produto

MVISIA
Máquinas de Visão e Inteligência Artificial

Case de Sucesso - Citricultura

- **Empresa multinacional, centenária e líder no setor de maquinário para indústrias de suco de laranja**
- **Dispositivo de travamento de emergência em caso de identificação de objetos estranhos, com aviso visual e sonoro.**

MVISIA
Máquinas de Visão e Inteligência Artificial

MVISIA
Máquinas de Visão e Inteligência Artificial

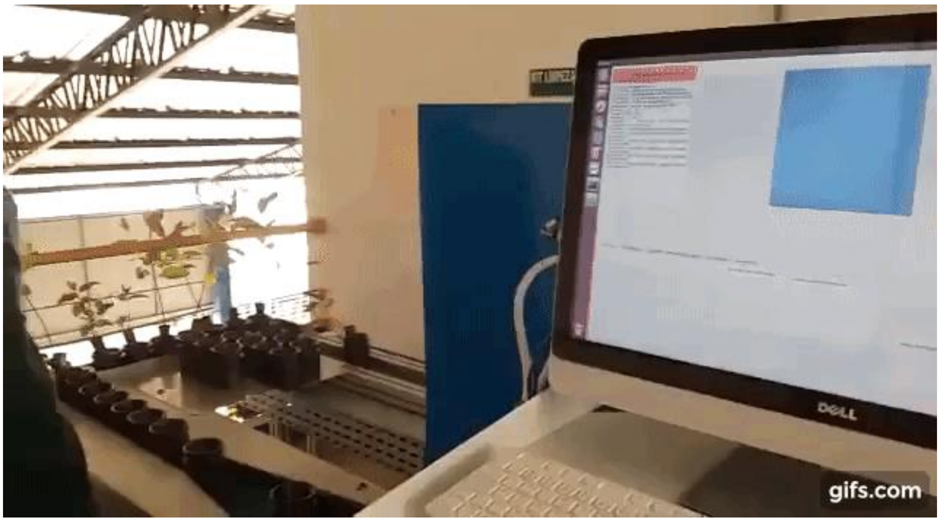
Case de Sucesso - Papel & Celulose

Foto original | Foto binarizada

- **Empresa brasileira, maior produtora de celulose de eucalipto do mundo.**
- **Seleção manual das mudas de eucalipto gera altos custos com mão-de-obra e é um processo subjetivo.**
- **Sistema capaz de automatizar o processo de seleção das mudas.**

.

MVISIA
Máquinas de Visão e Inteligência Artificial



MVISIA
Máquinas de Visão e Inteligência Artificial

Case de Sucesso - Horticultura

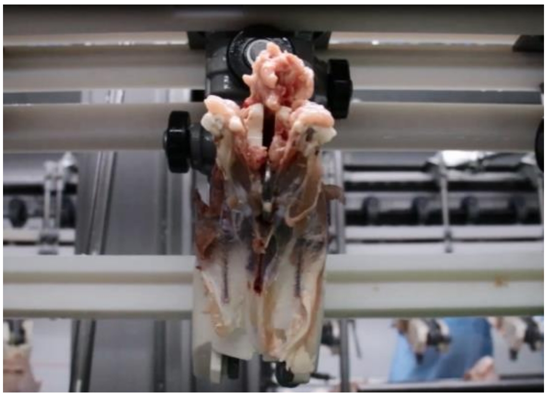
- **Grandes produtores de frutos miúdos, como tomate grape, mini-tubérculo, seriguela, jabuticaba, etc.**
- **Seleção automática utilizando visão computacional por tamanho, coloração e defeitos superficiais.**

.

MVISIA
Máquinas de Visão e Inteligência Artificial

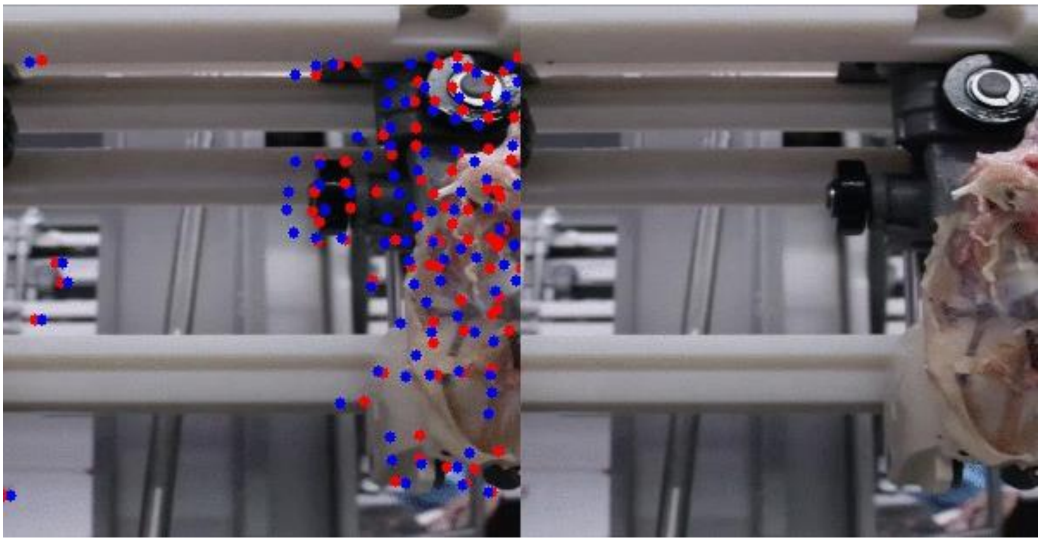
MVISIA
Máquinas de Visão e Inteligência Artificial

Case de Sucesso- Avicultura



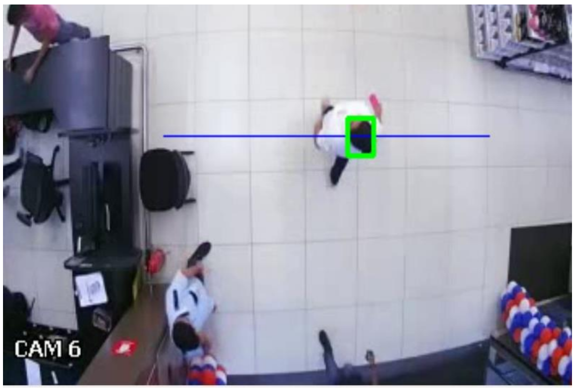
- **Empresa brasileira produtora de frangos de corte.**
- **Instalação do sistema ESOS Food, capaz avaliar a qualidade das carcaças de frango automaticamente em uma linha industrial de abate.**

MVISIA
Máquinas de Visão e Inteligência Artificial



MVISIA
Máquinas de Visão e Inteligência Artificial

Case de Sucesso - Segurança



- **Controle de acesso e contagem de pessoas é um processo custoso e com altas taxas de erros.**
- **Instalação do sistema ESOS Security, capaz automatizar o controle de acesso.**

MVISIA
Máquinas de Visão e Inteligência Artificial

MVISIA
Máquinas de Visão e Inteligência Artificial

MVISIA – Prêmios & Fomentos

Prêmio Odebrecht
para o Desenvolvimento Sustentável
Brasil | 2016

PRÊMIO SANTANDER
EMPREENDEDORISMO

FAPESP

Finep
INOVAÇÃO E PESQUISA

MVISIA
Máquinas de Visão e Inteligência Artificial

MVisia – O que fazemos?

Computer Vision	Machine Learning
Image Processing;	Deep Learning (CNNs, LSTMs);
Image Filtering;	Supervised Machine Learning (SVMs, Cross Validation);
Image Segmentation;	Unsupervised Machine Learning (K-Means, DBSCAN, PCA);
Image Feature Detection;	
Image Classification;	

MVISIA
Máquinas de Visão e Inteligência Artificial

MVisia - Linha do Tempo

2012 — Fundação da Empresa

2014 — Lançamento do Primeiro Produto

2015 — Entrada em Novos Mercados

2016 — Prêmio Santander de Empreendedorismo

2017 — Membro Fundador da Associação Brasileira de Inteligência Artificial

2018 — Lançamento do sistema ESOS

MVISIA
Máquinas de Visão e Inteligência Artificial

Contato

(11) 4302-5902

(11) 98134-9727

fernando.velloso@mvisia.com.br

www.mvisia.com.br

www.facebook.com/MVisia

https://www.youtube.com/user/MVisiaBrasil

Avenida Queiroz Filho, 1700 - Torre E, sala 512 - Villa Lobos Office Park - Vila Hamburguesa, São Paulo 18

Eng. Fernando Coelho Ferraz

Formado em Engenharia de Materiais pela UFRJ, MSc e MBA, tem 32 anos de experiência profissional. Iniciou sua carreira na Embraer atuando como responsável pelo desenvolvimento de materiais e processos especiais como colagem estrutural, tratamentos de superfície, conformação superplástica, fundidos, forjados, solda, e por ensaios mecânicos e análises de falhas. Na Akaer atuou como engenheiro sênior em projetos para diversos setores como Aero-espacial, Automobilística, Bens de Capital, Bens de Consumo, O&G e Defesa. Extensa experiência em desenvolvimento de produtos com ênfase em estruturas e sistemas; utilizando ferramentas si-mulação, CAX, na análise e solução de problemas multidisciplinares. Neste período atuou com diversos materiais metálicos e compostos, diversos processos produtivos, e diversos tipos de ensaios. Atuou como gerente de programa comandando e-quipes multidisciplinares em mais de 10 programas no Brasil e no exterior, totalizando mais de 5 milhões de horas de engenharia. Desde 2002 é responsável pela área de qualidade, configuração e planejamento, tendo desenvolvido e implementado o sistema integrado de gestão da Akaer, incluindo ERP, PLM, BPM, CRM e MES. Desde 2012 atua como COO do grupo Akaer, sendo responsável por uma equipe de mais de 350 engenheiros e técnicos em diversas áreas como Estruturas, Sistemas, Manufatura, Industrialização, Automação ,Qualidade, Configuração, Planejamento, TIC e Suprimentos. Responsável pela implementação da área de P&D+I que gerencia uma equipe de mais de 70 pesqui-sadores em 11 projetos envolvendo parcerias com 5 universidades, 4 centros de pesquisa e diversas empresas parceiras. Mais de 50 artigos publicados em congressos e periódicos científicos. Larga experiência em programas internacionais, liderando equipes simultaneamente em diversos projetos e países. Atuação profissional em mais de 10 países.

Akaer

A Akaer é uma empresa genuinamente Brasileira e independente que se dedica a desenvolver soluções integradas, principalmente para as Indústrias Aeronáutica, Espaço e Defesa. Na origem era uma empresa voltada para engenharia de estruturas aeroespaciais e sistemas mecânicos (mais de 4 milhões ao longo de 20 anos), mas também atuou no desenvolvimento de produtos, máquinas especiais e sistemas para a Indústria Geral. A Akaer diversificou seu portfólio desenvolvendo capacidades em engenharias de sistemas e de manufatura. Com mais de 1 milhão de horas entregues, estas disciplinas representam hoje 40% da capacidade. Aquisições de empresas de alto conteúdo tecnológico como a Opto SD, optônicos, a Equatorial, sistemas espaciais, e a Troya, ferramentais, aceleraram o crescimento em novas áreas e setores.

fernando.ferraz@akaer.com.br

Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept

Abstract

During this decade, took place a technological 'Blietzkrieg' where everybody were forced to a new world with new challenges, concepts and words. In the manufacturing environment, it is a bit clearer what that means and what are the trends; but for product development, the VUCA environment is almost the general rule. Akaer established a project in order to prepare the company to be a 'smart enterprise' and mainly, to have its people prepared for this new scenario. This project, conceived to take 5 years, has focus in 4 areas: development environment, management integration, advanced manufacturing and advanced inspection. However, the most important results expected are: to integrate processes and to shape a T-skill for our people (be more flexible, adaptive and resilient).This paper, in addition to a brief project's description, aims to present and discuss the experiences during the development of 4 different products in the light of those integrated processes. The products are from different applications areas and complexity, but are innovations and are being developed using an integrated approach and also having as basic driver the product 'values' and the users' experiences.

Keywords

Industry 4.0; Advanced Manufacture; Innovation Models; Product Development; Aerospace; Defense.

Authors

Eng. Fernando Coelho Ferraz
Operational Vice-President, COO
fernando.ferraz@akaer.com.br

Joselito Rodrigues Henriques, M.Sc.
Head of R&D+I
joselito.henriques@akaer.com.br

1 Introduction

It is clear in all forums, analysis and reports that the way things are being produced is changing very quickly. Even being part of the human nature to believe that things today and in the future are faster than use to be in the past, it is astonishing to see how widespread is the urgent feeling about changes, challenges and innovation. In this scenario, appears a “consolidated” concept that assumes different names and characteristics around the world as Industry 4.0, Advanced Manufacture, Smart Industry and others, depending on the country, but as rule all those brands have behind it a structured group of organizations methods, technologies and policies conceived in order to enhance the companies / countries competitiveness, efficiency, flexibility and ability to adapt to new customers and markets requirements.

In general, it is being easier to see this revolution in the way how products are being produced, how companies and businesses are being managed and how services are being performed by means of a long list of new technologies, tools, systems, etc. But a new and dramatic revolution is taking place in the product/services creation and development realms; and here it is not only associated to new technologies, but mainly associated to values and basic concepts.

It is easy to worship the technology as a new goodness, associating to it the reasons of all success of some companies and the big failures of others. But in fact, behind this important factor are still old factors as people, culture and organization taking very important roles in the lives of companies and societies.

Hereafter is presented the Akaer’s limited view and experience running a project designed to prepare the company for its next steps. In the sequence, are also presented the example of some different products that are being developed in this new environment.

2 Basic Review

Nowadays there are thousands of very good papers, reports and books about Industry 4.0 and this new environment [1, 2, 3, 4, 5]; for sure we do not aim to create, propose or discuss a new definition or concept about it. But we need to generate our understanding in order to driven the action plan designed to be our roadmap for the company grow.

Along this section is presented a condensed overview about Akaer’s slant related to the mains drivers, which defined its innovation program. After a long discussions were elected some specific themes as more relevant to be specifically addressed as pillars for the program:

- Smart Enterprise concept;
- New scenario.

What is Smart Enterprise?

According to KPMG [5], in the report “**The factory of the Future**” 2016, Smart Enterprise is the “Integration of all business units and value chain by means of the Digitalization”. In the future enterprise the ICT and automation processes will be fully integrated.

All enterprise areas and processes as R&D, commercial, suppliers, partners, manufacturing and customers will be connected in a unified and consolidated environment; making possible the simulation of results in all significant dimensions based on adjustments in key parameters defined previously. In other words, all relevant parameters related to the product life cycle are modeled, simulated and analyzed since the product conception. In such way, all development and industrialization process can be taken into account and managed since the product life cycle very beginning.

In the limit, the Smart Enterprise is an operation where the whole enterprise runs in a cyber and physical environment.

The most significant realms for Advanced Manufacturing Technologies [3], within an Integrated Environment are:

- Advanced Manufacturing;
- Digital Transformation;
- Digital Innovation;
- Digital Cooperation Network; and
- Integrated Digital Production.

New Scenario

According to many authors and Akaer’s experience, in addition to the Smart Enterprise concept it is necessary to take into account other important factors, which are affecting the global scenario. In a simplified way, those factors are grouped in: labor market, product value and business complexity.

Labor Market

The second fact that should guide any analysis in this sense is the evolution or revolution of the **labor market** on a global scale. The hurricane of change is profoundly and definitively affecting existing forms and concepts of labor relations that have crystallized over the past two centuries [7].

In the late 1990’s, the US military coined the term "VUCA" to describe the volatile, uncertain, complex, and ambiguous landscapes in which today's soldiers must operate. More recently, the corporate world has embraced the term as an adequate description of the challenges companies face when competing in a business environment characterized by steady, rapid and unpredictable developments [2].

This lack of trust stems from a mismatch between how we generally promote leaders and the unprecedented complexity that these leaders face at the lower levels of organizations. Most of our promotion criteria are based on past performance, not on whether leaders have the skills they need to succeed. We need leaders who are not just talented, but also agile learners.

- Potential to learn;
- Motivation to learn;
- Adaptability to learn.

In the WEF report [7], about the Future of the Labor, is presented a singular fact: a large number of occupations, which nowadays occupy a great number of workers, do not exist 5 to 10 years ago.

Another important point is to recognize what are the driven factors for those changes. And here again, the most important are not the expected ones.

According to data shown in figure below [7], the more important driven factors are associated to the *efficient information management* and to the *quick adaptation to a new set of technologies*, and not to aspects directly linked to manufacturing and production's means. Those new technologies and the way that the information is managed are dramatically affecting the way how things are done; in fact now the things are done in a much more *integrated and systematized* approach.

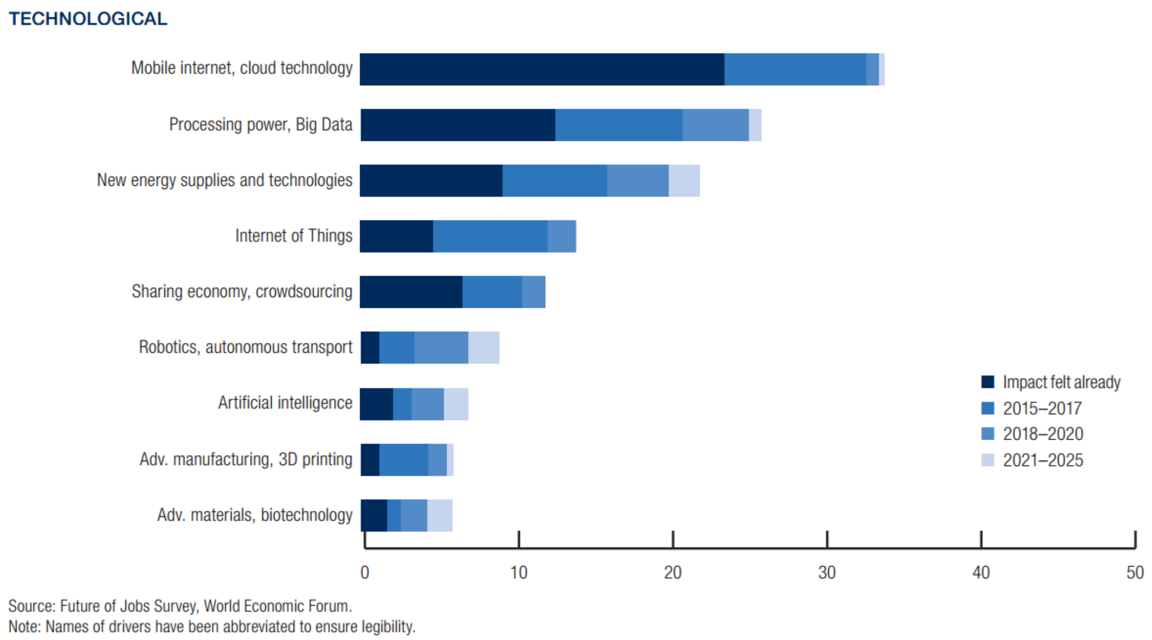


Figure 1: Impact of Technologies in the Labor Market

Product Value

Another set of fundamental factors for positioning ourselves is associated with a historical paradigm shift. Throughout the history of mankind the 'power' was concentrated in that it dominated the means of production. Today produce turned commodity, quality is prerequisite. The 'power' today focuses on those with the ability to set the standards and requirements.

Very quickly, changes in the consume standards are favoring services and products super-intensive in services. In fact, the participation of services in the mix of consumed goods and in the companies' cost matrix are continuously and sharply growing. They are services of all kinds; but the fastest growing part is "embedded" services in tangible products, such as R & D, design, software, branding, and other events able to add direct value or to connect goods to the Internet or to add new features/functionalities to the existent product. When calculated by added value, services already account for 54% of global trade, but are estimated to be 75% by 2025 (Jorge Arbache, Jornal O Valor).

Another way how to see it is that the large majority of 'new' technologies, processes and materials that are 'shocking' the market are not really new; they already exist by more than 30 years. The difference today is that those technologies, processes and materials are being effectively applied in a widespread way around the world in an affordable cost. In other words, the impact comes from the fact that to produce with high quality becomes a commodity.

Business Complexity

Finally, the development and industrialization of new products has become an activity of high complexity not only technical, but requires intricate relationships between partners, suppliers, authorities and customers, and has become extremely capital intensive.

In this scenario, there is an actual race to achieve the new 'holy grail', which can be represented by different names as Industry 4.0, Advanced Manufacturing, Smart Industry, Intelligent Manufacturing, etc. In this race, there are some countries that have taken the lead as Germany and USA, but there many others trying to recover.

Currently, there are many countries developing dedicated policies and programs in order to improve their industrial / business performance [1, 2]. For each specific case, the characteristics vary based on local strength, strategy and interests, but all of them have in common the strong commitment of the triple helix environment (Government, Academia and Industry).

In Brazil, since 2015, many studies and documents [8, 9, 10, 11] were elaborated, but up to now, at least for us, the Brazilian objectives and directives are not clear. Consequently, there is no convergence among the local triple helix stakeholders.

3 Overview about Akaer

Akaer is a genuinely and independent Brazilian company that is devoted to develop integrated solutions, mainly, but not only, for the Aeronautics, Space and Defense Industries. For more than 20 years Akaer has made the strategic decision to diversify its portfolio through organic growth and capacity building in specific areas as aerostructures, systems engineering, manufacturing engineering, and industrialization. In this period it was performed more than 5 million hours of services and product development activities.

As a next step of the growing strategy, in 2015 Akaer took the decision to acquire strategic companies of high technological content in order to strengthen and accelerate its growth in some specific areas and sectors. In this group are included Opto S&D with a long tradition in the optics industry (cameras for space and defense, lasers, integrated vision systems, missile guiding systems and fuzes, electronics and mission critical software), Equatorial renowned in the area of space systems (missions study and definition, critical systems and software) and Troya with great recognition in the area of toolings (design and manufacturing, tooling of parts and assembly, development of manufacturing process, automation of assembly lines). At the moment it is being studied association with other companies in order to enlarge the portfolio.

The headquarters of the Akaer Group is located in São José dos Campos. The Akaer Group operates in 4 business areas with multiple skills, acting as Program Integrator; Development and Integration; Services and Consulting; Technological Development applied.

Figure 2: The Akaer Group General Structure

During the last 25 years, Akaer was directly involved in more than 15 aircraft developments and 5 modernization processes, had released more than 75000 drawings/models, more than 500 engineering reports, and production documentation for more than 10000 parts and assemblies.

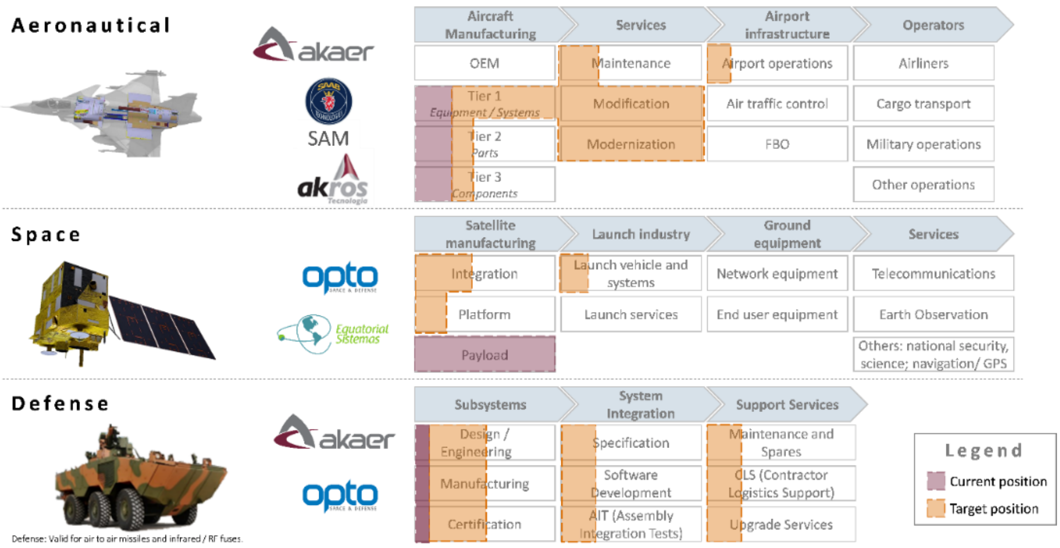


Figure 3: The Akaer Group Actuation Areas and Growing Strategy

Akaer Group has more than 350 employees, mostly with a high level of specialization, as shown in figure below. Within the Group, more than 65% of the employees have a higher education level, of which more than 20% have postgraduate degrees. With regard to project allocation, about 2/3 work with the development of innovative products for customers or own, and about 10% work with pure R&D, i.e., investments in innovations not directly associated with existing projects, products and contracts.

4 Overview about InovAkaer Project

Akaer has established a goal of becoming a 1st Tier supplier of segments and complex systems for the aeronautics, space and defense (AS&D) market in Brazil and worldwide.

The conventional capacitation approach foresees the outline of technological obstacles and in general puts the company at the same level as the majority of the competitors in the market, obliging each player to seek to differentiate mainly through the costs reduction.

Another approach commonly adopted is the search for alternative technological solutions, but without a systemic view of the problem and/or the structuring of the company for it. Most often, this approach leads to the consumption of many resources and time, and the results are not very different from the traditional one.

The option adopted by Akaer is an adaptation of the technological approach where a systematic and integrated innovation environment is the guideline for the technologies selection and application. In this approach the support and interaction with the Academy and partners takes an important role.

The figure below presents an illustration of the three technological approaches discussed.

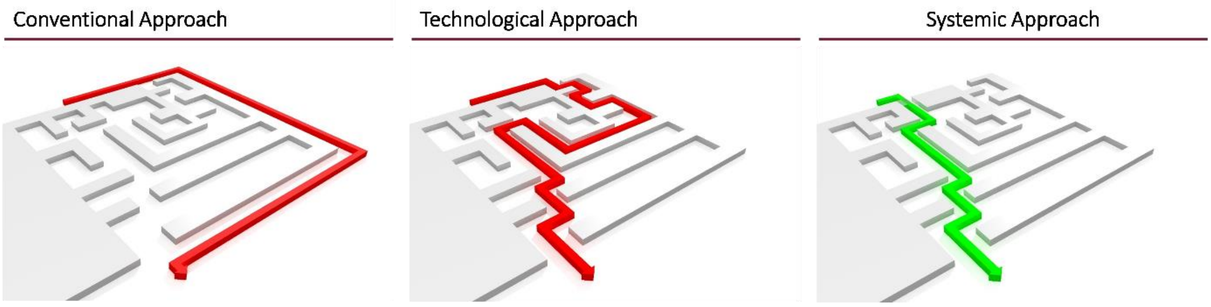


Figure 4: Technological Approaches

In order to be able to achieve the goals coming from the strategic planning, Akaer, with the collaboration of Finep, ITA, Fatec, Siemens and other partners, structured an innovation program with the objective of establishing a 'Center of Excellence' in development and production of integrated aerostructure and systems for the AS&D market.

