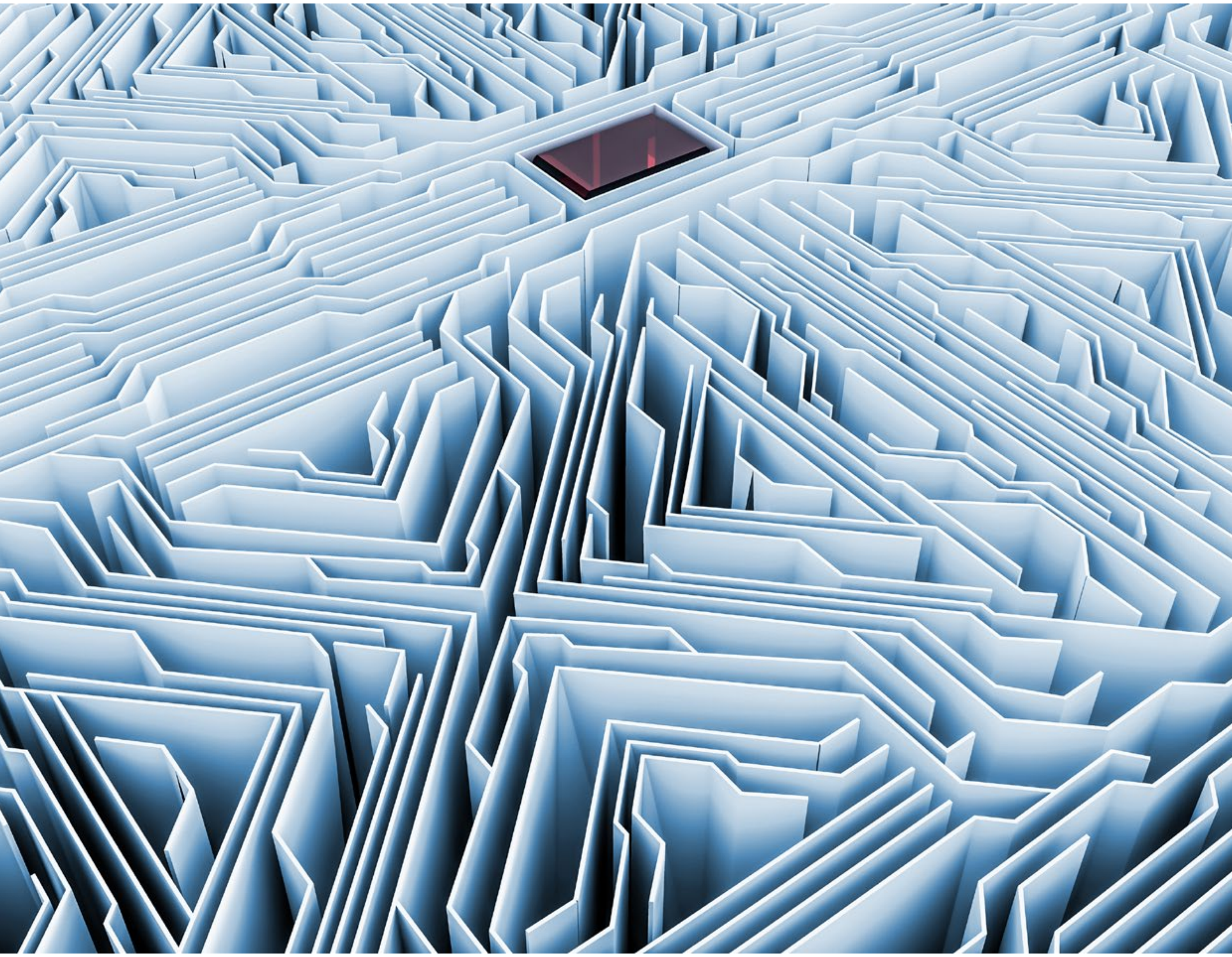

PAiCE MONITOR

Market, Technology, Innovation

Imprint

Published by

PAiCE Scientific Assistance
iit – Institut für Innovation und Technik in der
VDI / VDE Innovation + Technik GmbH
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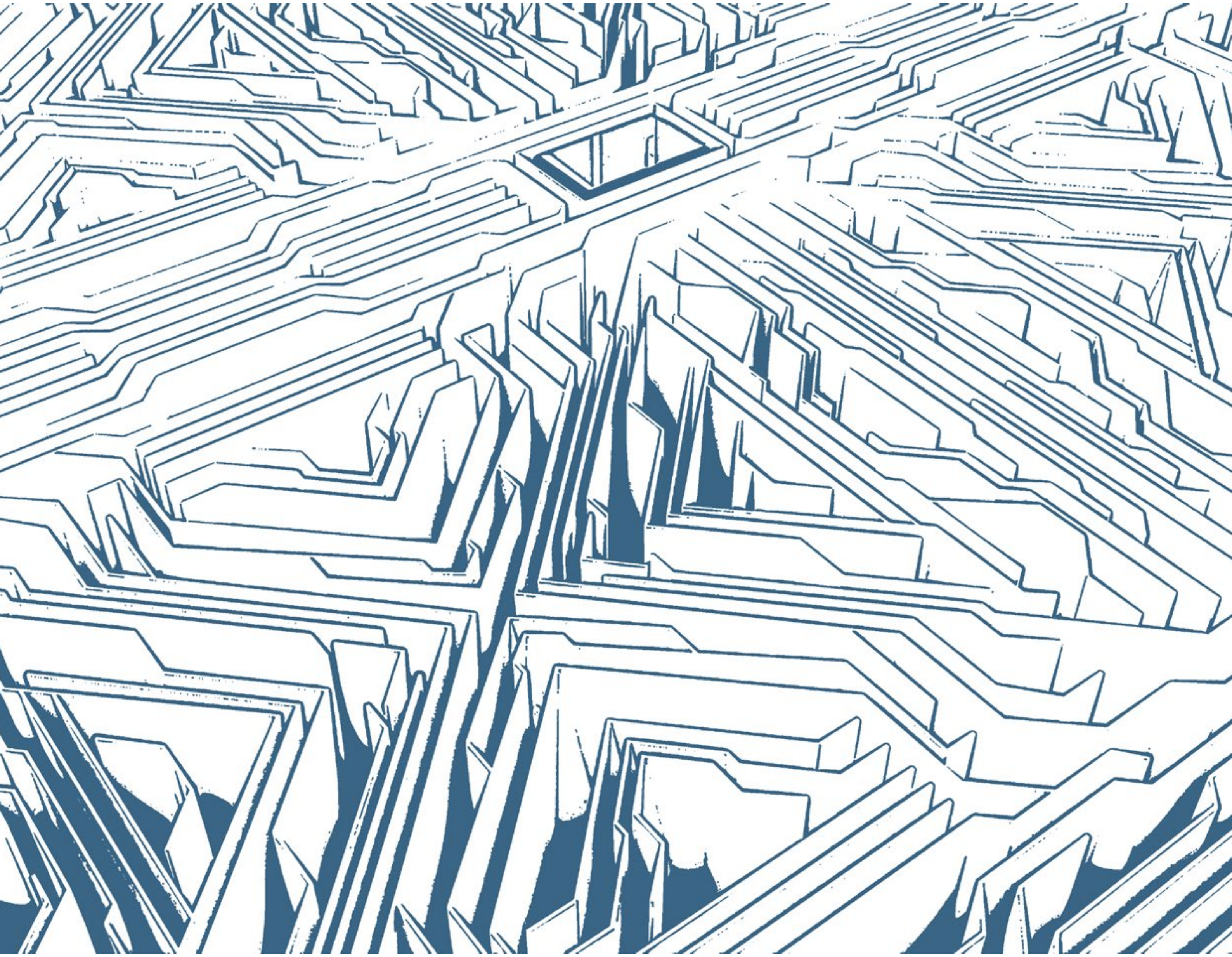
Status

April 2018

Supported by:

Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag



PAiCE MONITOR

Market, Technology, Innovation

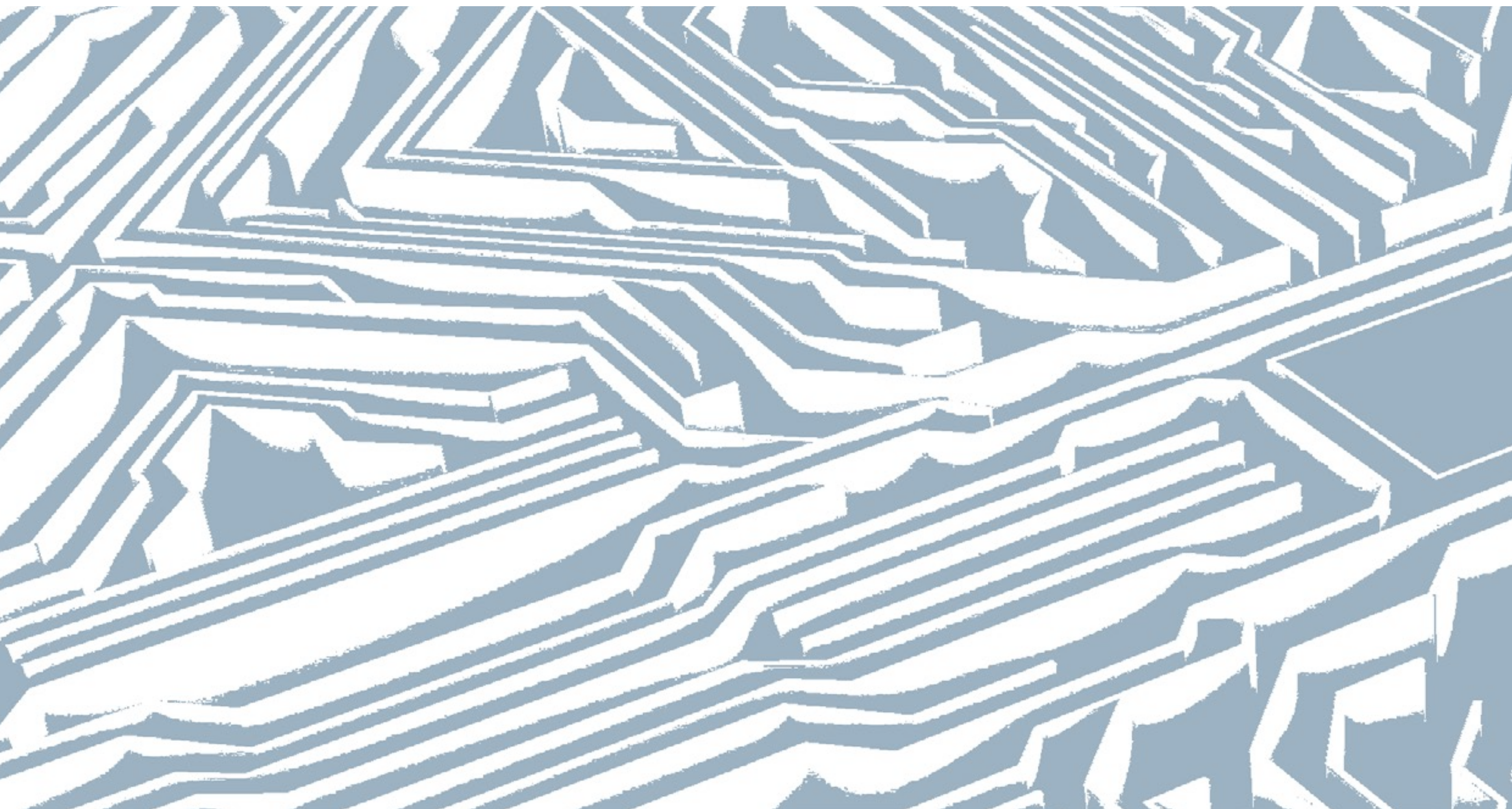
Inhalt

1 Introduction

Industry, research and politics are driving the horizontal and vertical interconnection of production and logistics under the overall ‘Industry 4.0’ vision. All-encompassing digitalisation of processes in development, production, transport and use will not only make it possible to once again boost the efficiency of work, resources and capital, , it will create opportunities to provide private and business customers with customised projects in a timely fashion. This will create the basis for maintaining and strengthening the leading international position of Germany’s manufacturing industry.

With the PAiCE technology programme (Platforms | Additive Manufacturing | Imaging | Communication | Engineering), the Federal Ministry for Economic Affairs and Energy (BMWi) supports the implementation of the overall ‘Industry 4.0’ vision in business practice as part of the Federal Government’s Digital Agenda. In 16 projects, companies and research institutions are testing the use of innovative digital technologies in production and logistics in large, application-near pilot projects. The Federal Ministry for Economic Affairs and Energy supports the more than one hundred partners in the various projects with a total of EUR 50 million. Together with the project partners’ own shares, PAiCE has a volume of over EUR 100 million.

PAiCE is continuing the work of predecessor programmes, i.e. Next Generation Media, AUTONOMIK and AUTONOMIK for Industry 4.0, where basic technologies for decentralised or even autonomous process control in industrial applications were tested and new resultant requirements analysed with regard to their impact on business models, work organisation and the legal treatment of liability, certification and data protection issues.



The projects in PAiCE are now taking the next step, addressing the development of digital industry platforms as well as collaboration between companies using these platforms. Five clusters have been set up for this purpose:

- The **Robotics** cluster, which consists of the BakeR, QBIIK, RoboPORT, ROBOTOP and SeRoNet projects, works on open modular systems for service robots in industry and the service sector.
- The **3D cluster** encompasses the Add2Log, DigiKAM, M3D and SAMPL projects and works on platforms for additive manufacturing.
- The projects of the **Engineering cluster** – DEVEKOS, EMuDig 4.0, INTEGRATE and VariKa – develop and test concepts for cooperative engineering.
- The **Logistics cluster** consists of the iSLT.NET and SaSCh projects that deal with platforms for managing logistics networks.
- The IC4F cross-sectional project finally represents the **Communication** cluster. Based on the work in the PAiCE projects, IC4F is developing a communication and computing architecture for Industry 4.0.

The PAiCE projects were launched between 2016 and 2017. Sections two to six of this first progress report issued under the programme describe the current status of the projects for all the clusters. In order to better illustrate the respective economic and technical environment of the different projects, we will first describe the market environment, the start-up scene, the state of the art and the research landscape for each cluster.

Scientific assistance for the PAiCE programme also started in March 2017. Section 7 describes the first activities of the three newly set up expert groups, i.e. Cooperative Business Models, Law and Trustworthy Architectures, and also provides an overview of the events and studies of the scientific assistance component in 2017 and 2018.

2 The Robotics cluster

Service robotics for industry, services and end customers

Today, mobile service robots are playing an increasingly important role in professional applications. Five projects of the PAiCE technology programme are dedicated to this topic: the QBIIK, RoboPORT, ROBOTOP and SeRoNet platform projects as well as the BakeR project that develops a modular system for cleaning robots.

The term 'service robotics' is neither self-explanatory nor clearly differentiated from classical industrial robotics. The concept is much easier to understand by identifying key characteristics of service robots rather than focusing on their variable technological features or their intended application contexts:

1. No special skills are required in order to use the application which is simple enough even for lay people.
2. The structure of the working environment of service robots is simple or open or sometimes even non-existent. This is due to a certain extent to the fact that:
3. Service robots are not used in fully automated industrial production.

2.1 Market analysis

Service robotics is a growth market. The 'International Federation of Robotics' (IFR) as the robotics industry's umbrella organisation estimates that between 2018 and 2020 nearly 400,000 service robots will be used worldwide in the professional and almost 43 million service robots in the end consumer sector and that sales in these sectors will total around EUR 23 billion and around EUR 16 billion, respectively, during the same period. [1] IFR expects growth rates to reach the double-digit percentage range in the coming years.

With a total market of around EUR 7 billion in 2017, the professional sector (B2B) accounts for 62 percent (sales of approx. EUR 4.4 billio, around 80,000 units sold), whilst the end consumer market (B2C) accounts for 38 percent (approx. EUR 2.6 billion, approx. 8.6 million units sold). Although the number of units sold in the end consumer sector is a hundred times higher, total sales are significantly lower compared to the professional sector.

A look at market estimates for service robotics in the entire professional (civilian[2]) sector (including the manufacturing industry) reveals three areas of application that promise significantly higher market potential than the rest (see Fig. 1). The highest sales in 2017 were recorded in medicine (diagnostics, surgery, therapy and rehabilitation) coming in at just under EUR 1.6 billion. Robotic surgery is dominant in this area (approx. 70 percent of all units sold belong to this category). Field robotics[3] and logistics are characterised by similarly high market shares (approx. EUR 1 billion in 2017), with significantly stronger growth being predicted for logistics in the years to come. Milking robots (approx. 83 percent of all units sold in this segment) and, in logistics applications, driverless transport vehicles (DTVs) for non-production activities (also approx. 83 percent of all units sold in this segment), were clearly the drivers of sales in field robotics in 2017. Together, the three specific robot types (surgical robots, milking robots, DTVs) account for around 50 percent of all units sold for professional applications in 2017.

1 IFR: World Robotics 2017 – Service Robots, 2017.
2 In the defence sector, sales of just under 640 million EUR were recorded in 2017. Sales of just under 3 billion EUR are forecast for the period from 2015 to 2018 (see footnote 1). However, it should be noted that the publicly available figures for defence expenditure are not necessarily representative.
3 Besides agriculture, field robotics applications also exist in deep sea, space, outdoor inspection, forestry and mining. Field robots are used for surface and underground operations in natural, unstructured and expansive outdoor areas.

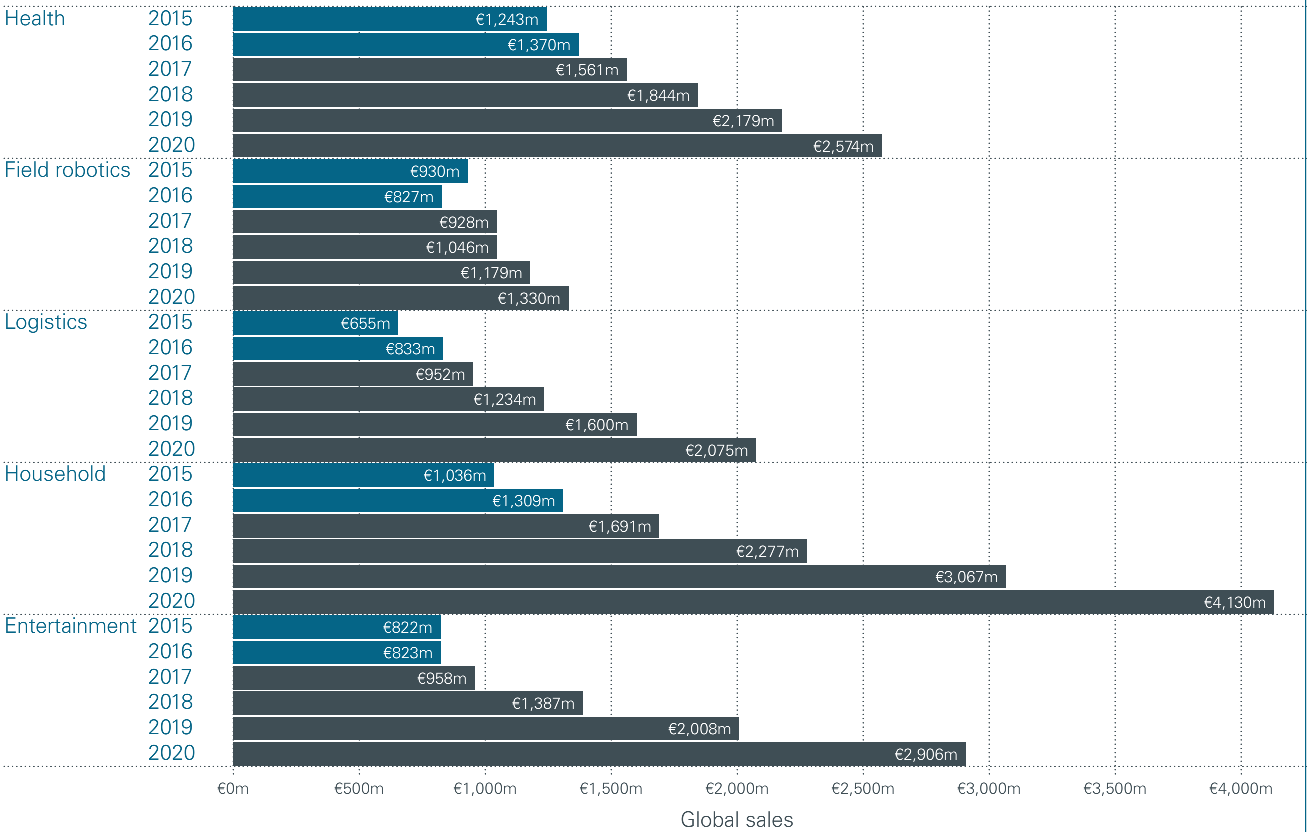


Fig. 1: Market potential in the five top-selling segments of service robotics. The figures for 2017 are preliminary estimates. Sales figures for the years from 2018 to 2020 are based on interpolation of estimated total sales for the three years assuming a constant annual growth rate in each segment (diagram by the authors, data from IFR[1])

The analyses of the market for the service robots currently available often disregard the aspect of manufacturing in production. At present, it is not possible to make a reliable quantitative assessment of the market potential for robots as production assistants (sometimes also called 'co-bots'). Especially for human-robot collaboration, and more specifically, when using robot arms in assembly or component production, reliable sales figures are practically non-existent since most applications are still in their pilot phase or in very early productive use. Initial estimates assume global sales of just under EUR 150 million in 2016 and forecast growth to reach EUR 3.6 billion in 2023, corresponding to annual growth rates of over 50 percent.[4] A quick return on investment is crucial for the introduction of co-bots. Meanwhile, competition is intensifying with the number of suppliers growing and prices falling at the same time. Current systems prices vary strongly between EUR 3,000 (Dobot, China), EUR 10,000 (Franka, Germany), EUR 28,000 (Sawyer, US), EUR 33,000 (UR10, Denmark), EUR 56,000 (ABB, Switzerland) and EUR 90,000 (Kuka, Germany).

Two types of robots dominate the end-consumer market: household and entertainment. The household segment (2017: sales of approx. EUR 1.4 billion, approx. 6 million units sold) is strongly dominated by robot vacuum cleaners (96 percent of all units sold), whilst the enter-

4 www.marketsandmarkets.com/Market-Reports/collaborative-robot-market-194541294.html (retrieved 12 December 2017).

tainment segment (2017: sales of approx. EUR 960 million, approx. 2.5 million units sold) is dominated by toy robots (91 percent of all units sold). This means that toy robots and robot vacuum cleaners account for around 95 percent of the total end consumer market.