The main objectives of this program are:

- To structure a Brazilian first-tier supplier for the AS&D market;
- To be a reference center for the development and production of short series;
- To be a reference in the AS&D market for aerostructures and systems;
- Develop and deliver integrated segments; and
- Develop and provide integrated engineering services.

Within the approach chosen by Akaer, the R&D+I area plays an extremely important role not only in the development and capacitation of new technologies, but also in the preparation of our professionals to act in the global environment of high competitiveness and uncertainties that we operate, VUCA (volatile, uncertain, complex and ambiguous).

Today the Akaer Group has more than 10 active R&D+I projects involving several partners such as Universities, Research Centers and Companies, in Brazil and abroad. In total this network includes more than 100 researchers directly involved in these projects.

4.1 Justification for the Project

Despite having one of the largest OEM, leader in the aeronautical market, Brazil does not really have an Aeronautical Industry since there is a big gap in the value chain as shown Figure 5.

For more than a decade, Akaer has sought out compositional forms with the local base to develop an organic solution to fill this gap. Unfortunately, for various internal and external reasons, the results obtained were not satisfactory.

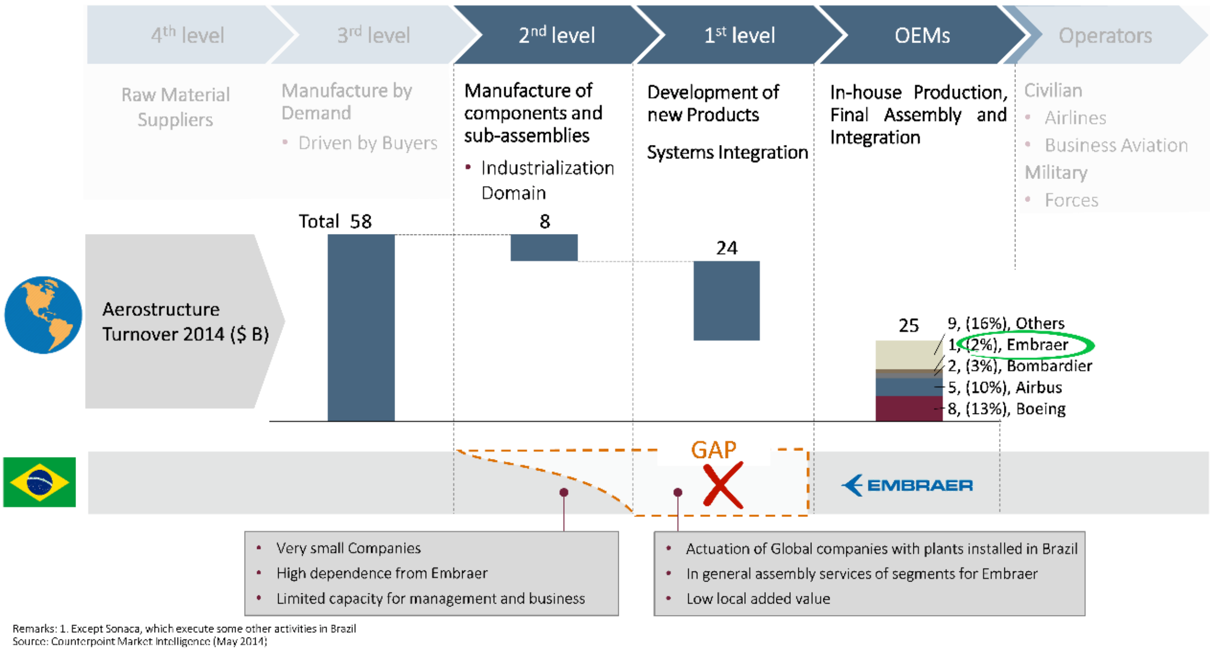


Figure 5: Technological Implementation

From 2013 Akaer has made the strategic decision to change the approach and invest in an internal solution based on a model where the excellence in the development and production of integrated aerostructures is strongly associated with the efficiency and innovation of the technological and management processes involved.

Within this new strategic approach, actions associated with 'organic' capacitation were taken through the structuring of systems engineering, manufacturing and industrialization, and the hiring / qualification of resources to meet existing or short-term demands. However, the main focus of this strategic process is centered on the 'development of innovative technologies' capable of giving Akaer the ability to position itself as the leading integrator and supplier of complex products and services for the AS & D market.

The InovAkaer Program was designed to create the environment and provide the means to achieve the 'technological' branch objectives of Akaer's transformation project into the best and most important first level supplier for the AS&D market in Brazil and to have a significant position in the global market.

4.2 Project Description

The aim of the project InovAkaer is to prepare Akaer to be a 1st Tier integrator, providing complex products and services to the AS&D market.

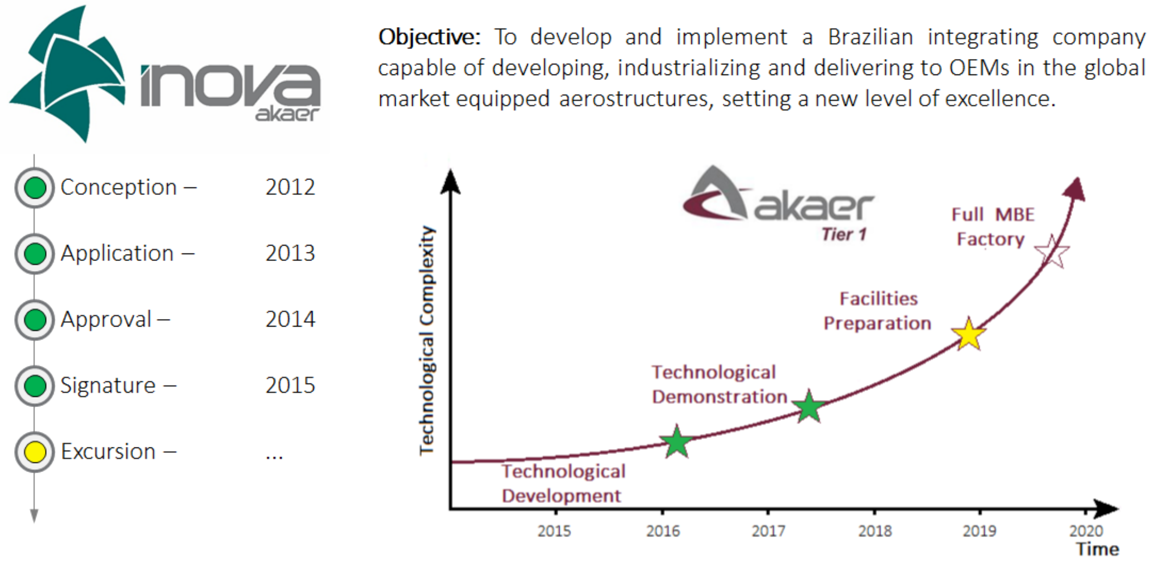


Figure 6: InovAkaer Phases and Project Status

The project is comprised of four development fronts, i.e. the integrated product development environment, the integrated management system, the flexible manufacturing environment and the active inspection environment.

INTEGRATED PRODUCT DEVELOPMENT	• Full MBD – product's requirements & information available in a single 'model'; • Intensive application of computational simulation (digital twin);. • Unified Virtual Platform connecting all partners/suppliers.
INTEGRATED INFORMATION SYSTEMS	• Unified database for different systems as – PLM, ERP, MES, etc. • Full Virtual Twin – digital operation and integration with customers, partners, suppliers, authorities, etc.
MANUFACTURING TECHNOLOGY	• High performance flexible tooling; • Secondary guidance system, virtual positioning/relative reference system; • Virtual commissioning.
INSPECTION TECHNOLOGY	• Automatic and online dimensioning inspection and analysis; • Dynamic and active compensation system; • Online best fitting.

Figure 7: InovAkaer Fronts and their Objectives

4.3 Requirements and Assumptions

In addition to the global objective presented above, it is clear that the Akaer's team capacitation and the implementation of a new strong culture focused in innovation, adaptive and agile organization, strong organization with efficient management processes designed for each specific phase and situation are key issues to be achieved.

This new ecosystem is being called as Akaer's Knowledge Environment and intends to drive and support the way how people should actuate and conduct new developments and innovations. In general it is being proposed a more active behavior looking for knowledge and not only just waiting for receiving some pieces of knowledge if and when necessary.

Some specific results from this Knowledge Environment are:

- Develop competence to meet future market demands for complex product development and integration, including aerostructures, by applying advanced management and engineering (product, manufacturing, automation and inspection) systems;
- Use the technologies, systems and processes developed to extend Akaer team competency in product development in an integrated manner;
- Develop Akaer's competence and capacity in the formation / operation of integrated networks for research, development and supply chain of complex products;
- Expand Akaer's competencies to operate in new markets and technologies.

In order to maximize the project's comprehensiveness, it is important the involvement of as many Akaer employees as possible, looking for to disseminate and multiply the knowledge, skills and culture developed by all areas and teams inside Akaer.

Since the cultural and personal aspects are very important for building the Knowledge Environment, it is fundamental the commitment of the High Staff and of all the direct and indirect collaborators.

The environments, technologies, systems and processes developed must be flexible and scalable so that they can be adjusted according to the reality of each project or scenario.

The solutions developed should be designed considering a technology integration environment, with multiple partners and suppliers directly connected to the processes at their various levels throughout the product / service life cycle.

Akaer should develop a close and healthy relationship with the Academia, funds Agencies and any other partner in the Triple Helix R&D+I environment.

4.4 Organization and Methods

In order to run the project, Akaer defined a dedicated team comprised of 27 technicians and support people that was organized originally following the traditional program management organization used for the different complex projects in development at Akaer.

In addition to the Akaer employees joined to the program around 25 researches from ITA, 10 from Fatec and circa of 10 other floating collaborators from partner companies as Siemens, Dassault, Totvs and SoftExpert.

It was defined a physical infrastructure for the project able to accommodate simultaneously up to 40 people having access to the environment and tools defined for the project. In the same way a remote site was created at ITA/CCM facility in order to emulate external clients interacting with the integrated system.

The allocated resources were organized in 8 fronts defined in such way that all main disciplines identified as necessary in the preliminary studies were properly addressed. The defined fronts are listed below:

- General Integration – responsible by the design and development of corporate systems and integration of the other different fronts;
- Business Program Management – responsible by the definition of the business processes and management flow and by the project organization tools;
- Integrated Product Development – responsible by the integrated product development environment organization and development of associated technologies;
- Requirement Management – responsible by the development of the requirements management process and tools insuring the integration of all disciplines;
- Configuration Management – responsible by the development of configuration management process and tools from the development up to the product disposal;
- Advanced Manufacturing – responsible by the study and development of advanced manufacturing technologies as automation, sensors and actuators, active inspection, additive manufacturing, advanced composites, etc;
- Digital Manufacturing – responsible by the study and development of technologies associated to manufacture simulation, virtual and augmented reality and digitalization;
- Research, Development and Innovation – responsible by the coordination of the periphery and correlated R&D+I projects developed with the support and/or to support the InovAkaer.

The first stage of the project, around 3 months, was dedicated to perform a deep review in the available technical literature, , looking for mainly four realms: engineering and manufacturing advanced processes, product development organization, technological foreseen technics, and trends, and knowledge management. As a result of this first stage it was defined a basic organization and associated set of tools based on classical literature [17, 18, 19]. In this stage were also defined technologies of interest using data and processes defined in the literature [13, 14, 15, 16].

Both, organization and set of technologies, are being analyzed, adjusted and evolved during the project evolution. Figures below show the current references for the project organization and product development.

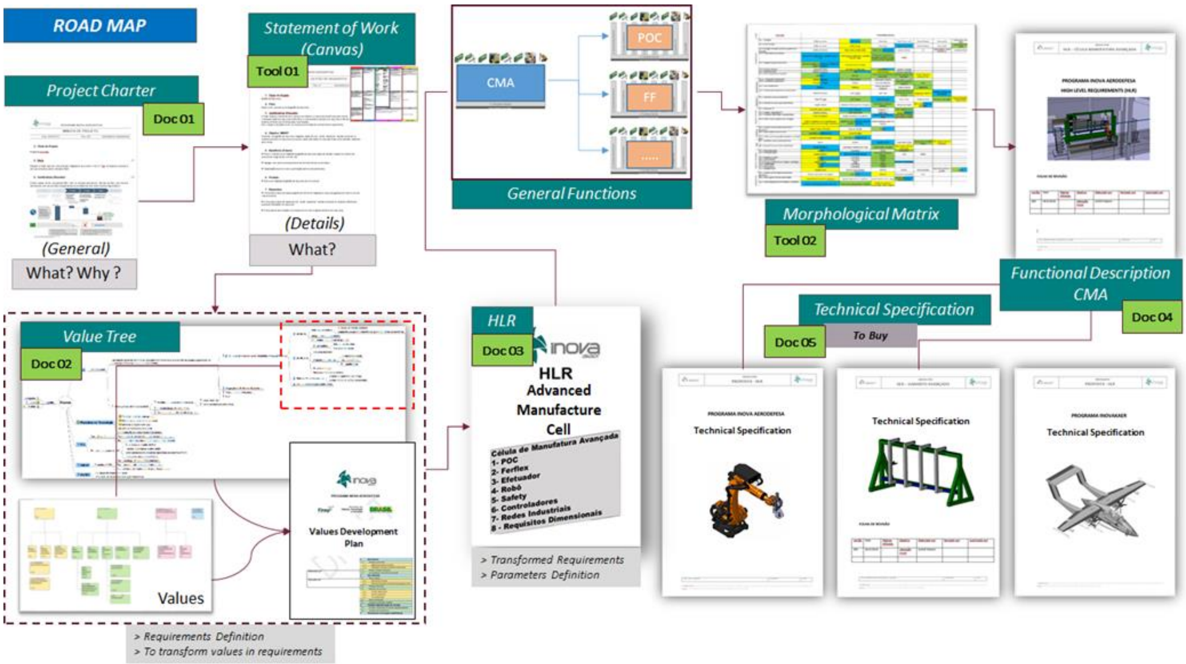


Figure 8: General Roadmap used in the Project Organization

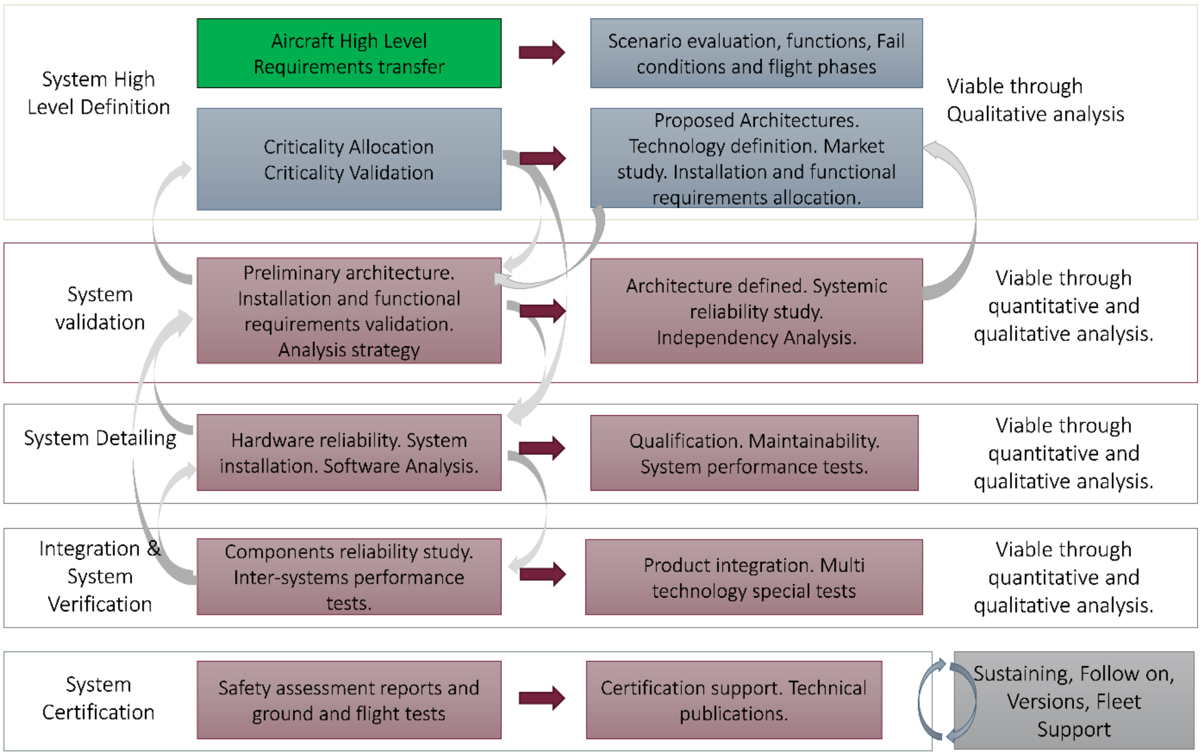


Figure 9: Reference System Development Flow

Another important concepts assumed as reference for the project were the **convergence of technologies** and efforts using demonstrators and **collaboration nets** integrating a large number of partners in common projects. Figures below presents an illustrative view of those concepts.

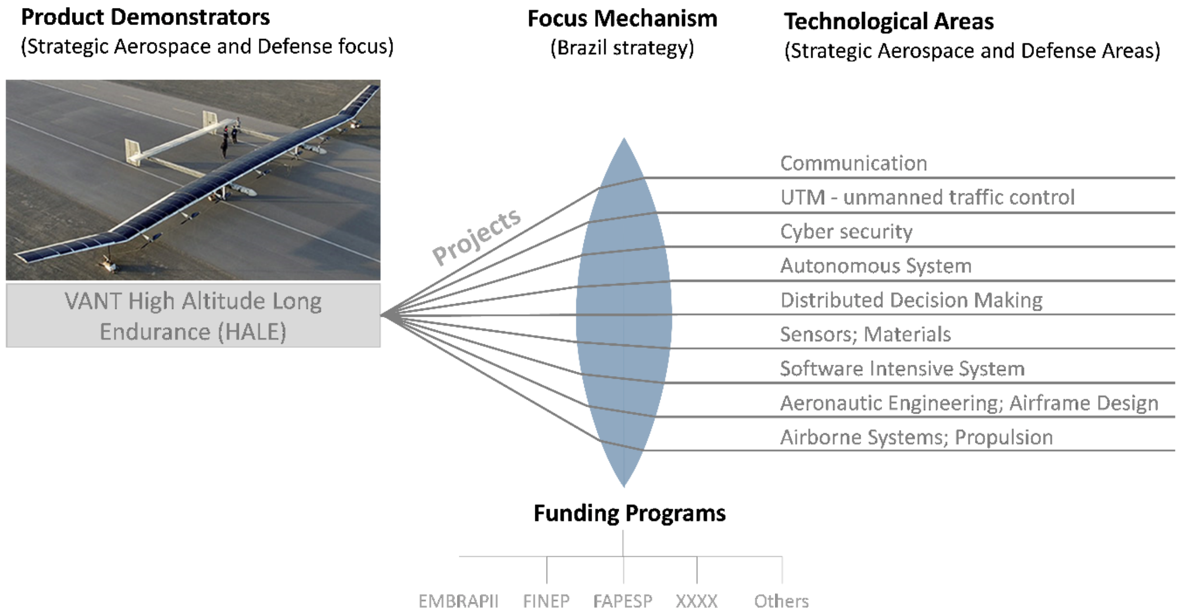


Figure 10: Concept of Technological Demonstrators Adopted

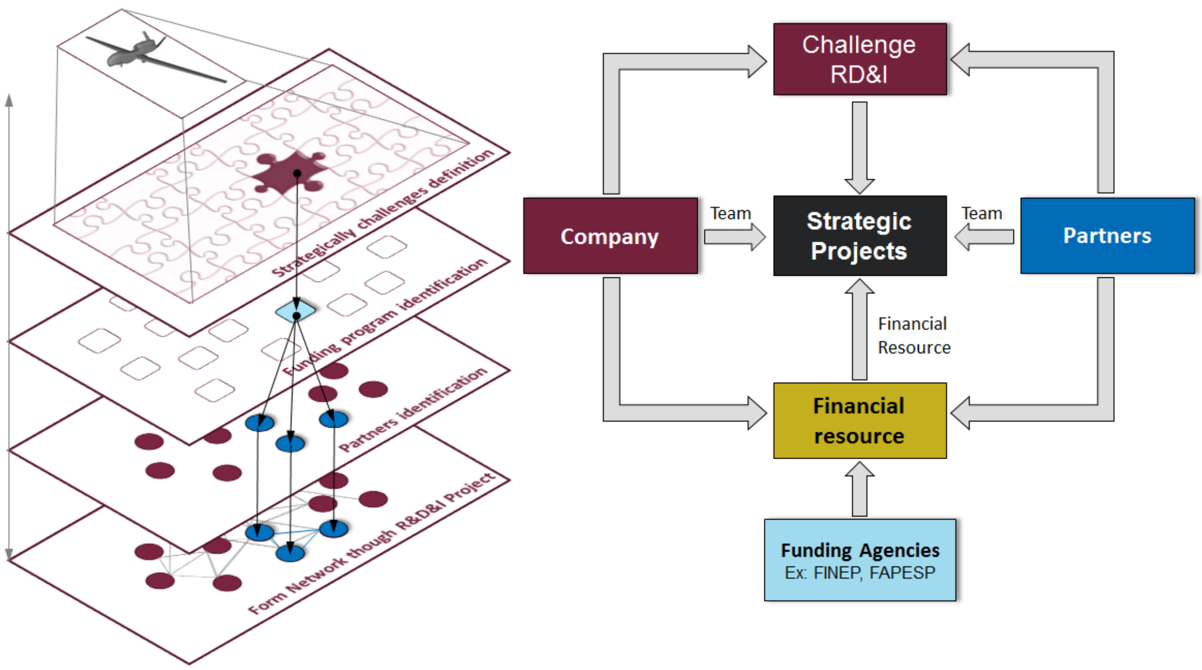


Figure 11: Concept of Research Networks

4.5 InovAkaer – Facts, Numbers and Results

Below are presented some facts, numbers and results associated to the project InovAkaer that can summarize it up to now:

Addressable Market in 2024

According to the market analysis performed [6, 20, 21], a Brazilian 1st tier company has the potential to reach annual sales of more than 1 B USD in 2024. Just for reference, according to AIAB [22], the annual average sales of the Brazilian Aeronautic Industry, excluding Embraer, does not reach 100 M USD in the last decade.

First tier companies have a strong leverage factor from both a technological and a financial point of view, 1st tiers companies [6], generate 12x more value than 2nd tiers ones.

New Site and Industrial Facility

Akaer invested in the acquisition of a brand new facility with more than 10000 m^2 of outstanding industrial area read to start aerostructures assembly and systems integration.

Investments in the Project

The total investment just in the InovAkaer Project is 40,5 M R$; the total amount of investments including the new site, companies, infrastructure and tools overpass 100 M R$.

Project Hours

The total amount of direct hours predicted to the project is 180 thousands, in addition there are more than 20 thousand hours being executed in correlated projects.

According to the last project review report delivered to Finep in May, were performed more than 94 thousand hours, as shown in figure below. The expectation is that at the end of this year it will be performed at least 120 thousand hours.

Involved Researchers

In the peak of the project, at the end of the first phase, there were 72 researchers directly involved; currently there are around 50 dedicated researchers. In the correlated R&D+I projects that Akaer is involved there are more than 20 others researchers working with.

Institutions Involved

In the InovAkaer project there are 2 Academia members, 3 partner Companies and 1 Fund Agency directly involved. In the correlated projects there are 8 Academia members, 10 Companies and 3 funds Agencies.

Correlated R&D+I Projects

There are 2 directly correlated projects, associated to advanced manufacturing processes, linked to the InovAkaer and other 7 projects associated to product/technologies development that are taking advantage of the Knowledge Environment and tools developed inside InovAkaer.

New Systems Deployed / Implemented

As part of the integrated development environment is now validated and running 2 different PLM's, an extended ERP application covering all operational cycle of a 1st tier company, other corporate applications as CRM and BPM, many engineering new tools for digitalization and simulation, and one manufacture management application, MES.

Assembly Lines Designed / Optimized

As part of the industrialization capacitation and training were fully developed and optimized 3 assembly lines, two of those are being or will be implemented. The third one is still being used as development reference.

Spin-off

Since the project InovAkaer started it were performed 3 internal workshops with the presence of all involved researches, floating partners and support team, around 75 people each.

4.6 Current Status and Next Steps

In this phase, are being performed three group of activities in the project. The first group is linked to complementary studies and optimization of manufacturing management processes including production and supply chain planning, manufacture documentation and corporate systems.

The second group of activities are associated to an experimental advanced manufacturing cell designed in order to test and validate all developments achieved in the different fronts. Figures 12 and 13 below show illustrative views of the flexible assembly cell and the Flexible Tooling architecture.

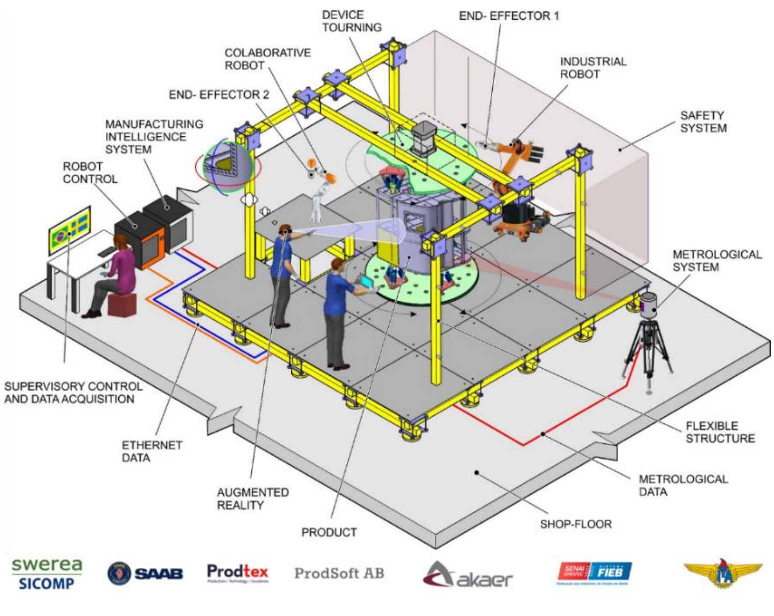


Figure 12: Flexible Assembly Cell

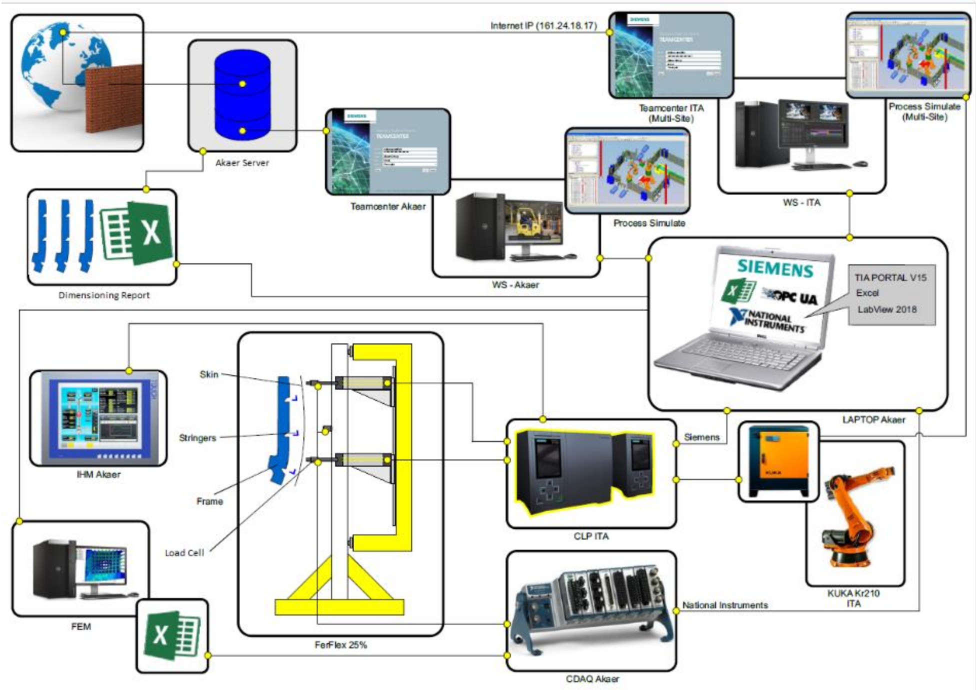


Figure 13: Flexible Tooling Architecture

The technical activities predicted for this phase are listed below:

- Plant Simulation:
    - Optimization tools as classical probabilistic, discrete event simulation, queueing theory, Petri net, Monte Carlo and other modern computational algorithms.

- Process Simulation:
    - Manufacture:
        - Actuators kinematics, programing and integration applied in the FerFlex;
        - Robots kinematics, programing and integration with sensors, actuators & controls;
        - Sensors and virtual commissioning;
        - Integration with PLM;
    - Human:
        - Human kinematics and performance simulations and analysis;
        - Ergonomic and performance simulations and analysis;
        - Vision envelope simulation and analysis;
        - Operations and processes times and cycles.

The last front in course in the InovAkaer project is the propagation and full implementation of the operational and management processes developed and tested in the project environment.

This front will take the advantage of a running project, presented in Section 6.1, to validate the proposed approach mainly for the Industrialization and Production environment.

5 Product Development Scenario

The product development environment has changed a lot in the last few decades, but different from what ones might think at first, the main reasons are more associated with organization and methods than new technologies. In other words, it is possible to say that the new technologies that had the greatest impact on the way products are developed were those associated to information organization and management and not direct engineering tools.

As shown in figure below, the basic disciplines and phases associated to product developments still being the same as 30 years ago, at least. In the same way, even being visible due to use of new engineering tools as CAX, the differences in each individual step are also not enough to explain the huge reduction in the development cycles and costs. The key aspect, which is driven the new scenario is the significant overlap between phases and the deep integration between different disciplines.

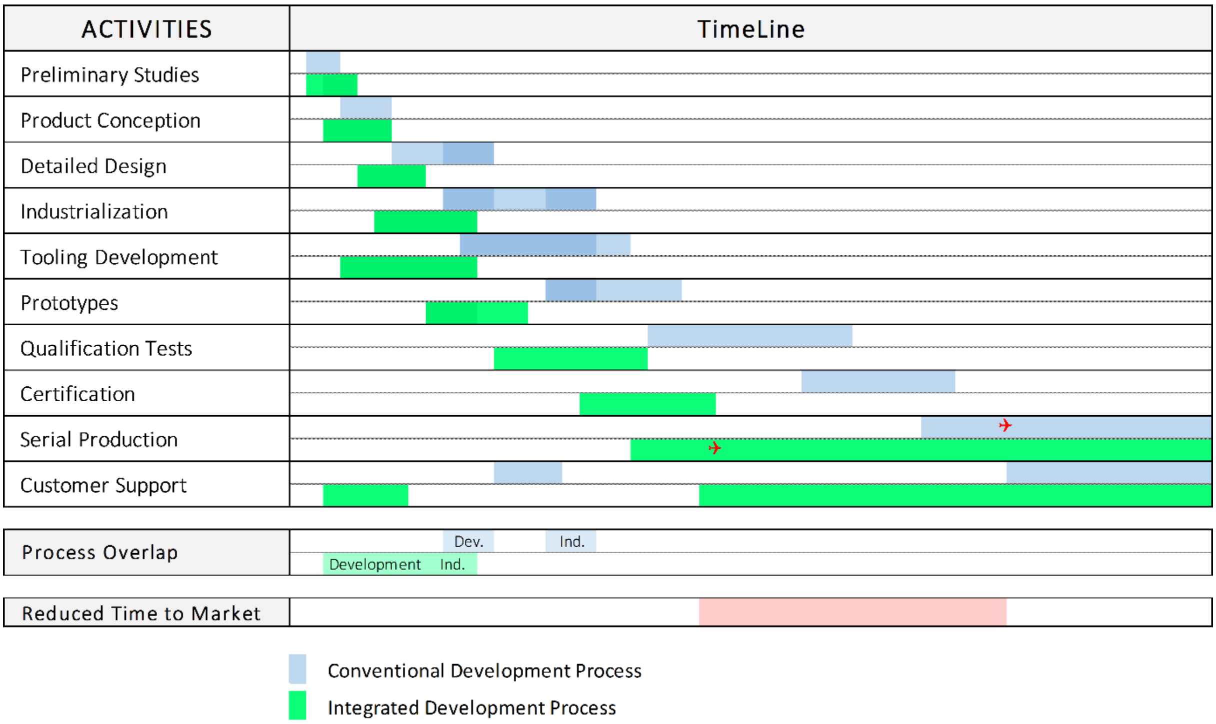


Figure 14: Complex Product Development Cycle Comparison

These phases' overlaps and disciplines' integration are achievable mainly by the use of new systems and tools, which make possible an efficient management of a large amount of information, allowing different teams, even in different sites and using different environments, to access and work in a unified, updated, reliable and controlled database. This unified virtual plateau, illustrated below, should containing all necessary requirements and information used by the different teams along the complete product lifecycle. A simplified view of some disciplines involved in one aircraft development and the systems normally applied for each one are shown below.

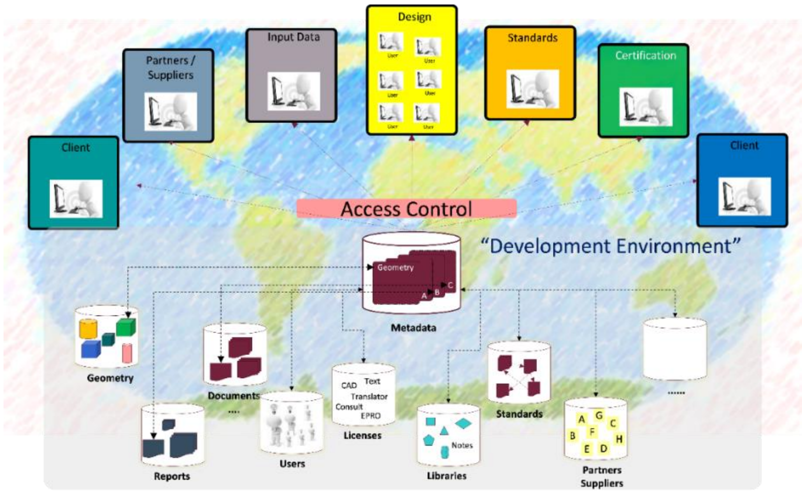


Figure 15: Illustrative View of Integrated Development Environment

In general, the vehicles defined as the collectors for the different information and requirements related to the product during its lifecycle are the models, or old drawings. Those models and associated metadata, managed in different systems as PLM, ERP, MES, define the product, and generate the concept Model Based Design or MBD.

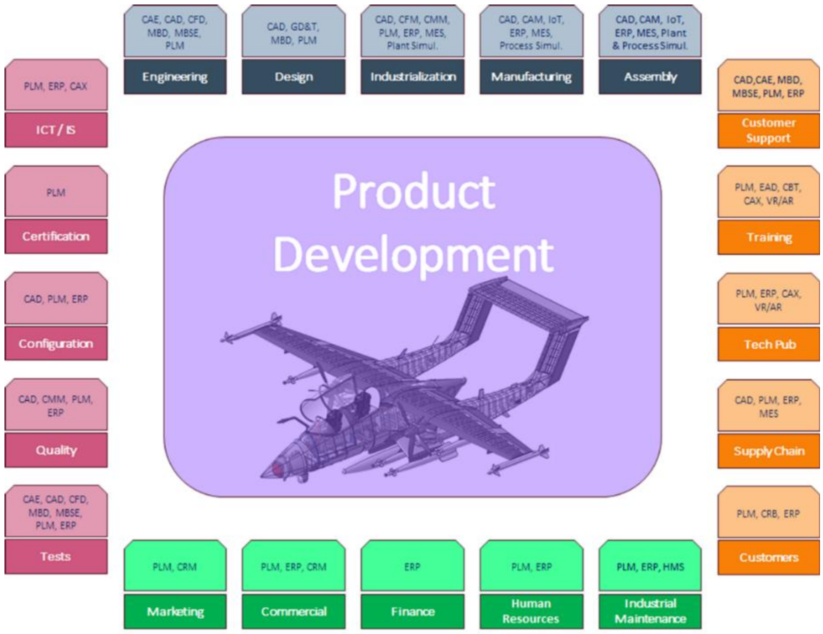


Figure 16: Illustrative View of Disciplines and Systems Involved

A direct effect of the new integration reference can be seem in the next table, where are compared the amount of activities performed and deliverables generated for three similar aerostructure segments developed in the last three decades. It is easy to see that the amount of information concentrated in the product development phase increased significantly and that this phase is incorporating a lot of activities and tasks performed formerly in subsequent phases.

The consequence of this new project organization is that the teams must to identify and make explicit the necessary requirements early than did before. Additionally, the teams must to interact in order to harmonize the requirements and the project management process must to deal in a much more efficient way with lack and/or conflict of requirements since that now a failure in the input management can generate a cascade of impacts.

Table 1: Example of Complexity

AREA	1990'	2000'	2010'
Product Development	Structural Engineering	Structural Engineering	Structural Engineering
	Strcutural Design	Strcutural Design	Strcutural Design
	Configuration Control	Configuration Control	Configuration Control
	System Installation Design	System Brackets Design	System Brackets Design
	Certification	System Installation Design	System Installation Design
		Harnesses Design	Harnesses Design
		Certification	System Engineering
			Tests & Certification
			Reliability & Safety Engineering
			TechPub & Maintenance Engineering
Manuf. Develop.	Manufacturing Infos inside Dwg	Manufacturing Engineering	Manufacturing Engineering
		Manufacturing Documentation	Manufacturing Documentation
		Quality Engineering	Quality Engineering
			Industrialization Engineering
			Plant & Processes Engineering
Program Management	Program Management	Program Management	Program Management
	W&B Management	W&B Management	W&B Management
		Configuration Management	Configuration Management
		Risks & Readiness Management	Risks & Readiness Management
		Planning & Control	Planning & Control
			Resources & Costs Management
			Supply Chain Management
Dwg	~ 1.000	~ 1.500	~ 1.750
Hours	< 100.000	< 300.000	> 500.000
Docs	< 1.000	> 5.000	> 15.000
Size (Gb)	< 100	< 500	> 10.000

6 Study of Cases

Here after are presented briefly four cases where some concepts, methods, tools and organization coming from the InovAkaer project were applied.

These cases are very different from each other; they are connected to different Industries, they are different in sizes, applications and technologies, they have different complexities and costs, and by the end, they are associated to different development stages.

The first one is just an evolution of an existent and tested product, with improvements in the organization and in the processes applied. Two of them are radical innovations from previous concepts, but still keep some features and functions of previous products. Finally, the fourth product is a whole new concept bringing a disruption in the way certain activities are performed.

What these cases have in common is that they were and/or are being developed simultaneously by a relatively small team; with multidisciplinary characteristics, with the collaboration of several partners and suppliers, and mainly, following a form of organization conceived in the InovAkaer project.

Soon after, the teams began to study the applications and uses/users' needs, in order to identify the real values sought. This was an interactive process, both with respect to the relation between the values identified with the preliminary requirements received and with the restrictions collected from the preliminary studies, partners, suppliers, customers, etc.

In all cases, the early interaction between different skills in addition to the long sections discussing first the values and after requirements, can be associated to the significant reduction in the development cycles and other good improvements as discussed below.

6.1 Wing Assembly Line

During the last years a local operator is studying many different alternatives to extend the operational lives of its fleet. Those aircraft had their avionics and mission systems fully modernized some years ago with a state of art technology, but the structural cell are facing some operational limitations. The big challenge is to achieve an economical balance between the life extension requirements and the reconfiguration costs.

After many studies it was chosen a solution derived from an existent one having a Brazilian integrator with optimized industrial/management processes, but without affecting the original materials and technologies in order to avoid new certification costs.

For sure it is not a new product, but it was decided to use the development methodology and project organization in order to insure the full achievement of the tight schedule and budget defined. Since the original design, material and construction processes must to be kept, the few open variables were associated to the Industrialization processes, plant layout and internal logistics, team organization and training, and the management processes.

In this case, since the product is already defined and the new version must be the same as the certified product, the main values identified to be pursuit are: efficiency in traceability and configuration management, integration and efficiency in each work stations.

Based on those values and in the previous defined requirement it was prepared a detailed Industrialization and Manufacturing Plan, which was the baseline for all other activities.

According to the master schedule, the physical assembly line will be ready only in the first quarter 2019, but since April 2018 there is a team working in study of the plant layout, workstation definitions and organization, material organization and flow, processes and production documentation, organization and management system, and resources planning.

The plant simulations and the optimization cycles, tested more than 5000 configurations up to achieve the elected one, where the balance between many production and logistic variables were considered good and cost effective.

In the same way, the bill of material and bill of processes for each production station were simulated, tested and optimized. Based on that it was defined the production documentation and the flow, including planning, follow-up, control and management.

After this phase, it was possible to achieve a theoretical efficiency around 20% higher than the original process performed by the OEM. In the same way, the expected time to have the industrialization phase ready and running, including the team training, is around of 6 months instead of 18 months as took in the original installation.

For sure, those values are theoretical and must be checked and validate after the assembly line start actually to produce, but anyway the gains related to the process knowledge in advance using the digital twin are good enough to justify the use of those tools even without other results. Figures below show some of the performed simulations and optimizations cycles.

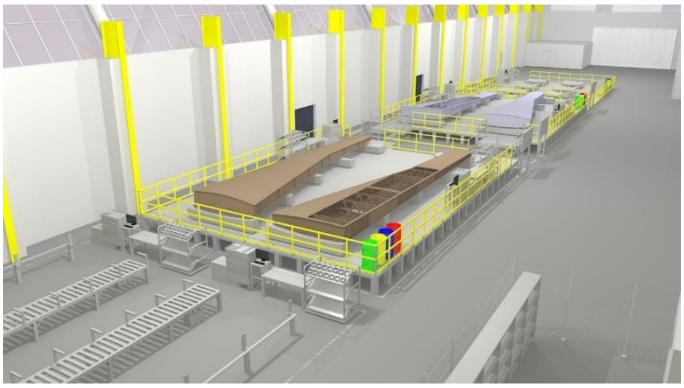


Figure 17: Conceived Assembly Line

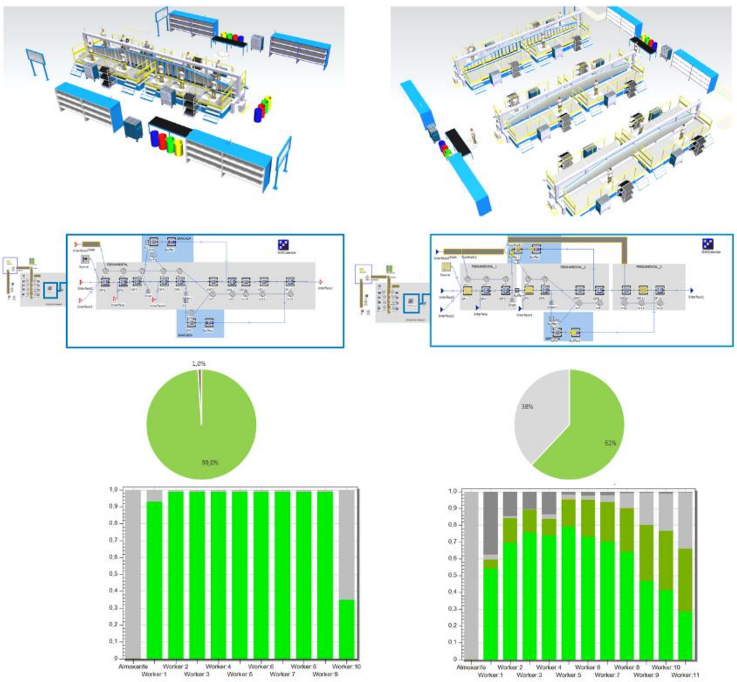


Figure 18: Examples of Layout and Process Breakdown Analysis

6.2 High Resolution Space Camera

The traditional approach used to develop space camera up to now follow a very complex and expensive process. In the last 5 years the way how space products are being developed is facing a revolution, not much due to new technologies but mainly due to new approaches that can be synthetized in the 'new space' concept.

Many services and application that before were restricted to large satellites in GEO orbits are now being performed by micro and nano satellites in LEO orbits and in a constellation arrangement.

In order to adapt the existent products to this new scenario it was designed a roadmap aiming to evolve from the traditional products and their development processes to the new standards where are required a significant reduction in the size, weight, cost and development cycle in combination with much better resolution and embedded services.

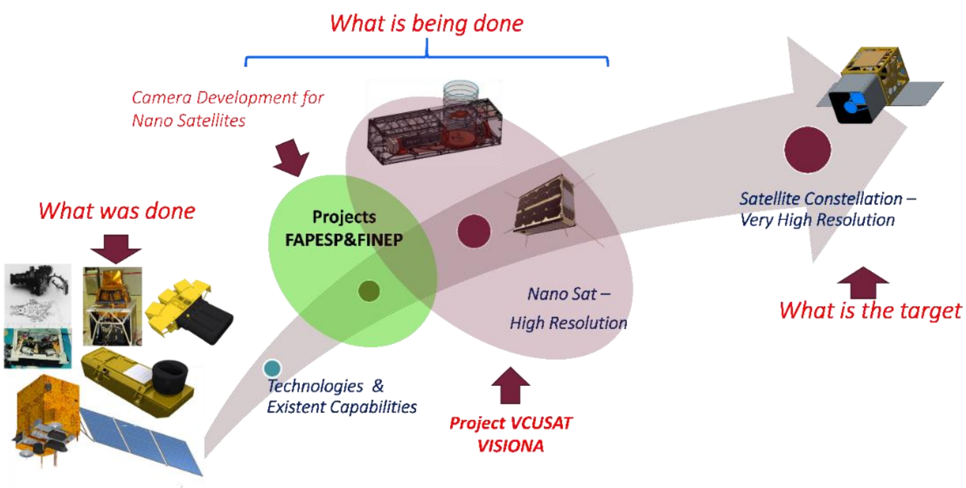


Figure 19: Product Development Roadmap

Another important change in the product development process is the way how those processes are funded. In the traditional approach the products were developed in a tailored way, designed to a specific product/application. In general, those equipment were developed with large time intervals and not following an incremental evolution. Additionally the percentage of technological reuse was small.

In the new scenario, mainly in the Brazilian reality, this design to spec model driven by previous orders is not feasible anymore. It is necessary to develop a model based on aggregation of small funds, more flexible and adaptive products able to evolve easily and requiring short development cycles.

This is a more active approach where the products are conceived based on identified market needs or even in values/applications not mapped yet, instead of wait for specifications coming from the space agencies.

The characteristics of the new line of product are significantly different from the traditional ones as can be verified in the sequence: development cycle 18 X 60 months, dimensions 1500 X 300 mm length, weight 150 X 5 kg, resolution 5 to 20 m and cost around 1 order smaller.

Other interesting characteristic is that the same platform and concepts are being adapted to three different customers covering different applications.

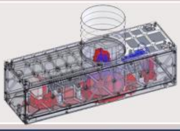
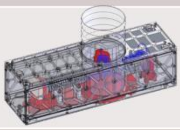
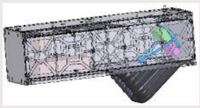
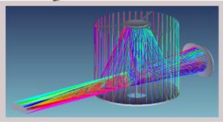
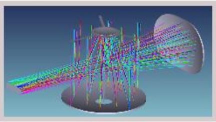
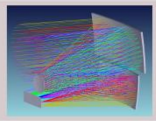
	Mini-Korsch	OptoGom	NanoMUX
Project client	VISIONA	GOMSPACE	TMA Fapesp
Mechanical Layout (3U)			
Optical Layout			
Input aperture	ϕ80mm	ϕ80mm	70mm x 35mm
Resolution (GSD)	≈3.5m @500Km	≈7.5m @500Km	≈20m @500Km
F-number	10	5.2	4.2
Swath across track	≈14.4Km	≈30Km	≈80Km
Sensor	4096 x 5.4µm / TDI x 256	4096 x 5.4µm / TDI x 256	4096 x 5.4µm / TDI x 256 or CCD x 1
Bands	RGB-NIR (TDI)	RGB-NIR (TDI)	RGB-NIR (TDI or CCD)
Optical MTF@Nyquist	0.30 (theoretical)	0.40 (theoretical)	0.7 (theoretical)
NIIRS	2.1	1.2	not applicable
Applications	Tactical, law enforcement, city planning	Law enforcement, natural disasters, city planning	Environment monitoring, natural disasters

Figure 20: Example of the new Product Portfolio

6.3 Dump for Heavy Mining Truck

Akaer was contracted this year to develop in a very short time a new dump following a very simple and challenging list of requirements, shown in figure below. In few words, the new dump shall be installed on existent trucks carrying out 20% more load, weighing 33% less and with a twice-longer operating life.

3.0 CARACTERÍSTICAS GERAIS

As básculas devem apresentar as seguintes caracteristicas:

- Capacidade volumétrica: 160±3 m^3;
- Massa total (estrutura e revestimento): 20+3 t (toneladas métricas). O alvo deve ser 20 t, porem poderá ser considerado massa total de até 23 t, ou seja, ser 15 (t) mais leve que as básculas standard utilizadas atualmente. A diminuição de massa da báscula deverá ser convertida em aumento massa de produto transportado, aumentando a produtividade.
- Vida útil minima: 12.000 horas de operação ou 2 anos. Sem necessidade de reformas ou reparos devido a desgaste ou fadiga decorrente de utilização normal;
- Ao final do periodo de utilização a báscula será substituida, logo deve ser projetada considerando que não haverá reformas ou reutilizações.
- Não deverá ocorrer nenhum tipo de efeito colateral no caminhão fora de estrada.

Figure 21: New Dump Basic Requirements

This is a traditional product with many global suppliers, but the concept and performance of the existent products are being challenged by the mining companies eager for solutions able to improve the mining productivity after the commodities super cycle.

The challenge here was to identify the values and hidden constraints in such way to open new fronts where the new product could achieve the expected breaking through.

After the technical review, product benchmarking and in situ survey it was prepared a technical specification defining the requirements and targets for the new product lifecycle.

The innovation efforts in this case were concentrated in 5 fronts as described below:

- Clear understanding on the operational life constraints as loading and unloading, vehicular dynamics, typical failure modes and abusive loads – intensive use of simulation tools and field tests;
- Simulation of all phases and details including structural behavior, operational kinetics and dynamics, manufacturing processes, ergonomic and handling aspects, and maintenance – intensive use of simulation tools as CAE, CAD, CAM and other engineering tools;
- Selection of better and adequate materials and processes for the dump manufacture and protection – joint development with material suppliers as special steels and welding process;
- Development of partners/suppliers able to understand, support and comply with the defined requirements – definition of clear communication and qualification process; and
- To design and run an efficient management process integrating all links in the product lifecycle – MBD concept.

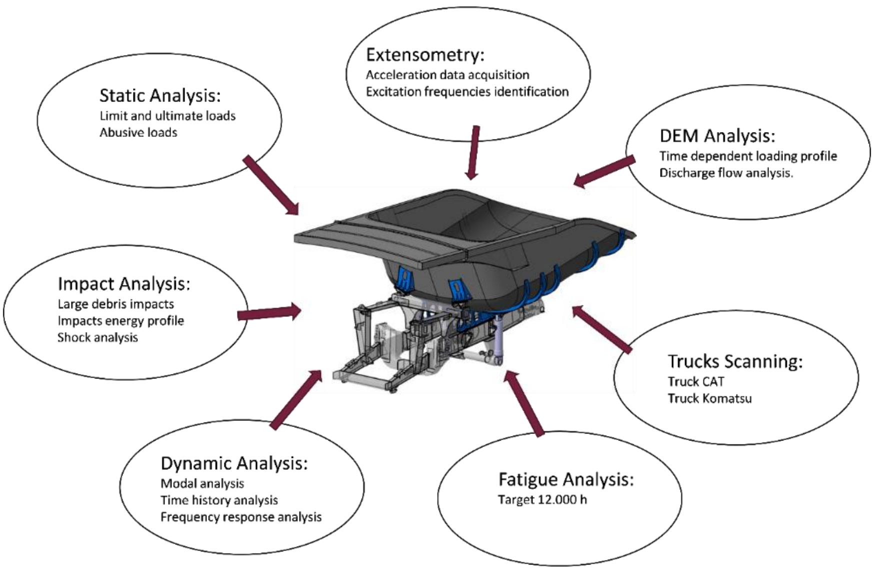


Figure 22: Summary of the Technical Aspects Analyzed

Figure 23: New Developed Dump

The result of this experience was to have a completely new product developed and produced in less than 100 days from the scratch to the delivery to the final customer. But more important, it was achieving all original requirements and adding new concepts and values to the product, which now define a new standard for the expected operational efficiency.