2.2 Start-up environment

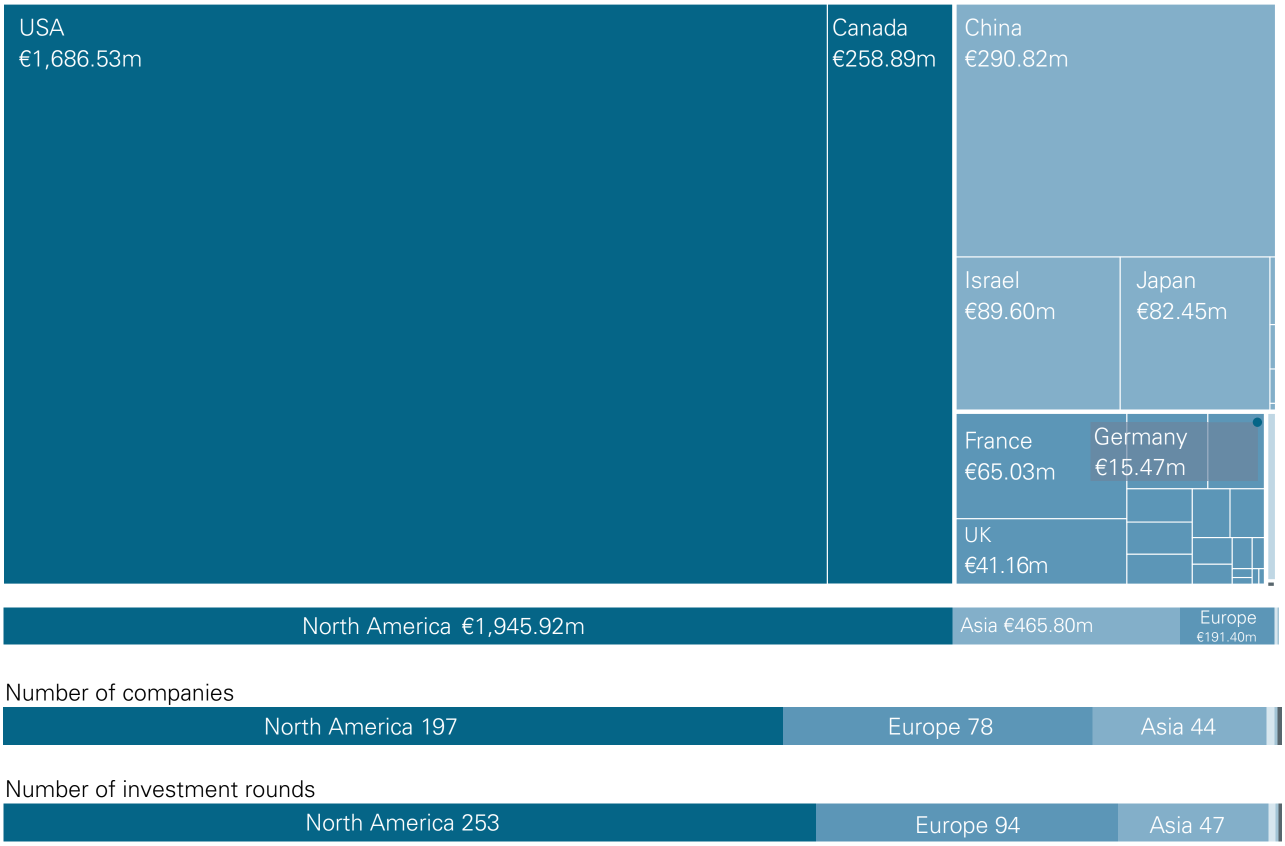


Fig. 2: Investments in robotics start-ups in 2016 (diagram by the authors, data from www.crunchbase.com)

Very strong regional differences exist with regard to investments in start-ups in 2016 (see Fig. 2)[5]. Compared to Europe, investment sums in Asia were just under two and a half times higher, and ten times higher in the Americas. Country-specific differences are even more pronounced. Officially reported investment sums were more than a hundred times higher in the US and almost twenty times higher in China. Similar to engineering (see section 4), this situation can also be seen with regard to robotics where the level of individual investments in China (average of approx. EUR 24 million per round; number of cases: 12) is significantly higher than in the US (approx. EUR 10 million per round, number of cases: 172) or in Germany (approx. EUR 1.7 million per round, number of cases: 9), despite many significant upward trends, especially in the US (see Fig. 3).[6]

5 This and the following analyses are based on the www.crunchbase.com database, here taking into account all entries assigned to the 'robotics"' category.

6 However, due to the very small number of cases of investment rounds with known financing conditions, this interpretation should be generally regarded with caution.

Land	Start-up	Anwendungsbereich	Investment (2016)
USA	Zoox	Transport (autonomous driving)	€215,595,250
	Velodyne LiDAR	Transport, logistics, sensors	€129,357,150
	Zymergen	Healthcare, biotechnology	€112,109,530
	Quanergy Systems	Transport, logistics, sensors	€77,614,290
	Carbon	Mechanical engineering, manufacturing	€69,852,861
	Anki	Entertainment	€45,275,003
	Roboteam	Field robotics	€43,119,050
	Auris Surgical Robotics	Health	€42,285,703
China	ROOBO	Household, entertainment	€86,238,100
	Ubtech	Entertainment	€86,238,100
	Rokid	Household, entertainment	€43,119,050
	Zero Zero Robotics	Entertainment, drones	€19,834,763
	Flypro Aerospace Technology	Entertainment, drones	€19,834,763
	Simtoo	Entertainment, drones	€9,359,856
	A. I. Nemo	Household, entertainment	€8,623,810
	Rockrobo	Household	€7,399,229
DE	Rewalk Robotics	Health	€10,348,572
	Kinematics	Entertainment	€2,500,000
	ReActive Robotics	Health	€1,293,572

Fig. 3: The largest financing rounds in the US, China and Germany in 2016 (diagram by the authors, data from www.crunchbase.com)

In all regions, investment activities focus on the five areas that offer the greatest market potential, i.e. field robotics, logistics, healthcare, household and entertainment (see section 2.1). One exception is the Asian region (especially China) with its particularly strong focus on the end-consumer market (entertainment, household). In conjunction with comparatively high investments and (still) low production costs, the Asian market can be expected to have a strong competitive edge in this segment, making it very difficult for other competitors to catch up.

In the US, strikingly large sums were invested in autonomous driving, robotics in the biotech sector, logistics, entertainment and field robotics in 2016 (see Fig. 3). These are the most important market segments in service robotics (see section 2.1) with the exception of the household sector (where US manufacturer iRobot dominates the robot vacuum cleaner market and invested heavily in the years prior to 2016).

Even if investments in start-ups in Germany are significantly lower, there are numerous start-ups in the professional sectors, including some with heavy investments (see Fig. 3), but the end consumer market is only addressed by very few start-ups (such as Kinematics TinkerBots or Babybe).

2.3 State of the art

The technical developments in service robotics depend very much on the different fields of application:

Healthcare

In addition to surgical robots, service robots can be used in all areas of medicine (diagnosis, treatment, rehab, care and support, medical training) and to assist people with disabilities or impaired health. Significant progress has been achieved in the control of diagnostic equipment, especially in radiology and biopsy. Exoskeletons especially have also reached a high level of technical maturity in rehab with first prototypes already in use. In addition, first telecommunications systems are also available for treatment and care, treatment and rehab support, emotional therapy (for instance, for autism), visual aids, semi-autonomous wheelchairs and assistance for persons with disabilities (household, personal hygiene, mobility).

The current challenges lie in the precise control of robots and their adaptability to the specific characteristics of patients. Data protection concerns and a lack of acceptance are preventing the rapid spread of telemedicine.

Field robotics

Besides milking robots as the dominant application, field robotics covers a very wide range and includes the robots in natural, unstructured, expansive outdoor areas, for surface and underground operations, in the deep sea and even in space. The most important applications can be found in agriculture, livestock, inspection, forestry, mining and space missions.

First robot prototypes are already in use in order to achieve optimum sowing results, for irrigation and harvesting with autonomous vehicles, quality control through air monitoring, automatic feeding of livestock, smart fencing for optimum pasture grazing, semi-autonomous cutting or planting of trees, automatic and regular mapping of areas using drones, blasting and subsequent stabilisation operations in mining, exploring and observing the deep sea or space as well as maintenance work.

Many challenges will have to be mastered in the coming years if we are to make use of the full potential of field robotics. Autonomous agricultural machines for field work call for advanced sensor data processing and consistent interconnection. Harvesting robots must be perfected to a level where the need for residual manual harvesting work will be reduced to a minimum. The use of robots is largely seasonal, especially in agriculture. This means long unproductive downtimes that may render the systems unprofitable. In forestry, further autonomisation is currently not possible because complex environmental conditions require complex navigation, something that remains a major challenge with the technology currently available.

Logistics

The greatest progress in recent years has been achieved in logistics. Especially in warehouses where the use of DTVs is now widespread and has gained a strong foothold on the market. The first robots have been used outside warehouses, for instance, at ports, airports, post centres, hospitals and offices. The testing of first autonomous courier systems in public spaces is already underway.

Outside warehouses, autonomous logistics systems very often share work areas with human operators. Ensuring safety in human-robot interaction whilst at the same time maintaining a high level efficiency is a major challenge –the current standard behaviour of robots is still very slow navigation or even at a complete standstill. What's more, logistics robots generally still require relatively flat and even surfaces and find it extremely difficult to handle obstacles (stairs, etc.), so their use in the near future will focus primarily on areas without barriers, such as warehouses, supermarkets or hospitals.

Household

The robot vacuum cleaner dominates the household segment. In addition, other applications for robots are being tested in households, for instance, as home help and assistants in everyday life (especially as help for the elderly and for persons with disabilities), for additional cleaning work (floor and window cleaning, lawn mowing, pool cleaning) or surveillance (house, children, elderly/persons with disabilities, pets). These are currently still prototypes or niche products.

One of the central challenges is the fact that private households are rarely barrier-free (doors, stairs, door thresholds) and many areas of application cannot yet be opened up technologically. It should also be remembered that cleaning robots need more time and produce inferior results than manual cleaning. Robots therefore have to be used more frequently and manual rework is still necessary. Moreover, liability issues are becoming increasingly relevant, for instance, in the case of window cleaning (potentially dangerous for people in outdoor areas when robots fall down). Autonomous navigation and 'acting' in complex, frequently changing environments, such as a typical household, is still difficult for robots. Until now, communication and interaction with humans was too technically orientated and often not sufficiently intuitive. However, recent and very promising voice system developments give hope for a very high application potential in the short term.

Entertainment

Apart from the obvious and currently dominant use of robots as toys, there are other areas of application that were occupied up to now by niche products or prototypes. Simple robots with only a few degrees of freedom of movement can serve as interfaces with the cloud for leisure activities, entertainment and private education in conjunction with multimedia services. Unlike tablets and similar mobile devices, they can be used as physical information and multimedia tools with at least one autonomous degree of freedom of movement, both at home and at educational institutions and other public buildings. Robots are also suitable for private education, for example, for learning languages or programming skills.

One characteristic element of the end consumer market in the entertainment segment is its price sensitivity. More complex products with correspondingly high prices are therefore seldom accepted for private use. It is as yet not foreseeable to what extent correspondingly simplified systems would still be able to adequately handle the above-mentioned applications without overburdening end consumers who do not have the required capabilities.

2.4 R&D developments

Robotics initiatives are currently being launched and supported in all regions of the world (see Table 1).

Table 1: Selected international initiatives directly related to robotics (compilation by the authors)

Region	Programme/initiative	Term	Support volume (in EUR)
China	Made in China 2025	Since 2016	2,7bn
Japan	New Robot Strategy Robot Revolution Initiative	Since 2014	26m
South Korea	KIRIA – Korea Institute for Robot Industry Advancement	Since 2010	34m p. a.
South Korea	Second Basic Plan for Intelligent Robot Development	2014-2018	2,2bn
UK	RAS 2020 – Robotics and Autonomous Systems	Since 2014	217m
USA	NRI-2.0 National Robotics Initiative 2.0: Ubiquitous Collaborative Robots	2017-2021	25–38m p. a.
EU	Smart Robots for Smart Regions	Since 2017	500m
EU	IoF2020: Internet of Food and Farm 2020	Since 2017	30m
EU	SPARC	2014-2020	700m
EU	I4MS – ICT Innovation for Manufacturing SMEs	Since 2013	110m

At a European level, the European Commission has earmarked the largest budget for robotics projects to date. The most extensive programme is the public-private partnership SPARC. With total funding of EUR 700 million and a planned additional industry contribution of EUR 2.1 billion for the period from 2014 to 2020, it claims to be the largest civil robotics programme world-wide.

SPARC is committed to strengthening the European robotics industry and the use of European robots in factories, on land, in the air and under water, in agriculture, in the healthcare sector as well as many other areas with an economic and social impact. As a public-private partnership between the European Commission, European industry and academia, SPARC aims to foster growth and to strengthen the robotics industry and the value chain from research to manufacturing.

In 2017 alone, 17 robotics projects were launched as part of the EU's Horizon 2020 research programme (see Table 2). The projects serve all important market segments either directly or via their planned use cases (see section 2.1). In the professional sector, the logistics and health segments where strong growth is forecast receive particularly strong support. As expected, the consumer sector is clearly underrepresented since only areas of high public interest can be generally considered for funding. German partners are involved in approximately 80 percent of all projects, most of them with more than one partner.

The focus of the robotics-oriented PAiCE projects (see project presentations in the following sections 2.8 to 2.6) is the creation of platforms for service robotics solutions in the different relevant application areas. The rationale for these efforts is that the development of a mass market, essentially requires significant reductions in acquisition and integration costs and a stronger orientation of (smart) capabilities towards user demand.[7] Simplified reuse of software components can especially lead to cost savings for system integration, i.e. in the area

7 BMWi: PAiCE – Digitale Technologien für die Wirtschaft. Platforms | Additive Manufacturing | Imaging | Communication | Engineering. Funding programme for digital innovations in industrial value creation processes, 2017 (Förderprogramm für digitale Innovationen in industriellen Wertschöpfungsprozessen, 2017).

Table 2: Robotics projects launched in 2017 and funded under the Horizon 2020 programme as well as the application areas addressed by these projects (diagram by the authors, data from www.cordis.europa.eu)

	Field robotics	Logistics	Health	Household	Entertainment	Other	Partners from D
An.Dy Advancing Anticipatory Behaviors in Dyadic Human-Robot Collaboration			■			Production	3
Badger: RoBot for Autonomous unDerGround trenchless opERations, mapping and navigation	■						1
Co4Robots: Achieving Complex Collaborative Missions via Decentralized Control and Coordination of Interacting Robots		■	■	■		Production	1
CYBERLEGs Plus Plus: The CYBERnetic LowEr-Limb CoGnitive Ortho-prosthesis Plus Plus			■				0
Dreams4Cars: Dream-like simulation abilities for automated cars		■					2
HEPHAESTUS: Highly automatEd PHysical Achievements and PerformancES using cable roboTs Unique Systems	■					Construction industry	2
ILIAD: Intra-Logistics with Integrated Automatic Deployment: safe and scalable fleets in shared spaces		■					2
IMAGINE: Robots Understanding Their Actions by Imagining Their Effects						Recycling	3
MoveCare: Multiple-actOrs Virtual Empathic CARgiver for the Elder			■	■			0
MULTIDRONE: MULTIple DRONE platform for media production	■					Film industry	1
REELER: Responsible Ethical Learning with Robotics						ELSI	1
REFILLS: Robotics Enabling Fully-Integrated Logistics Lines for Supermarkets		■					3
RobMoSys: Composable Models and Software for Robotics Systems		■	■	■	■	Production, robotics platforms	4
ROSIN: ROS-Industrial quality-assured robot software components		■				Production, robotics platforms	2
ROPOD: Ultra-flat, ultra-flexible, cost-effective robotic pods for handling legacy in logistics		■					3
SMARTsurg: SMart weArable Robotic Teleoperated Surgery			■				0
VERSATILE: Innovative robotic applications for highly reconfigurable production lines – VERSATILE						Production	0

that today still accounts for the largest share of investments in service robotics solutions in the professional sector. Service robotics platforms that enable a stronger division of tasks in the development of service robots will open up potential for faster and more cost-effective implementation of innovative ideas on the basis of existing and reusable solutions as well as available standard components and service offerings. In PAiCE, three projects (RoboPORT, ROBOTOP and SeRoNet) in particular focus on these approaches. In this context, two of the above-mentioned EU projects deserve special mention: ROSIN and RobMoSys.

The RobMoSys[8] project, launched on 1 January 2017, aims to ensure the integration of the different robotic components by using model-driven methods and tools and by applying them to existing technologies, and to improve existing tools for further use. In this context, the consortium chiefly uses the SmartSoft[9] open source framework which is developed by Ulm University of Applied Sciences. Fifty percent of the total funding of EUR 8 million for the RobMoSys project will be made available through open calls within the framework of competitions in the robotics community so that the planned ecosystem can be expanded with concrete application examples from different domains.[10]

The ROSIN[11] project, which was also launched at the beginning of 2017, aims to improve the availability and quality of software components for robotics. The project mainly focuses on the further development of the existing ROS Robot Operating System and its ROS-Industrial[12] pin-off which specialises in factory automation. In analogy to the RobMoSys project, more than EUR 3 million (approx. 50 percent of the total support sum) will also be provided in ROSIN for so-called focused technical projects of the robotics community in order to develop specific service robotics applications based on ROS-Industrial.[13]

A key prerequisite when it comes to developing an efficient and readily accessible service robotics offering is agreement among the different initiatives regarding standardised modules. This specifically applies to the machine-interpretable description of functional and non-functional properties of hardware and software components, interoperability of the different components and integration of different interfaces and communication protocols. Standardisation is the only way to enable the efficient development of new modules and the reuse of existing ones. Within the framework of PAiCE, the individual projects are involved in an ongoing coordination process. Individual project partners from the PAiCE projects are also an integral part of the two above-mentioned central EU projects, i.e. RobMoSys and ROSIN.

8 www.robmosys.eu/ (retrieved 20 December 2017).
9 www.servicerobotik-ulm.de/drupal/?q=node/19 (retrieved 20 December 2017).
10 www.robmosys.eu/open-calls/ (retrieved 20 December 2017).
11 www.rosin-project.eu/ (retrieved 20 December /2017).
12 www.rosindustrial.org/ (retrieved 20 December /2017).
13 www.rosin-project.eu/ftps (retrieved 20 December /2017).

2.5 Projects of the Robotics cluster

The progress of the BakeR, QBIIK, RoboPORT, ROBOTOP and SeRoNet projects since the beginning of the PAiCE technology programme is presented on the following pages.

BakeR

Modular system for cost-efficient, modular cleaning robots

Brief description

The overall aim of the BakeR project is to develop a universal service robot that can be adapted to individual work processes using reusable software and hardware modules. Within the scope of the project, a mobile robot platform is to be developed that will be equipped with various modules for automated cleaning. The resultant robot prototype, which is capable of selecting and picking the modules required for the specific location and cleaning process, is to be tested in an office cleaning application.

www.baker-projekt.de

Current developments from the project

The planned application scenario of the mobile cleaning robot was developed in detail in cooperation with experts from the cleaning industry. The scenario is as follows: The cleaning personnel start the robot in the evening and they only perform activities that the robot is unable to perform (such as cleaning office furniture surfaces, window sills, etc.). The robot works during the night and cleans the floors (vacuuming in order to remove any dirt found in offices, wet cleaning of all hallway surfaces, etc.) as well as emptying waste paper baskets into appropriate collection containers. In the morning, personnel only have to empty the collecting containers, the vacuum cleaner bag and the waste water tank of the robot and top up cleaning fluid.

The hardware concept was designed from the very beginning to be as modular as possible. A first integrated overall concept was developed for the robot (see Fig. 4). In order to enable practical tests of the individual components of the cleaning robot as early as possible, the first simple test platform of a mobile robot was set up at the beginning of 2017. The integration of the i-Mop wet cleaning system from Kenter into the mobile platform enabled initial testing of cleaning performance. This led to changes in the position and control of the cleaning brushes and to an increase in contact pressure. The design of the plug connection for power and data transmission between the modules was found to be good.

Next, a revised version of the integrated wet cleaning robot was set up and will be used in first practical tests in the spring of 2018 after further optimisation. This model already includes the option of replacing the currently installed wet cleaning module with another module suitable for dry cleaning, for example. The dry cleaning module is based on a commercially available battery vacuum cleaner which is originally designed to be carried on the cleaning worker's back and which was adapted here for integration into the robot. Furthermore, an actuator system was developed that makes it possible to swivel the brush head of the vacuum cleaner forwards and backwards, so that even poorly accessible areas, such as the floor under tables, can be easily cleaned. Another key element of the modular robot hardware is the robot arm that was initially designed as a separate system. It is to be used to open doors, move obstacles, such as chairs, and to empty waste paper baskets. The actuator system chosen includes a linear axis and an articulated arm with four degrees of freedom as well as a gripper that was specifically developed for the chosen field of application.

The custom-developed control software enables segmentation of floor plans into individual rooms. This is a prerequisite for calculating the optimum cleaning sequence and for generating systematic cleaning patterns for the inspection or surface cleaning of individual rooms. Established navigation methods were adapted to the new robot hardware and the planned movement patterns. A simple state machine for wet cleaning was implemented as a basis for first practical tests. Both software development and hardware focus on a modular overall structure. The different software components, for example, for navigation, dirt detection or object manipulation, as well as their interaction and interfaces are being developed with a view to enable a consistent plug-and-play functionality.

Fig. 4: Illustration of the BakeR cleaning robot (source: BakeR)

Consortium

Fraunhofer Institute for Manufacturing Engineering and Automation IPA (consortium leader), Dussmann Service Deutschland GmbH, KENTER Bodenreinigungsmaschinen Vertriebs und Service GmbH, MetraLabs GmbH Neue Technologien und Systeme, AMTEC Robotics Consult (subcontractor)

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QBIIK

Autonomous, learning logistics robot with gripper system and human-machine interface

Brief description

The QBIIK project combines the advantages of autonomous technologies with human capabilities. The aim is to develop an autonomous picking system capable of learning in the form of a decentralised vehicle with a gripping robot. The vehicle orientates itself in space, navigates autonomously to its destination and reaches for the required items. Remote-controlled support from humans via a virtual reality user interface can be requested via a man/machine interface.

www.qbiik.de

Current developments from the project

In the QBIIK funded project, the overall demonstrator was designed in 2017. As a result, a vehicle can be presented which is generally capable of acting autonomously and of using mobile shelves for transport. The so-called rack trolleys are used, for instance, in the logistics centres of consortium partner Audi. A practical application is the supply of a supermarket. The vehicle can transport the trolleys autonomously to the right place in the supermarket. Once the trolley has arrived there, the robot gripper can remove trays from the rack trolley and the turntable can deposit the trays on the flow rack.