6.4 Cattle Monitoring System

This case is different than those presented before. In this case there is not a reference product. Instead of it, there were a collection of tasks performed in different ways and some not consolidated ideas of what should be sought.

In Brazil, as a rule, the meat cattle was created in extensive farms, where the animal eat natural pastures. This is the easiest and cheapest approach, but the new quality and performance requirements brought new challenges for the producers. It is being required a 100% traceable animal also able to achieve the cut weight in minimum fatting cycles.

The more common solution for it is the semi-extensive approach, where the animal still eat outside pastures but also complements feed by means of feeding stuffs. In those cases, even the outside pastures are not natural anymore, it is defined and planted following scientific studies to fulfill the specific need of one local livestock.

In this environment, it becomes fundamental to increase the knowledge about each animal evolution, including movements, daily diet, health and weight. This is the scenario was this project started.

The first challenge for the development team was to get immerse in this new environment with different language and culture. In the same way, to understand the animals' habits and environment constraints, to identify the critical parameters and their inter-relations, and to take into account the large variety of lands where the solution must to fit in were also part of the 'non-technical' issues to be early addressed.

By the end, in this case the product is not one individual piece, but it is a system comprised of sensors installed in each individual animal making an integrated net communicating each other and to the control room. Figure below shows a simple overview about the proposed system.

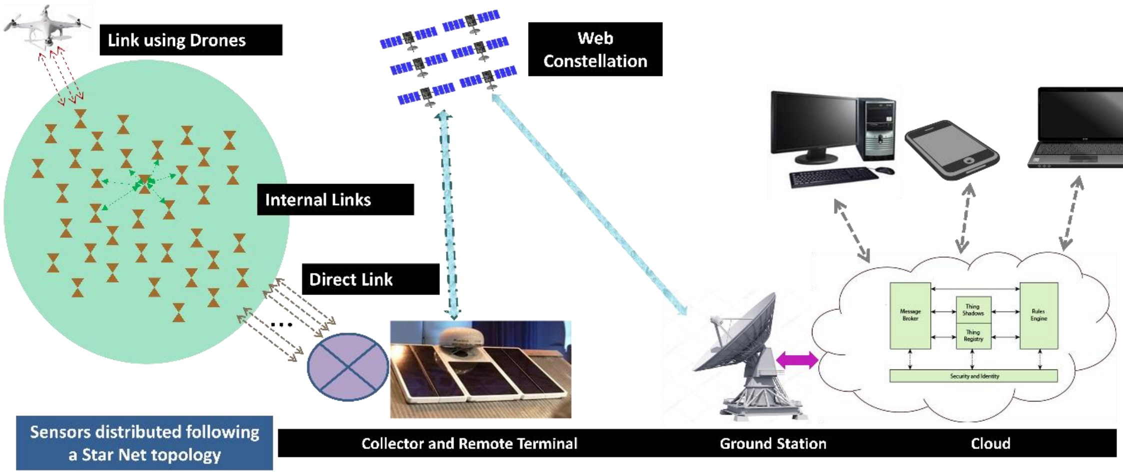


Figure 24: System Basic Architecture

In this project are being developed integrated sensors able to acquire in real time and in a non-invasive way some parameters from each individual animal bringing a great amount of data that after specific treatment and analysis become full traceable information that support many operational and business decisions.

To insure the system efficiency it is necessary the definition of a robust devices network including the embedded hardware and software, the signal processing and control, the sensors/system integration, the communication and security protocols and the data presentation architecture.

In the current stage, the integrated system is being tested in two different farms and it is planned to be available in the market during 2019.

7 Discussion

This article has not the intention to be or follow an academic formality; in fact it is much more a collection of ideas and experiences coming from the Akaer's innovation project, InovAkaer, and the application of the concepts, methods and tools defined up to now, in the development of products in different Industrial areas.

Based on that, more than discuss formally the results and/or propose new concepts or methodology, hereafter are discussed a particular view of the main trends observed, the results of the project designed to prepare the environment and people for the new scenario, and some comments about the experience with product development.

The first point important to be treated is the vision about the current environment that we are calling 'Smart Enterprises' since it is involving the all areas of the enterprises and all business areas not only industrial or manufacture. According to our view what define this new environment is the total integration of processes, areas, systems and business; and the key success factor is the high efficiency managing information, in all of their aspects, forms and sources.

The new way how goods or platforms are being produced, where to produce is becoming a commodity, and the growing need to quickly capture, develop and implement new features/services to be embedded in the platforms bring to the local markets a huge range of opportunities.

Still according to our view, this new environment more than be focused in automation and robot, is being driven by a significant change in the culture and in people, i.e., how much companies and countries are educated and ready to adapt and adopt the new concepts, which will keep coming continuously.

Based on those assumptions was designed the project InovAkaer that has as its main objective to create a proper environment where the new concepts could be developed, tested and validates, and where the Akaer's people could be prepared to assume a more active role in the new projects and activities. Instead of to perform well and efficiently the defined activities, what is being expected is that each one should be able to identify the values and requirements for each activity and to participate in the development of more effective way how to perform it.

In terms of approaches how to achieve the required improvements we identified the first one based on extensive uses of new tools and methods as digitalization, simulations, automation, etc. The second is associated to the continuous sought for innovation or innovative solutions. In fact, both are complementary and must be adopted simultaneously, but it is important is to have in mind that for each specific situation the correct balance between them must be identified.

About the product development process, it is clear that the great revolution is associating the use of new tools that allows more detailed and complete analysis and a new organization system, which is allowing a significant compression of the development cycle by the overlapping of the development phases.

In general, the vehicles defined as the collectors for the different information and requirements related to the product during its lifecycle are the models, or old drawings. Those models and associated metadata, managed in different systems as PLM, ERP, MES, define the product, and generate the concept Model Based Design or MBD.

After three years running the project InovAkaer many improvements are achieved; the physical improvements in the infrastructure and corporate systems are remarkable, but by far, the most difficult task and the largest rewards are linked to the new mind set and culture developed in the group and cascaded to the others teams inside Akaer.

Even without being concluded the examples of product development presented in this article show the effectiveness of the innovation project. It is important to have in mind that up to 5 years ago Akaer was a company which has expended more than 15 years just developing aeronautic products for large OEM's, in general following requirements and processes defined by the customers.

The fact that in a period of less than 24 months those four different and complex products were developed successfully indicates that we are in the wright way.

But, on the other hand, this project also taught us that this is an endless route; after each new conquered station, new large avenues begin that must to choose and covered to keep pursuing the market evolution. Just as an example, it was identified a huge need to improve the integration process with the complete value chain, not only with the internal actors but with all stakeholders involved in the process.

8 Conclusions

Based on the exposed above, the conclusions made by Akaer, a medium size Brazilian company is clear that the new scenario of continuous quick and deep changes in the business development environment, including product development, will still be pushing the companies, at least during the near future.

In parallel with the high demand for process development and performance, the market is also forcing the companies to achieve new standards of time to market associated with prices unthinkable few years ago. The sustainable solution for this equation must to come from the balance of technological improvements and innovative solutions.

Efficient handling of product data and development knowledge is one of the key challenges in today's product development. The interaction between digital technology, the information network, software functionality, and processes for decision-making based on needs throughout the product and plant life must still be established as a central competence.

The changes and innovations are requiring a new professional with transverse skill, T-skill, able to be adaptive, agile and with more broad view prone to integrated available solutions and new technologies in innovative arrangements.

To enable competitiveness and survive in the next decade, companies must to reshape their classical organization and approach, being much more proactive, services oriented and ready to innovate. It will be mandatory to be very efficient in the information management.

9 References

[1] ACATECH – National Academy of Science and Engineering – Securing the future of German manufacturing industry: recommendations for implementing the strategic initiative Industrie 4.0 – Final Report of the Industry 4.0 Working Group, 2013;

[2] Roland Berger – The Industrie 4.0 transition quantified: How the fourth industrial revolution is reshuffling the economic, social and industrial model – Think Act, beyond the Mainstream, 2016;

[3] Domingos, D. Dr.-Ing – Industrie 4.0 – Advanced Manufacturing Technologies within the Digitally Integrated Production – IPK Fraunhofer, 2018;

[4] Ketzner, L., Cailliau, S., Mallory, G., Szczepanski, K., Hattori, S., Plouvier, P. and Justus, J. – Becoming a Digital Frontrunner in Aerospace and Defense – The Boston Consulting Group, 2017;

[5] KPMG – The Factory of the Future – Industry 4.0, the Factory of Tomorrow, KPMG AG Wirtschaftspürfungsgesellschaft, 2016;

[6] Aerostructures 2015 – The 11th Review of the Aerostructures Market from Counterpoint – Counterpoint Market Intelligence Limited, 2015, England;

[7] WEF – The Future of Jobs: Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution – Executive Summary, World Economic Forum, 2016;

[8] ABDI – Plataformas Demonstradoras: Tecnológicas Aeronáuticas Experiências com programas internacionais, modelagem funcional aplicável ao Brasil e importância da sua aplicação para o País – Agência Brasileira de Desenvolvimento Industrial – ABDI, ISBN: 978-85-61323-17-2, 2014;

[9] MCTIC – Plano de CT&I para Manufatura Avançada no Brasil – ProFuturo, 2016;

[10] Daudt, G. e Willcox, L. D. – Comunicação de participação no Seminário BNDES de Manufatura Avançada – Revista do BNDES nº 47, 2016;

[11] MDIC et MCTIC – Perspectivas de Especialistas Brasileiros sobre a Manufatura Avançada no Brasil. Ministério da Indústria do Comércio Exterior e Serviços (MDIC) e Ministério da Ciência, Tecnologia, Inovações e Comunicações e Ministério (MCTIC), Brasília. 2016;

[12] Schuh G., Anderl R., Gausemeier J., Hompel M., Wahlster W. (Eds.) – Industrie 4.0 Maturity Index - Managing the Digital Transformation of Companies – acatech STUDY, 2017;

[13] Firat, A. K., Madnick, S. And Woon, W. L. – Technological Forecasting - A Review – Working Paper CISL# 2008-15, 2008;

[14] Vantson, L. K. – Practical Tips for Forecasting New Technology Adoption – Telektronikk 3/4.2008 ISSN 0085-7130 ©Telenor ASA, 2009;

[15] Singh, S. et al – World's Top Global Mega Trends and Implications to Business, Cultures and Society – Frost & Sullivan, 2014;

[16] NSTC – Advanced Manufacturing: A Snapshot of Priority Technology Areas Across the Federal Government – Product of the Subcommittee for Advanced Manufacturing of the National Science and Technology Council, 2016;

[17] Cross, N. – Engineering Design Methods, John Wiley & Sons, 2001;

[18] Rozenfeld, H., Forcellini, F. A. et. al. – Gestão de Desenvolvimento de Produtos. Uma referência para a melhoria do processo. Editora Saraiva, 2006;

[19] Pessoa, M.V.P. and Trabasso, L.G. – Lean Product Design and Development: a Practical Journey. Springer, 2016;

[20] Deloitte – 2018 Global aerospace and defense sector outlook, 2018;

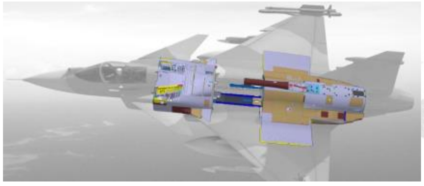
[21] Grasseli, C. – Akaer Group Business Plan – 2018 Edition, Akaer Internal Document, 2018;

[22] AIAB web site – Associação da Indústrias Aeroespaciais Brasileiras.

akaer group

Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept

04/10/2018



23º Seminário Internacional de Alta Tecnologia

inovakaer

Introduction

Today scenario there is little consensus, but no one disagrees that we are experiencing an era of rapid change, much greater and more drastic than in the past. The great question for all is to guess which is the wright way; mistakes can be fatal.

The first important fact is to verify that we live a kind of race for the 'Holy Grail', which at the moment may respond by the nicknames of Industry 4.0, Advanced Manufacturing, Smart Manufacturing, Smart Company, etc. In this race some countries have taken the lead, but practically all the others look for to discover how to enter this wave. In addition to the 'State Policies' raised by some countries, virtually all major OEMs and their Tier 1 suppliers are also involved in this process; and the expected 'penalty' for the losers of this race is the expulsion from paradise.

MANUFATURA AVANÇADA
A Indústria 4.0 no Brasil

indústria do futuro

Introduction

Labor Environment

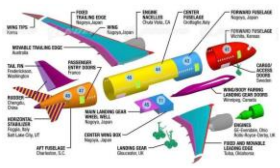
The second fact that should guide any analysis in this sense is the evolution or revolution of the labor market on a global scale. The hurricane of change is profoundly and definitively affecting existing forms and concepts of labor relations that have crystallized over the past two centuries.

Product's Values

Another set of fundamental factors for positioning ourselves is associated with a historical paradigm shift. Throughout the history of mankind the 'power' was concentrated in that it dominated the means of production. Today produce turned commodity, quality is prerequisite. The 'power' today focuses on those with the ability to set the standards and requirements.

Business Complexity

Finally, the development and industrialization of new products has become an activity of high complexity not only technical, but requires intricate relationships between partners, suppliers, authorities and customers, and has become extremely capital intensive.



Smart Enterprises – Basic Concepts

According to KPMG, in the report “**The factory of the Future**” 2016, Smart Enterprise is the “Integration of all business units and value chain by means of the Digitalization”. In the future enterprise the ICT and automation processes will be fully integrated.

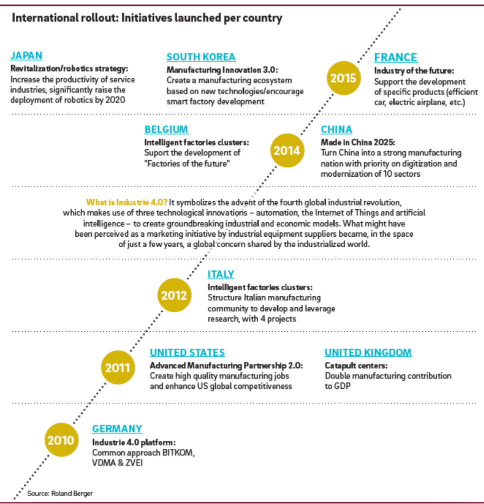
Smart Enterprises – Basic Concepts

Advanced Manufacturing Technologies, within an Integrated Environment are:

- ✈ Advanced Manufacturing;
- ✈ Digital Transformation;
- ✈ Digital Innovation;
- ✈ Digital Cooperation Network; and
- ✈ Integrated Digital Production

Efficient handling of product data and development knowledge is one of the key challenges in today's product development. The interaction between digital technology, the information network, software functionality, and processes for decision-making based on needs throughout the product and plant life must still be established as a central competence.

Smart Enterprises – Basic Concepts – Different Models

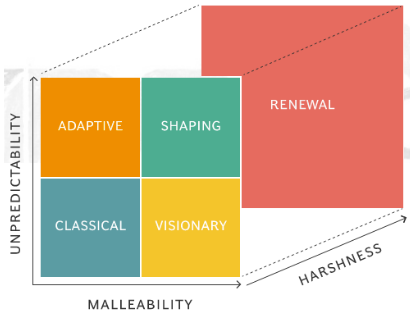


Smart Enterprises – Basic Concepts – Brazilian Models

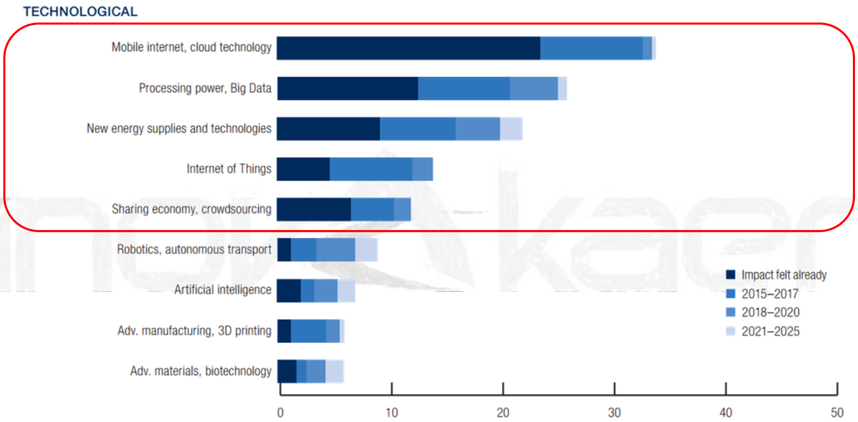
Theoretical X Real

Smart Enterprises – Basic Concepts – Agility & Adaptiveness

New Business environments are requiring a new approach



Smart Enterprises – Basic Concepts – Influences on Labor Market



Source: Future of Jobs Survey, World Economic Forum.
Note: Names of drivers have been abbreviated to ensure legibility.

Smart Enterprises – Basic Concepts – Servitization

The Revolution of the Services

- Mobiles – Nokia X Apple;
- Automotive – 'überization'/autonomous;
- Agro – John Deer – 70% incomes from services;
- Michelin – tires by km;
- Equipment, robots, ROV's – selling point is operational hours not the goods;
- Lodgment – Hotels X Airbnb
- Press and TV's – paper X digital, linear TV X OTT.

The user is the King, the most important is the User Experience – UX is the trend

10 23º Seminário Internacional de Alta Tecnologia
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO
inova akaer

Smart Enterprises – Basic Concepts – Technologies, Materials & Processes

For at least 50 years the materials and processes of the 'future' are practically the same. We are basically talking about new materials (composite, new metal alloys, lithium aluminum, titanium alloys, new ceramics, etc.), dedicated processes (HIP casting, compounding, high speed machining, welding, laser / electron beam, injection , special conformation, etc).

NANOMATERIALS
STIRWELDING
GRAPHENE
MULTIFUNCTIONMATERIALS
HIGHSPEEDMACHINING
ADVANCEDCERAMICS
RTM
SUPERPLASTICFORMING
FLEXIBLETOOLING
COLLABORATIVEROBOT
OUTOFAUTOCLAVE
INTERMETALLICS
ATL
AUTOMATION
COMPOSITE
FIBERPLACEMENT
HIBRIDMANUFACTURING

11 23º Seminário Internacional de Alta Tecnologia
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO
inova akaer

About Akaer – Group Overview

akaer group

akaer
akros Tecnologia
opto
Equatorial Sistemas
troya

Aerial view Akaer Optrônica (OPTO)

Aerial view of new Akaer headquarters

opto

akaer akros Equatorial Sistemas troya

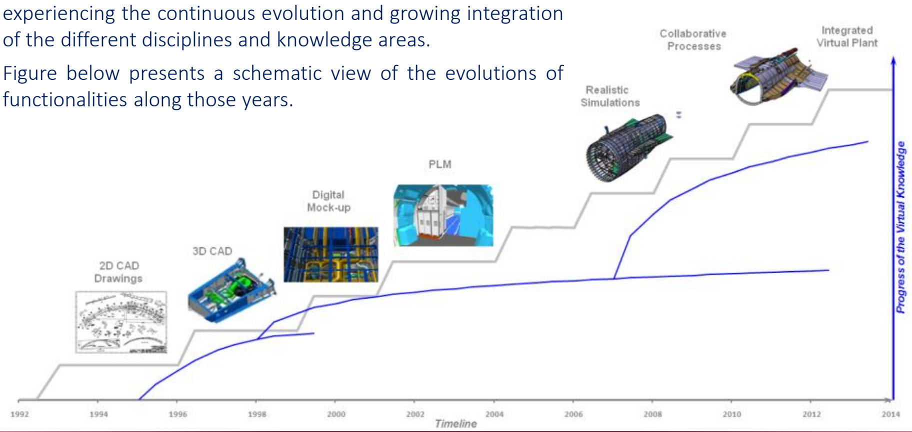
Notes: Akaer Group, razão social Akaer Participações Ltda, is the holding company. Majority owner of all companies in the Group
Akaer, razão social Akaer Engenharia Ltda; Akros, razão social Akros Tecnologia Ltda; Opto S&D, razão social Optrônica Ltda

12 23º Seminário Internacional de Alta Tecnologia
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO
inova akaer

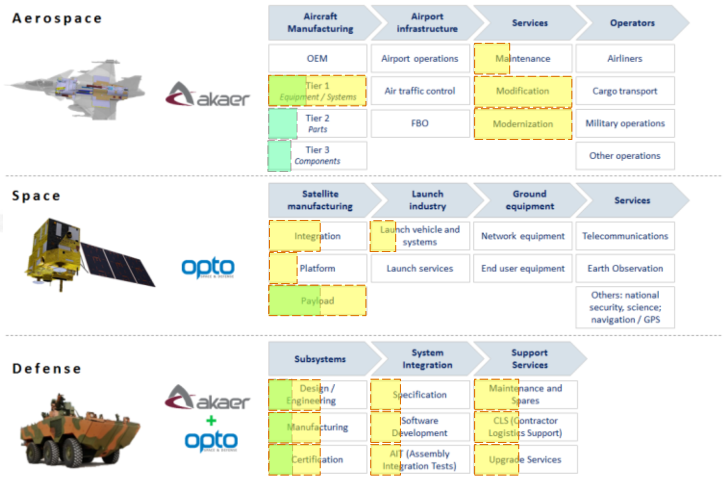
About Akaer – Experience Developing Products

Akaer has being working in the development of complex products since the early 90' and along this journey is experiencing the continuous evolution and growing integration of the different disciplines and knowledge areas.

Figure below presents a schematic view of the evolutions of functionalities along those years.



About Akaer – Market and Strategy



Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO
inovakaer

InovAkaer – Technological Approach

Conventional

The conventional capacitation approach foresees the outline of technological obstacles and in general puts the company at the same level as the majority of the competitors in the market, obliging each player to seek to differentiate mainly through the costs reduction.

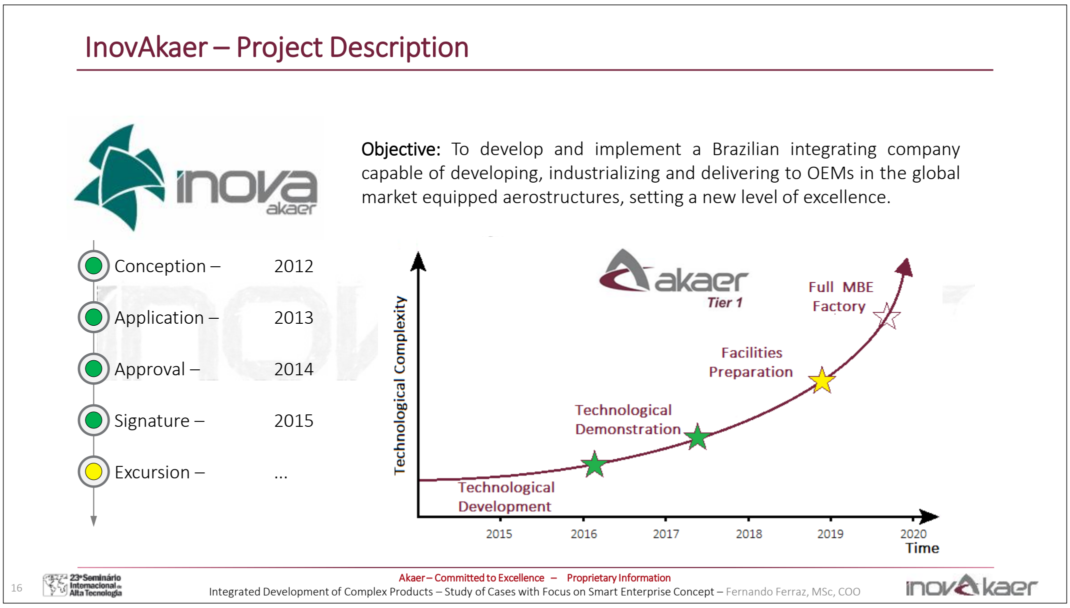
Innovative

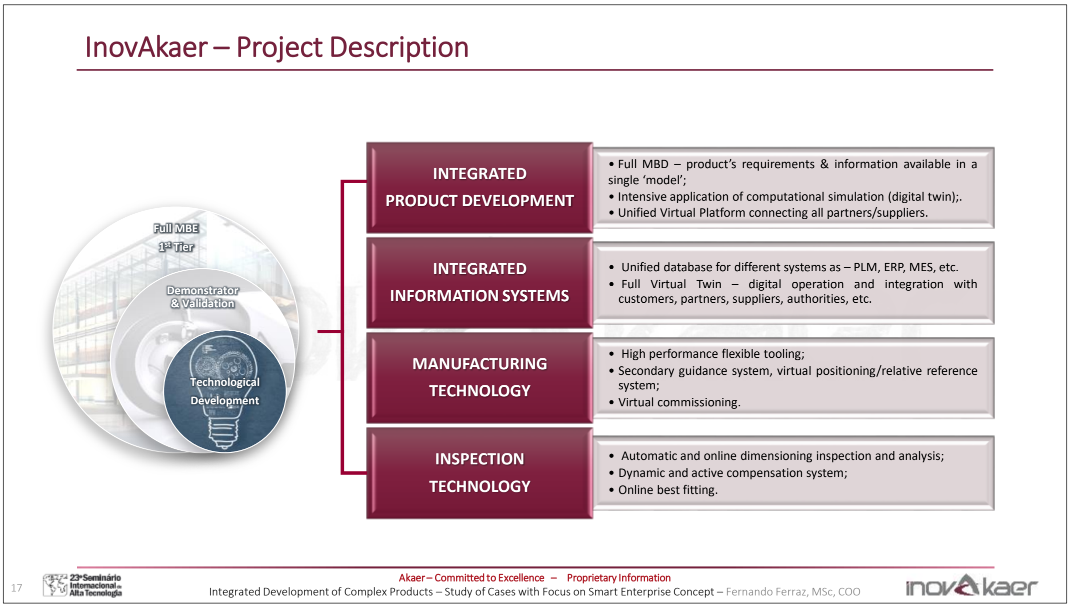
Another approach commonly adopted is the search for alternative technological solutions, but without a systemic view of the problem and/or the structuring of the company for it. Most often, this approach leads to the consumption of many resources and time, and the results are not very different from the traditional one.