Bär Automation GmbH was in charge of the design phase which so far addressed the modules of the robot console, the turntable, the laser scanner, the battery module, the coupling and the robot gripper. The draft design of the demonstrator is shown in Fig. 5.

In order ensure safe operation of the entire demonstrator, Still GmbH carried out a risk analysis as part of the research project. 116 hazards were identified and suitable preventive measures were defined and documented. For example, a virtual 'safety fence' prevents the relatively fast moving vehicle, and the robot, from colliding with workers or objects. The sensors on the demonstrator scan the environment and can thus determine the safety buffer.

The integration of the sensors into the gripper was planned at the Karlsruhe Institute of Technology (KIT). These are mainly a stereo camera and tactile proximity sensors based on capacitive operating principles. The proximity sensors can detect the position and distance of nearby objects and even report contact events to the controller including spatial information. Furthermore, object recognition, control interfaces and remote control of the robot using virtual reality techniques have already been tested with the real robot.

The remote control system of the robot is also to be integrated into a smaller demonstrator that will be based on a Panda robot from manufacturer Franka Emika. The demonstrator will illustrate the control of the robot using remote control, visual feedback via the stereo camera system and tactile feedback via the tactile proximity sensors. It will be exhibited both at automatica (19 to 22 June 2018) and at the KIT Innovation Day (27 June 2018).

Fig. 5: Illustration of the QBIIK robot with rack trolleys (source: QBIIK)

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RoboPORT

Crowd engineering in robotics: Web platform for idea and prototype development

Brief description

The RoboPORT project is developing a platform on which community members can jointly develop and implement components for service robotics applications. This community approach is already widely used in software development has the potential to reform the development of robotics hardware too. The platform provides many collaborative developer tools, a library for open-source robotic as well as knowledge and project management tools.

www.roboport.eu

Current developments from the project

As part of the RoboPORT project, open innovation software has already been set up within the project and is used to discuss the requirements of the future development platform with potential users. In a parallel effort, processes and workflows of existing open innovation platforms are being analysed and examined with a view to their suitability for supporting the distributed development process.

Current activities focus on the development of concrete concepts for essential platform functionalities: Which tools can be used to map which development steps and workflows in order to enable a consistent and distributed development process? To this end, mock-ups of the platform are created early on and potential users are involved as early adopters in the development of the concept and the implementation of the platform right from the start.

Several pilot use cases for RoboPORT are currently being defined in more detail and their requirements for agile and distributed development processes are being analysed by a community for service robots. The pilot use cases for RoboPORT cover several areas of service robotics, from household service robotics (Mykie from BSH) to mobile platforms (Rob@Work3 from Fraunhofer Institute for Manufacturing Engineering and Automation IPA) right through to humanoid robot systems (Roboy from TU München).

The RoboPORT platform is to become the starting point for new robotics developments in service robotics and will interconnect many previously independent stakeholders and users to form a community. For this reason, the consortium began early to build a community and, in order to support this effort, created two annual event formats that will already enter their second round in 2018. Under the motto 'Co-Creation, crowd engineering and distributed development for companies', the following challenges and opportunities, which are of particular interest to smaller companies, were discussed in initial discussions with companies: How can external resources be integrated into one's own product development and how can open development processes be both coordinated and used in a sensible manner? With its platform in the field of service robotics, RoboPORT already offers solutions in development and advises companies on site.

On 28 and 29 November 2018, the Smart City Robotics Makeathon will take place at the 'Morgenstadt' workshop. All robot enthusiasts and developers are invited to jointly design innovative robotic applications using open-innovation methods and to produce prototypes using 3D printing processes (see Fig. 6).

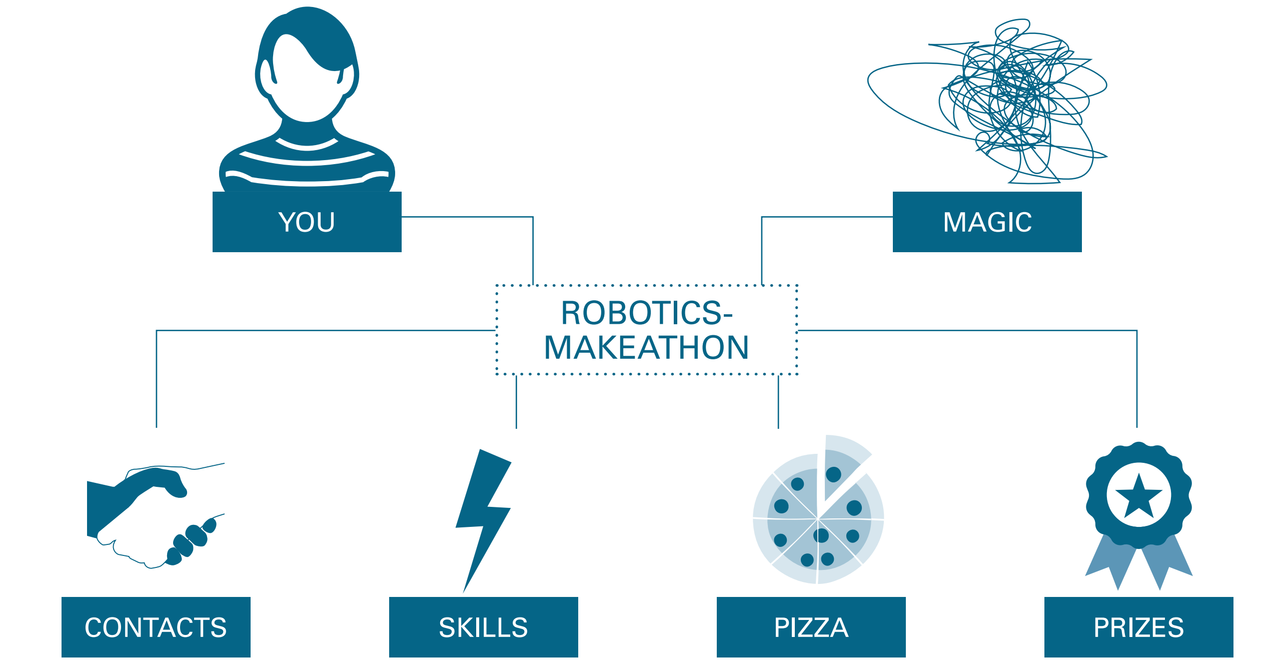

Fig. 6: Robotics Makeathon as part of the RoboPORT project (source: RoboPORT)

Consortium

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ROBOTOP

Open platform for robot applications in industry and service

Brief description

The ROBOTOP project is developing an open platform to open up the mass market for robots in service, logistics and manufacturing applications. The platform enables intelligent combinations of standardised and reusable hardware and peripheral components to create customised service robotics solutions. Before real installation, the solutions can be tested for suitability using 3D simulation. This approach enables significant savings in quotation and engineering development costs as well as in planning and design costs for industrial robotic solutions.

www.robotop-konfigurator.de

Current developments from the project

As part of the ROBOTOP project, flexible robot solutions based on a modular concept with a modular system are being developed and implemented in real production operations. In a first step, sub-processes were classified and a tool for the standardised recording of use cases and the associated requirements was implemented. Furthermore, work is currently underway to break down the sub-processes according to functions with links to solutions from the current production environment (best practice). The core objective is to develop a database-based, function-orientated architecture for a robotics kit with a focus on the flexible integration of robotics applications with minimal engineering effort.

Several real processes were systematically analysed for the design of automation solutions. On this basis, it was already possible to identify a first set of relevant information (such as the work space required for the systems used, possible cycle time, necessary intermediate operations), so that a uniform description of the solutions will be subsequently possible. A draft concept for a systematic execution of the individual work steps and for the generation of automation solutions was additionally created. This will be supplemented by developing a structured questionnaire that can be used to determine automation options for largely manual production environments at a reasonable cost. For the future evaluation of this questionnaire, first best practices implemented by industry where employees interact with lightweight robots were already surveyed.

A user-friendly configurator is essential for the success of the platform (see Fig. 7). An extensive system architecture facilitates the handling of interdisciplinary complexity, helps to structure processes, creates transparency and enables isolation of different system aspects. A microservice for creating and editing virtual components ensures integration of the individual components and will be used to create first components (smart components) and to test the exchange with other services of the platform. In the area of OsIRIS online simulation, first technologies for simulation in the network have been identified. A first step involved porting the Java Cactoos library to C# and provision as an open source project.[14]

14 www.github.com/icarus-consulting/Yaapii.Atoms (retrieved 20 December 2017)

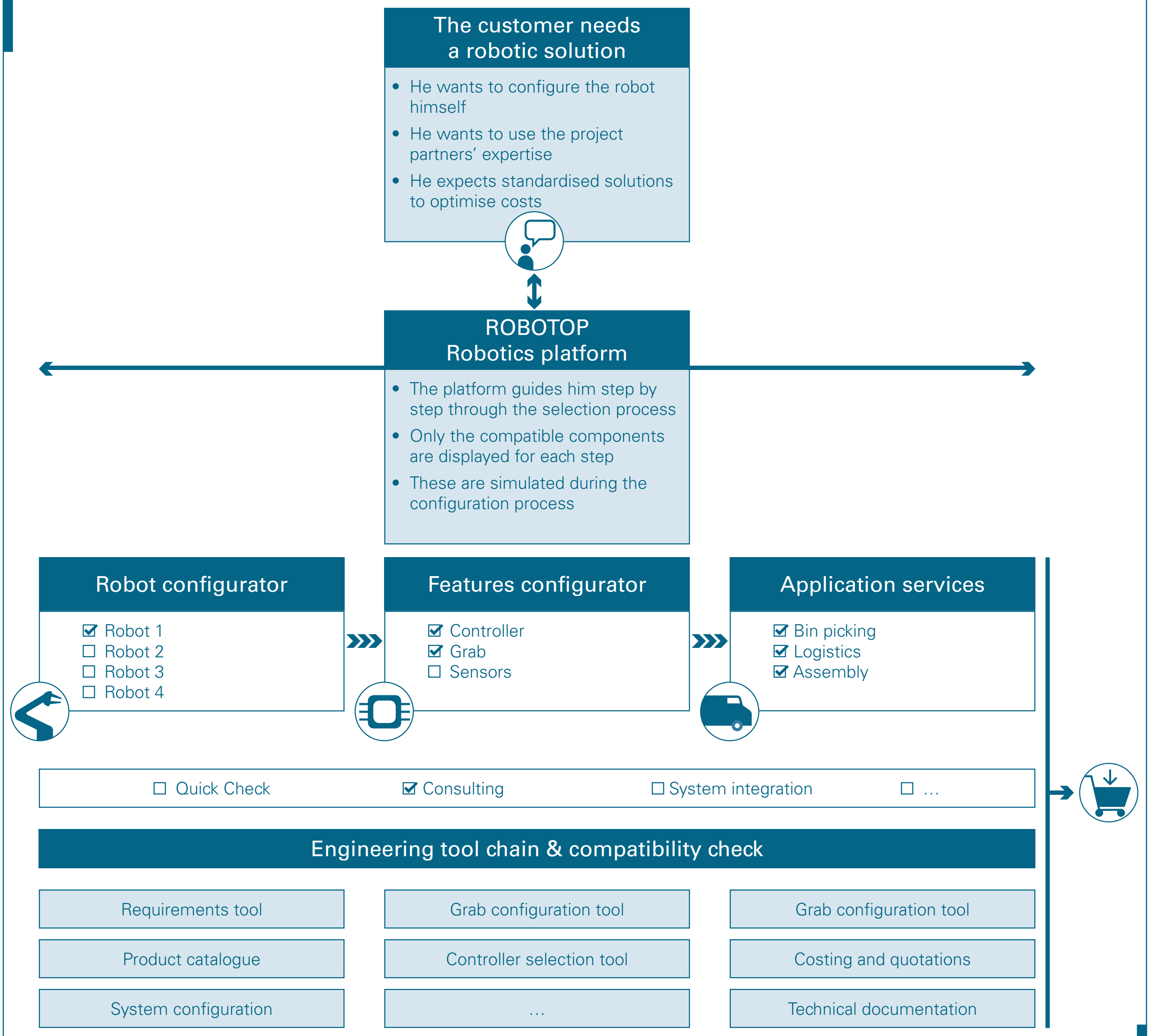

Fig. 7: Schematic overview of the ROBOTOP configurator (source: www.robotop-konfigurator.de)

Consortium

ICARUS Consulting GmbH (consortium leader), Friedrich-Alexander-Universität Erlangen-Nürnberg, Infosim GmbH & Co. KG, Karlsruhe Institute of Technology (KIT), Robert Bosch GmbH, Ruhr-Universität Bochum – Chair of Production Systems, SCHUNK GmbH & Co. KG, TU Dortmund University – Institute for Production Systems

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SeRoNet

Platform for the development of service robot solutions

Brief description

The SeRoNet project is developing an open IT platform for users, system service providers as well as robotics and component manufacturers in the field of service robotics. The platform is used by software and hardware manufacturers, service providers and customers to develop solutions for service robot tasks according to their specific requirements. The aim is to significantly reduce the software development effort in professional service robotics through a modular, collaborative and composition-orientated development approach where solutions are assembled from prefabricated modules. System integrators can open up new markets thanks to shorter development cycles, especially at small and medium-sized enterprises (SMEs). At the same time, end users can offer their own software services to other companies via the platform. The technical basis for co-operation between systems isOPC-UA (Open Platform Communications Unified Architecture) with model-driven tools (see Fig. 8).

www.seronet-project.de

Current developments from the project

At the beginning of the SeRoNet project, several pilot demonstrators were defined in more detail and their requirements for modular, model-driven software development for service robot solutions were analysed. SeRoNet covers various areas of professional service robotics, from intralogistics for a pharmaceutical supplier and services for hospital staff right through to support for assembly tasks in the automotive industry. Parallel to this, existing software frameworks for robotics were examined with a view to their strengths and weaknesses as a basis for open, modular and model-driven software development in service robotics. The results are available on the project homepage (www.seronet-project.de).

An essential component of SeRoNet is a model-driven development environment ('toolchain') for modular development of robot solutions (see Fig. 8). The aim is a manufacturer-independent exchange format for software components. This supports both smooth component interaction during operation of the service robot and the systematic, tool-supported selection of suitable and matching components for a given task. Various approaches for the acquisition and automatic representation of the necessary metadata for software (and possibly hardware) components are currently being analysed. It is expected that this will lead to an online platform for the development and sale of software components for service robotics with standardised descriptions by the end of 2018/early 2019. At the same time, a first implementation of the OPC-UA-based runtime and communication infrastructure in SeRoNet is currently underway. A deliberately low entry threshold was chosen for component manufacturers and system integrators to participate in the SeRoNet platform (both as a standardised runtime and development environment and as a marketplace). This is supported by the consistent use of established standards and formats, such as OPC-UA and AutomationML. At the same time, open standards allow extended and systematised component descriptions for tool-supported selection from a component market, their composition to systems and their application-specific configuration.

The essence of a platform is its participants. The SeRoNet project will therefore invite component manufacturers and system integrators in a series of open calls to present themselves and their products and services on the SeRoNet market platform which will go live in late summer 2018. The adaptation of components to the SeRoNet runtime environment as well as pilot projects conducted by integrators and end users having the financial backing and technical support of the SeRoNet project amounting to around one million EUR.

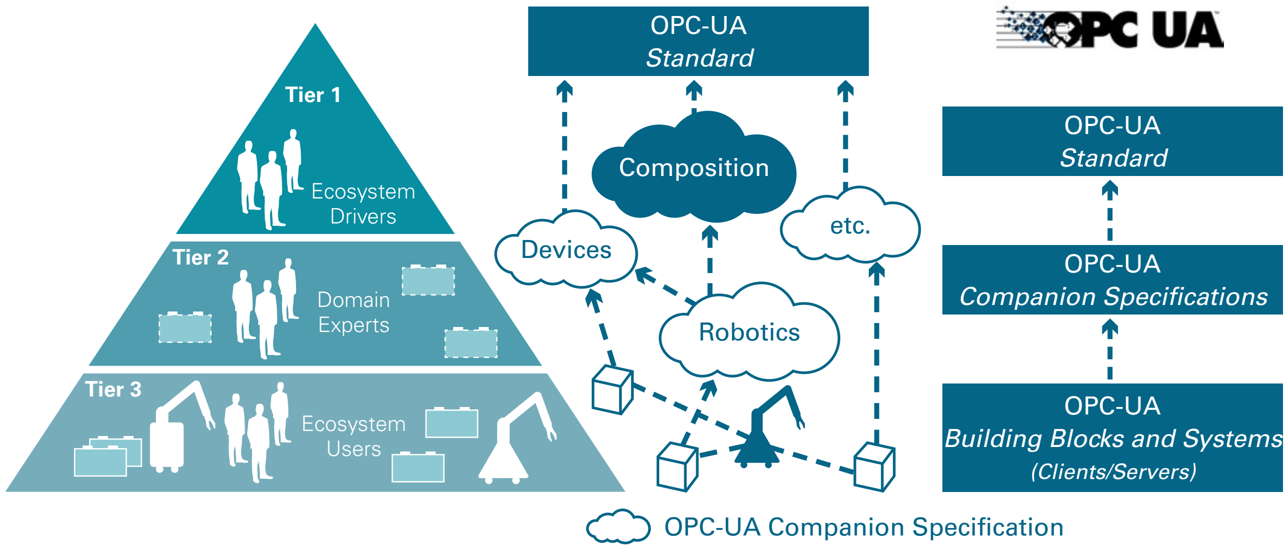

Fig. 8: The SeRoNet ecosystem (source: SeRoNet)

Consortium

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3 3D cluster

Additive manufacturing in production

Additive manufacturing, referred to here as 3D printing, has undergone dynamic development in recent years and is very popular. The maturity of the technology is well advanced in various application areas, so that 3D printing is used in a growing number of industries.[15] 3D printing means greater flexibility in production since this technology enables economies of scale in the production of small batches, shorter time-to-market processes in product development and customisation of products such as implants. 3D printing can also be used to produce complex structures with added functional value that are impossible or too expensive to produce with subtractive or formative processes. Within the PAiCE technology programme, four projects are assigned to the 3D cluster, three of which (Add2Log, DigiKAM, SAMPL) are working on developing platform solutions to interconnect the participating members in 3D printing value creation networks. Each of the three projects provides independent and integrated platform solutions to coordinate business processes between print customers, print service providers and other stakeholders. However, the projects focus on highly specific aspects, including the security solution (SAMPL), special requirements of small and medium-sized enterprises (DigiKAM) and integration of an agile logistics system (Add2Log). The fourth project addresses the field of mobile three-dimensional data acquisition for 3D printing of spare parts and for component identification (M3D).

3.1 Market analysis

The rapid development in 3D printing is leading to a rapidly growing market for goods and services, bringing with it a large number of new suppliers (machines and services) and users. Global sales in 2016 totalled EUR 5.2 billion and thus almost tripled in the four years since 2012. Sales generated with products, including machines, system upgrades, materials, software, lasers, etc., accounted for EUR 2.3 billion in 2016, including EUR 1.5 billion from the sale of 3D printers and their system upgrades alone. However, the largest share of EUR 2.9 billion in 2016 was generated by 3D printing service providers offering printing and consulting services, seminars, training and contract research, etc. With a view to the market shares (MS) of individual companies, a few players that dominate the market are particularly prominent: 3D printer manufacturers include Stratasys Ltd (MS of 29 percent; 2015), 3D Systems Corporation (MS of 28 percent; 2015) and EOS GmbH Electro Optical Systems (MS of 12 percent; 2015); 3D printing service providers Materialise NV (MS of 55 percent; 2015), Proto Labs Inc. (MS of 13 percent; 2015) and Citim GmbH (MS of 5 percent; 2015).

There has been a steep increase in global annual sales of industrial and desktop 3D printers since 2012 (see Fig. 9). Between 2012 and 2016, sales of desktop 3D printers rose rapidly (see Fig. 10). During the same period in which the number of industrial 3D printers sold almost doubled, the number of desktop 3D printers increased more than eleven-fold.[16]

With sales of industrial 3D printers[17] almost tripling, Germany is far ahead of the global average (see Fig. 11). This is partly due to the special role of German 3D printer manufacturers and German companies as early users of

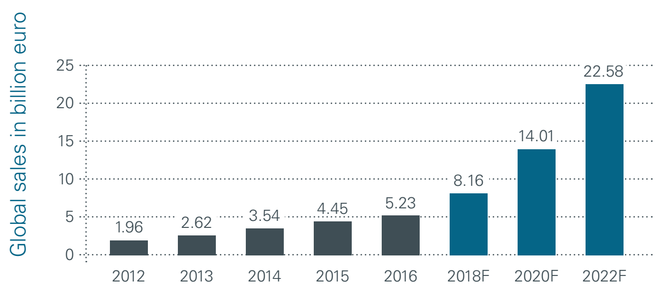

Fig. 9: Global sales through the sale of products and services in the area of additive manufacturing (diagram by the authors, data from Wohlers 2017[16])

15 Stephan Richter and Steffen Wischmann: Additive Fertigungsmethoden. Entwicklungsstand, Marktperspektiven für den industriellen Einsatz und IKT-spezifische Herausforderungen bei Forschung und Entwicklung, 2016.
16 Terry Wohlers: Wohlers Report 2017: 3D Printing and Additive Manufacturing State of the Industry, Annual Worldwide Progress Report, 2017.
17 Andreas Müller and Stefana Karevska: How will 3D printing make your company the strongest link in the value chain? EY's Global 3D printing Report 2016, 2016.

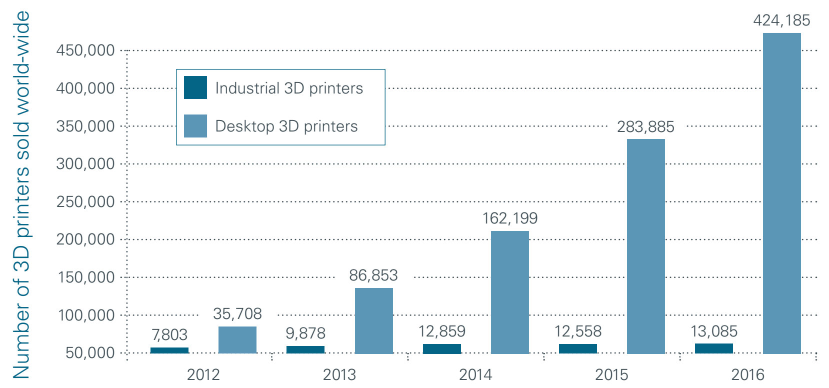

Fig. 10: Global sales of industrial and desktop 3D printers (own diagram, data from Wohlers 2017[16]).

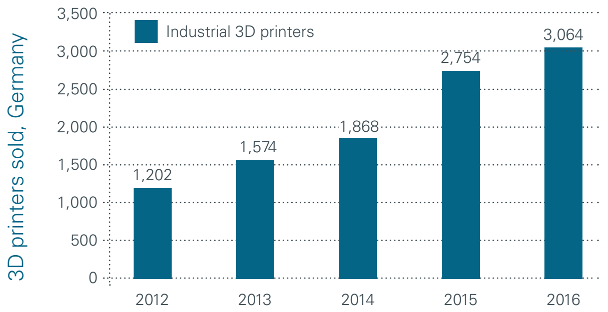

Fig. 11: Sales of industrial and desktop 3D printers by German companies (own diagram, data from Wohlers 2017[16]).

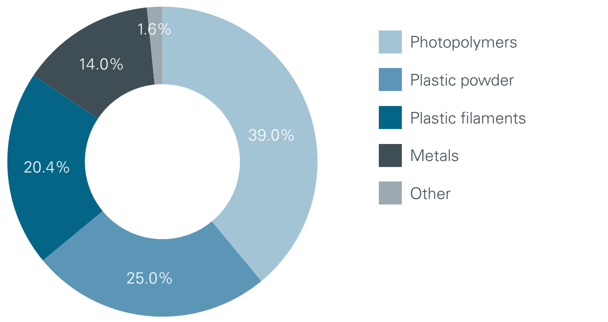

Fig. 12: Global sales of materials for 3D printing (own diagram, data from Wohlers 2017[16])

3D printing technologies. According to Ernst & Young's 'Global 3D printing report'[18], German companies are currently leaders in terms of application experience, ahead of China, South Korea, the US, the UK and other EU countries. This is also reflected in Germany's share of global sales which accounted for around one tenth in 2016.[19]

The distribution of global sales of materials for 3D printing (see Fig. 12) shows the most commonly used 3D printing processes:

- In photopolymerisation processes, liquid light-curing resins (photopolymers) are generally crosslinked by UV radiation on a substrate platform, either point by point or in layers, so that the polymer solidifies. The UV source is usually a laser. This principle is used, for instance, by stereolithography,— a widely used method.
- In powder-based processes, a thin layer of powder, usually metal or plastic powder, is applied to a work surface and melted by a laser into a defined contour which then subsequently solidifies. A new layer of powder is then applied and the process repeated. Typical examples of these processes are selective laser sintering and selective laser melting.
- In extrusion-based processes, thermoplastics or plastic filaments are made malleable by a heated nozzle and deposited in a geometrically defined manner. Fused deposition modelling is a common example of such a process.

The highest global sales in 2016 were generated with the sale of photopolymers (39.0 percent), followed by plastic powder (25.0 percent), plastic filaments (20.4 percent) and metal (14.0 percent) (see Fig. 12). Further details of the different 3D printing processes can be found in the technical literature[20].

18 ibidem
19 ibidem
20 Andreas Gebhardt: Generative Fertigungsverfahren. Additive Manufacturing und 3D-Drucken für Prototyping, Tooling, Produktion, 2013.

3.2 Start-up environment

It is still early days for the 3D printing industry, which has the potential to revolutionise industrial production processes and paths. Open technological issues and the existence of yet to be developed niche markets are fertile breeding ground for the emergence of start-ups which are being closely watched by industrial and financial investors and, when necessary, supported by corresponding investments.

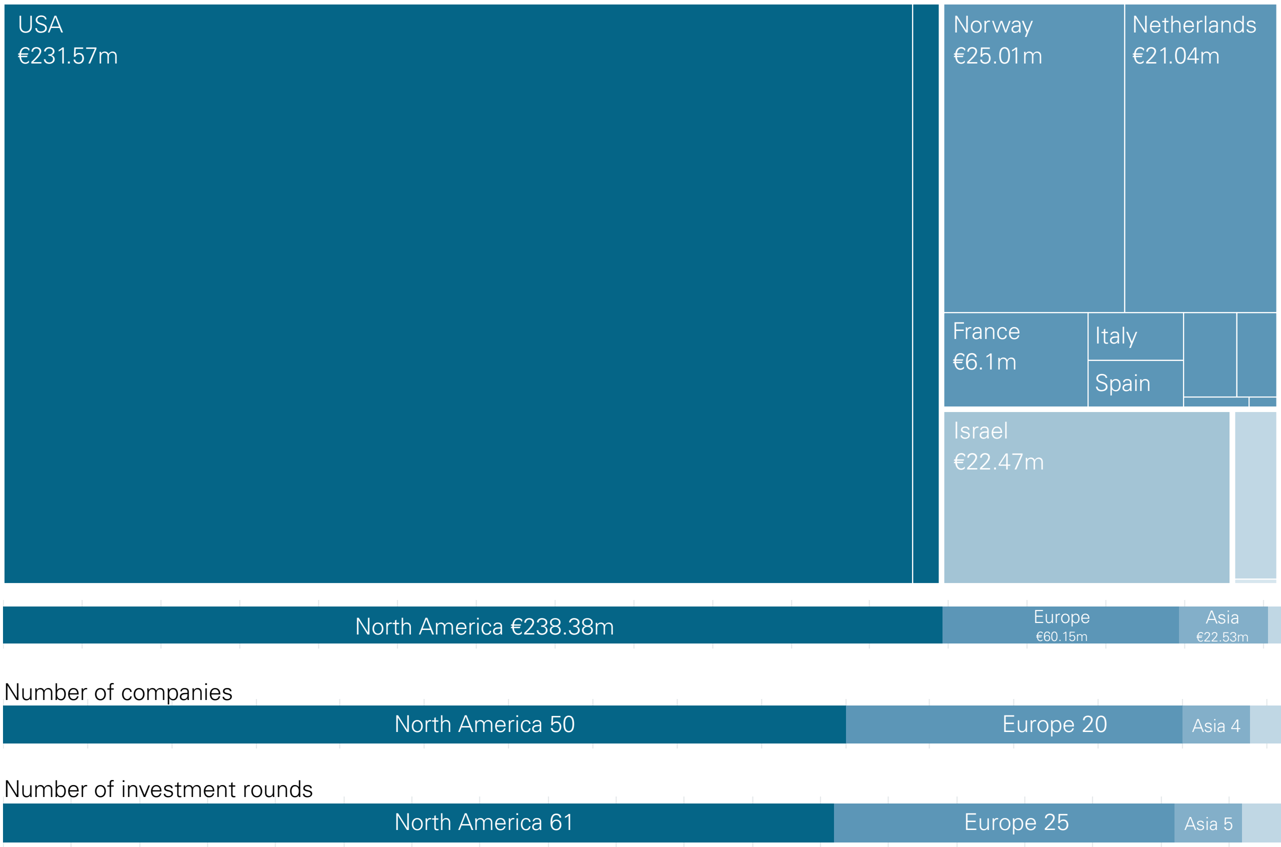

Fig. 13: Investments in start-ups for 3D printing in 2016 (diagram by the authors, data from www.crunchbase.com)

To analyse global investments in start-ups and the related regional differences, investments and venture capital investments from previous financial years were compiled.[21] Fig. 13 shows the results for 2016. Concrete investment sums are known for around 75 percent of investments and venture capital investments in 2016 (called 'investment rounds' in Fig. 13). The large share of US start-ups, which accounted for 71.3 percent of global investments in 2016, is obvious.

US start-ups, which expanded their portfolio of industrial stakeholders through strategic partnerships, benefited particularly from investments in 2016. BMW, General Electric and Nikon, for example, invested EUR 69.9 million in the Californian start-up Carbon3D Inc. which launched the first 3D printer with a new printing process in 2016. This process has similarities to stereolithography, but can achieve a particularly high printing speed. In 2016, a

21 For the purposes of this analysis, the database www.crunchbase.com was used, taking into account all entries in the 'additive manufacturing' and '3d printing' categories.

consortium around Stratasys Ltd. invested heavily (EUR 29.1 million) in the start-up company Desktop Metal Inc. which manufactures 3D printers for metal components. The Israeli start-up company XJet Ltd, which also focuses on 3D metal printing, received investments (EUR 21.6 million) in 2016 from an Israeli-Chinese private equity company and American software manufacturer Autodesk. According to the Crunchbase analysis, investors primarily from the financial sector invested higher amounts (more than EUR 7 million) in European companies. Norsk Titanium AS (Norway) was supported by US financial investors (EUR 21.6 million) and the State of New York (EUR 3.4 million), whilst the start-up Ultimaker B.V. (Netherlands) received funds from the European Investment Bank (EUR 15 million).

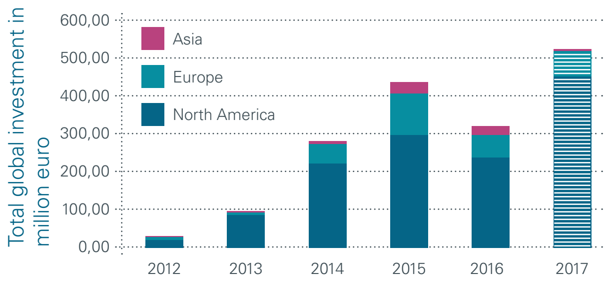

Fig. 14: Global investment volume 2012-2016, Jan. 2017-Nov. 2017 (diagram by the authors, data from www.crunchbase.com)

As Fig. 14 shows, the share of investments in North American start-ups remained persistently high by international standards throughout the last five years. Since global annual investment exceeded the 100 million euro mark for the first time in 2014, 68 to 78 percent of total global investments went to North American start-ups, with US sources accounting for by far the largest share of these investments. In contrast, the share of investments in European start-ups over the same period totalled 18 to 25 percent and in Asian start-ups 2 to 7 percent, whilst investments in corresponding start-ups in other regions of the world were only marginal. According to the data available, investments in German start-ups (2014: EUR 2.6 million; 2015: EUR 7.9 million; 2016: unknown) remained at a relatively low level. In 2016, no investment sum was published for any of the three investment rounds. However, there are signs that investment in German start-ups will be significantly higher in 2017 compared to 2015. An analysis of absolute global investments in the years from 2012 to 2016 (see Fig. 14) shows a consolidation trend.[22] Nonetheless, preliminary figures for 2017 suggest a further strengthening of global investments in start-ups in the 3D printing sector. The main reason for this being that investments in North American start-ups, mainly US companies, will almost double in 2017 compared to 2016.

It should be mentioned that the majority of investments in Asian start-ups is currently flowing to Israel (EUR 22.6 million in 2016, see Fig. 13) and that Japan, India and China as the major Asian economies, are underrepresented throughout the entire period from 2012 to 2016 shown in Fig. 13. While investments in Japanese and Indian start-ups saw at least a temporary increase to EUR 10.7 million in 2015, investments in Chinese start-ups were as low as EUR 2 million in the period from 2012 to 2015. According to the Crunchbase database, it is remarkable that no investments were made in Japanese, Indian or Chinese start-ups in 2016. Irrespective of this, China in particular has clearly set its technological focus on 3D printing. A national plan for the development and promotion of the 3D printing industry for 2015 and 2016, for instance, earmarked a budget of EUR 211.2 million to support the development of 3D printers for industrial production and the establishment of the corresponding industrial parks.[23] The aim of these investments was to establish two to three internationally competitive Chinese companies by 2016.[24]

22 In a similar form, this was also observed and/or predicted by Müller and Karevska: How will 3D printing make your company the strongest link in the value chain? (See footnote 17).
23 Richter and Wischmann: Additive Fertigungsmethoden, 2016 (see footnote 15).
24 Müller and Karevska: How will 3D printing make your company the strongest link in the value chain?, 2016 (see footnote 17).

3.3 State of the art

Even though 3D printing is already used in many industrial sectors, the current state of the art is still unable to keep up with conventional production processes. Within the framework of the 'Additive Manufacturing' statement by the National Academy of Science and Engineering (acatech, Deutsche Akademie der Technikwissenschaften e. V.), the German National Academy of Sciences Leopoldina (Deutsche Akademie der Naturforscher Leopoldina e. V.), and the Union of the German Academies of Sciences and Humanities (Union der deutschen Akademien der Wissenschaften (Akademieunion)), a success factor portfolio for the technology field of additive manufacturing was developed in a collaborative project involving 84 members from academia and industry.[25] The study concludes that the availability of machines and materials suitable to create reproducible printing results is still a challenge. 'Printable' (certified) materials, in particular, are still available to a limited extent only, and printed components which were produced on the basis of identical printing parameters have sometimes different component properties or geometries. Another 'critical success factor' for the implementation of 3D printing at companies in the near future, is the need to boost machine productivity and to make 3D printing part of existing production processes. At the same time, methods for quality assurance as well as standards and norms must be developed. Furthermore, one should not forget the challenges posed by occupational safety and health, sustainability as well as resource efficiency in the further development of tomorrow's 3D printing technology.

3D printing technologies are already used extensively in a wide variety of industries, such as the plastics and chemical industries, mechanical and plant engineering, the automotive and aviation industries, as well as the pharmaceutical and medical technology sectors (see Fig. 15). Companies currently rely primarily on in-house solutions for 3D printing, but this will change in the future. In an international study, 41 percent of the companies surveyed stated that they were planning to purchase 3D printed products from service providers in the future, and only 26 percent stated that they were planning to use or purchase their own 3D printers.[26] In terms of infrastructure aspects, this also means that platform-based communication between companies and 3D printing service providers – including secure, reliable data transfers – will have an increasingly significant role to play.

Companies currently use 3D printing processes primarily in the fields of prototyping, tooling, manufacture and repair. In rapid prototyping applications, 3D printing processes are used for the rapid production of partly functional prototypes and sample components, in rapid tooling for tool and mould making, for instance, for the just-in-time production of complex tools for plastic injection moulding, in rapid manufacturing for the flexible, fast production of components, (small) series and spare parts, and in rapid repairing for component repair, for instance, for gas turbines. Only a few companies are currently active in this latter field of application.

The specific application areas of 3D printing at companies are shown in Fig. 16. Some of these can be assigned to several application fields. It is obvious that companies currently use 3D printing primarily to produce functional prototypes and components, but also to produce tools, templates and moulds and to print models.

25 acatech (National Academy of Science and Engineering (Deutsche Akademie der Technikwissenschaften e. V.), Leopoldina (Deutsche Akademie der Naturforscher Leopoldina e. V.), Akademienunion (Union of the German Academies of Sciences and Humanities (Union der deutschen Akademien der Wissenschaften e. V.)): Additive Fertigung, 2017.

26 Müller and Karevska: How will 3D printing make your company the strongest link in the value chain?, 2016 (see footnote 17).

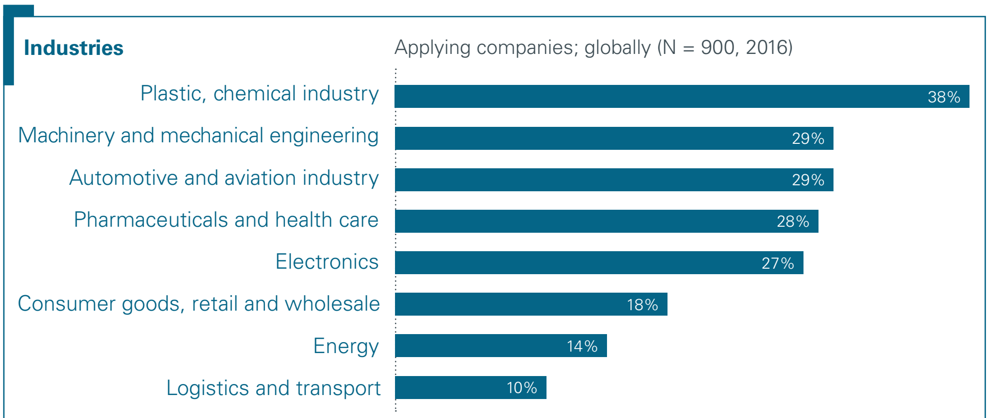

Fig. 15: Industries where 3D printing is already in use; global (own diagram, data from Müller/Karevska 2016[17])

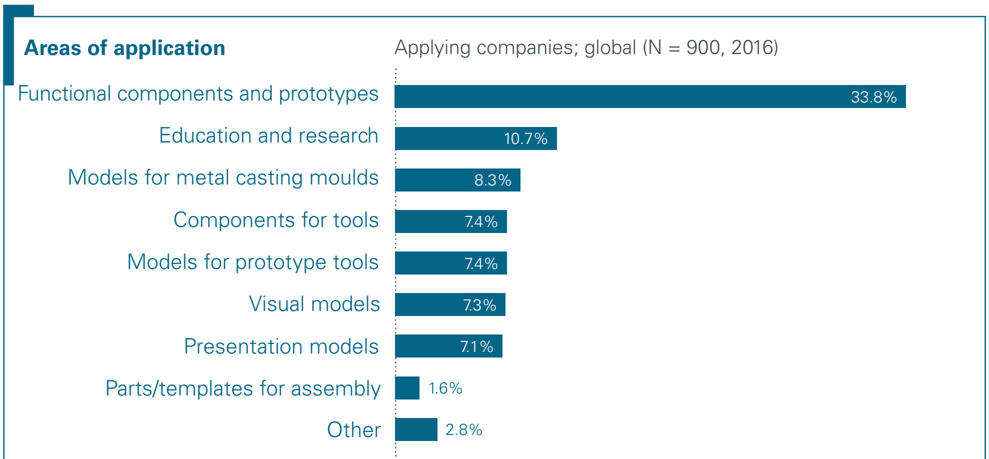

Fig. 16: Applications where companies use 3D printing; global (own diagram, data from Müller and Karevska 2016[17])

3.4 R&D developments

In order to map the current scientific discourse, publication data from the Web of Science database was analysed. With around 50,000 books, 12,000 journals and 160,000 conference proceedings from the fields of natural sciences, humanities and social sciences, this database contains a host of English-language scientific publications and is updated and expanded daily. The multitude of metadata collected there allows publications to be assigned to both regions and thematic categories.[27]

Between 2012 and 2017, the international output of scientific articles on additive manufacturing[27] increased from one year to the next (see Fig. 17). This also applies to Germany and is an indication of the intensive expansion of research activities. Scientists working in Germany are among those who publish most – followed by their colleagues in the US, China and the UK (see Fig. 18). Fig. 19 summarises the most relevant thematic categories for publications in Germany between 2012 and 2017. Publication activities clearly focus on the field of material sciences, but are also strong in medical technologies (including biomaterials). Another

27 The analysis covered publications from 2012 to 2017 with hits for the search terms '3d print*' or 'additive manufac*' (database query on 16 November 2017).

focus is on engineering, with the further development of optical technologies also playing an important role.

Additive manufacturing processes are supported in Germany primarily in the context of specific application areas and within the framework of institutional and project funding by the federal government. Current funding measures by the Federal Ministry of Education and Research (BMBF) include the 'Additive-Generative Manufacturing' project – 3D Revolution for Product Manufacturing in the Digital Age (term until 2020; total budget: approx. EUR 45 million) which is funded within the framework of the twenty20 regional funding programme, and the funding measure 'Additive Manufacturing - Individualised Products, Complex Mass Products, Innovative Materials – ProMat_3D' funding measure (Term until 2022; total budget: approx. EUR 40 million) which is part of the federal government's new high-tech strategy. The objectives of the support measures are in particular:

- Development of additive-generative production to a key technology
- Development of sustainable network structures
- Measurable increase in export demand and positioning Germany as a leading supplier
- Development of innovative methods and tools for product development and manufacture
- Development of new or improved materials for 3D printing

Besides funding measures specifically designed to develop new 3D printing technologies and materials, projects related to 3D printing are also supported within the framework of other technology programmes, for instance, in PAiCE. The overarching goal of all 3D printing projects funded here is to achieve the best-possible integration of 3D printing technologies into digital value chains in Industry 4.0. The benefits expected from digitalisation in the context of Industry 4.0 include better possibilities for planning and managing production and logistics, greater customer satisfaction thanks to the integration of user data, greater flexibility in production, faster time-to-market in product development, better quality and the possibility of customising products.