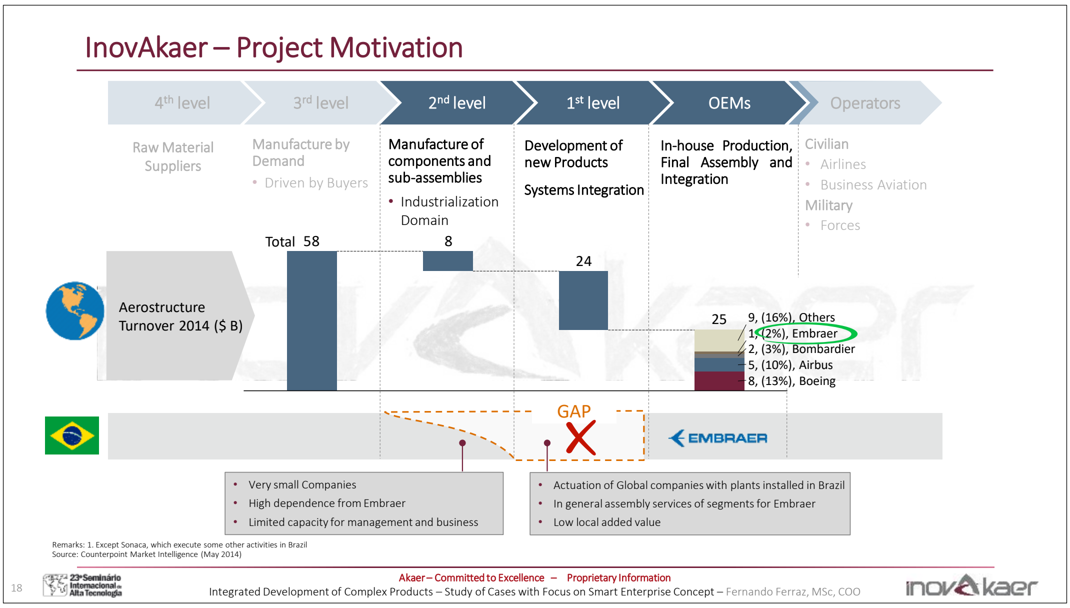
Systematic Innovation

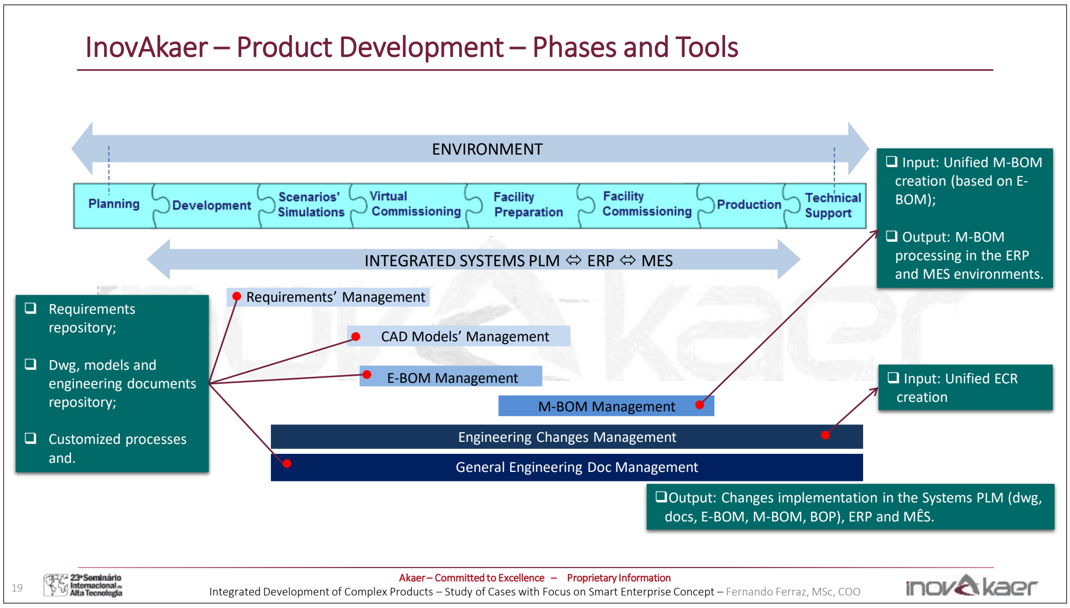
The option adopted by Akaer is an adaptation of the technological approach where a systematic and integrated innovation environment is the guideline for the technologies selection and application. In this approach the support and interaction with the Academy and partners takes an important role.

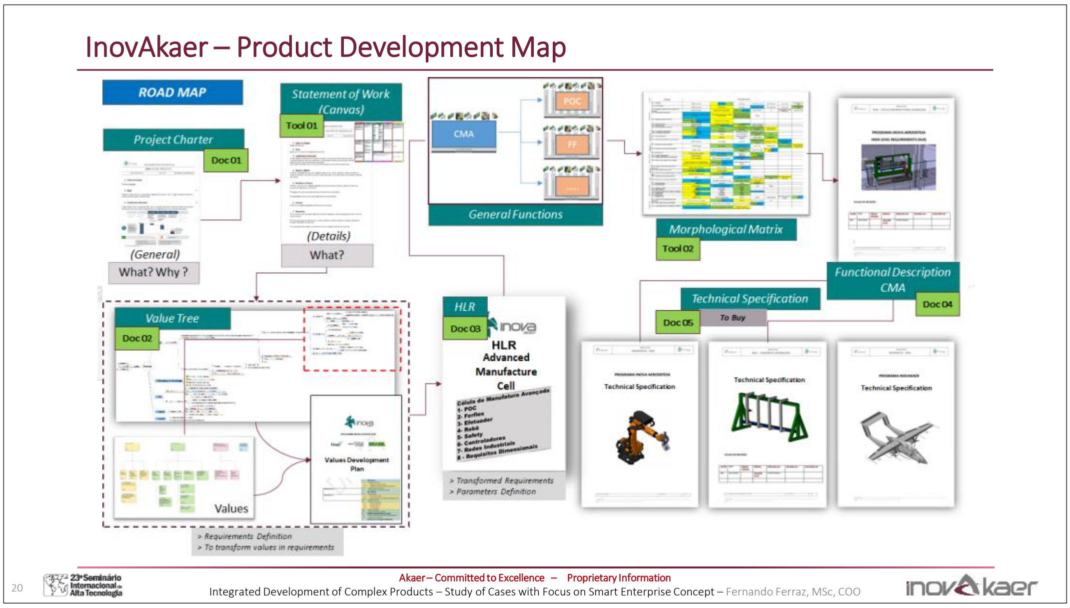
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO
inovakaer

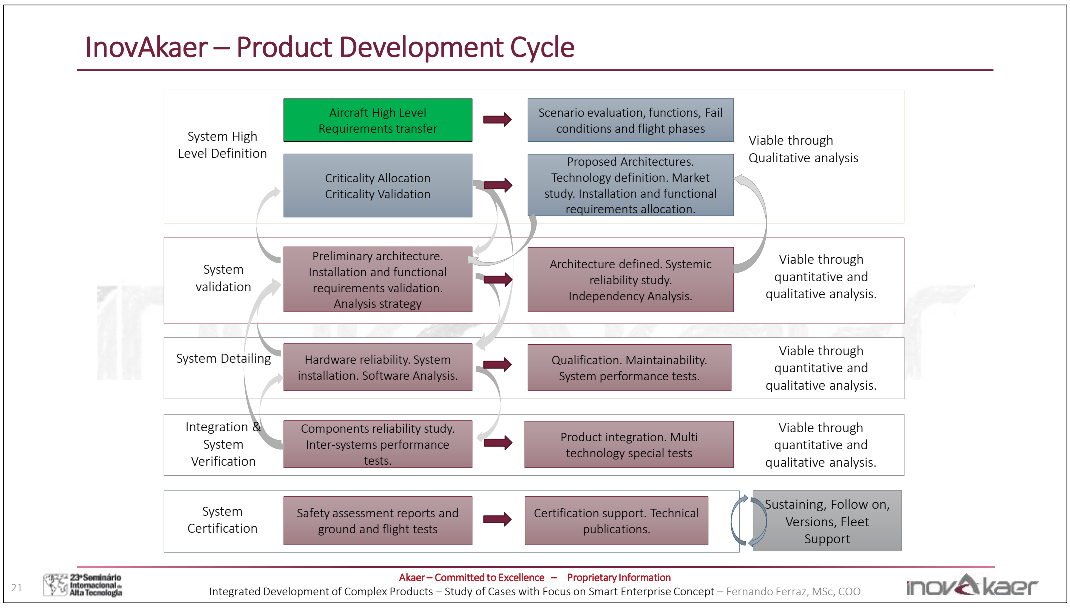

InovAkaer – Project Description
Objective: To develop and implement a Brazilian integrating company capable of developing, industrializing and delivering to OEMs in the global market equipped aerostructures, setting a new level of excellence.
Conception – 2012
Application – 2013
Approval – 2014
Signature – 2015
Excursion – ...
Technological Complexity
Tier 1
Full MBE Factory
Facilities Preparation
Technological Demonstration
Technological Development
2015
2016
2017
2018
2019
2020
Time
16
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO

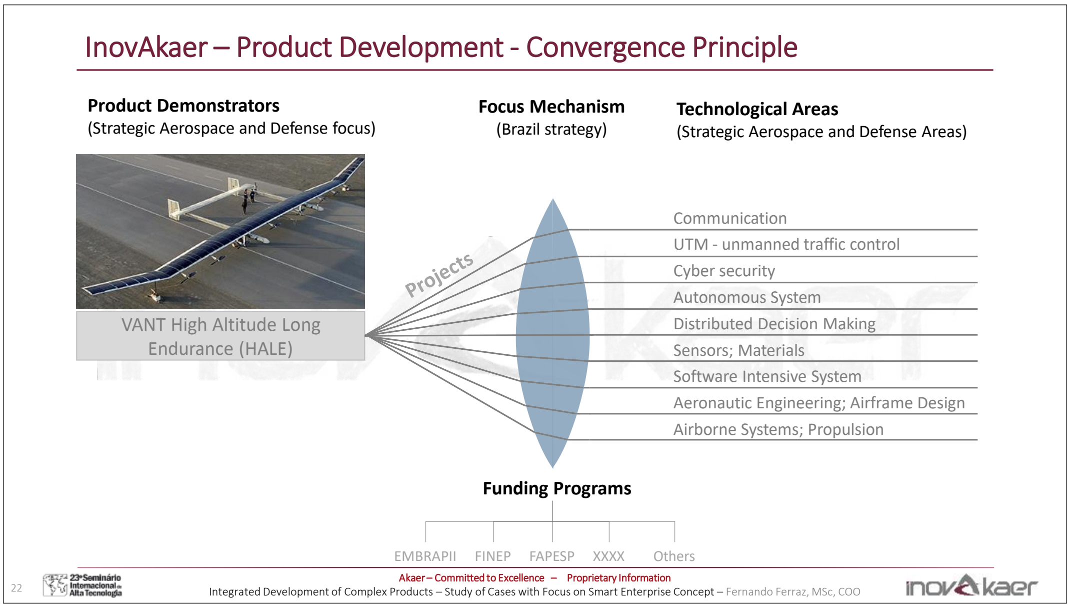

InovAkaer – Project Description
Full MBE
1st Tier
Demonstrator & Validation
Technological Development
INTEGRATED PRODUCT DEVELOPMENT
• Full MBD – product's requirements & information available in a single 'model';
• Intensive application of computational simulation (digital twin);.
• Unified Virtual Platform connecting all partners/suppliers.
INTEGRATED INFORMATION SYSTEMS
• Unified database for different systems as – PLM, ERP, MES, etc.
• Full Virtual Twin – digital operation and integration with customers, partners, suppliers, authorities, etc.
MANUFACTURING TECHNOLOGY
• High performance flexible tooling;
• Secondary guidance system, virtual positioning/relative reference system;
• Virtual commissioning.
INSPECTION TECHNOLOGY
• Automatic and online dimensioning inspection and analysis;
• Dynamic and active compensation system;
• Online best fitting.
17
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO

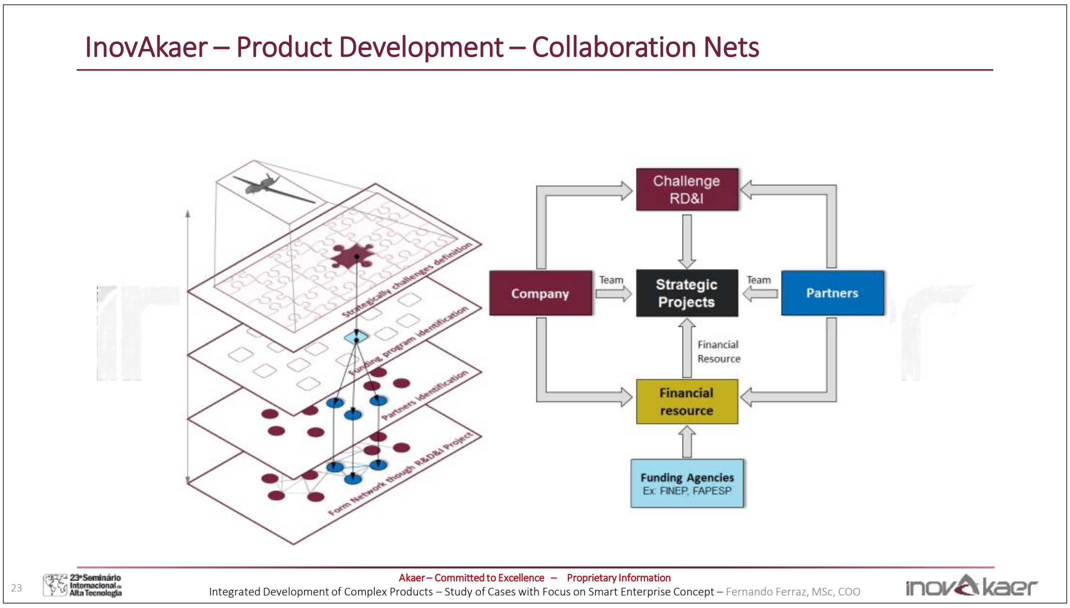

InovAkaer – Project Motivation
4th level
3rd level
2nd level
1st level
OEMs
Operators
Raw Material Suppliers
Manufacture by Demand
• Driven by Buyers
Manufacture of components and sub-assemblies
• Industrialization Domain
Development of new Products
Systems Integration
In-house Production, Final Assembly and Integration
Civilian
• Airlines
• Business Aviation
Military
• Forces
Aerostructure Turnover 2014 ($ B)
Total 58
8
24
25
9, (16%), Others
1, (2%), Embraer
2, (3%), Bombardier
5, (10%), Airbus
8, (13%), Boeing
GAP
EMBRAER
• Very small Companies
• High dependence from Embraer
• Limited capacity for management and business
• Actuation of Global companies with plants installed in Brazil
• In general assembly services of segments for Embraer
• Low local added value
Remarks: 1. Except Sonaca, which execute some other activities in Brazil
Source: Counterpoint Market Intelligence (May 2014)
18
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO

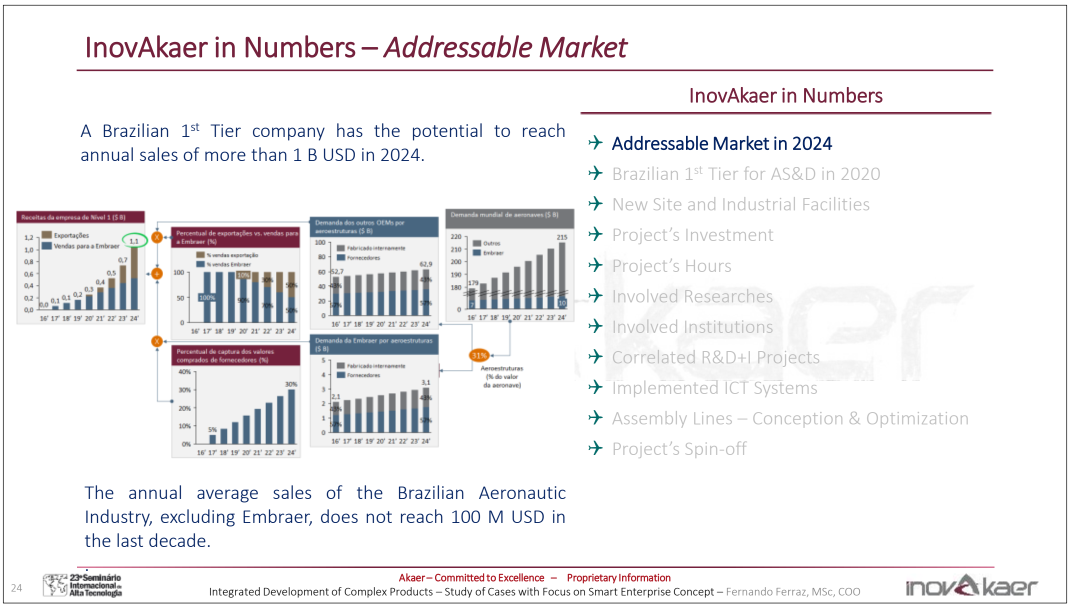

InovAkaer – Product Development – Phases and Tools
ENVIRONMENT
Planning
Development
Scenarios' Simulations
Virtual Commissioning
Facility Preparation
Facility Commissioning
Production
Technical Support
Input: Unified M-BOM creation (based on E-BOM);
Output: M-BOM processing in the ERP and MES environments.
INTEGRATED SYSTEMS PLM ⇔ ERP ⇔ MES
Requirements repository;
Dwg, models and engineering documents repository;
Customized processes and.
Requirements' Management
CAD Models' Management
E-BOM Management
M-BOM Management
Input: Unified ECR creation
Engineering Changes Management
General Engineering Doc Management
Output: Changes implementation in the Systems PLM (dwg, docs, E-BOM, M-BOM, BOP), ERP and MÊS.
19
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO


InovAkaer – Product Development Map
ROAD MAP
Project Charter
Doc 01
(General)
What? Why ?
Statement of Work (Canvas)
Tool 01
(Details)
What?
CMA
POC
FF
General Functions
Morphological Matrix
Tool 02
Functional Description CMA
Doc 04
Technical Specification
To Buy
Doc 05
Value Tree
Doc 02
Values
Values Development Plan
> Requirements Definition
> To transform values in requirements
HLR
Doc 03
HLR Advanced Manufacture Cell
> Transformed Requirements
> Parameters Definition
Technical Specification
Technical Specification
Technical Specification
20
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO


InovAkaer – Product Development Cycle
System High Level Definition
Aircraft High Level Requirements transfer
Scenario evaluation, functions, Fail conditions and flight phases
Criticality Allocation Criticality Validation
Proposed Architectures. Technology definition. Market study. Installation and functional requirements allocation.
Viable through Qualitative analysis
System validation
Preliminary architecture. Installation and functional requirements validation. Analysis strategy
Architecture defined. Systemic reliability study. Independency Analysis.
Viable through quantitative and qualitative analysis.
System Detailing
Hardware reliability. System installation. Software Analysis.
Qualification. Maintainability. System performance tests.
Viable through quantitative and qualitative analysis.
Integration & System Verification
Components reliability study. Inter-systems performance tests.
Product integration. Multi technology special tests
Viable through quantitative and qualitative analysis.
System Certification
Safety assessment reports and ground and flight tests
Certification support. Technical publications.
Sustaining, Follow on, Versions, Fleet Support
21
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO

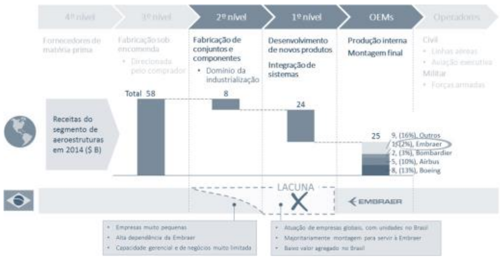

InovAkaer – Product Development - Convergence Principle
Product Demonstrators
(Strategic Aerospace and Defense focus)
Focus Mechanism
(Brazil strategy)
Technological Areas
(Strategic Aerospace and Defense Areas)
VANT High Altitude Long Endurance (HALE)
Projects
Communication
UTM - unmanned traffic control
Cyber security
Autonomous System
Distributed Decision Making
Sensors; Materials
Software Intensive System
Aeronautic Engineering; Airframe Design
Airborne Systems; Propulsion
Funding Programs
EMBRAPII
FINEP
FAPESP
XXXX
Others
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO
22


InovAkaer – Product Development – Collaboration Nets
Strategically challenges definition
Funding program identification
Partners identification
Form Network though R&D&I Project
Challenge RD&I
Company
Team
Strategic Projects
Team
Partners
Financial Resource
Financial resource
Funding Agencies
Ex: FINEP, FAPESP
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO
23


InovAkaer in Numbers – *Addressable Market*
A Brazilian 1st Tier company has the potential to reach annual sales of more than 1 B USD in 2024.
InovAkaer in Numbers
Addressable Market in 2024
Brazilian 1st Tier for AS&D in 2020
New Site and Industrial Facilities
Project's Investment
Project's Hours
Involved Researches
Involved Institutions
Correlated R&D+I Projects
Implemented ICT Systems
Assembly Lines – Conception & Optimization
Project's Spin-off
The annual average sales of the Brazilian Aeronautic Industry, excluding Embraer, does not reach 100 M USD in the last decade.
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO
24

InovAkaer in Numbers – *Brazilian 1st Tier for AS&D Market*

1st Tier companies have a strong leverage factor from both a technological and a financial point of view, 1st Tiers companies, generate 12x more value than 2nd Tiers ones



InovAkaer in Numbers

- Addressable Market in 2024
- **Brazilian 1st Tier for AS&D in 2020**
- New Site and Industrial Facilities
- Project's Investment
- Project's Hours
- Involved Researches
- Involved Institutions
- Correlated R&D+I Projects
- Implemented ICT Systems
- Assembly Lines – Conception & Optimization
- Project's Spin-off

25 Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO

InovAkaer in Numbers – *Site and Facilities*

Akaer invested in the acquisition of a new facility with more than 10000 m² of outstanding industrial area read to start aerostructures assembly and systems integration

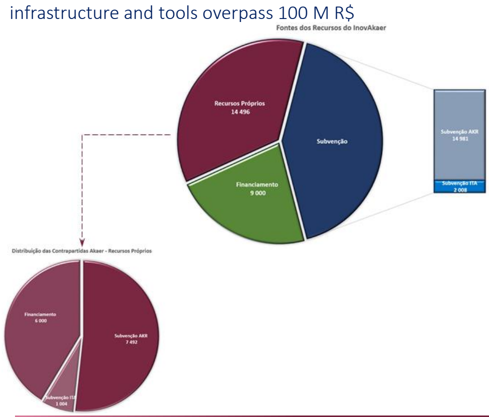
InovAkaer in Numbers

- Addressable Market in 2024
- Brazilian 1st Tier for AS&D in 2020
- **New Site and Industrial Facilities**
- Project's Investment
- Project's Hours
- Involved Researches
- Involved Institutions
- Correlated R&D+I Projects
- Implemented ICT Systems
- Assembly Lines – Conception & Optimization
- Project's Spin-off

26 Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO

InovAkaer in Numbers – *Project's Investments*

The total investment just in InovAkaer is 40,5 M R$; the total amount of investments including the new site, companies, infrastructure and tools overpass 100 M R$



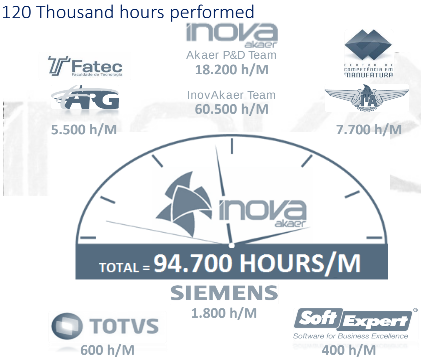
InovAkaer in Numbers

- Addressable Market in 2024
- Brazilian 1st Tier for AS&D in 2020
- New Site and Industrial Facilities
- **Project's Investment**
- Project's Hours
- Involved Researches
- Involved Institutions
- Correlated R&D+I Projects
- Implemented ICT Systems
- Assembly Lines – Conception & Optimization
- Project's Spin-off

27 Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO

InovAkaer in Numbers – *Project's Hours*

The total amount of direct hours predicted to the project is 180 thousands, in addition there are more than 20 thousand hours being executed in correlated projects.
> 120 Thousand hours performed



InovAkaer in Numbers

- Addressable Market in 2024
- Brazilian 1st Tier for AS&D in 2020
- New Site and Industrial Facilities
- Project's Investment
- Project's Hours
- Involved Researches
- Involved Institutions
- Correlated R&D+I Projects
- Implemented ICT Systems
- Assembly Lines – Conception & Optimization
- Project's Spin-off

28 Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO

InovAkaer in Numbers – *Involved Researches*

In the peak of the project, at the end of the first phase, there were 72 researchers directly involved; currently there are around 50 dedicated researchers.
> 20 researchers involved in correlated projects.