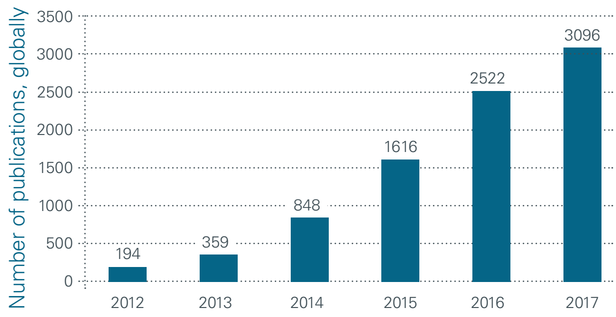

Fig. 17: Number of scientific publications in the Web of Science between 2012 and 2017 (source: Web of Science – search words '3d print*' or 'additive manufac*', database query on 16 November 2017)

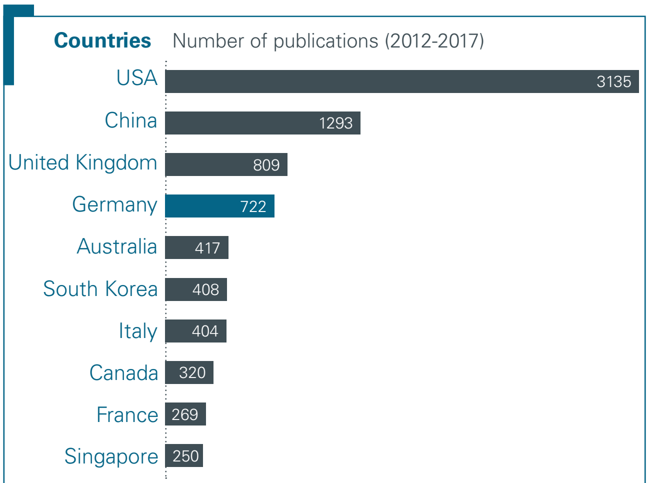

Fig. 18: Countries with the highest number of publications between 2012 and 2017 (source: Web of Science – search words '3d print*' or 'additive manufac*', database query on 16 November 2017)

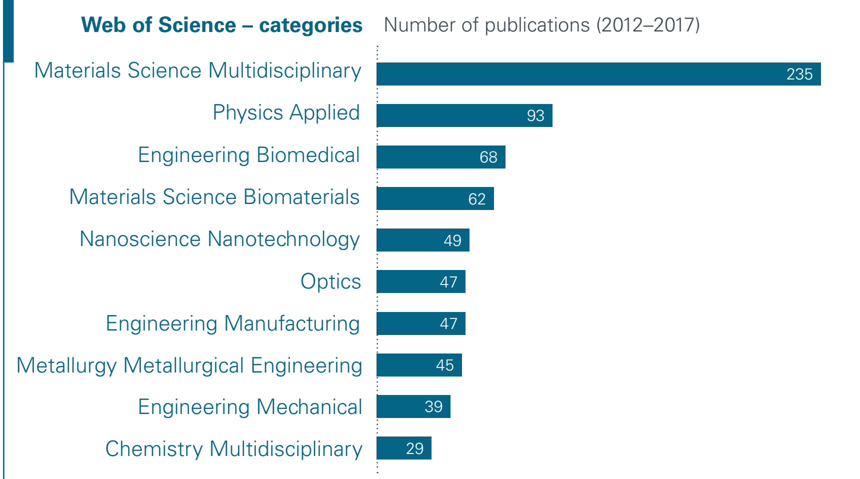

Fig. 19: Web of Science – categories in which most publications took place between 2012 and 2017 (source: Web of Science – search words '3d print*' or 'additive manufac*', database query on 16 November 2017)

3.5 Projects of the 3D cluster

The progress achieved in the Add2Log, DigiKAM, M3D and SAMPL projects since the PAiCE technology programme was launched is presented on the following pages.

Add2Log

Decentralised production based on additive manufacturing and agile logistics

Brief description

The Add2Log project aims to develop a software-based platform to interconnect companies so that the advantages of decentralised additive manufacturing of new and spare parts can be combined with an agile logistics system. The Add2Log platform performs central coordination functions for a newly created value network between manufacturers, logisticians and third parties.

www.projekt-add2log.de

Current developments from the project

During the course of digitalisation, value chains are being transformed to value creation networks where manufacturers, industrial service providers and software providers co-operate on digital platforms. Co-operation not only changes processes; even entire organisational structures have to be flexibly adapted to current circumstances. The division of tasks between manufacturers, suppliers and service providers and the underlying business models are undergoing radical change. In addition, new processes, such as additive manufacturing, are increasingly used as fully fledged substitutes for conventional manufacturing processes.

The Add2Log project aims to develop a cross-company, software-based platform that will be implemented as a prototype for an interface between manufacturers, logisticians and third parties. The Add2Log platform will form a central coordination structure that interconnects all stakeholders and serves as a basis for companies to access additive production facilities and options of third parties and to have new and spare parts manufactured by distributed manufacturers. The advantages of this include shorter delivery times, greater efficiency and the ability to respond faster to customer requirements.

After kicking off in May 2017, the ecosystem of (additive) manufacturing (AM) and logistics was analysed. The overarching processes for ordering, manufacturing and transporting new and spare parts were included by setting up a service blueprinting concept. First overarching processes for the manufacture of AM parts in one pass were also developed at the same time. The result was a description of the market structures of the common ecosystem of additive manufacturing and logistics and the associated impacts of digitalisation.

In the next step, a common target picture of the Add2Log platform for distributed production was developed with all project partners. The various design options and possible changes were described and evaluated in this context. The future network of manufacturers, logisticians and third parties was transposed into consistent scenarios so that future developments can be predicted at an early stage. The consistent target picture of the Add2Log platform was developed on this basis.

The requirements for implementing the Add2Log platform were then defined on the basis of these two first results, the as-is analysis and the target picture. For this purpose, the as-is analysis was compared with the target picture and requirements were laid down in the form of a specification sheet.

Parallel to this, work began on the experimental identification of the advantages and disadvantages of data editing and on processing scan vectors and curves directly from native CAD format in comparison to the previously used STL route with SLM. Furthermore, the experimental identification of equipment-independent, reproducible component properties (surface roughness, dimensional and shape accuracy) of additively manufactured test specimens as a function of process parameters (laser power, laser beam diameter and layer thickness) began in an experiment with a selected material.

The as-is analysis of the ecosystem is currently used as a basis for developing a reference process for additive manufacturing of new and spare parts along the entire value chain. To this end, the processes of the different stakeholders along the entire value chain are recorded in detail and combined to form a reference process. Furthermore, the concept and the detailed version of the use cases will be set up and used to test the Add2Log platform. The use cases will serve to demonstrate in industrial practice that the Add2Log platform is suitable for practical use and that it has considerable potential for ordering processes for both spare and new parts.

In 2018, the business models of various platforms will be analysed and the defined requirements transferred into a platform concept, and the prototypical implementation of the Add2Log platform will begin.

Consortium

Software AG (consortium leader), RWTH Aachen – FIR e. V., Fraunhofer Institute for Laser Technology ILT, Materialise GmbH, DMG Mori Spare Parts GmbH, Top Mehrwert Logistik GmbH

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Dirk Mayer, Software AG
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DigiKAM

Digital network for additive manufacturing

Brief description

DigiKAM aims to set up a digital network that enables additive manufacturing throughout the entire value process. A scalable platform will help to interconnect companies across all industries throughout the entire transparent and securely designed production process. The network is primarily designed for small and medium-sized enterprises (SMEs) which are unable to generate the necessary know-how for additive manufacturing in-house due to their limited resources.

www.iem.fraunhofer.de/de/forschung/forschungsprojekte/digitales-kollaborationsnetzwerk-zur-erschliessung-von-additive-manufacturing.html

Current developments from the project

Application scenarios: In the interest of quick integration into the joint project, the AM (Additive Manufacturing) technology was presented to the application partners and its potential benefits for them were demonstrated. The partners then agreed on possible application scenarios for the collaboration platform. The application scenarios describe, from a user-specific perspective, how an AM collaboration platform can be used and the potential components the application partners believe to be suitable example candidates for AM-compatible development on the collaboration platform. The requirements for the platform and the supporting 3D technologies were identified on this basis.

AM development process: Based on the application scenarios, the overarching overall development process for AM-compliant collaboration between the application partners was defined for the platform. The development process first describes how experts and user companies come together via the platform. After signing the contract for a joint development project, two parallel development processes are then executed. From the expert's perspective, this is the reference process that describes the perfect target process. From the user company's perspective, this is typically the company-specific development process (see Fig. 20). The development process as such focuses on the early phases of product development right through to the AM-compliant printable component.

Synchronisation points: Several synchronisation points were identified for the necessary exchange of information between the development partners involved. At these points, the necessary data and formats for exchanging information were determined in order to be agreed upon by the partners who define the interdependent timelines for the parallel development processes executed on both sides. Some of these synchronisation points form the basis for development milestones in the emergence process.

3D technologies: The supporting 3D technologies are also used at the synchronisation points. These can initially be used for data provision (3D scanning). Subsequently, they form the basis for augmented reality design reviews where the user critically evaluates development proposals for an AM-compliant, redesigned component of the expert using a mobile augmented reality application and where the user provides feedback to improve the AM design.

Public relations activities: As part of public relations work, contributions to four events are planned for 2018 (HMI 2018, Metav 2018, Inside 3D Printing 2018 and ViProSim 2018).

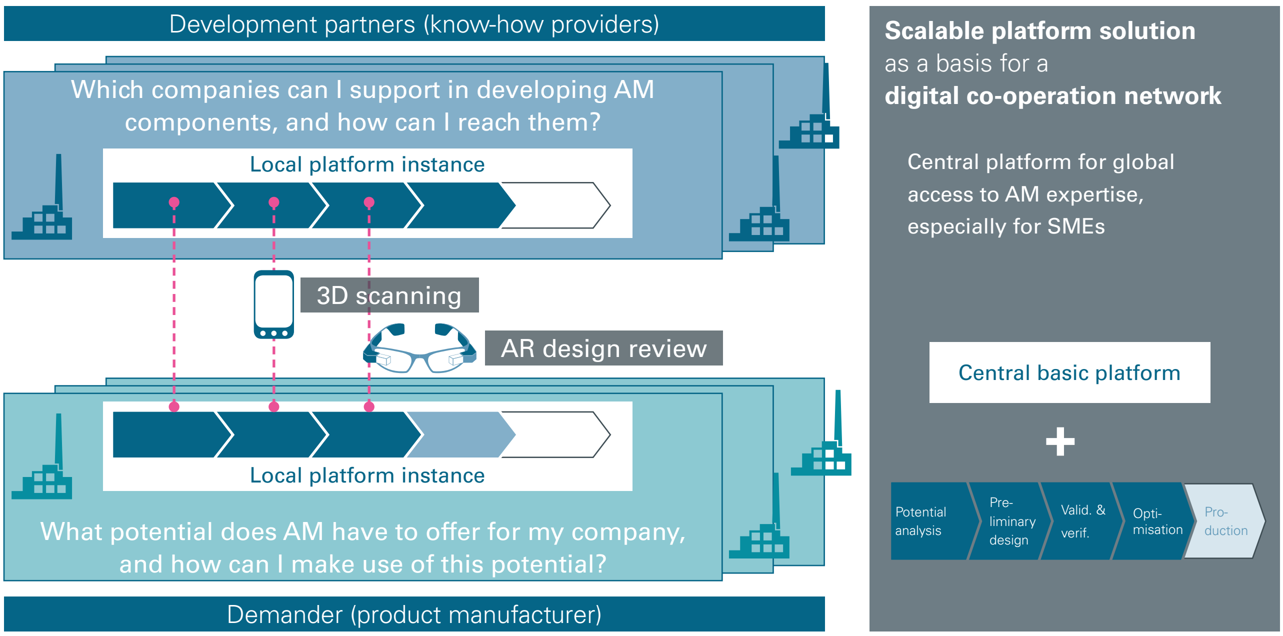

Fig. 20: AM collaboration platform with parallel development processes and synchronisation points for information exchange supported by 3D technologies (source: DigiKAM)

Consortium

Fraunhofer Institute for Mechatronic Systems Design IEM (consortium leader), Atos Information Technology GmbH, Krause DiMaTec GmbH, Miele & Cie. KG, Friedrich Remmert GmbH

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M3D

Mobile 3D data acquisition for on-site 3D printing

Brief description

Progress in three-dimensional data acquisition and 3D printing offers enormous potential for savings in the logistics and storage of components and spare parts. Logistics costs are reduced by individual on-site manufacture, which is particularly advantageous for small batches or for supplying spare parts. With M3D, components are scanned using mobile devices so that the ordering process can be started immediately, automatically and directly. This avoids production downtimes and reduces the costs for the storage of components and spare parts.

www.hhi.fraunhofer.de/en/departments/vit/projects/m3d.html

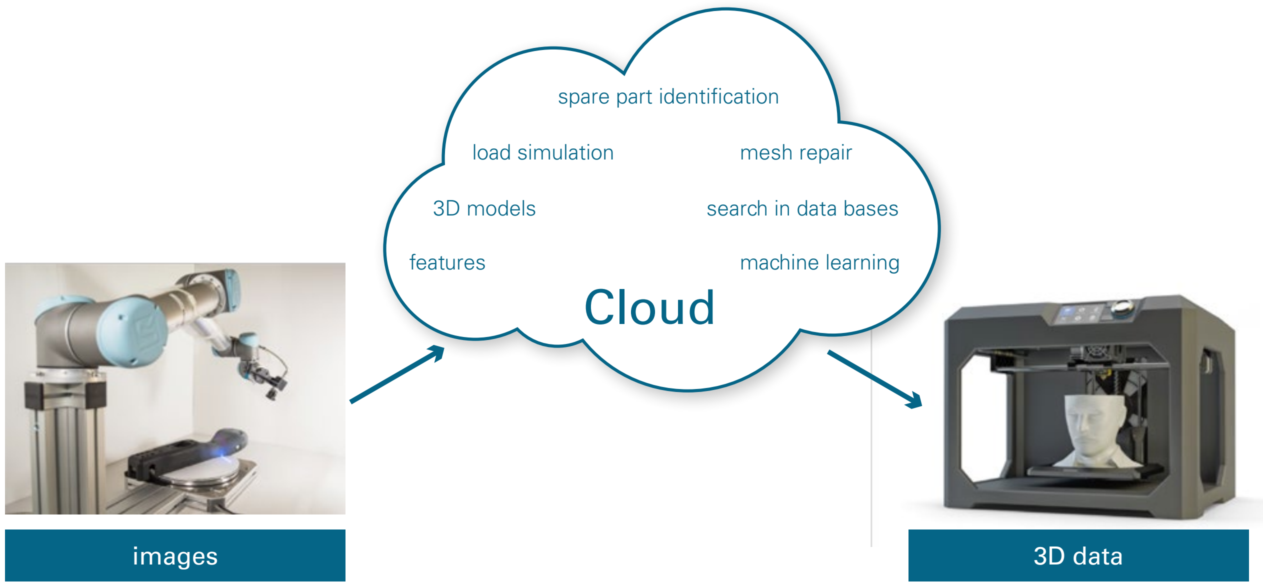

Fig. 21: Schematic representation of the processing steps from data acquisition and identification to 3D printing in the M3D project (source: M3D)

Current developments from the project

The M3D project has three main topics (see Fig. 21):

- Mobile scanning of components for identification and to determine whether they are available from stock or whether they must be manufactured. The search is based on 3D models which are created during the acquisition process, such as from CAD or component databases.
- 3D scan of disassembled components using a (mobile) scanning robot, subsequent 3D modelling of the component, electronic repair of the component, if possible, and simulation of the 3D model with regard to mechanical stress, if necessary
- 3D printing of the component

At the milestone workshop of the M3D project during the 3IT summit[28], a total of three demonstrators were presented to demonstrate the progress of the project:

1. Mobile 3D scanning system based on a robot arm
2. System for simulating mechanical stress of 3D component models
3. System for mobile scanning and 3D modelling of components and for their search in CAD and component databases. A first system for the hardware-based acceleration of computational operations in 3D modelling was also demonstrated for this purpose.

Furthermore, first 3D print results of scanned defective components were presented, including some that were repaired 'electronically' before printing.

Following the implementation of the entire framework of the process chain for component identification, current work is now focusing on optimising recognition rates during component identification. With the procedures implemented to simulate load cases for components as a starting point, further work in this area will focus on providing users with suggestions for modifications that can increase the stability of a component.

Based on first implementations, work is also underway on user guidance and interaction systems during the data acquisition process using mobile camera sensors via Android app and on the further development of algorithms for 3D modelling in an existing cloud infrastructure.

28 www.3it-berlin.de/index.php?option=com_content&view=article&id=582 (retrieved 22 December 2017)

Consortium
Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute HHI (consortium leader), cirp GmbH, cpu 24/7 GmbH, Fraunhofer Institute for Computer Graphics Research IGD, Siemens AG, TU Berlin – Faculty IV Electrical Engineering and Computer Science

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SAMPL

Secure Additive Manufacturing Platform

Brief description

SAMPL is developing a consistent security solution for additive manufacturing processes. The solution protects and secures the entire process, including the generation of 3D print data, the exchange of such data, the licensing of printing processes, the output on specially protected 3D printers and marking the printed components with an RFID chip or other methods in order to enable traceability. All relevant information is mapped using blockchain technology.

www.sampl-3d.org

Current developments from the project

SAMPL is based on PROSTEP's OpenDXM GlobalX data exchange solution which will be upgraded to include digital license management based on blockchain technology in addition to the existing encryption mechanisms (see Fig. 22).

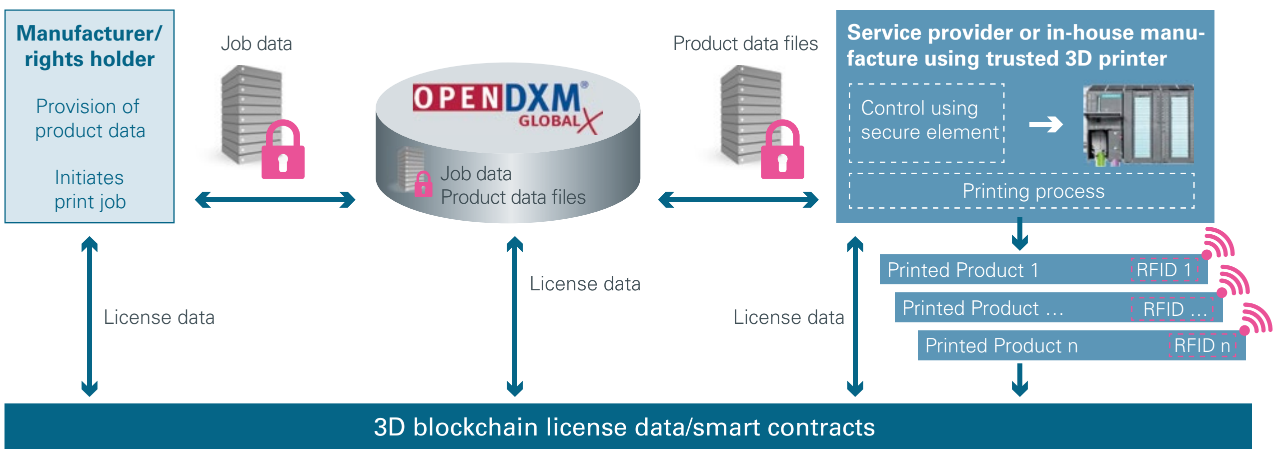

Fig. 22: Schematic presentation of the system architecture in the SAMPL project (source: SAMPL)

Blockchain technology, which is used, for instance, for digital payments in Bitcoin crypto currency, includes procedures to verify the authenticity of transactions. However, it can also be used to issue licenses to print a predefined number of components. The necessary mapping mechanisms in so-called smart contracts are developed within the framework of SAMPL. Consortium partner 'consider it' implements the blockchain technology. NXP Semiconductors provides the secure elements to connect the 3D printers to the blockchain and the RFID-based component identification. EOS subsidiary 3D MicroPrint ensures the completeness of the chain of trust from the owner of the rights to the 3D printer. Hamburg University of Technology is examining risk management while Universität Hamburg is looking at the business models. The blockchain architecture is developed by Ulm University whilst Fraunhofer Institute for Electronic Nano Systems ENAS is handling the integration of the controllers into the security solution.

Fig. 23: Demonstration of the SAMPL project at HMI 2017

An essential aim of the SAMPL project is to develop a platform that supports the above-stated requirements. With this platform, the technical feasibility and economic efficiency will be verified on the basis of concrete application cases together with associated partners Airbus and EvoBus. Legal aspects, such as copyright, liability issues or data protection, are being examined by associated partner DWF.

A first demonstrator of the SAMPL platform for 3D component printing and licensing in the blockchain was presented at Hannover Messe (HMI) 2017 (see Fig. 23). Further presentations followed at more than ten events and trade fairs. The SAMPL project will once again be present as an exhibitor at Hannover Messe 2018 where the latest developments will be on display.

Consortium

PROSTEP AG (consortium leader), 3D MicroPrint GmbH, consider it GmbH, Fraunhofer Institute for Electronic Nano Systems ENAS, NXP Semiconductors Germany GmbH, Hamburg University of Technology – Institute for Aircraft Cabin Systems, Universität Hamburg – Hamburg Research Center for Information Systems, Ulm University – Institute of Distributed Systems

Associated partners

AIRBUS Operation GmbH, EvoBus GmbH, DWF Germany Rechtsanwaltsgesellschaft mbH

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4 Engineering cluster

Multi-disciplinary and phase-spanning engineering for Industry 4.0

The shift towards digital and interconnected production systems in Industry 4.0 also involves a change in engineering. The technical, methodological and legal developments required for the engineering of the future are only just beginning.[29] The central challenge is to overcome traditional boundaries between the different engineering disciplines (mechanical, electrical, etc.). Future interdisciplinary integrated engineering tools will need standards for exchanging data at all design levels which at the same time will also enable an abstraction of functions and capabilities at the respective subordinate levels. Product life cycle management too requires a new approach, especially for long-life products. The current challenges are being addressed in four PAiCE projects:

- Standards for data exchange in engineering: INTEGRATE, DEVEKOS
- Engineering and data in cross-process design: VariKa, DEVEKOS
- Engineering and data for existing machines: EMuDig4.0, VariKa

4.1 Market analysis

An analysis of the market in the engineering sector must consider the different roles in the value chain separately. The market began in the 1980s with the development of computer-aided tools for individual engineering steps (computer-aided engineering/CAE). These tools range from classical computer-aided design (CAD) and the design of electronic circuits and components (electronic design automation (EDA)) to numerical simulations, for example for loads, motion sequences or thermal processes. Most of these tools were developed by software development companies that were newly established at that time or by system integrators who expanded or completed their product portfolio.

The growing complexity of CAE tools and the related software (such as simulation) was one of the forces that fuelled the emergence of engineering service providers beginning in the 1990s.

The first steps towards interconnecting engineering services with manufacture were taken more than 30 years ago with computer-aided manufacturing (CAM). These solutions were mostly proprietary and were not comparable with the power of today’s solutions.

In the future, the market can be expected to be divided into three roles (business models) (see Fig. 24), with hybrid forms and multiple ownership of roles by one and the same provider being expected more frequently at least in off-the-shelf business. The role of tool providers essentially corresponds to that of today’s CAE tools, supplemented by suitable interfaces and domain-spanning multimodal CAE tools (system engineering). The role of service providers is based on the numerous engineering firms already operating today, but further diversification of the value chain will have to be expected in this area too. This will range from generalist system service providers to specialists for special cases. The roles as tool provider and service provider can also be linked to product manufacturing.

The role of the platform operator is completely new. This is where we can expect to see the entry of both CAE tool providers who supplement their tool portfolio with an integration layer (bottom-up) and the entry of generic platform operators from other industries (‘side entrants’) can be expected.

29 Matthias Künzel, Jens Schulz and Peter Gabriel: Engineering 4.0. Grundzüge eines Zukunftsmodells, Bundesministerium für Wirtschaft und Energie, 2016. Available online at: www.digitale-technologien.de/DT/Redaktion/DE/Downloads/Publikation/autonomik-engineering%2040.pdf?__blob=publicationFile&v=3 (retrieved 20 November 2017).

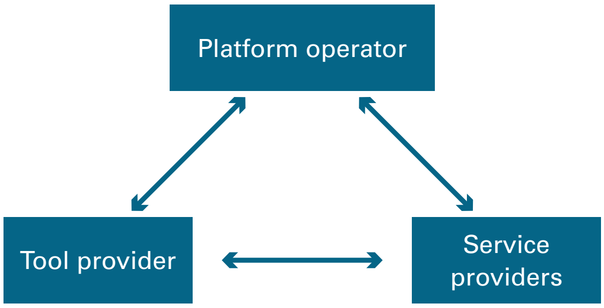

Fig. 24: Engineering tools: Sub-markets (diagram by the authors)

Tool providers

Most of today's engineering tool providers developed in individual fields of application. An example of this is mechanical design: AutoCAD (Autodesk), Catia (Dassault Systemes), Creo (previously Pro/ENGINEER PTC), Solid Edge (Siemens AG), SolidWorks (Dassault Systemes) and Allplan (Nemetschek AG). With the exception of the latter system, which focuses on construction/architecture, all of these systems are used in mechanical and vehicle engineering. They differ in terms of the scope of their 3D capability, the connection of simulation options, the integration into complete packages and the available interfaces. Other typical fields for CAE solutions are electrical systems (for instance, ePLAN – Friedhelm Loh Group), PCB design and circuit design (EDA).

Studies estimate the current global market for CAE tools, including simulation, to be around EUR 4.5 billion[30,31], with mechanical design (CAD) accounting for more than half of this volume. A subdivision is usually made according to user industries (automotive, aviation, etc.) and fields of application (design, manufacture, visualisation, geo-based applications).

The total number of providers active in the CAE market is likely to exceed 50, with studies estimating that up to 500 program packages are available from the individual providers (whereby the packages of the individual providers can be usually interconnected with other packages). In each segment (mechanical, electrical, PCB, architecture/buildings, etc.), around five program packages cover the largest part of the market. The majority of these products have a development history of more than ten years.

Engineering service providers

A general driver for the outsourcing of engineering services is the increased differentiation of the value process. This includes the effective use of highly specialised (and competence-intensive) special software as well as increased outsourcing by large companies (the automotive industry is an example of the latter development). Furthermore, simple activities are automated. This results in changed earnings models and stronger temporary co-operation among interdisciplinary teams across company boundaries.

According to estimates by the market research and consulting firm Lünendonk, Kaufbeuren, the market for technology consulting and engineering services in Germany grew by 5 percent to EUR 9.3 billion in 2014.[32] This study reports further growth expectations of around 5 percent per annum. The structure of this market is generally not uniform, with companies employing far more than a thousand employees on the one hand and sole proprietorships (engineering firms) at the other end of the scale. Engineering service providers, for instance, have to cope with high fluctuation rates, with the respective customer companies being the preferred new employers. This market can be expected to consolidate, especially due to moves by large customers to reduce the number of service providers and to subcontract ever larger jobs. This development is less likely to affect smaller players who are either

30 Cambashi CAE Observatory 2017: USD 5.37 billion, 2016.
31 Grand View Research 2017: USD 5.23 billion, 2015.
32 Michael Schlaug and Hartmut Lüerßen: Führende Anbieter von Technologie-Beratung und Engineering Services in Deutschland. Lünendonk-Sonderanalyse 2016, Lünendonk GmbH, 2016. Available online at: www.luenendonk-shop.de/out/pictures/0/lue_mc_tbes_2016_sonderanalyse_f190916_fl.pdf retrieved 20 November 2017).

highly specialised or work primarily for smaller companies (typical niche players), whilst medium-sized providers are more likely to be affected.

Platforms

The emergence of engineering platforms will reshape the market. Studies estimate this market volume at a current EUR 8.5 billion and almost EUR 25 billion in 2022. Growth rates are hence significantly higher than for CAE tools, with the figures available for platforms and CAE tools overlapping. Growth for platform services in the narrower sense is expected to be significantly higher than for CAE tools.

Irrespective of this, no universal new value creation model is expected since the requirements of the different industries vary too much. The operators of such platforms are most likely to be established system houses with an engineering focus and large software companies, but also associations or company groups (see Table 3 for a comparison, with the order of listing being no indication of relevance). It is not yet possible to predict which of these models will prevail on the market. The future structure of the prevailing model in the automotive industry, for instance, may differ from that in the construction industry.

Table 3: Comparison of operator types for engineering platforms (chart by the authors)

	Type of provider		
	Systems house	Software house/cloud operator	Association/group of companies
Market access	Bottom-up market entry with already established products Established market position	Lateral entrants Top-down market entry with PLM software or computing capacity/cloud	By members
Basic concept/ features	Continuity: Hardware + software + engineering concepts	Based on platform architecture and experience with BigData; focus on interchangeability	Pooling Open-X concept[33]
Benefits for users	Perfect coordination between hardware and engineering tools possible	Neutral in relation to individual applications	Focus on members' interests High presumption of competence Neutrality
Disadvantages for users	Proprietary solution, lock-in effects Less support for heterogeneous environments	Risk of less competence in engineering-specific aspects Risk of lock-in effects	Risk of limited financial resources in the case of insufficient commitment on the part of members

4.2 Start-up environment

Die heute etablierten sektorspezifischen Engineering-Werkzeuge haben ihre Wurzeln meist iMost of the sector-specific engineering tools established today have their roots in the 1980s and 1990s. Company start-ups are hardly likely to be able to catch up on the experience and expertise gained since then by the respective providers. The situation is different for solutions that complement established engineering skills. One example is the field of virtual reality/augmented reality. These solutions are additionally supported by the trend to-

33 Open-X concept: Platform according to the Open Innovation model.

wards providing interfaces (with the maximum possible degree of standardisation) in established program packages and the trend towards open source solutions ('solution provider'). They provide new capabilities for CAE, but make only a small contribution towards overcoming traditional application boundaries (such as mechanical vs. electrical engineering).

Investment activity

In order to identify regional investment priorities, the Crunchbase database was analysed.[34] Fig. 25 shows the result for investments in 2016. The diagram is an expression of different investment and corporate cultures. Owner-managed company structures developed with equity capital remain invisible here. China has the second highest capital share after the US – even after elimination of statistical outliers –, but in terms of the number of companies and investment rounds, North America and Europe are roughly on par in leading this market.

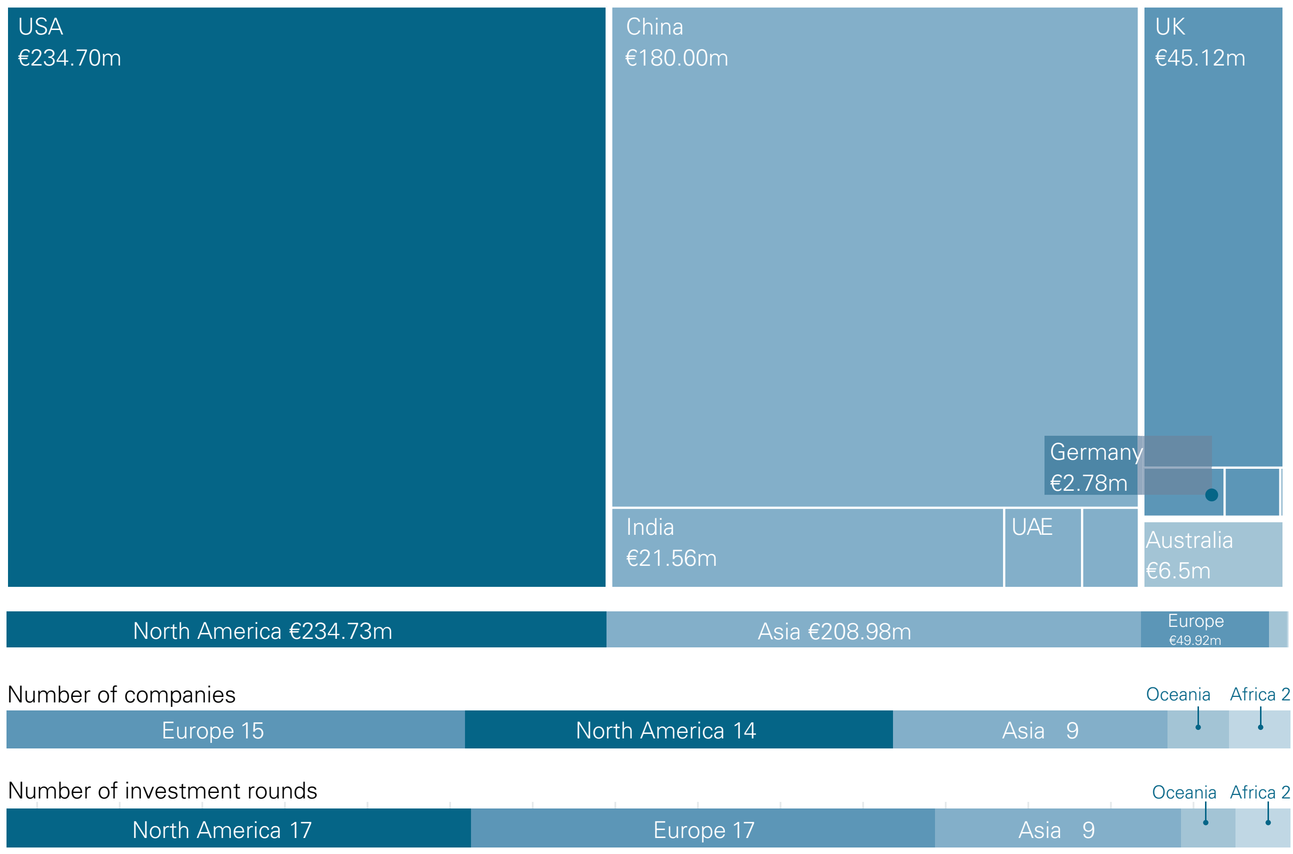

Fig. 25: Investments in engineering in 2016 (diagram by the authors, data from www.crunchbase.com)

An analysis of developments in recent years shows that there are no special features or trends towards change in 2016. Even if the data in Table 4 and Table 5 is considerably uncertain – for example, half of the data records were excluded due to a lack of information regarding investment amounts –, important conclusions can nevertheless be drawn:

- Approximately 70 percent of all investments considered were made in North America or Europe.

34 Search filter at case level (companies): 'industrial engineering' OR 'mechanical engineering'. The data was adjusted for obvious outliers (Evonik acquisition, two industrial parks in China).

- In terms of the number of companies and investment rounds, North America and Europe are roughly on par. However, the average investment sum in Europe is only one third of that of North America (with only minor differences between the US and Canada).
- Only a few, but very large investments are made in this area in Asia.

Table 4: Investments in industrial and mechanical engineering by continents in the period from 2008 to 2017 (diagram by the authors, data from www.crunchbase.com)

Continent	Total investment [EUR]	Mean value [EUR]	Number of cases
Africa	10,364,695.81 EUR	3,454,898.60 EUR	3
Asia	352,542,736.15 EUR	32,049,339.65 EUR	11
Europe	185,272,701.59 EUR	2,940,836.53 EUR	63
North America	1,380,431,566.85 EUR	10,537,645.55 EUR	131
Ozeania	13,222,561.50 EUR	3,305,640.38 EUR	4
South America	13,130,100.00 EUR	13,130,100.00 EUR	1

Table 5: Investments in industrial and mechanical engineering in the period from 2008 to 2017 – the TOP 10 countries (diagram by the authors, data from www.crunchbase.com)

Country	Total investment [EUR]	Mean value [EUR]	Number of cases
United States	1,326,757,697.15 EUR	10,614,061.58 EUR	125
China	184,891,037.30 EUR	61,630,345.77 EUR	3
India	144,233,222.25 EUR	28,846,644.45 EUR	5
United Kingdom	86,761,562.20 EUR	2,892,052.07 EUR	30
Canada	53,673,869.70 EUR	8,945,644.95 EUR	6
Finland	38,807,145.00 EUR	38,807,145.00 EUR	1
UAE	20,313,905.00 EUR	10,156,952.50 EUR	2
Germany	17,248,010.34 EUR	2,156,001.29 EUR	8
Australia	13,222,561.50 EUR	3,305,640.38 EUR	4
Brazil	13,130,100.00 EUR	13,130,100.00 EUR	1

Table 5 shows the most important countries for investments individually. This analysis supports the observation of the different company and start-up cultures mentioned earlier. Especially in Germany, a certain degree of reluctance can be seen when it comes to using outside capital. The German companies included in the above tables tend to view engineering more as a kind of internal product development (for instance, BigRep GmbH) or as a service (for instance, Plant Systems & Services PSS GmbH). Start-ups in an engineering context are also not visible on job portals. The lack of start-ups in this field could be due to the complexity and quality requirements of systems engineering.

4.3 State of the art

The definition of engineering and, accordingly, the state of the art are currently changing, moving away from concept design as a phase model towards system analysis. Up to now, engineering has been strongly influenced by design, whilst a systemic view of product, production and use was neglected. Many application contexts highlighted the key function of engineering without giving a clear interpretation or, even better, systematic classification of the term.

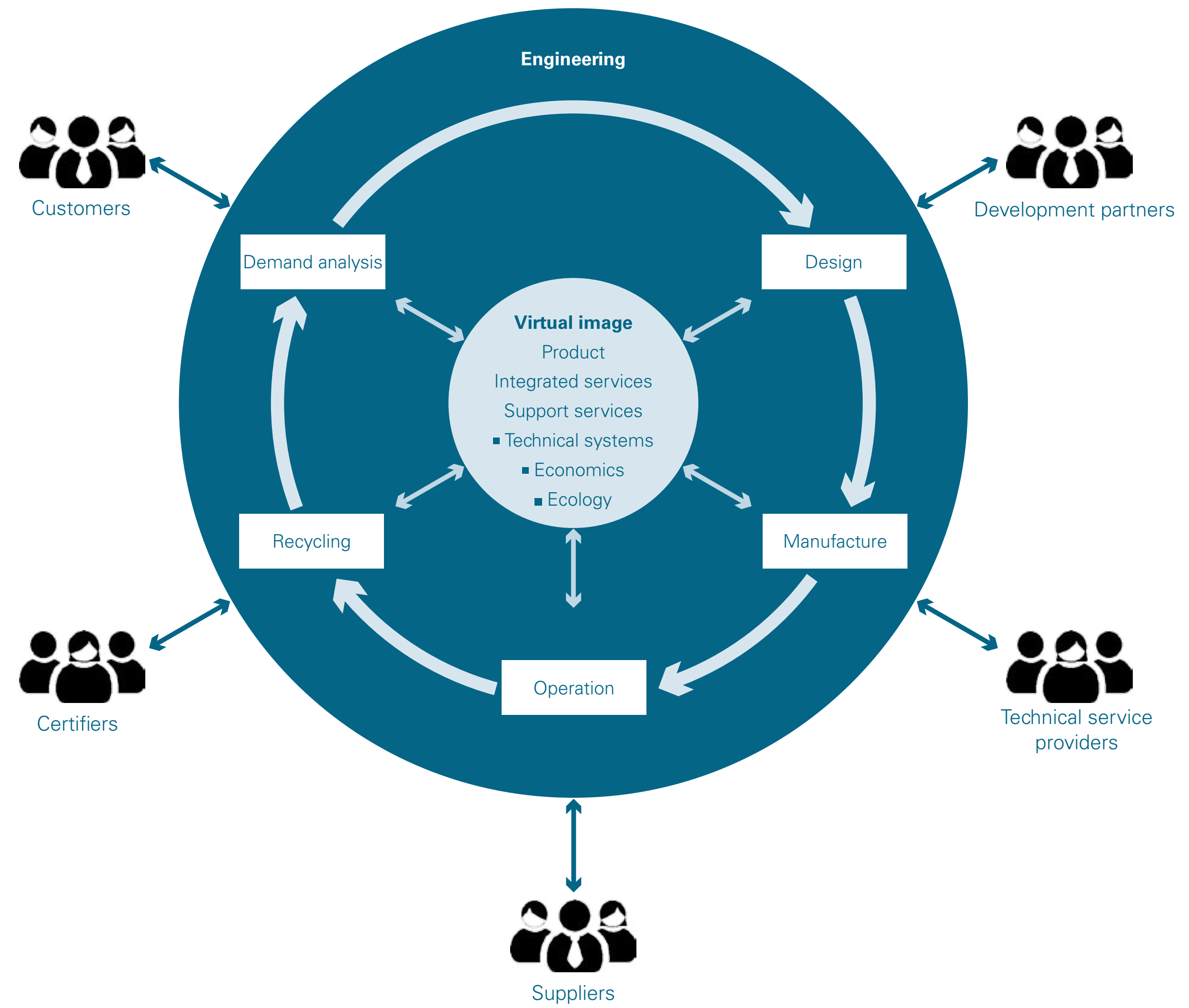

Fig. 26: Feedback architecture of engineering 4.0 (source: iit)

Compared to Künzel et al. 2016, the situation regarding the state of the art has not changed fundamentally: The turnaround predicted in the study is merely taking place as a gradual transition rather than as a disruptive revolution. The planned future notion of engineering as a feedback process that accompanies the entire product lifecycle is still a future model (see Fig. 26). This process includes all stakeholders in the value chain across company borders, provides a holistic view of the product, maps the integrated services and equally considers technical, economic and ecological aspects.

Even if first steps have been taken, the current state of the art – not least in industrial practice – is still a long way from this model. The components available on the market from different manufacturers are often incompatible and there are still no standardised function and capability descriptions. Manufacturer-independent standards for automation functions are also often missing, hindering the flow of data between component manufacturers, machine builders and operators. Third-party providers face major obstacles when it comes to rendering their services for the production process. Furthermore, recognised interfaces are not yet widely used for cross-domain and cross-discipline engineering and often require manual conversion.

AutomationML represents a promising approach to overcome some of these challenges. IEC 62 714 marks an important stage in the standardisation of data exchange.

Transparent production data along the value chain is missing in subsequent operations. This applies first and foremost to the large number of existing production facilities for which sensible migration paths must be opened up. In operational practice, it is often not only standardised data formats and implemented recording methods that are missing, but also digital documents and/or their exchange in general.

The increasing use of new engineering methods and digital processes to boost efficiency still focuses too often on individual segments rather than the entire value chain. One example is the rapid further development of products in the field of virtual commissioning. Even if this approach is understandable as a policy of 'picking the low-hanging fruit first' in the short term, future action will need to increasingly focus on future (and investment) security.

4.4 R&D developments

Framework conditions

The breakthrough in engineering discussed in the previous section is characterised by a number of framework conditions that have a major impact on ongoing R&D work and the further development of value processes:

- Mechanics, electronics and software have **completely different innovation cycles and lifetimes**. It is therefore necessary to follow an economic migration path that includes (re-) engineering/retrofitting these capital goods.
- In the future, engineering should, at least to a large extent, do without physical functional models and/or prototypes, so that ideally engineering will be largely or even fully software-based. **Simulation and virtual reality** thus become vital prerequisites and are an important research topic.
- Engineering also includes creating the **technical prerequisites for services** for diagnostics, maintenance, etc., which may not be defined until later in the course of iterative development.
- **Sustainability** will also become **increasingly important** for Germany as a business centre for Engineering 4.0. In value-oriented approaches, calculation methods are used today which refer to the total cost of ownership (TCO), i.e., the total operating costs over the entire product lifecycle, as a central decision criterion.

- The application of **agile development methods** for software to physical products is attractive because it promises shorter time-to-market and a stronger customer focus. However, direct implementation is prevented by the fact that, unlike software, the hardware components of real machines cannot be easily updated while the system of liability, contractually agreed product performance, certification and approval is much more pronounced for physical products than for software.
- Engineering 4.0 brings with it requirements, not only at a technical level. There are also urgent **legal issues**, especially with regard to liability. Some initial approaches already exist which must be continued. These are the **virtual certification** of modular and configurable machines and the certification of production processes in order to master the vast number of variants, as well as liability issues related to the collaboration of autonomous machines or between humans and machines.

The EU's Vanguard Initiative for Regional Development (Smart Specialisation) is driven by a political commitment made by regions to use their smart specialisation strategy to boost new growth through bottom-up entrepreneurial innovation and industrial renewal in European priority areas. Despite the obvious key role that the further development of engineering has to play in this context — keywords include, for instance, manufacture close to the end customer, small batches and spare parts –, engineering is not addressed by the Vanguard initiative, not even within the context of the five pilot projects (bioeconomics, efficient and sustainable production, high-performance production with 3D printing, post-technology-based products, components for offshore power generation and use). The underlying reasons require further analysis.

R&D trends

A current analysis of European R&D activities in the engineering context shows a very wide range of current joint projects. In a first step, projects in the field of biotechnology (tissue engineering, etc.) and projects in the field of material sciences/nanotechnologies were excluded from the detailed analysis. The remaining project pool will probably include the following focal topics:

- Simulation and analysis (usually in the context of specific applications), including reliability and operational safety
- Software development (such as software-as-a-service, testing)
- Engineering in photonics and smart systems
- Projects in the context of additive manufacturing

On a European scale, it is striking that research is strongly focused on production technology in a wide range of industries. New processes, such as additive manufacturing, are very common topics. These projects consider engineering more as a marginal issue and not as their core. This also reflects the different approaches: In Germany, computer science created the basis for Industry 4.0. Other European countries focus on the renaissance of manufacturing technology (see industrie du future, Vanguard Initiative). Focused engineering projects, like those funded in PAiCE, are therefore hardly represented at European level.

One initiative and two projects at European level related to engineering and PAiCE are presented below:

PPP Factories of the Future (PPP-FoF)

This public-private partnership at European level was launched in 2008. Since then, almost 180 projects have been funded under the EU's 7th Framework Programme and Horizon 2020 as part of the 'Factories of the Future' programme. The private side is represented by the European Factories of the Future Research Association (EFFRA) in which around a hundred companies, research institutions, associations and clusters are represented as members.