InovAkaer in Numbers

- Addressable Market in 2024
- Brazilian 1st Tier for AS&D in 2020
- New Site and Industrial Facilities
- Project's Investment
- Project's Hours
- Involved Researches
- Involved Institutions
- Correlated R&D+I Projects
- Implemented ICT Systems
- Assembly Lines – Conception & Optimization
- Project's Spin-off

29 Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO

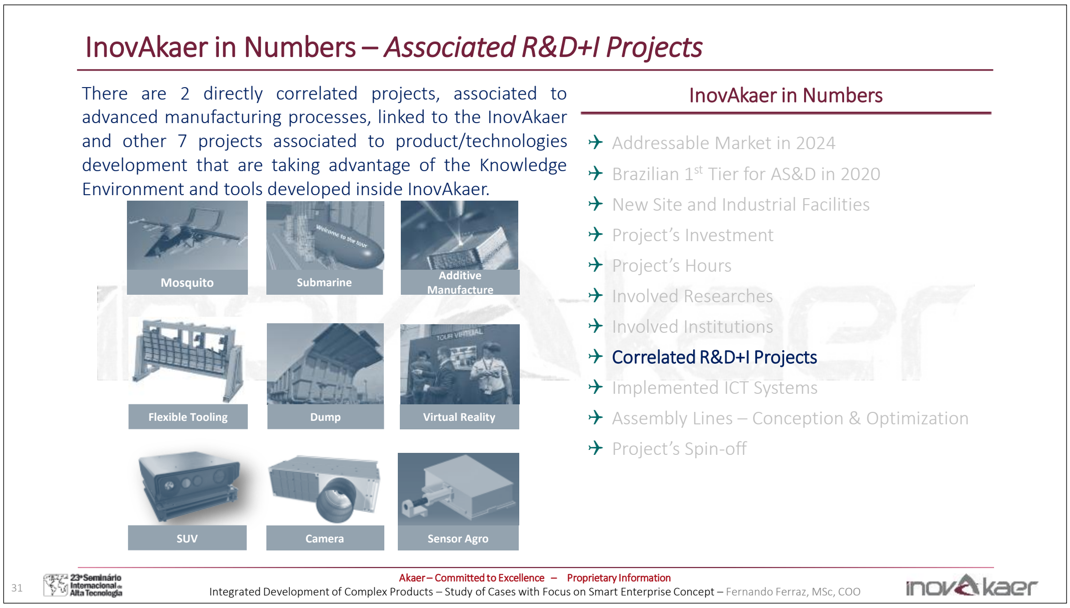
InovAkaer in Numbers – *Involved Institutions*

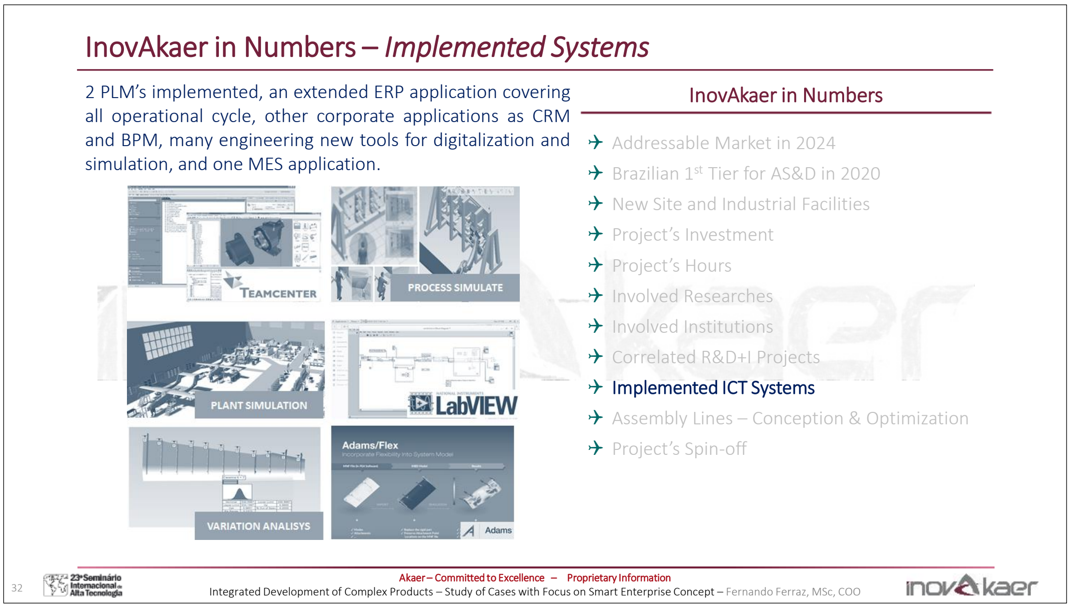
In the InovAkaer project there are 2 Academia members, 3 partner Companies and 1 Fund Agency directly involved. In the correlated projects there are 8 Academia members, 10 Companies and 3 funds Agencies.

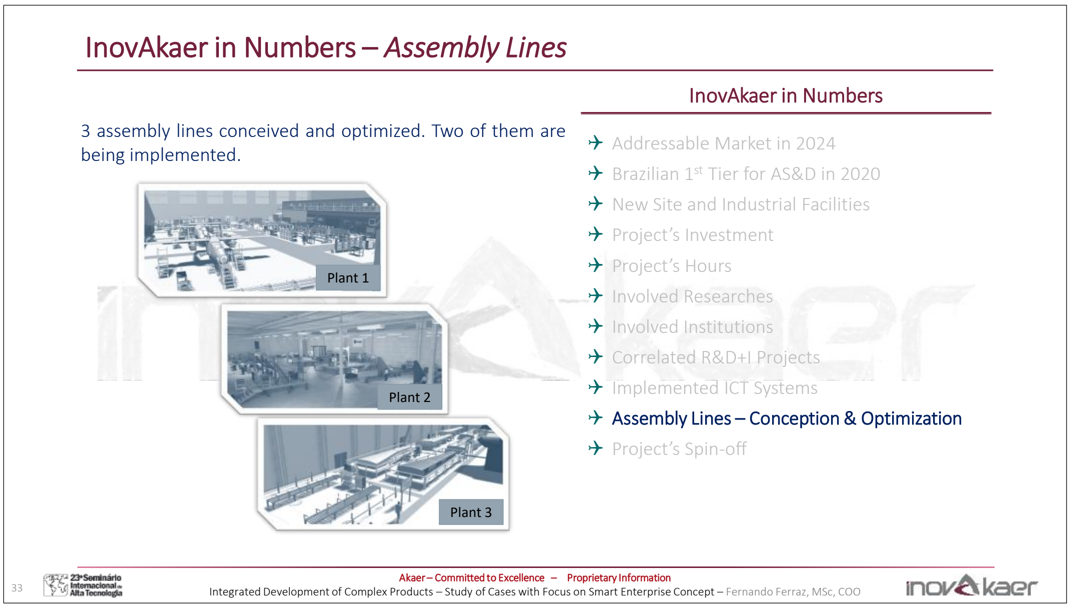
InovAkaer in Numbers

- Addressable Market in 2024
- Brazilian 1st Tier for AS&D in 2020
- New Site and Industrial Facilities
- Project's Investment
- Project's Hours
- Involved Researches
- Involved Institutions
- Correlated R&D+I Projects
- Implemented ICT Systems
- Assembly Lines – Conception & Optimization
- Project's Spin-off

30 Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO


InovAkaer in Numbers – Associated R&D+I Projects
There are 2 directly correlated projects, associated to advanced manufacturing processes, linked to the InovAkaer and other 7 projects associated to product/technologies development that are taking advantage of the Knowledge Environment and tools developed inside InovAkaer.
Mosquito
Submarine
Additive Manufacture
Flexible Tooling
Dump
Virtual Reality
SUV
Camera
Sensor Agro
InovAkaer in Numbers
Addressable Market in 2024
Brazilian 1st Tier for AS&D in 2020
New Site and Industrial Facilities
Project's Investment
Project's Hours
Involved Researches
Involved Institutions
Correlated R&D+I Projects
Implemented ICT Systems
Assembly Lines – Conception & Optimization
Project's Spin-off
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO
31


InovAkaer in Numbers – Implemented Systems
2 PLM's implemented, an extended ERP application covering all operational cycle, other corporate applications as CRM and BPM, many engineering new tools for digitalization and simulation, and one MES application.
TEAMCENTER
PROCESS SIMULATE
PLANT SIMULATION
LabVIEW
VARIATION ANALISYS
Adams/Flex
Adams
InovAkaer in Numbers
Addressable Market in 2024
Brazilian 1st Tier for AS&D in 2020
New Site and Industrial Facilities
Project's Investment
Project's Hours
Involved Researches
Involved Institutions
Correlated R&D+I Projects
Implemented ICT Systems
Assembly Lines – Conception & Optimization
Project's Spin-off
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO
32


InovAkaer in Numbers – Assembly Lines
3 assembly lines conceived and optimized. Two of them are being implemented.
Plant 1
Plant 2
Plant 3
InovAkaer in Numbers
Addressable Market in 2024
Brazilian 1st Tier for AS&D in 2020
New Site and Industrial Facilities
Project's Investment
Project's Hours
Involved Researches
Involved Institutions
Correlated R&D+I Projects
Implemented ICT Systems
Assembly Lines – Conception & Optimization
Project's Spin-off
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO
33

InovAkaer in Numbers – *Spin-offs*

Virtual and Augmented Reality developed and implemented as design tool.

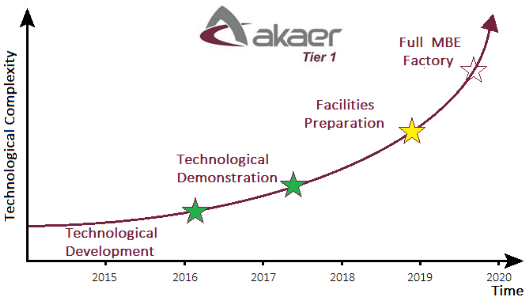
InovAkaer in Numbers

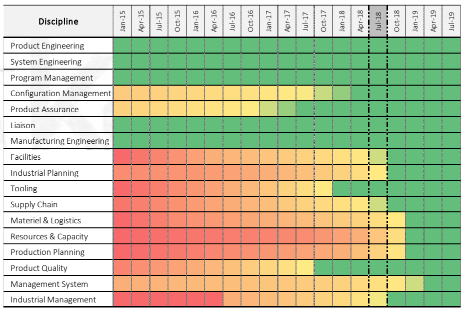
- Addressable Market in 2024
- Brazilian 1st Tier for AS&D in 2020
- New Site and Industrial Facilities
- Project's Investment
- Project's Hours
- Involved Researches
- Involved Institutions
- Correlated R&D+I Projects
- Implemented ICT Systems
- Assembly Lines – Conception & Optimization
- **Project's Spin-off**

InovAkaer Program Status

The figures below present an overview of the status of the program and the evolution on the various fronts identified as critical on the route to make Akaer a 1st Tier supplier.

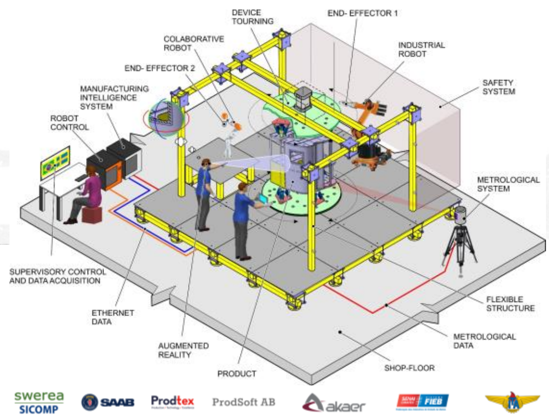
The technological maturity plan was conceived considering a reference product, which was the fabrication and equipping of one large wings.





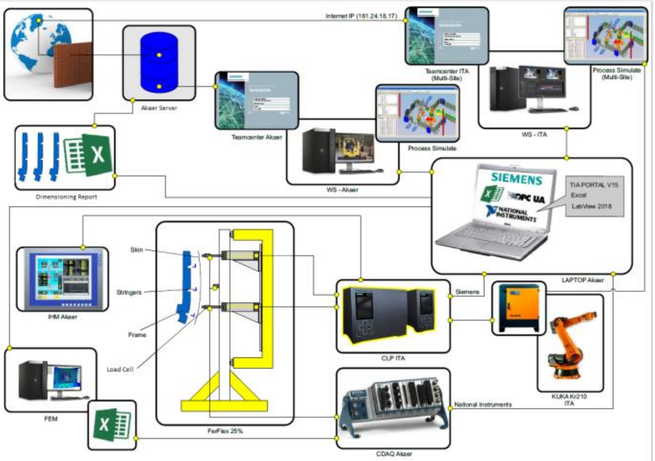
InovAkaer – Flexible Assembly Line

Figure below shows a general overview of the



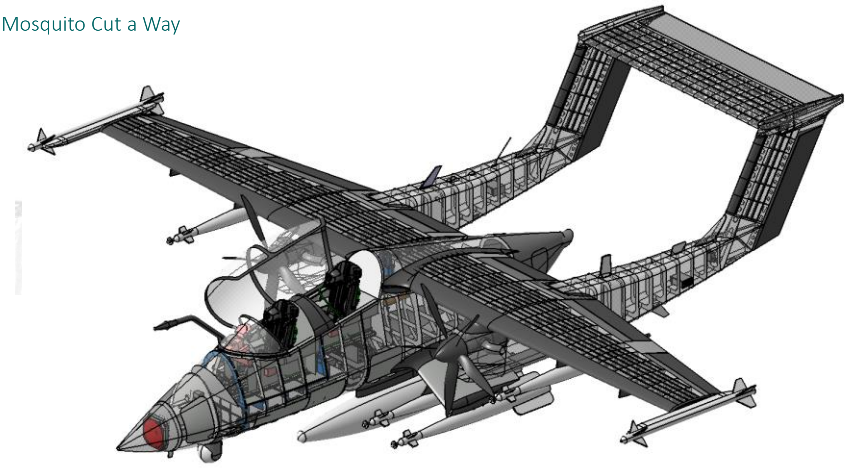
InovAkaer – Flexible Tooling Architecture

General view of the architecture designed for the flexible tooling that is being constructed in order to demonstrate, test and validate the concepts and functions of the flexible tooling to be used in the fuselage panel assembly.



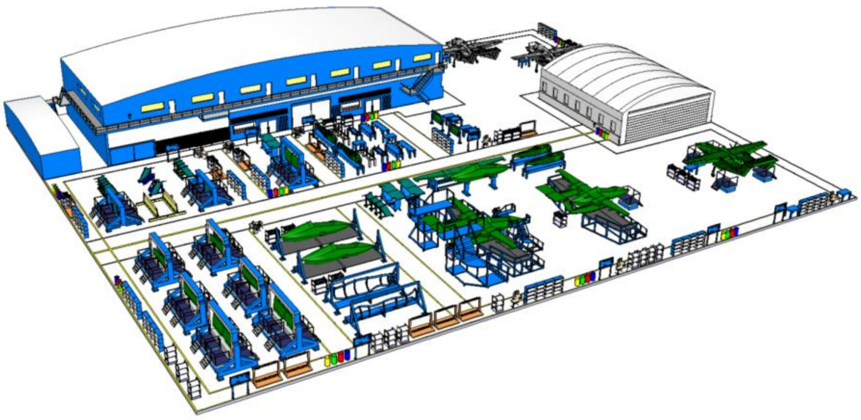
InovAkaer – Reference Aircraft - Mosquito – Structural Architecture

Mosquito Cut a Way



InovAkaer – Reference Aircraft - Mosquito – Industrialization

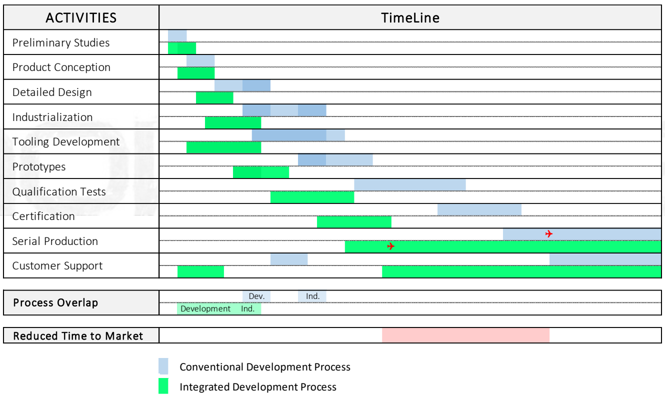
Industrial layout designed to occupy the smallest possible area using digital simulations and new assembly concepts to achieve very high levels of efficiency and optimization of processes.



Akaer's View – Complex Product Development

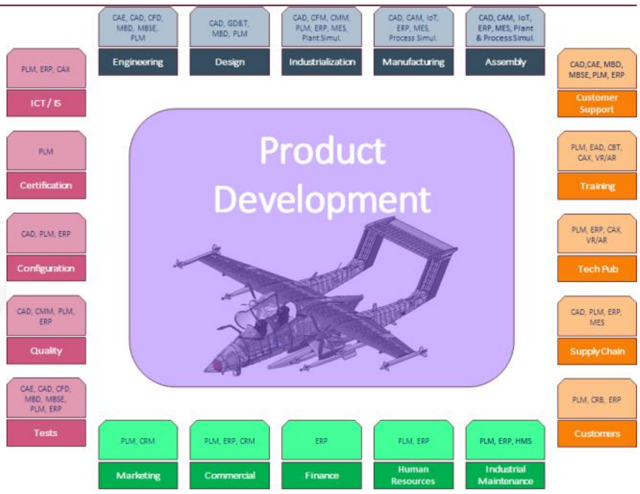
The main characteristic of complex products is the high interdisciplinary and integration of diverse players and systems.

What changed in this environment in the last 10 years? Changed the product or changed the production?

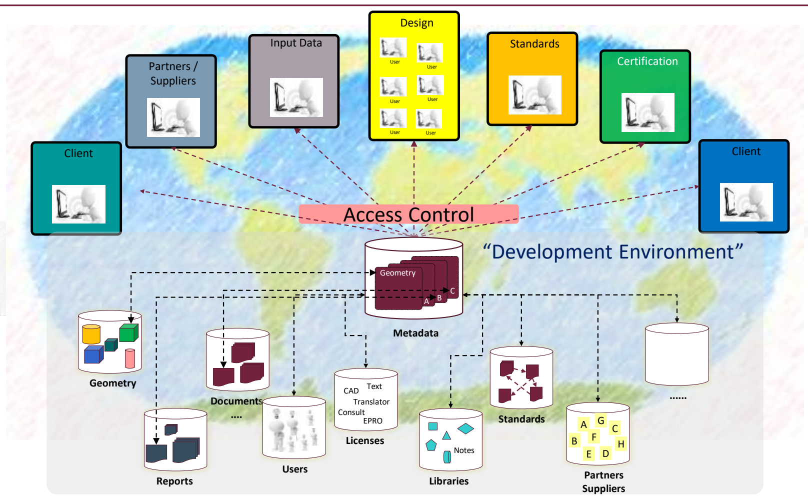


Akaer's View – Complex Product Development

Currently, for any new Project it is mandatory to start integrating all areas, systems, processes and all levels of the value chain in one unique environment where all requirements and solutions are tested since the product conception phase.

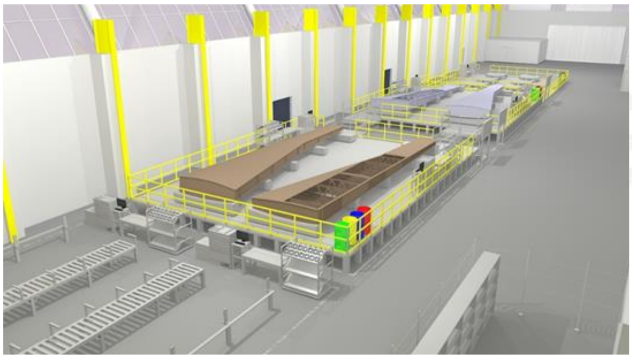


Development Environment – Current Concept and Metadata



Case 01 – Wing Assembly Line

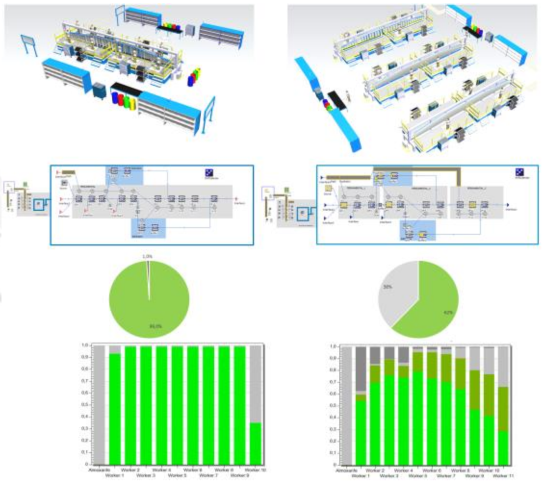
The first case analyzed is related to the development of an assembly line for a large wing. In fact, this is an old product, and the challenge here is to achieve improvements in the Industrialization and Production processes do not affecting the original design, materials and processes, in order to be fully compliant with the original type certification and documentation received from the OEM/Authorities.



Case 01 – Wing Assembly Line

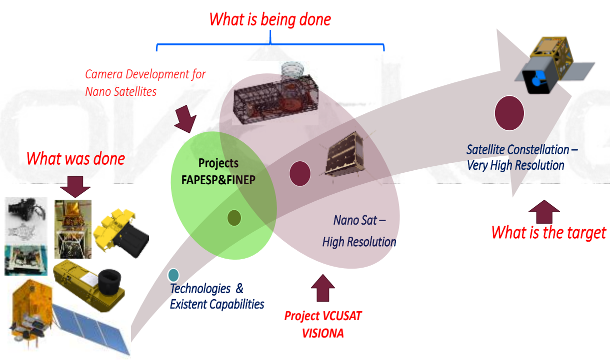
In this case the development were centered in three fronts:

- Plant Simulation – optimization of the workstation organization, material flow, logistics and ergonomic aspects;
- Program Management – definition of efficient systems to manage program documentation, inventory, supply chain configuration control and quality;
- Production Management – optimization of the Bill of Processes (BoP), Manufacturing Bill of Material (MBoM), production planning, production control



Case 02 – High Resolution Space Camera

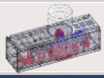
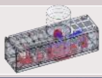
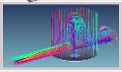
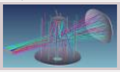
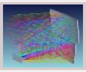
In order to adapt the existent products to the new space it was designed a roadmap aiming to evolve from the traditional products and their development processes to the new standards where are required a significant reduction in the size, weight, cost and development cycle in combination with much better resolution and embedded services.



Case 02 – High Resolution Space Camera

The characteristics of the new line of product are significantly different from the traditional: development cycle 60x18 months, length 1500x300 mm, weight 150x5 kg, resolution 20x5 m and cost around 1/10.

The same platform and concepts are being adapted to three different customers covering different applications.

	Mini-Korsch	OptoGom	NanoMUX
Project client	VISIONA	GOMSPACE	TMA Fapesp
Mechanical Layout (3U)			
Optical Layout			
Input aperture	ϕ80mm	ϕ80mm	70mm x 35mm
Resolution (GSD)	≈3.5m @500Km	≈7.5m @500Km	≈20m @500Km
F-number	10	5.2	4.2
Swath across track	≈14.4Km	≈30Km	≈80Km
Sensor	4096 x 5.4µm / TDI x 256	4096 x 5.4µm / TDI x 256	4096 x 5.4µm / TDI x 256 or CCD x 1
Bands	RGB-NIR (TDI)	RGB-NIR (TDI)	RGB-NIR (TDI or CCD)
Optical MTF@Nyquist	0.30 (theoretical)	0.40 (theoretical)	0.7 (theoretical)
NIIRS	2.1	1.2	not applicable
Applications	Tactical, law enforcement, city planning	Law enforcement, natural disasters, city planning	Environment monitoring, natural disasters

46 23º Seminário Internacional de Alta Tecnologia

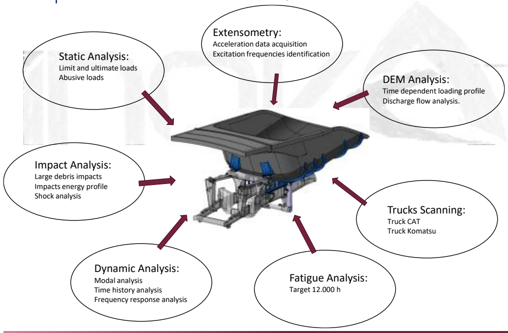
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO

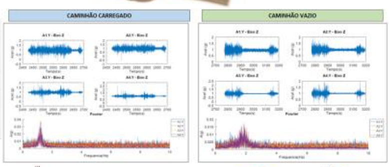
inovakaer

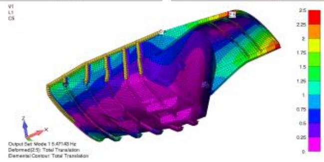
Case 03 – Dump for a Heavy Mining Truck

The challenge here was to conceive, detailed and produce a dump in 100 days. The targets were:

- Capacity increase – 20%;
- Dump weight reduction – 30%;
- Operational life increase – 100%







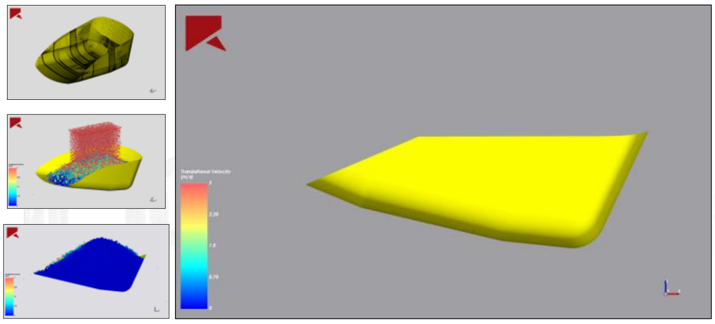
47 23º Seminário Internacional de Alta Tecnologia

Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO

inovakaer

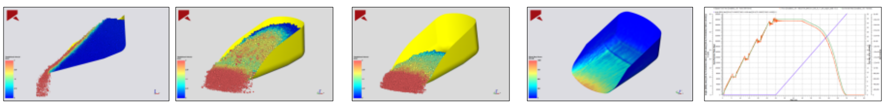
Case 03 – Dump for a Heavy Mining Truck

As described in the previous slide, were performed many different type of simulations and analysis, but for sure the must unusual for was the DEM simulating the ore loading and unloading processes.



Objective of Analysis:

- Input load definition;
- Ore flow analysis;
- Wear analysis.



48 23º Seminário Internacional de Alta Tecnologia

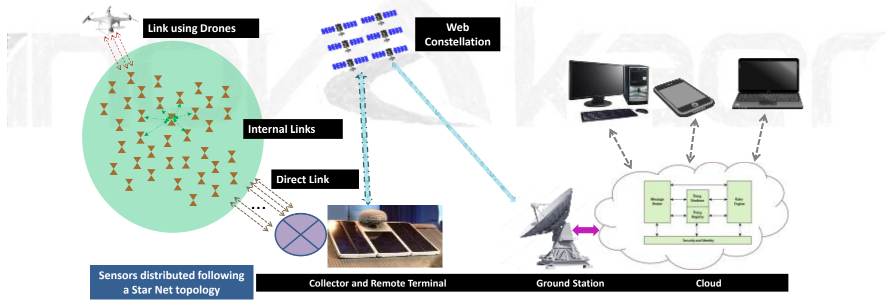
Akaer – Committed to Excellence – Proprietary Information
Integrated Development of Complex Products – Study of Cases with Focus on Smart Enterprise Concept – Fernando Ferraz, MSc, COO

inovakaer

Case 04 – Cattle Monitoring System

The first challenge for the team was to get immerse in this new environment. It was needed to understand the animals' habits and environment constraints, to identify the critical parameters and their inter-relations, and to take into account the large variety of lands where the solution must to fit in.

To insure the system efficiency it was defined a robust devices network including the embedded hardware and software, the signal processing and control, the sensors/system integration, the communication and security protocols and the data presentation architecture.