The FoF roadmap for the period from 2014 to 2020 describes a vision and the key technologies required for clean, highly productive, environmentally friendly and socially sustainable production in the future. The analysis of the market situation in the roadmap clearly shows Germany's leading position in this field. Germany accounts for around 40 percent of all European R&D expenditure in the manufacturing sector (including the corresponding engineering shares under this item). The FoF roadmap identifies the following research priorities in conjunction with engineering:

- MMultidisciplinary engineering tools for mechatronic design (in the 'Adaptive and smart manufacturing systems' section)
- In the 'Key Technologies/IKT' section:
- Software tools for collaborative and distributed development
- Modelling and simulation tools
- Secure, performant and open platforms
- Data backup and information mining

All the manufacturing processes mentioned as a research focus in the roadmap must be indirectly considered in engineering because these new or further developed manufacturing technologies will influence the design of future products.

Future Directions of Production Planning and Optimized Energy and Process Industries (FUDIPO)

- Website: www.fupido.eu
- Coordinator: Maelardalens Hoegskola, Hogsskolenplan 1, 72123 Västeras
- A total of eleven alliance partners (German participation: Fraunhofer ISC, Center for High-Temperature Materials and Design Bayreuth)
- Term: 1 October 2016 to 30 September 2020

Unlike the PAiCE projects, this project addresses the energy-intensive process industry (target industries: refineries as well as ceramics, paper and chemical industry). The discussion in working groups in the follow-up to the engineering study clearly showed that this industry must be considered on an equal footing with product manufacturing and/or mechanical engineering. The project can thus provide complementary experience to the PAiCE projects. In addition, the FUPIDO project also takes energy aspects into account. Published project results are only available to a limited extent.

The project is integrating machine learning functions on a large scale into various critical process industries. This should enable significant improvements in energy and resource efficiency as well as an increase in competitiveness. The project will develop three major site-wide system demonstrators and two small technology demonstrators. For this purpose, FUDIPO brings together five end-user industries in the pulp and paper, refinery and power generation sectors, one stakeholder from the automation industry (LE) as well as two research institutes and one university. The expected result is a set of tools for diagnostics, data reconciliation and decision support, production planning as well as process optimisation including a model-based control concept. The approach is based on the creation of physical process models which are then continuously adapted using 'good data' and 'bad data' for error diagnosis. The machine learning process can then be followed by automated classification of data. Furthermore, statistical models are developed from measurements with several new sensor types that are combined with standard process sensors. Operators and process engineers interact with the system in order to understand and improve system performance. The platform will include an open platform as a basic functionality and extended functions as add-ons. The basic platform can be connected to large automation platforms and databases. The model library is also used to evaluate the effects of process changes. The use of tried-and-tested simulation models with new components and the connection to the process optimisation system thus developed provides a precise picture of the actual operating processes of the modified plant. At the same time, the engineering and process design can be handled together with the development of process automation concepts.

An Integrated Collaboration Platform for Managing the Product-Service Lifecycle (ICP4Life)

- Website: www.icp4life.eu
- Coordinator: PRIMA INDUSTRIE S.p.A.; Via Antonelli, 32-10097 COLLEGNO (TO) ITAL
- Twelve partners in total (German participation: Fraunhofer Institute for Industrial Engineering IAO Stuttgart)
- Term: 1 January /2015 to 31 December 2018

In contrast to the PAiCE projects, this project primarily addresses the power industry and its often medium-sized suppliers. However, the challenges involved do not differ from product manufacture or mechanical engineering in qualitative terms. The project can thus provide complementary experience to the PAiCE projects. Various publications on project results are already available.

The ICP4Life project is developing an integrated collaborative platform which consists of three functional areas:
- The creation and management of product and service data by users from several disciplines using a common semantic model
- The simple and intuitive configuration of products and services by customers with different profiles for different product types
- Semi-automatic design and reconfiguration of piping systems and power supply networks through cloud-based simulation services, combined with a common data model for the entire supply chain

With its data consistency, the project is primarily expected to save time between the different phases of the value chain. The project also aims to reduce the time to market by 20 percent, process times in the repair sector by up to 40 percent and product development times by up to 30 percent.

4.5 Projects of the engineering cluster

The progress achieved by the funded DEVEKOS, EMuDig 4.0, INTEGRATE and VariKa projects since the beginning of the PAiCE technology programme is shown on the following pages.

DEVEKOS

DEVEKOS

Consistent engineering for secure, distributed and communicating multi-component systems

Brief description

The aim of the DEVEKOS project is to develop manufacturer-independent standards for all components that contribute towards the automation of machines or assets, in order to make engineering and production processes smarter, more flexible and efficient. The automation components have to interact automatically and in real time across manufacturer boundaries. The project is therefore aiming to create standardised interfaces that also enable efficient development co-operation between the sales, mechanical, electrical and software functions.

www.devekos.org

Current developments from the project

The aim of the DEVEKOS project is manufacturer-spanning standardisation of the capabilities of individual components and subsystems and will be explained on the basis of different manufacturing and assembly processes. These standardised descriptions are a precondition for efficient, capability-based engineering independent of a specific manufacturer or vendor (Fig. 27).

The CODESYS Depictor is a prototype for logical 3D simulation (virtual commissioning). For operating machines, inIT and CODESYS are developing a first prototype for an OPC-UA[35]-based communication solution for capability-based systems. Integrated components are being developed in DEVEKOS (initially independent of the demonstrator) by the partners Afag Automation AG (Switzerland), elrest Automationssysteme GmbH, eps GmbH and Festo. A concept for the security solution for modular and distributed systems (safety and security) is also currently being developed independent of the demonstrator. Users in DEVEKOS (mechanical engineers) can then implement and test the results partly in the demonstrator, but partly also in their own applications.

Since the summer of 2017, DEVEKOS has been working intensively outside the project with the IAS (Integrated Assembly Solutions) working group of VDMA on the manufacturer-independent standardisation of automation capabilities in order to consolidate the project goals. A substantial number of well-known manufacturers of automation components are involved in this working group. This provides a good basis for the dissemination and acceptance of capability standardisation. This working group decided to develop and build a concrete machine for Automatica 2018, which is expected to involve between 20 and 30 companies. All of the manufacturers' components are integrated into the machine based on their capabilities. This will be supplemented by a prototype for capability standardisation across manufacturers within the framework of the components used. Based on their capabilities, these are combined to form control processes (orchestration). The 4DIAC and CODESYS Application Composer engineering tools are used for this capability-based design.

35 OPC-UA = Open Platform Communications Unified Architecture – a term that refers to standardised software interfaces which enable the exchange of data between applications from different manufacturers of automation systems, whilst UA refers to the current generation of these interfaces

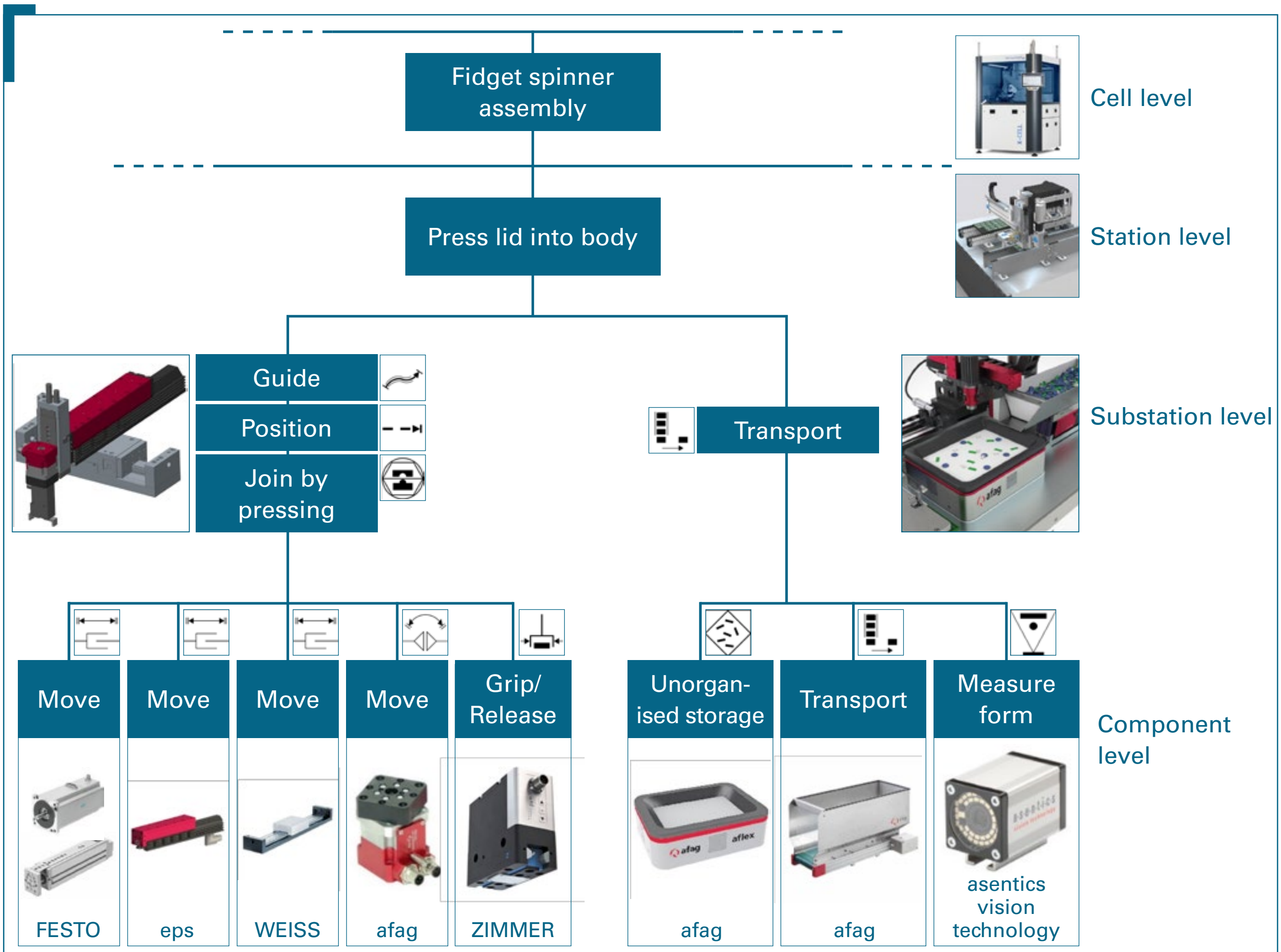

Fig. 27: DEVEKOS – Capability-based architecture (source: DEVEKOS)

Consortium

FESTO AG & Co. KG (consortium leader), ASYS Automatisierungssysteme GmbH, CODESYS GmbH, elrest Automationssysteme GmbH, fortiss GmbH, Häcker Automation GmbH, Harro Höfliger Verpackungsmaschinen GmbH, Ostwestfalen-Lippe University of Applied Sciences, inIT – Institute for Industrial Information Technology, NewTec GmbH, SCHAEFF Maschinen GmbH & Co. KG, Softing Industrial Automation GmbH, University of Stuttgart – Institute for Machine Tool Control Engineering

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EMuDig 4.0

Efficiency boost in solid forming by integrating digital technologies in engineering along the entire value chain

Brief description

EMuDig 4.0 aims to enable the interconnection of manufacturing processes, machines and assets, people, products and tools in solid forming. For this purpose, digital technologies and methods specifically developed or adapted for forming processes are being integrated along the entire value chain. The analysis of the resulting data is used to gain further insights into the process and to thereby increase overall plant efficiency.

www.massivumformung.de/forschung/emudig-40

Current developments from the project

The application partners, i.e. Hirschvogel Automotive Group, SMS group GmbH and OTTO FUCHS KG, selected representative applications (demonstrators) in the steel and aluminium process chains in the industrial environment. Special attention was paid to the targeted implementation of new sensors and hardware for existing production plants in industry against the background of the given operating conditions (high temperatures and mechanical stress). Initial evaluations already provided immediate practical results with forging presses (see Fig. 28).

The analysis of data records is currently underway. The data will then be interpreted and thresholds determined in bilateral workshops of industry and research stakeholders. The assignment of signal behaviour to failure-relevant events forms the basis for the forecast model to be developed. The aim is to significantly increase the overall machine efficiency of forging presses by avoiding unscheduled downtimes. The focus is on the most relevant causes of availability losses.

Studies on forming processes conducted by University of Stuttgart showed that continuous and automated tracing of individual aluminium parts throughout the entire process chain is generally possible with laser marking. The scale layer must be removed from the steel parts before marking.

As part of its work on production tools, South Westphalia University of Applied Sciences was able to create the theoretical basis for increasing the tool life by reducing the tool life spread. This specifically includes the objective determination of the end of tool life and the development of a digital tool passport in order to record the tool life history along the entire value chain.

The Institute for Automation Engineering and Software Systems developed a concept for data-driven component tracing. This includes automated data integration based on an ETL stack, the assignment of process and component information using multidimensional data modelling and the web-based visualisation of results.

ZIH developed a concept for a factory cloud based on the given requirements of the project. This enables the variable use of statistical data analyses for different production chains. A corresponding workflow was defined and prepared, so that a reliable analysis of production chain data is possible from an IT perspective.

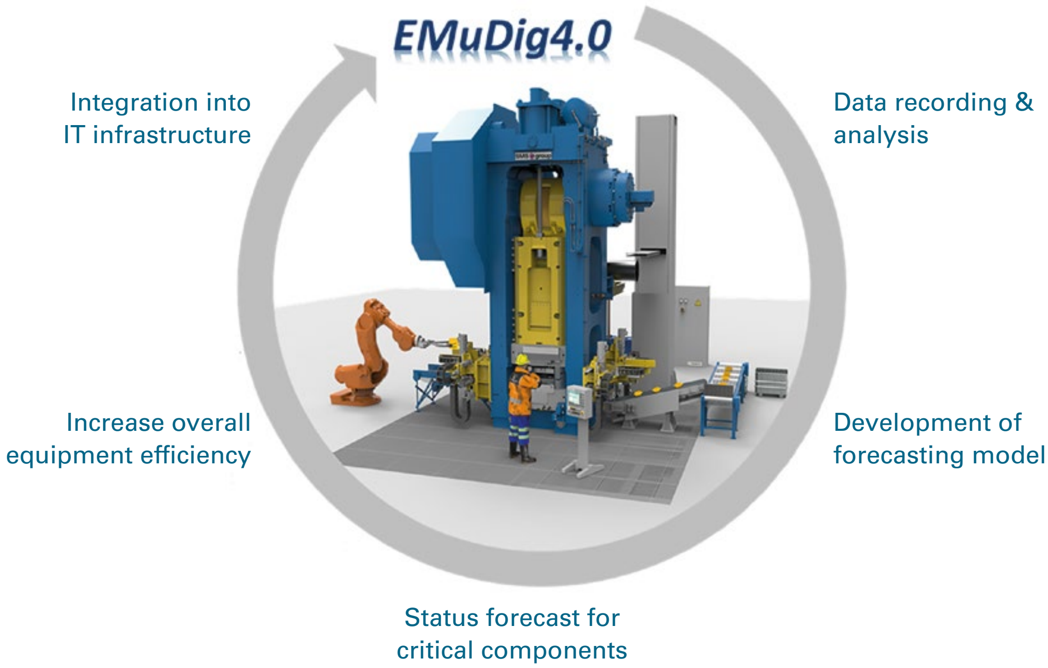

Fig. 28: Interaction between forging press and digital technologies (source: EMuDig 4.0)

Consortium

OTTO FUCHS KG (consortium leader), Hirschvogel Automotive Group, SMS group GmbH, South Westphalia University of Applied Sciences – Laboratory for Solid Forming, University of Stuttgart – Institute for Forming Technology and Institute for Automation Technology and Software Systems, TU Dresden – Center for Information Services and High Performance Computing (ZIH)

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INTEGRATE

Open platform for cooperative engineering

Brief description

The INTEGRATE project develops an open platform for cooperative engineering across companies and manufacturers. All engineering tools involved in a production process can use the platform for the secure and synchronous exchange of data, and thirdparty providers can offer and integrate their own services, whilst basic requirements, such as data security and rights management, are controlled by the platform. This is expected to significantly boost the flexibility and speed of the design process.

www.integrate.ovgu.de

Current developments from the project

During the first project phase, essential requirements for the INTEGRATE platform were collected and prioritised. For this purpose, a detailed analysis of design processes for production plants was carried out, including both an academic examination and the recording and stock-taking of real processes. As a result, it was possible to identify typical scenarios that must be supported by the INTEGRATE platform in order to enable the engineering of plants and assets capable of being integrated both vertically and horizontally in Industry 4.0 environments. It became clear that vertical and horizontal integration must create a win-win situation for all participants in the value chain, or at least should not deteriorate the econom-

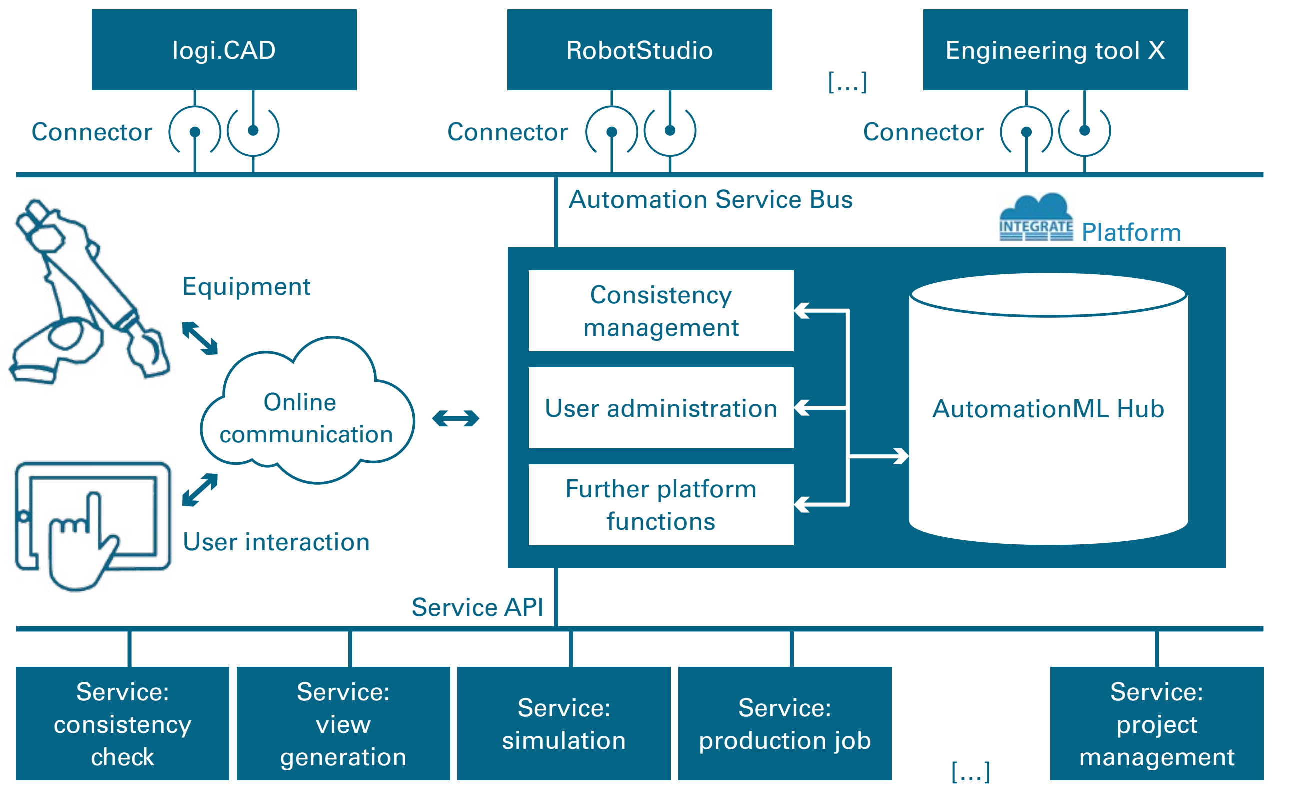

Fig. 29: Platform structure of the INTEGRATE project (source: INTEGRATE consortium)

ic and technical framework conditions. Otherwise, there is a risk of the (sub-) services in question being taken off the market.

Other focal points of the analysis included the flow of information within the planning processes and the interdependence of planning information. The focus was on which information (such as capabilities, dimensions, interfaces) would already have to be considered in engineering in order to take Industry 4.0 components into account in the early planning phases. The findings of the analysis formed the basis for the catalogue of requirements for the INTEGRATE platform which defines, among others, the access processes and interfaces for the platform via the engineering tools.

In addition to the technical work, the value chain scenarios established by the INTEGRATE consortium were analysed in order to assess the economic potential. Several business models were identified that can be implemented with the INTEGRATE platform (see Fig. 29).

Parallel to the analytical work, a first demonstrator for the planned data exchange was developed by consortium partners ABB and logi.cals. This first project result was presented in October 2017 at the 4th AutomationML PlugFest.

Furthermore, the first members of the 'INTEGRATE Industrial Interest Group – I3G' were signed up at the PlugFest. I3G provides interested companies with information about current project results and allows them to address their own needs to the project. The official kick-off meeting of I3G took place at SPS/IPC/Drives 2017. I3G members will have access to the cloud-based AutomationML.hub, a basic component of the INTEGRATE platform, for testing purposes. This will allow potential users to test current developments in the project at an early stage.

Consortium

inpro Innovationsgesellschaft für fortgeschrittene Produktionssysteme in der Fahrzeugindustrie mbH (consortium leader), FZI Reserach Center for Information Technology at Karlsruhe Institute of Technology (KIT), Otto von Guericke University Magdeburg, ABB AG, logi.cals automation solutions & services GmbH

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VariKa

Interconnected product and production engineering based on the example of multi-variant carbodies

Brief description

Today's electric vehicles come with a host of customisation options. These options influence, for example, the installation space for the battery – a vehicle with a hybrid drive, for instance, needs a different battery carrier than a purely battery-powered vehicle. In the VariKa project, methods are being developed based on the example of a multi-variant battery carrier and the associated process chain in order to evaluate the fatigue strength of additively manufactured components against the background of production influences and to evaluate welded joints between additively manufactured nodes and metal profiles. An evaluation of simple crash-type impacts completes the method development process in an effort to enable the economic production of small quantities. The demonstrator is a battery carrier based on a mixed design featuring both machined semi-finished parts and 3D-printed joining elements.

www.varika.de

Current developments from the project

VariKa demonstrates the potential of additive manufacturing in combination with jigless joining for manufacturing vehicle components. In the first project phase, a battery carrier was selected as an example application and the determination of characteristic CAE values for components produced by additive manufacturing (AM) was prepared.