Conclusions

Based on the exposed above, the conclusions made by Akaer, a medium size Brazilian company is clear that the

- The new scenario, continuous quick and deep changes in the business development environment, including product development, will still be pushing the companies, at least during the near future;
- The sustainable solution for the challenge of follow developing and improving the performances but reducing the time to market and costs must come from the balance of technological improvements and innovative solutions;
- Efficient handling of product data and development knowledge is one of the key challenges in today's product development. The interaction between digital technology, the information network, software functionality, and processes for decision-making based on needs throughout the product and plant life must still be established as a central competence;
- The changes and innovations are requiring a new professional with transverse skill, T-skill, able to be adaptive, agile and with more broad view prone to integrated available solutions and new technologies in innovative arrangements;
- To be able to be competitive and survive in the next decade, companies must to reshape their classical organization and approach, being much more proactive, services oriented and ready to innovate. It will be mandatory to be very efficient in the information management.

akaer

Muito Obrigado
Thank you
Vielen Dank

Fernando Ferraz, MSc, COO
Joselito Hernandes, MSc

Akaer Group

Phone: +55 12 2139 1100
e-mail: fernando.ferraz@akaer.com.br
joselito.hernandes@akaer.com.br
Inetrnet: www.akaergroup.com

Eng. Gustavo de Oliveira Andrade

Formado em Engenharia Mecânica no Centro Universitário FEI, trabalhou no início dos anos 90 no Desenvolvimento e implantação das tecnologias CAD/CAM no Brasil como engenheiro de suporte da DELCAM/SEACAM no Brasil. A partir de 1996 se tornou sócio fundador da empresa ANG, escritório de Projeto e Desenvolvimento de Produto. A partir de 1998, como Diretor Técnico, viabilizava o atendimento aos clientes como ARTEB, AUTOMETAL, BASF, PLASCAR entre outras visando inovações nos produtos para melhora na competitividade através da Manufatura. A partir de 2000, suportando os clientes como VW, GMB e FORD, desenvolveu métodos de Desenvolvimento de Produto integrados com a Manufatura que resultaram em ganhos qualitativos. Com uma equipe de trabalho na China, iniciou em 2006 os trabalhos de Projeto do Produto considerando as tecnologias da Manufatura avançada para a época, com grandes impactos em produtividade. Em 2010, como executivo do grupo AUTOMETAL, criou e gerenciou uma equipe Desenvolvimento do Produto e das Linhas Produtivas de um Programa Veicular FORD para a Planta de Camaçari, integrando o Projeto do Produto com a Engenharia de Manufatura e Processo. Em 2013, assumiu o CTA - Centro de Desenvolvimento AUTOMETAL, onde inicia a implantação do Conceito Fabrica Digital, tecnologia ainda embrionária no Brasil na época. Responsável por criar, implantar e validar toda e qualquer inovação em novos projetos corporativos do CTA, visita frequentemente as plantas do Grupo no mundo (são mais de 100 no total) para constante reciclagem dos Centros Tecnológicos, hoje apenas 2 no mundo, 1 deles no Brasil onde é o Gestor Geral. Hoje é responsável pelo lançamento de Linhas Produtivas e/ou Novas Plantas do Grupo, todas com metas agressivas de eficiência e eficácia operacional, implantando e validando as tecnologias da Industria 4.0 e Internet Industrial, base do Plano Diretor Global do Grupo.

gandrade@autometal.com.br

Autometal S.A.

A CIE Automotive é um Grupo Industrial, onde o Grupo AUTOMETAL faz parte, é fornecedor de componentes e subconjuntos para o mercado global de automação em tecnologias complementares (alumínio, ferro, metal, plástico e aço) com diversos processos associados: mecanização, soldagem, injeção termoplástica e montagem. Sua missão é crescer de forma sustentável e rentável, posicionando-se como fornecedor de referência, contribuindo a seus clientes soluções integrais, inovadoras e competitivas de alto valor agregado. O principal objetivo da CIE Automotive é a integração de soluções inovadoras às necessidades dos clientes, aplicando alta tecnologia para o desenvolvimento de produtos e da otimização de processos. Os 3 Centros tecnológicos da CIE Automotive, localizados em São Paulo (Brasil), Bérriz (Espanha) e Figueira da Foz (Portugal), colaboram estritamente com as engenharias de processos de cada uma das tecnologias e com a administração dos produtos que lideram os projetos de desenvolvimento.

CIE Automotive

A integração entre o conceito Indústria 4.0 e o Desenvolvimento do Produto

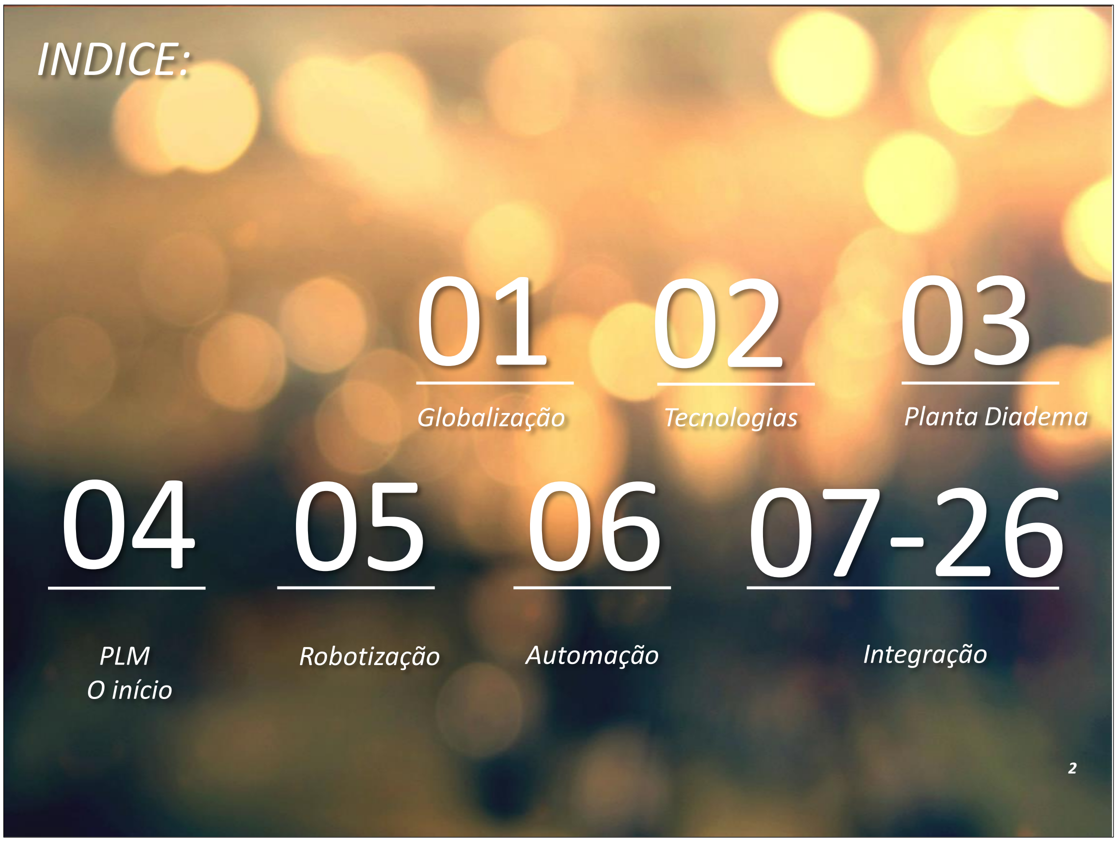
Resumo

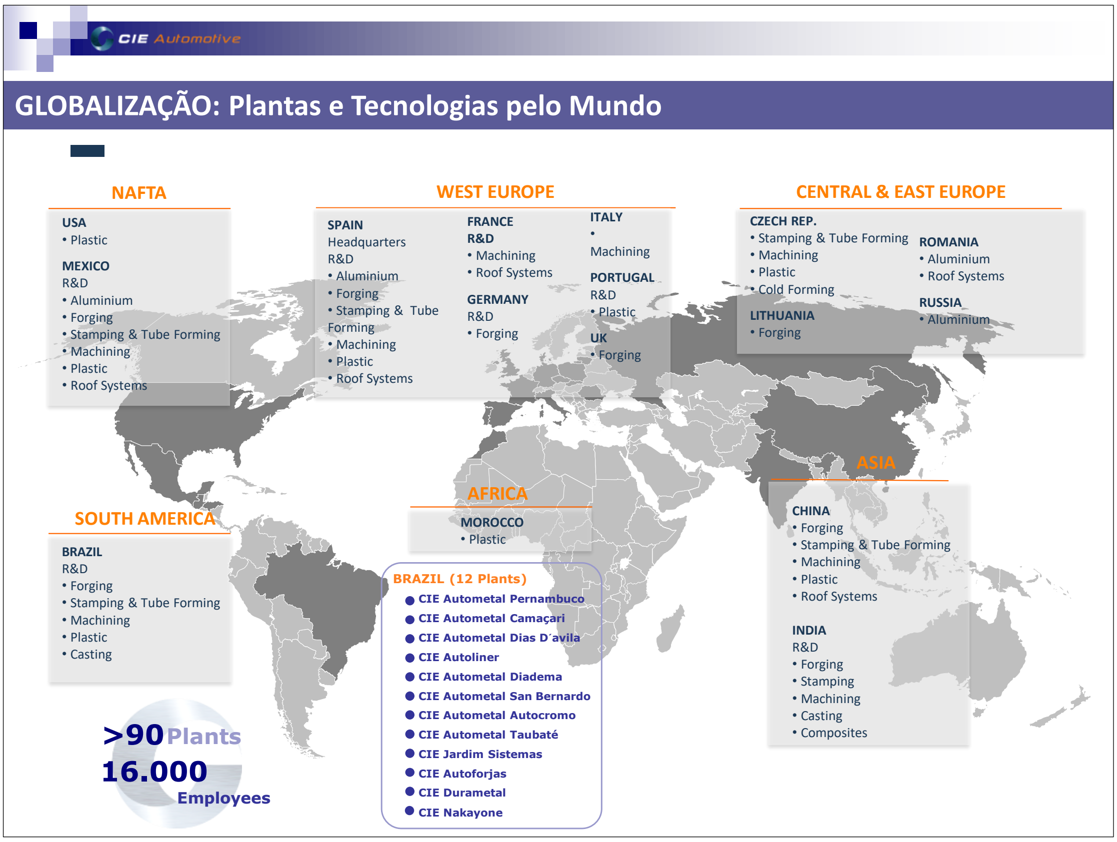
A Indústria da Manufatura já reconhece que investir nos conceitos e tecnologias que compõe a 4ª Revolução Industrial é um caminho relativamente seguro para se obter ganhos de competitividade, conforme várias evidencias já reconhecidas pelas empresas de ponta da Industria global. Todos também reconhecem que os desafios são enormes. Principalmente por não haver uma formula pronta e especifica, mas somente um conceito que exige uma remodelação da Cadeia de Valor e uma busca constante pelo conhecimento da aplicação das tecnologias propostas. Entretanto, alguns resultados positivos estão começando a serem validados na prática e estão sendo publicados por alguns setores que primeiro se arriscaram. Algumas empresas que já implantaram algumas das tecnologias da Indústria 4.0, estão sentindo algumas limitações na expansão dos ganhos de eficiência e performance. Estudos mais aprofundados estão evidenciando que os Projetos dos Produtos que não foram concebidos considerando estas tecnologias, são os maiores limitadores. Produtos considerados inteligentes, eficientes e inovadores agora necessitam ser concebidos com essa "inteligência" na sua criação para que os consumidores acreditem que estão comprando algo sustentável. O grupo AUTOMETAL / CIE AUTOMOTIVE está se estruturando para integrar ao Desenvolvimento do Produto todas as tecnologias inovadoras já implementadas nas linhas produtivas, porque o conceito Industria 4.0 já se mostrou altamente eficaz nos projetos em que nós validamos a implementação. Esta integração do Desenvolvimento do Produto com a Engenharia do Processo, utilizando os conceitos da Industria 4.0, a partir do início da Concepção do Produto, pode alavancar ainda mais a competitividade dos nossos produtos. Este trabalho demonstra como o Grupo AUTOMETAL / CIE AUTOMOTIVE se estruturou para implementar as tecnologias Industria 4.0, tanto nos Projetos Correntes, quanto nos sistemas de Gestão da Produção, e como agora estamos integrando nossos Sistemas de Desenvolvimento do Produto e Processo nos Centros Tecnológicos no Brasil e na Europa.

Palavras-chave

Inovação; Integração; Produto.


AUTOMETAL S.A.
O Plano Estratégico 2025
Caminhos Trilhados 2013-2018
CIE Automotive
Managing high value added processes
CIE Autometal
Diadema
MAR/2018


INDICE:
01
Globalização
02
Tecnologias
03
Planta Diadema
04
PLM
O início
05
Robotização
06
Automação
07-26
Integração
2


CIE Automotive
GLOBALIZAÇÃO: Plantas e Tecnologias pelo Mundo
NAFTA
USA
• Plastic
MEXICO
R&D
• Aluminium
• Forging
• Stamping & Tube Forming
• Machining
• Plastic
• Roof Systems
WEST EUROPE
SPAIN
Headquarters
R&D
• Aluminium
• Forging
• Stamping & Tube Forming
• Machining
• Plastic
• Roof Systems
FRANCE
R&D
• Machining
• Roof Systems
GERMANY
R&D
• Forging
ITALY
• Machining
PORTUGAL
R&D
• Plastic
UK
• Forging
CENTRAL & EAST EUROPE
CZECH REP.
• Stamping & Tube Forming
• Machining
• Plastic
• Cold Forming
LITHUANIA
• Forging
ROMANIA
• Aluminium
• Roof Systems
RUSSIA
• Aluminium
ASIA
CHINA
• Forging
• Stamping & Tube Forming
• Machining
• Plastic
• Roof Systems
INDIA
R&D
• Forging
• Stamping
• Machining
• Casting
• Composites
AFRICA
MOROCCO
• Plastic
SOUTH AMERICA
BRAZIL
R&D
• Forging
• Stamping & Tube Forming
• Machining
• Plastic
• Casting
BRAZIL (12 Plants)
CIE Autometal Pernambuco
CIE Autometal Camaçari
CIE Autometal Dias D´avila
CIE Autoliner
CIE Autometal Diadema
CIE Autometal San Bernardo
CIE Autometal Autocromo
CIE Autometal Taubaté
CIE Jardim Sistemas
CIE Autoforjas
CIE Durametal
CIE Nakayone
>90 Plants
16.000
Employees


CIE Automotive
CENTROS TECNOLOGICOS: Os Centros de Engenharia e Desenvolvimento do Grupo
CIE Autometal
Diadema
CIE Automotive
Fundación CIE I+D+i
CIE Technical Center
Bilbao – SPAIN
AUTOMETAL
Engineering Office
Dearborn – U.S.
AUTOMETAL
Technical Center C.T.A.
Diadema – BRAZIL
CONCEPTS
Autometal Engineering Offices supported by Autometal/CIE Technological Centers.
Simultaneous Engineering using last generation system for D&R
Engineering data linked with Clients by PLM
Program Manager per Vehicle Project.
Technical Center
Engineering Office

CIE Automotive

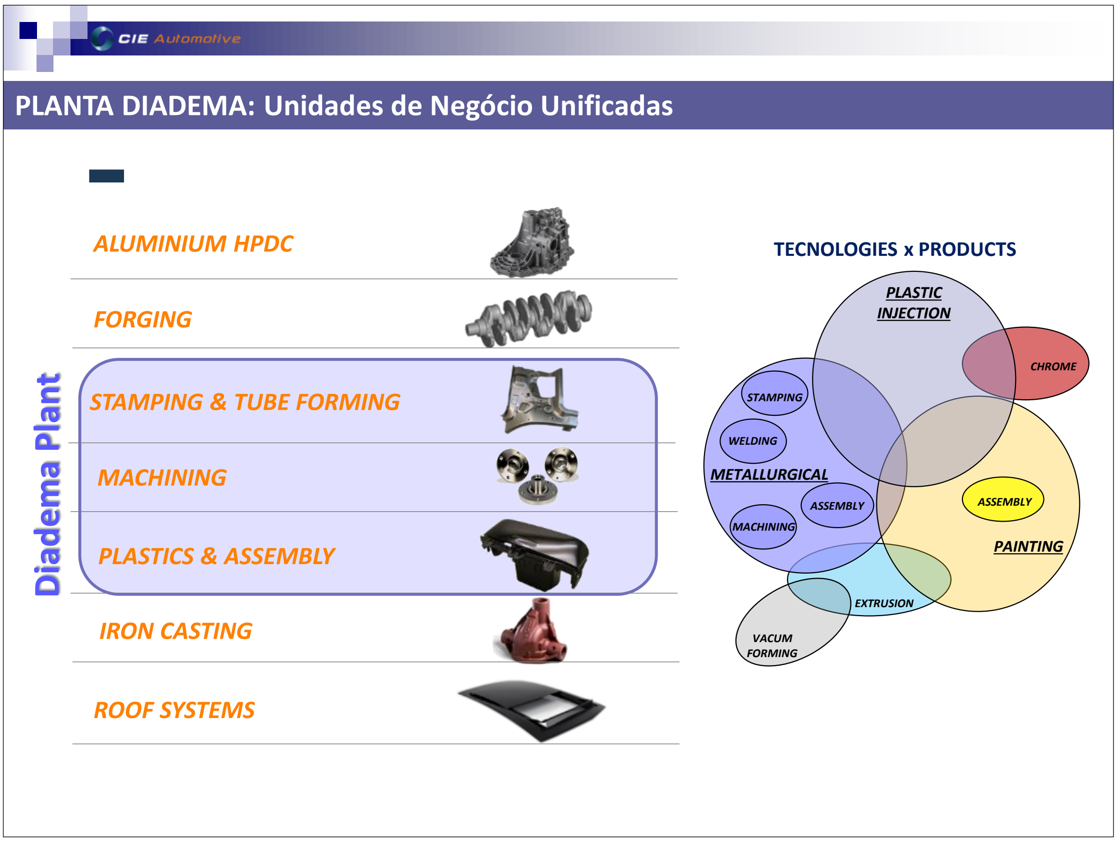
PLANTA DIADEMA: Unidades de Negócio Unificadas

Certificações

ISO TS 16949 - ISO 14001 - OSHAS 18001

Desde:
1964
Colaboradores:
968 pessoas
Area Construida:
55.000m2
Principais Clientes:
Ford/VW/GM/Fiat/Toyota/PSA/ Renault/MMC/Nissan/Hyundai/ Honda/Man
Atividades:

- ***Desenv. Produto / Manufatura APQP***
- ***Manutenção de Ferramental***
- ***Injeção, Extrusão peças Plásticas***
- ***Termoformagem e Vacum Forming***
- ***Estampagem & Estiramento Metalico***
- ***Solda Robotizada***
- ***Linhas de Pintura (Plastico / Metal)***
- ***Linhas de Montagem***

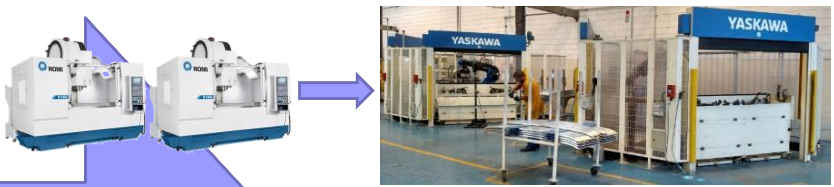

CIE Automotive
PLANTA DIADEMA: Unidades de Negócio Unificadas
Diadema Plant
ALUMINIUM HPDC
FORGING
STAMPING & TUBE FORMING
MACHINING
PLASTICS & ASSEMBLY
IRON CASTING
ROOF SYSTEMS
TECNOLOGIES x PRODUCTS
PLASTIC INJECTION
CHROME
STAMPING
WELDING
METALLURGICAL
ASSEMBLY
MACHINING
ASSEMBLY
PAINTING
EXTRUSION
VACUM FORMING


CIE Automotive
A DECISÃO PELO PLM: Adaptação aos Sistemas de Desenvolvimento de Produto
Autometal
TEAMCENTER
NX
TOTVS
HONDA
Ford
FIAT
Jeep
PSA PEUGEOT CITROËN
RENAULT
GM
Conceito
Programa
Protótipo
Piloto
Lançamento
Transferência
1 Planejamento e Definição: Programa AVTR
2 Projeto & Desenvolvimento PRODUTO
3 Projeto & Desenvolvimento PROCESSO
4 Verificação & Validação PRODUTO & PROCESSO
5 Avaliação & Correção PRODUÇÃO
AVANZA
Alcanzando grandes metas
AIAG
Production Part Approval Process
PPAP
Fourth Edition
APQP Certified
PLM
CÓPIA CONTROLADA
PLM PLATFORM
Start
Designs
Documents
BOMs
Process
MPP
Extend
Requirements
Service
Manufacturing
Supplier
QMS
PCM
Transform
Quality
Cost
Sustainability
Systems
Apps

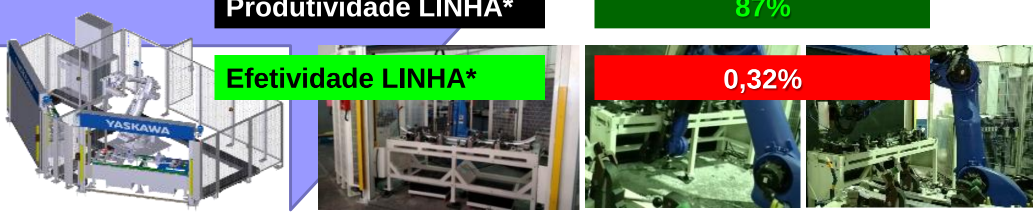
CIE Automotive

PROJETO PILOTO: Metas Agressivas de Eficiência e Eficácia Operacional

TECNOMATIX
Autometal
TEAMCENTER
NX

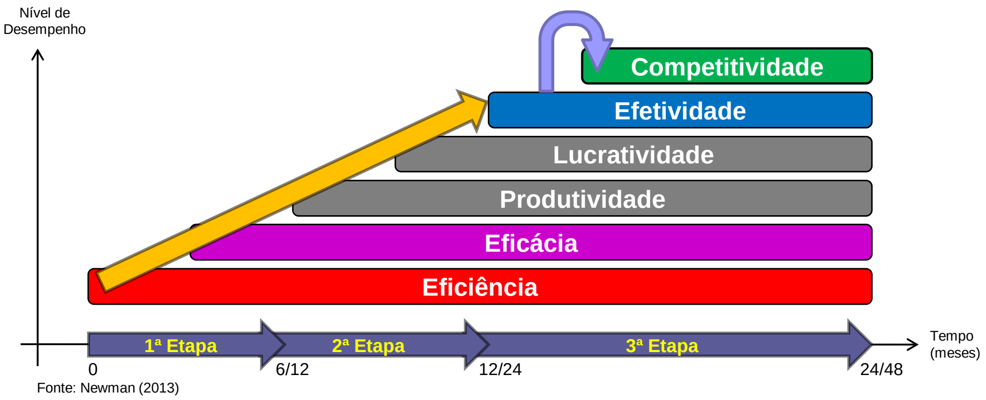


	Escopo Inicial (06/2015)	Revisão Aprovada (03/2016)
Capacidade	6	16
Mão de Obra	6	1
Turno	3	1
Efetividade*	74,4%	128,4%
	Produtividade LINHA*	87%
	Efetividade LINHA*	0,32%



CIE Automotive

INDICADORES DE DESEMPENHO: Modelo de Referencia para Planejamento



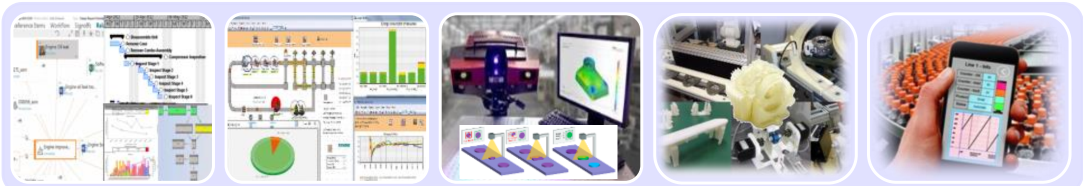
Fonte: Newman (2013)

SIEMENS *PCM*

INDICE DE EFETIVIDADE (**OK** > 100% / **NOK** < 100%) (BASE: MARGEM DE CONTRIBUIÇAO)	96,7% % *Real (54,9%) / Orçado (56,8%)*	
MELHORIA CONTINUA (**NÃO** > 100% / **SIM** < 100%) (PLANO DE AÇÃO EM ANEXO)	X SIM	NÃO

CIE Automotive

TECNOLOGIAS IMPLANTADAS / CONSCIENTIZAÇÃO CIE AUTOMETAL



PLM — CAD / CAM / CAE, DIGITAL TWIN

MOM — MES / APS / QMS, TIA

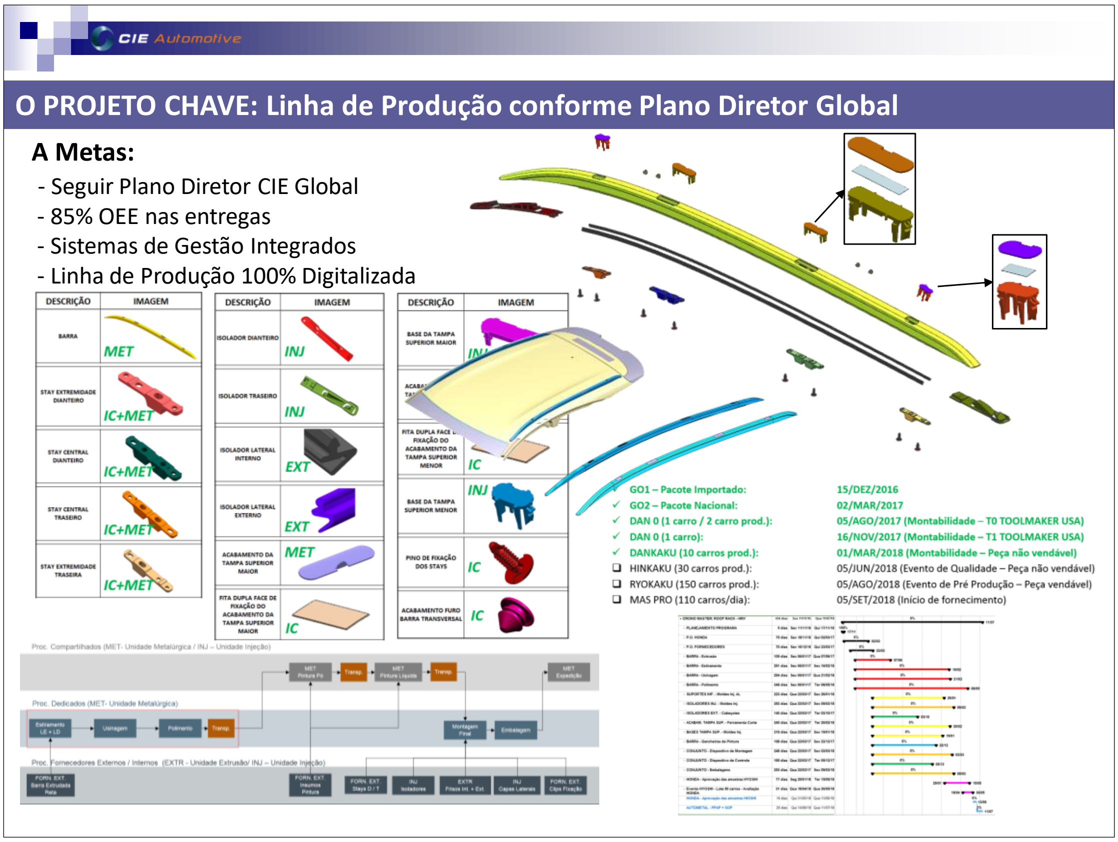
MVS — MACHINE VISION SYS., 3D SCANNER

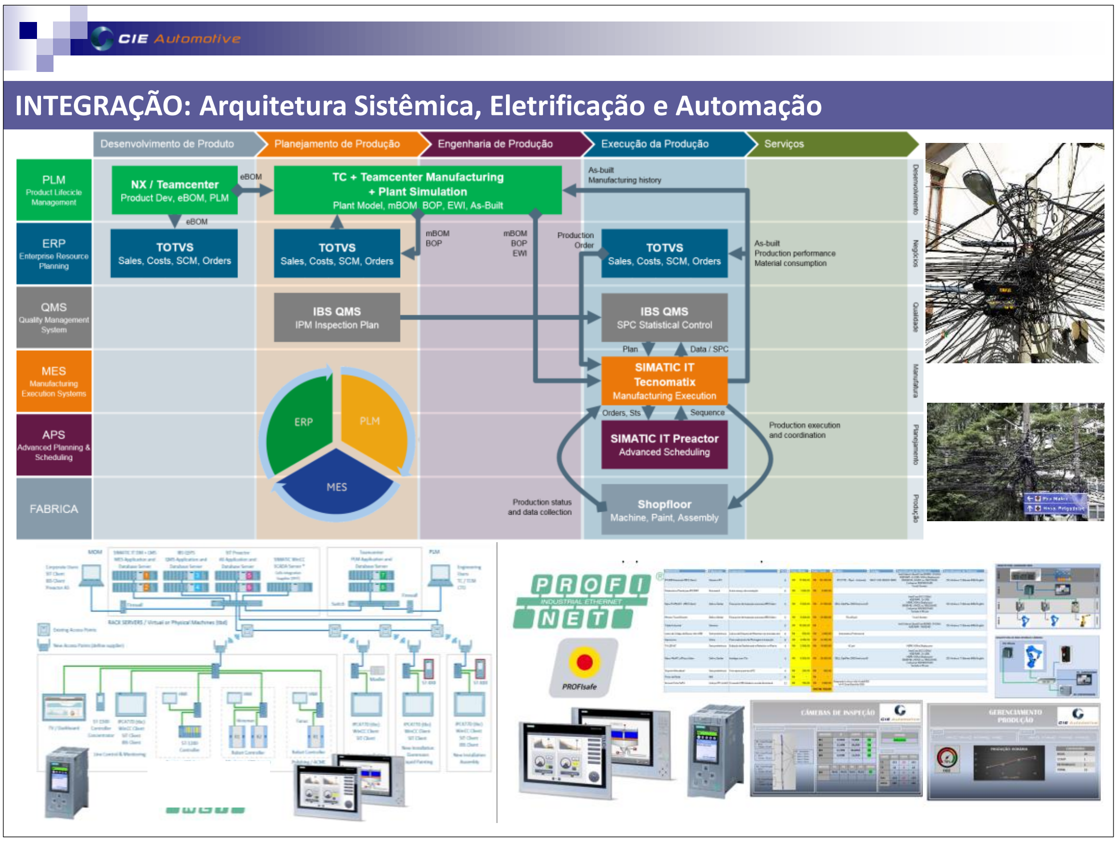
AM — ADDICTIVE MANUFACT., 3D PRINTING

DM — ROBOT PROCESS AUTOMATION; CLOUD COMPUTING; BIG DATA & ANALYTICS; CYBER SECURITY

	Indústria 4.0	Internet Industrial
Precursor	Governo Alemão	Grandes Multinacionais
Stakeholders	Governo, Academia, Empresas	Empresas, Academia, Governo
Plataforma de Suporte	Políticas Industriais Governamentais	Consórcio Aberto sem fins lucrativos
Foco Setorial	Manufatura	Manufatura, energia, transportes, saúde, utilidades, cidades, agro
Foco Tecnológico	Coordenação da cadeia de fornecimento, sistemas embarcados, automação, robótica	Comunicação entre dispositivos, fluxos de dados, integração e controle de dispositivos, *analytics* preditivo, automação industrial
Normatização	É parte da agenda	Recomendações para agências de regulamentação
Abordagem Econômica	Normativa	Positiva


CIE Automotive
IND. 4.0 / FABRICA DIGITAL: Plano Diretor Global - Grupo CIE Autometal
ERP
TOTVS
DATASUL
Lifecycle and Data Analytics
MES
PLM Software
Auto-mation
Supplier
Supplier
Logistics
Supplier
Siemens Collaboration Platform: Teamcenter
EVOLUCIÓN DE LA INDUSTRIA
4TA. REVOLUCIÓN INDUSTRIAL
Industry 4.0
How to navigate digitization of the manufacturing sector
Industry 4.0: Building the digital enterprise
2000+
US$493 bn
US$421 bn
US$907 bn
pwc
“ Perguntar é preciso, responder não é.
O sábio é aquele que pergunta sempre.”
“ As pessoas inteligentes estão sempre querendo saber os porquês.
Jorge Trindade - PhD Psicologia Forense


CIE Automotive
O PROJETO CHAVE: Linha de Produção conforme Plano Diretor Global
A Metas:
- Seguir Plano Diretor CIE Global
- 85% OEE nas entregas
- Sistemas de Gestão Integrados
- Linha de Produção 100% Digitalizada
✓ GO1 – Pacote Importado: 15/DEZ/2016
✓ GO2 – Pacote Nacional: 02/MAR/2017
✓ DAN 0 (1 carro / 2 carro prod.): 05/AGO/2017 (Montabilidade – T0 TOOLMAKER USA)
✓ DAN 0 (1 carro): 16/NOV/2017 (Montabilidade – T1 TOOLMAKER USA)
✓ DANKAKU (10 carros prod.): 01/MAR/2018 (Montabilidade – Peça não vendável)
❑ HINKAKU (30 carros prod.): 05/JUN/2018 (Evento de Qualidade – Peça não vendável)
❑ RYOKAKU (150 carros prod.): 05/AGO/2018 (Evento de Pré Produção – Peça vendável)
❑ MAS PRO (110 carros/dia): 05/SET/2018 (Início de fornecimento)


CIE Automotive
INTEGRAÇÃO: Arquitetura Sistêmica, Eletrificação e Automação
Desenvolvimento de Produto
Planejamento de Produção
Engenharia de Produção
Execução da Produção
Serviços
PLM
Product Lifecicle Management
ERP
Enterprise Resource Planning
QMS
Quality Management System
MES
Manufacturing Execution Systems
APS
Advanced Planning & Scheduling
FABRICA
NX / Teamcenter
Product Dev, eBOM, PLM
eBOM
TC + Teamcenter Manufacturing
+ Plant Simulation
Plant Model, mBOM BOP, EWI, As-Built
As-built
Manufacturing history
TOTVS
Sales, Costs, SCM, Orders
mBOM
BOP
EWI
Production Order
As-built
Production performance
Material consumption
IBS QMS
IPM Inspection Plan
IBS QMS
SPC Statistical Control
Plan
Data / SPC
SIMATIC IT
Tecnomatix
Manufacturing Execution
Orders, Sts
Sequence
Production execution
and coordination
SIMATIC IT Preactor
Advanced Scheduling
ERP
PLM
MES
Production status
and data collection
Shopfloor
Machine, Paint, Assembly
PROFI NET
INDUSTRIAL ETHERNET
PROFIsafe
CÂMERAS DE INSPEÇÃO
GERENCIAMENTO PRODUÇÃO

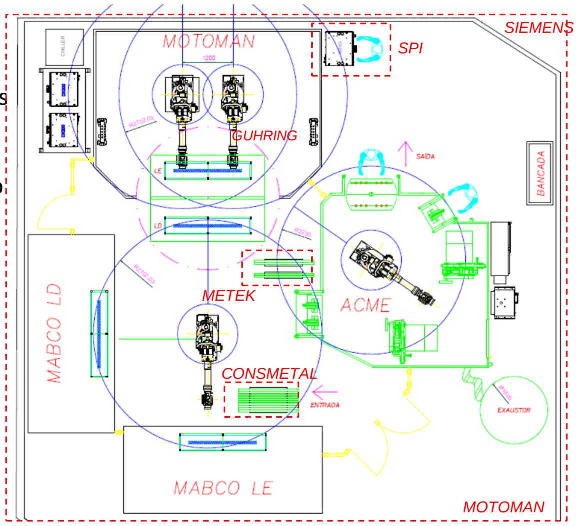

CIE Automotive
CÉLULA INTEGRADA: Unificação dos Processo de Curvar, Usinar e Polir
Equipamento: Célula de Produção de Barras
Fornecedor: Mabco / Motoman / Metek / ACME
Tipo: Integrada / Monitorada / Autoqualificada
YASKAWA
YASKAWA

CIE Automotive

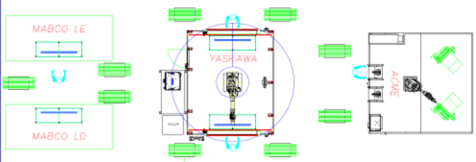
CÉLULA INTEGRADA: Unificação dos Processo de Curvar, Usinar e Polir

- **Equipamento:** Célula de Produção de Barras
- **Objetivos:**
  - **Layout:** 3 células integradas em 1 única
  - **Mão de Obra:** Redução de 21 operadores
    - **Antes:** 24 operadores (8 por turno)
    - **Atual:** 3 operadores (1 por turno)
  - **Qualidade:** Monitoramento, captura de índices sem interferência dos operadores e identificação preditiva
  - **Performance:** Ciclo garantido via Programação da Célula e Gerenciamento com alarmes de ação imediata da produção

MODELO DE LAYOUT ATUAL

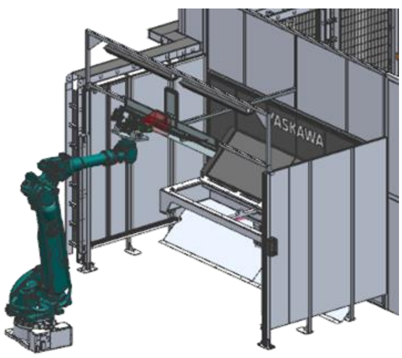


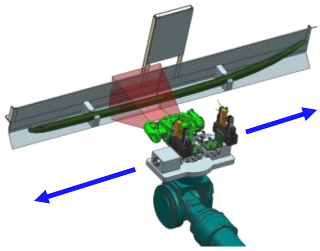
LAYOUT PADRÃO INICIAL

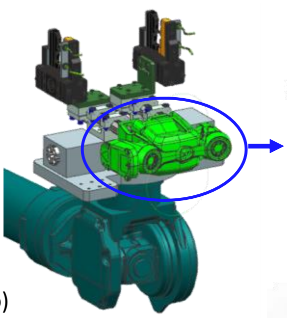


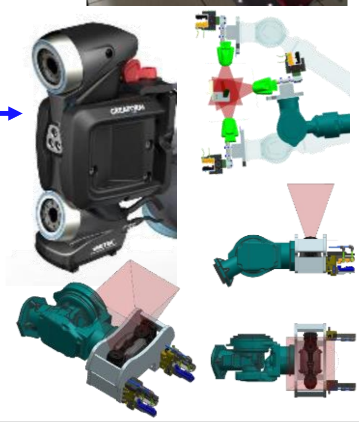
CIE Automotive

SISTEMA DE VISÃO: Processo Industrial de Controle Dimensional 3D



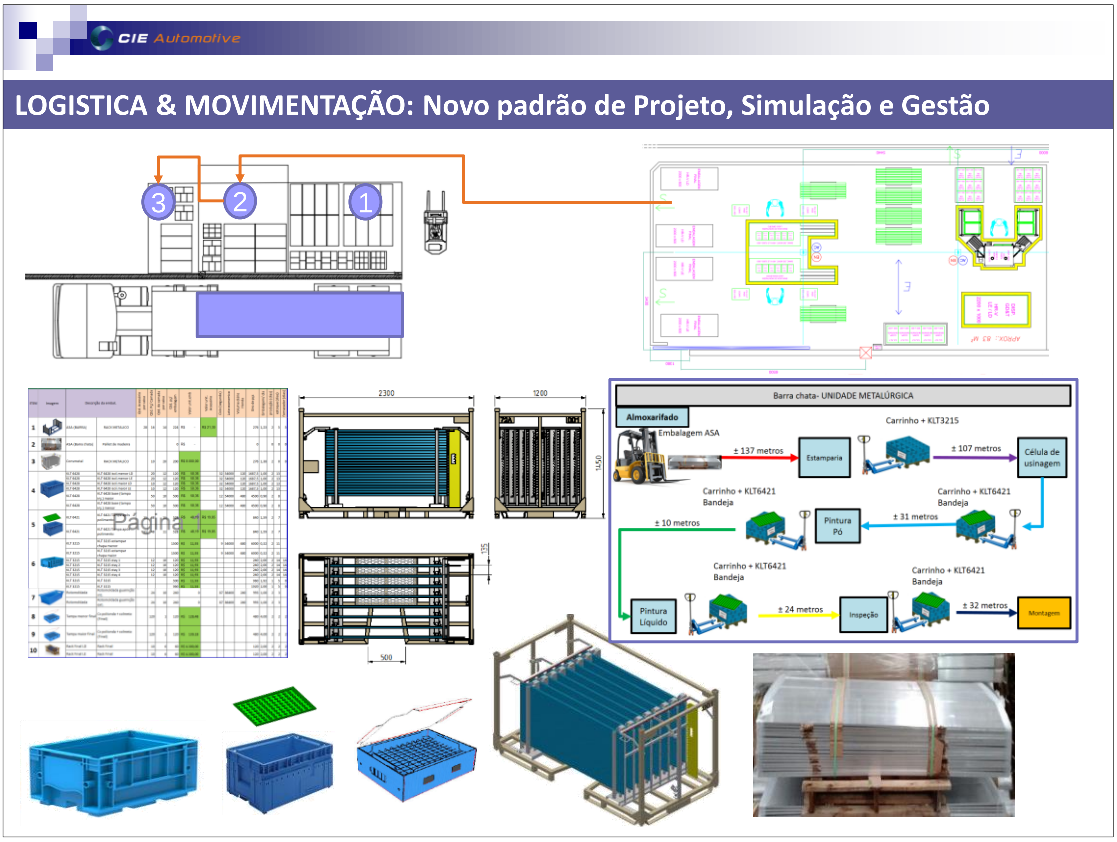






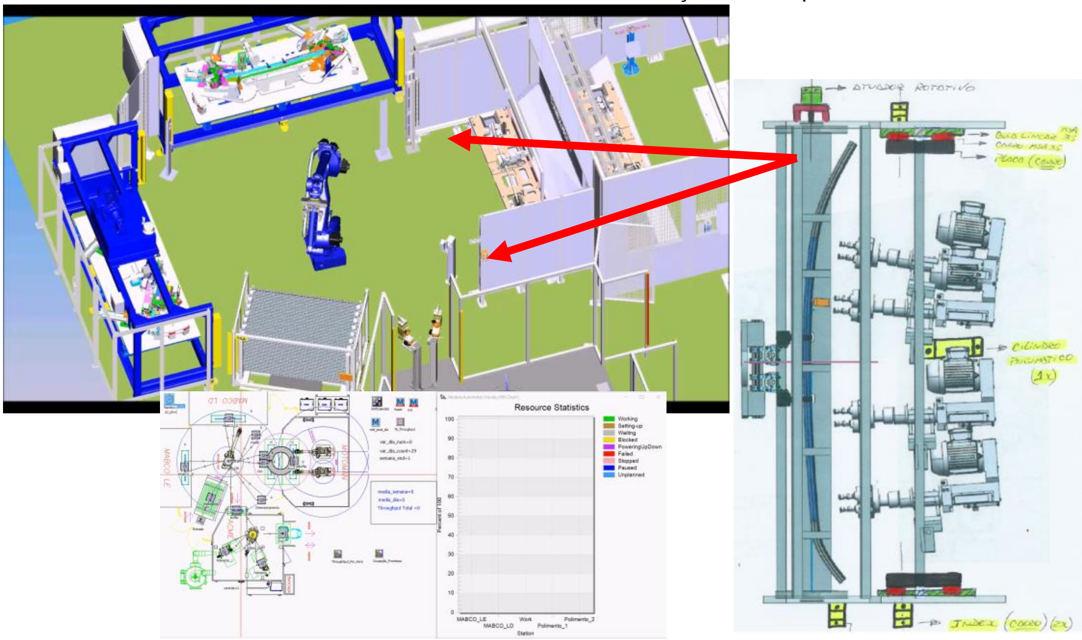
- **Equipamento:** Célula de Medição
- **Objetivos:**
  - **Medição:** 100% produção + 100% KPC
  - **Operação:** Redução de 1 operação
  - **Mão de Obra:** Redução de 2 pessoas
    - **Antes:** 2 pessoas (1 por turno)
    - **Atual:** 0 pessoa (0 por turno)
  - **Qualidade:** Médição e Capabilização da produção ON LINE
    Indicadores de manutenção PREDITIVA
  - **Performance:** Ciclo de medição de 90 segundos


CIE Automotive
DISPOSITIVOS GD&T: Projeto e Construção considerando Manufatura ADITIVA
Mobile App
User-friendly Interface
GrabCAD Print
Insight Software
Selection of Advanced Materials
SCA-3500 Cleaning Station
Stratasys
FORTUS 370

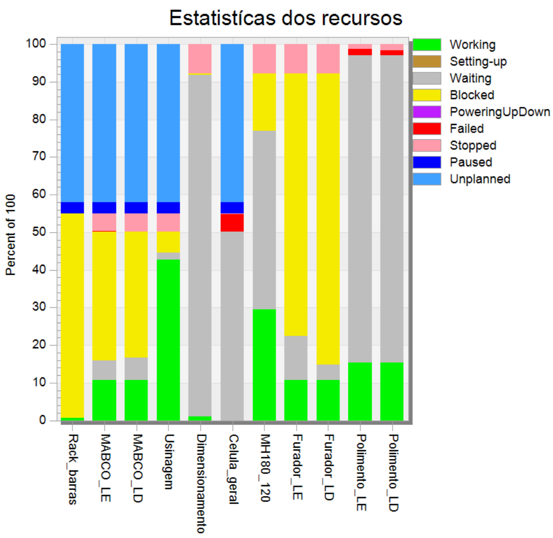

CIE Automotive
LOGISTICA & MOVIMENTAÇÃO: Novo padrão de Projeto, Simulação e Gestão
3
2
1
2300
1200
1450
500
Página
Barra chata- UNIDADE METALÚRGICA
Almoxarifado
Embalagem ASA
± 137 metros
Estamparia
Carrinho + KLT3215
± 107 metros
Célula de usinagem
Carrinho + KLT6421 Bandeja
Carrinho + KLT6421 Bandeja
± 10 metros
Pintura Pó
± 31 metros
Carrinho + KLT6421 Bandeja
Carrinho + KLT6421 Bandeja
Pintura Líquido
± 24 metros
Inspeção
± 32 metros
Montagem

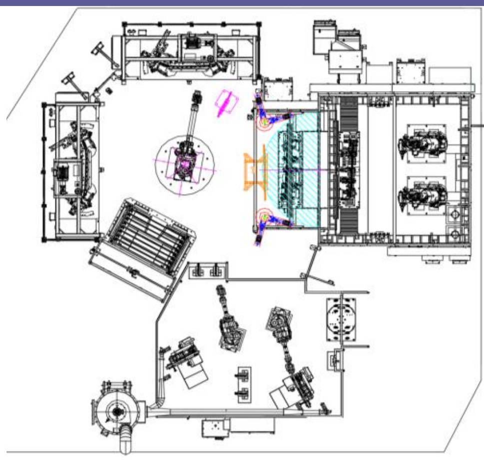
SIMULAÇÃO: Plano de Avaliação e Validação Digital do Processo Produtivo

- ***Simulação Virtual e Física*** como base mestre deste as primeiras fases do Desenvolvimento do Produto e Processo, até sua validação física após PPAP.



SIMULAÇÃO: Plano de Avaliação e Validação Digital do Processo Produtivo



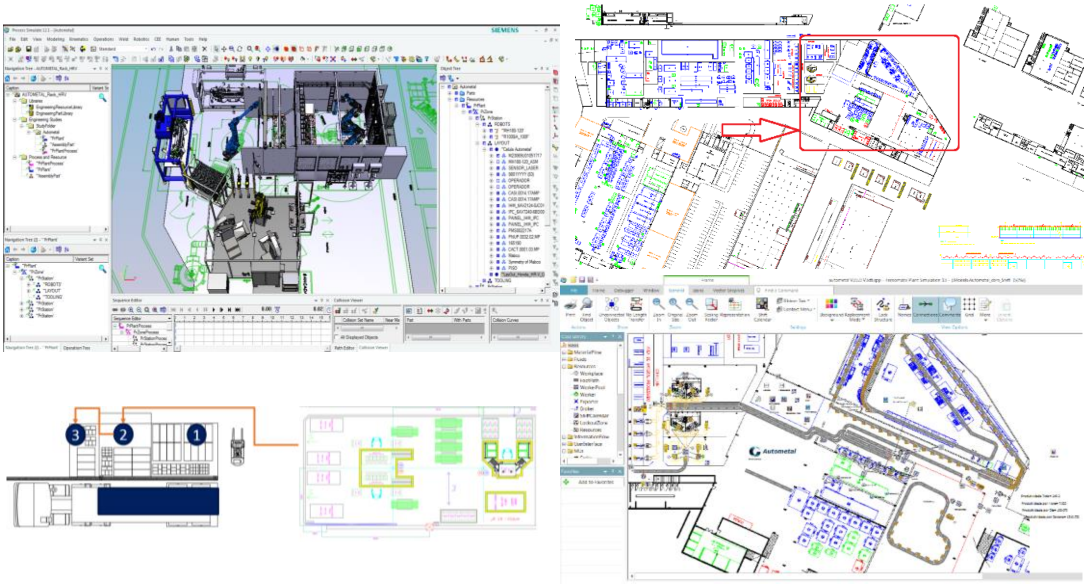


Tempo de ciclo médio
104 segundos

Célula Integrada:	Turno utilizado	Ocupação	Total Barras
• Estiramento • Usinagem • Polimento	• Turno 1 • Turno 2 • Turno 3	18 horas	• Barras LE: 311 • Barras LD: 311 • ***Total Barras: 623***

SIMULAÇÃO: Plano de Avaliação e Validação Digital do Processo Produtivo

Plano de Melhoria Contínua Estruturada como base de todos dados e informações contextualizadas para tomada de decisões com foco na META DE EFICIÊNCIA adotada para cada Projeto do Grupo.



SEQUENCIAMENTO / MONITORAMENTO PRODUTIVO: Novo Modelo Gerencial

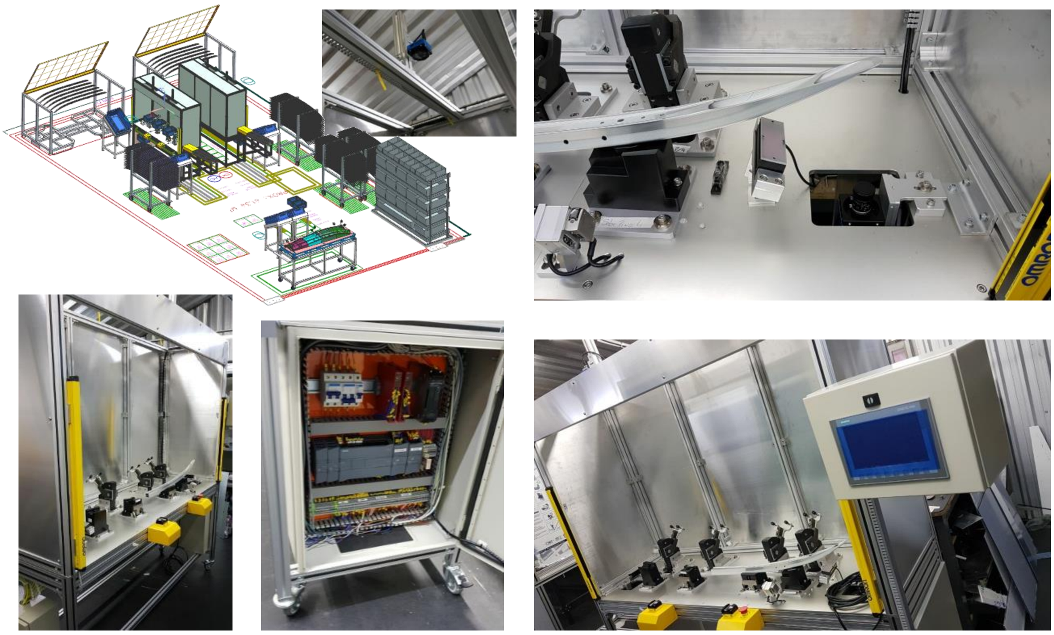
- ***APS:*** Sequenciamento e Planejamento da Produção

- ***MES:*** Monitoramento da Execução da Produção

CIE Automotive

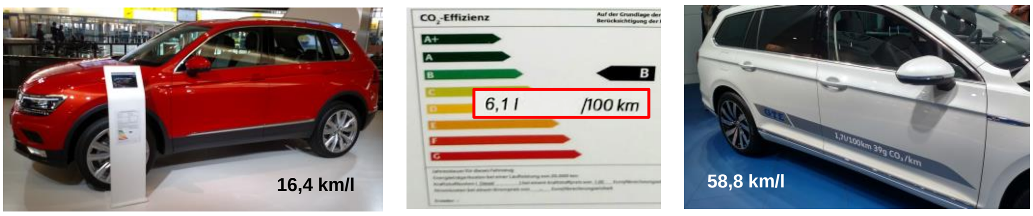
VISÃO ARTIFICIAL: Avaliação e Validação Digital do Processo Produtivo

- ***Células de Montagem Integradas:*** Novo padrão de Células Integradas para operações industriais automatizadas, monitoradas e gerenciadas digitalmente.



CIE Automotive

Necessidade – Planejamento – Consistência – Sustentabilidade



"COMECE HOJE, ACEITE A MUDANÇA E NÃO BUSQUE ATALHOS"

Informação -> Conhecimento -> Inteligência

"A quarta grande REVIRAVOLTA na Fabricação Moderna"

"É inevitável e irreversível"


Obrigado
gandrade@autometeal.com.br
(11) 4070-8200
CIE Automotive
Managing high value added processes
CIE Autometal
Diadema

ozonio

Patrocinadores

Realização

Apoio

Parceiros

ISSN 2175-9960