The system boundaries between carrier, battery and vehicle environment were specified for this purpose. The relevant criteria are:

- Position of the beam and the beam attachment points in the vehicle environment
- Scalability of the battery carrier length to accommodate one to three battery packs
- Advantageous combination of the 'strengths of both worlds' by minimising AM node dimensions and maximising profile lengths
- Development of a tolerance and joining concept for a minimum of rework at structure nodes and profile sections
- Maximum functional integration, especially in the additively manufactured structure nodes, as a driver for greater cost-effectiveness.

During the further course of the project, technological boundary conditions and economic aspects will be continuously weighed up in order to achieve the maximum possible utilisation of the AM assembly space. After modifying the component shape, it may be possible, for instance, to position several structure nodes in the assembly space of the AM printer, thereby reducing production costs for the individual AM nodes.

The result of a first topology optimisation of the AM nodes shows the significant potential for material savings when this force flow-orientated optimisation technique is used (see Fig. 30).

In order to prepare for the determination of the characteristic values, a test programme was drawn up and the need for test specimens was identified. In the first batch, 128 test specimens were produced for cyclic fatigue tests and varied in terms of dimensions and orientation in the assembly space. Half of the samples were then subjected to stress-relief annealing, with the rest remaining in the initial condition after additive manufacturing. Following removal of support structures, pore-like defects remained at the attachment points to the samples, so that these samples have to be tested under special precautions in order to avoid addressing the defects only. A roughness analysis is used to characterise the sample surface. During the further course of the project, correlations between surface and fatigue strength are also to be determined. The geometry of the specimens, especially distortion and deviation from the planned shape, was determined and documented by laser scanning. As an additional measure, test cubes were produced in the same batch for quality control of the assembly process, to determine the internal structure of the printed material and to subsequently analyse the density of the printed samples. Density determination using a light microscope is already underway.

At the same time, a test rig has been set up and clamping jaws and buckling supports have been manufactured. Furthermore, so-called incremental step tests have begun in order to determine basic cyclic material properties.

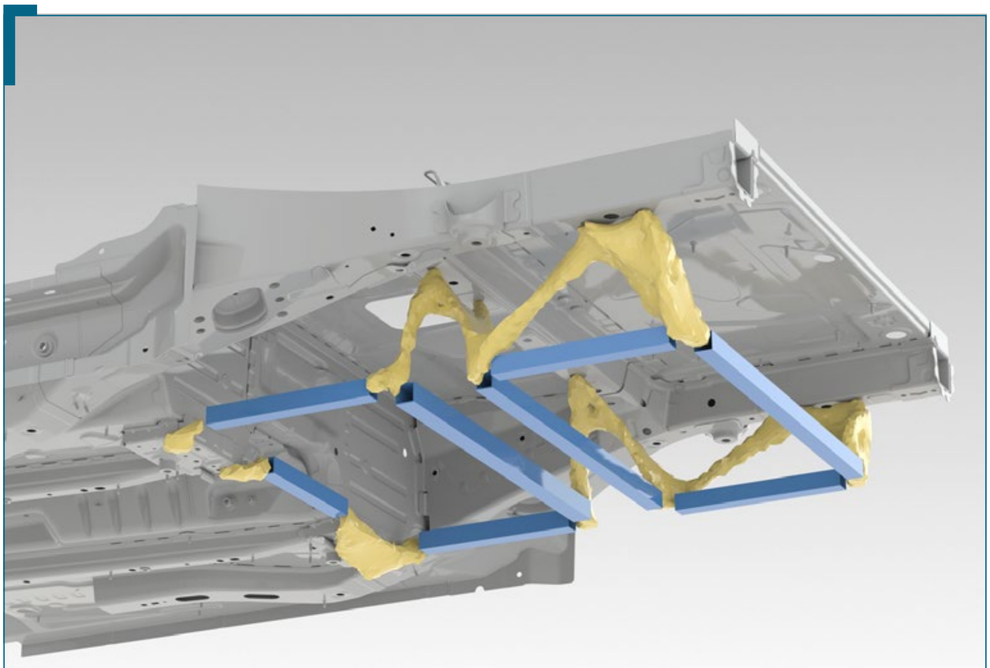

Fig. 30: Savings potential using topology optimisation for additive manufacturing components (source: Opel Automobile GmbH)

Consortium

EDAG Engineering GmbH (consortium leader), Opel Automobile GmbH, FFT Produktionssysteme GmbH & Co. KG, FKM Sintertechnik GmbH, Fraunhofer Institute for Structural Durability and System Reliability LBF

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5 Logistics cluster

Logistics networks in production

In digitally interconnected manufacturing too, raw materials, workpieces and products must be moved to and between production sites and between production sites and commercial or private customers. Logistics therefore has an important role to play in many Industry 4.0 concepts. Two projects in PAiCE address this topic: iSLT.NET and SaSCh. They are working to develop concepts for and testing of IT-supported logistics networks for manufacturing.

5.1 Market analysis

Logistics, i.e. the storage and transport of goods, has an important role to play in production. Depending on the particular industry, logistics costs can account for as much as 16 percent of overall costs.[36] The aim in commercial terms is to cut costs, if possible, but without jeopardising supply security and production processes. Prototypical for this are well established, tried-and-tested concepts, such as 'just-in-time', i.e. the delivery of goods to the production site at the precise time they are needed for production, or 'just-in-sequence', i.e. the delivery of goods in the exact order required to manufacture customised products.

High cost pressure in competition and the fact that many companies are planning to outsource more logistics activities have caused many logistics service providers to offer value-added services in addition to the transport and storage operations directly ordered. These activities can be simple assembly and finishing work, but also the independent planning and management of logistics processes. The term 'contract logistics' or 'third party logistics' (3PL) has become established in technical literature to describe this. Mere contract service providers for transport and storage operations are then sometimes referred to as 2PL, whilst the logistics service providers who no longer have any logistics resources of their own, but instead use the resources of third parties, are referred to as 4PL.[37] The services offered under these concepts are economies of scale and rationalisation gains due to the service providers' specialised logistics expertise. Typical 4PL offerings include logistics management services by a service provider who does not have any logistics resources of his own, brokerage between consignors and logistics service providers via marketplaces for freight, or the provision of IT infrastructures for cross-company logistics management. 3PL and 4PL concepts are based on comprehensive use of IT to plan and control logistics processes. Contract logistics is therefore a key element for implementing Industry 4.0.

The costs for industrial contract logistics services in Germany total EUR 74 billion[38] (in 2016) and EUR 430 billion in Europe.[39] Germany's importance for the manufacturing industry therefore also applies, not surprisingly, to logistics. Outside Europe, the world's major markets for contract logistics, which include not only industrial transport but also transport for trade, are located in North America, especially in the US, and in south east Asia, especially in China.[40]

36 Ulrich Berbner and Henning Witte: 4th Party Logistics – Chancen und Herausforderungen, ed. KPMG Wirtschaftsprüfungsgesellschaft and Technische Universität Darmstadt, 2014.
37 The terms 2PL, 3PL and 4PL are defined differently by different authors
38 Martin Schwemmer: TOP 100 der Logistik 2016/2017. Marktgrößen, Marktsegmente und Marktführer. A study by the Fraunhofer ISS Center for Applied Research on Supply Chain Services SCS, DVV Media, 2016.
39 Martin Schwemmer: TOP 100 der Logistik 2016/2017. Marktgrößen, Marktsegmente und Marktführer. A study by the Fraunhofer ISS Center for Applied Research on Supply Chain Services SCS, DVV Media, 2016.
40 Amstrong & Associates: Global 3PL Market Size Estimates, 2017. Available online at: www.3plogistics.com/3pl-market-info-resources/3pl-market-information/global-3pl-market-size-estimates/ (retrieved 24 November 2017). In addition to industrial contract logistics, the figures also include logistics for consumer goods.

In the manufacturing industry, some 25 percent of the typical contract logistics services in Germany and Europe are not performed in-house, but by external service providers. Demand comes mainly from the automotive, wood, glass and plastics industries, the chemical industry and from manufacturers of machinery and metals. Leading providers in Germany are Deutsche Bahn, including DB Schenker, Imperial Logistics, Schnellecke and VW Original Teile Logistik. Furthermore, several forwarding companies also serve this market segment in addition to other business fields.[41] Experts generally consider contract logistics for trade and industry, including asset-free 4PL concepts, to be a field with growth potential for logistics service providers. This is all the more true because many logistics service providers are under high cost pressure when it comes to simple transport and storage services. This is particularly the case for road transport, where especially eastern European freight forwarders with their lower personnel costs have a significant competitive advantage in the liberalised services market of the European Union.

However, the logistics industry is not only subject to high cost pressure, but – just like other sectors of the economy – it is also driven by globalisation and digitalisation. In addition to the growing importance of sustainability in logistics concepts and the clearly visible lack of technical and management personnel, the major trends include three topics of utmost relevance for PAiCE[42]:

- **Greater flexibility and complexity of the supply chain:** Shorter product lifecycles, customisation of products to meet demands by commercial and private customers as well as the growing number of suppliers call for greater agility of production networks. This can even mean repatriation and regionalisation of at least final manufacturing and assembly operations. This means that demands on logistics service providers are also increasing: Supply relationships are becoming shorter-term, transport volumes decreasing, and storage concepts are increasingly being decentralised.
- **Greater digitalisation and transparency of the supply chain:** In order to keep pace with the digitalisation of business processes and to master the growing flexibility and complexity of the supply chain, many industrial customers require a steady flow of digital information in logistics in order to ensure a high degree of transparency of the flow of goods across factories and companies.
- **Platform operators as new stakeholders:** Many operators of digital logistics platforms - be it marketplaces for freight or IT infrastructures for the management of logistics processes - do not come from the industry itself, but from the fields of IT and automation. The marketplaces, for instance, are mostly start-ups (more on this in the next section), while the systems for process management are supplied by established companies, such as SAP, Microsoft, General Electric or Bosch. This means that completely new stakeholders are entering the playing field. Many logistics service providers fear that direct contact with industrial customers will be restricted or even completely eliminated by such platforms.

5.2 Start-up environment

In recent years, there has been a sharp rise in logistics start-ups worldwide, both in terms of numbers and financing volumes. US provider Flexport, founded in 2013, for example, uses an online dashboard to broker logistics services offered by partners, primarily for sea and air freight. The start-up, which is still mainly active in the US, has received a total of USD 204 million in

41 Schwemmer: TOP 100, 2016 (see footnote 42); Schwemmer; TOP 100, 2017 (see footnote 43).

42 According to: Wolfgang Kersten et al.: Trends und Strategien in Logistik und Supply Chain Management – Chancen der digitalen Transformation, ed. Bundesvereinigung Logistik, DVV Media, 2017, as well as: Klaus van Marwyk and Sascha Treppte: Logistics Study on Digital Business Models. Results, ed. Roland Berger, 2016.

financing capital since 2014. Other companies offering online platforms are also currently being financed with large amounts of money. Besides Flexport, these include, for instance, German freight broker FreightHub which was financed by Rocket Internet with EUR 3 million. Platforms for data analysis are also popular, such as the Norwegian company Xeneta which was financed with EUR 20 million and enables consignors and shipping companies to carry out detailed analyses of freight rates on the market.

Overall, a large proportion of software-based logistics start-ups receive substantial financing from the US, Europe and Asia (see Fig. 31). Besides the US, China, Germany and France, nations with larger industrial production volumes also have a role to play here. Since venture capital financing is traditionally very strong in the US, the average amount of financing per company in North America (EUR 6.68 million) is also higher than in Asia (EUR 5.92 million) and Europe (EUR 4.66 million).

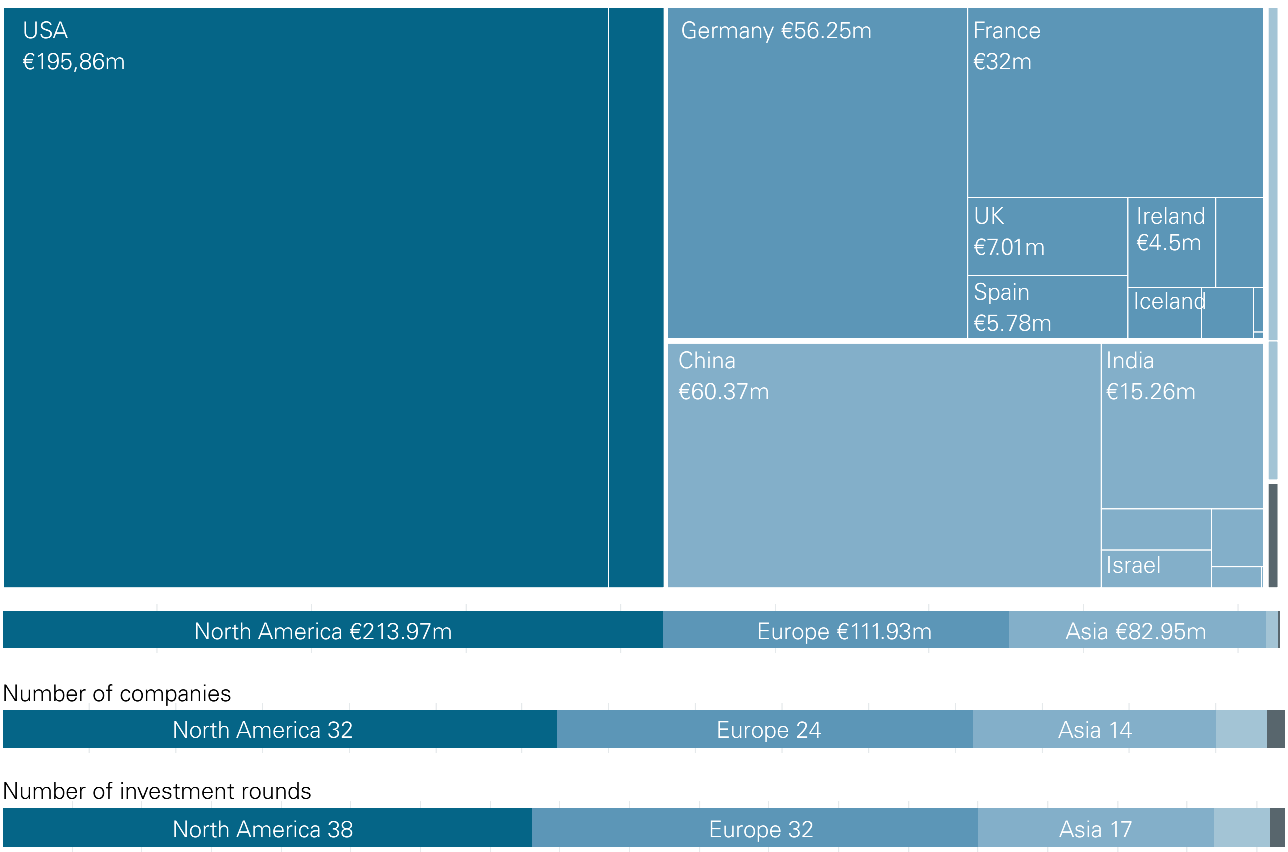

Fig. 31: Financing of software-based logistics companies worldwide in 2016 (diagram by the authors, data from www.crunchbase.com)

However, the business concepts of start-ups in the logistics sector go far beyond platforms and data analytics. A survey of 42 logistics start-ups in Germany, Austria and Switzerland by Oliver Wyman management consultancy lists other topics, such as robotics and autonomous trucks, dispatch and tracing, as well as asset management (in 2016).[43] In individual cases, however, it may be difficult to assign a start-up to the logistics industry. The Kinemic

43 Oliver Wyman: Logistik-Start-ups in Deutschland, Österreich und der Schweiz, 2016. Press diagram for a press release titled 'Start-ups rollen Logistikbranche auf', 3 January 2017 (http://www.oliverwyman.de/media-center/2017/Start-ups-rollen-Logistikbranche-auf.html, retrieved 21 December 2017).

start-up, for instance, offers a gesture control system for industrial use which can be used both in assembly and in order picking.

German logistics companies are currently still reluctant to invest in start-ups. Commitments such as DHL's investment in the Saloodo freight exchange and in e vehicle manufacturer Streetscooter or DB Schenker's investment in the uShip online freight exchange are still the exception. In the meantime, however, first companies from the logistics industry have also established their own accelerators, following the example set in other industries. Such logistics accelerators in Germany are the DB Accelerator of Deutsche Bahn, the Next Logistics Accelerator, supported by Logistics Initiative Hamburg and Hamburger Sparkasse, and Beyond1435, a joint accelerator of Alba, Bombardier, Deutsche Bahn, Plug and Play, Siemens, SBB and TUI.

5.3 State of the art

Information and communication technology (ICT) already has a key role to play today, especially when it comes to the value-added services of the 3PL and 4PL concepts. However, acceptance and dissemination of the individual ICT technologies in logistics differ considerably from sector to sector.[44]

Central ERP and warehouse management systems are state-of-the-art in the logistics industry. The same applies to logistics planning systems. Cloud technologies (software-as-a-service, infrastructure service, infrastructure-as-a-service, platform service, platform-as-a-service) are also tried-and-tested and are becoming increasingly common in practical applications. Cloud systems generally also form the technical basis for the above-mentioned logistics platforms, i.e., online marketplaces or middleware systems for managing logistics processes which are becoming increasingly important in practice. Optimisation of very large logistics networks is still a challenging exercise, especially if the different planning levels are to be interconnected: strategic planning of the network itself, tactical planning of the basic logistics processes and operative planning of the actual processes. Optimisation methods for very large networks or methods involving several planning levels currently remain a topic of applied research in mathematics.

Technologies for capturing the data of goods, containers and transport machines (barcode, 2D code and RFID for identification, localisation via satellites, sensors for condition monitoring) have been tried and tested for some time now and are already widely used.

Indoor navigation in warehouses, for instance, is still a challenge because satellite signal reception is difficult in industrial buildings. Although numerous technical approaches are available for localisation in buildings, such as WLAN cards or beacons, these are often unreliable in industrial areas where conditions for radio communications are difficult or they require very extensive and expensive infrastructure.

Data analytics, such as predictive analysis to predict future demand, and predictive maintenance to predict component and machine failure are well-known and tried-and-tested concepts in manufacturing (and trade). Predictive analyses can also be a very useful optimisation tool for logistics service providers. Given the availability of suitable analyses, the amount of data generated during transport and transshipment could be used to begin planning the provi-

44 This section is based on Kersten, 2017 (see footnote 46).

sion of logistics resources at an early point in time or to detect disruptions in logistics processes at a very early stage. In view of the volume of data, deep learning and machine learning methods would be particularly suitable for this challenge. However, logistics-specific AI-based methods of predictive analysis are still lacking.

In the field of assistance systems, mobile devices for employees are already very widespread. Light-controlled or voice-controlled picking (pick-by-light, pick-by-voice) are tried-and-tested, but still relatively uncommon concepts. Technically valid concepts are already in place for wearable devices (wearables), such as smart watches, and for augmented reality solutions, today typically in the form of data glasses, but real-life practical applications are still rare. The biggest challenge at present is voice or gesture control of the devices. Problems exist in industrial environments, which are often noisy and insufficiently lit to permit gesture recognition.

5.4 R&D developments

Besides the above-described ICT technologies, which are currently undergoing an evolutionary process, there are two R&D developments which, according to experts, have the potential for disruptive developments in industrial logistics:

Autonomous vehicles, especially HGVs, offer the possibility of relieving or even completely doing without drivers during monotonous activities, especially when driving on motorways. The latter case, in particular, could be of enormous importance for industry in view of the looming shortage of drivers. Driver assistance systems are already widely used, especially in HGVs, and some HGV manufacturers are also working on autonomous trucks. However, it is not yet foreseeable when and to what extent driverless HGVs will become a reality, and this also holds true for autonomous driving in general. An intermediate stage that has already been prototypically implemented is platooning, where several driverless HGVs on a motorway follow a vehicle which still has a driver. Autonomous driving of large vehicles has already been prototypically tested more frequently on non-publicly accessible sites, such as construction sites and factory premises, and autonomous HGVs are already in use in first mines.[45]

The biggest disruption of the logistics industry resulting from information technology is not so much expected from technical innovation as from process innovation, i.e. from the digital platforms. While online marketplaces for freight have become established, albeit to a limited extent, and no longer raise any fundamental technical or organisational questions, the situation is still different for management systems for logistics processes. These systems are directly connected to the real objects in production and logistics environments, where a high degree of reliability is required. Concrete application examples often still require complex development work in order to ensure that common data and communication standards are observed, that objects can in fact be identified automatically and that communications meet the relevant latency and bandwidth requirements. Most German technology projects for logistics platforms, which are largely supported by the Federal Ministry for Economic Affairs and Energy (BMWi), were and are therefore application-orientated and in each case implement individual pilot projects that serve as role models for the respective industry. These include the former RAN project (RFID based Automotive Network)[46] as well as current projects in PAiCE: iSLT.NET

45 In retail logistics, overcoming the 'last mile', i.e. the last section of the route to the end user, is believed to have considerable potential for autonomous vehicles, such as parcel drones and moving delivery robots. First prototypes already exist in this area too. R&D challenges lie especially in the robustness and functional safety of the devices, which ideally should operate in open and challenging environments. In the case of delivery drones, these are typically impassable terrain in mountains or on islands, and in the case of delivery robots, pavements in city centres.

46 www.autonomik.de/de/ran.php (retrieved 21 December 2017).

(Management of modular special load vehicles)[47], SaSCh (Tracing and monitoring of supply chain transport gaps)[48] and Add2Log (Production of spare parts in 3D printing by the delivering logistics service providers)[49]. Besides aspects of technical adaptation and expansion, these projects are also designed to test which operating and business models are suitable for the platforms. Apart from the still very generic patterns of business models for Industry 4.0, which were developed as part of the GEMINI[50] project, there are still no valid general statements regarding the economic design of such networks.

Most of the funding for further development efforts in technical sub-areas, such as sensors or industrial radio communication, which are in most cases evolutionary, is channelled via the research programmes of the Federal Ministry of Education and Research (BMBF), especially under the 'Innovations for production, services and work of tomorrow'[51] programme. The BMBF project on the 'Industrial Data Space'[52] has overarching relevance: Several Fraunhofer Institutes are working in this project to develop a reference architecture for a 'virtual data room' which companies can use to exchange data in shared value networks. The Industrial Data Space has the potential to become an enabling technology for logistics management, but it faces competition from numerous proprietary middleware systems such as the Bosch IoT Cloud and Microsoft Azure.

At European level, two projects are working on cooperative approaches in logistics. The NexTrust[53] project with 31 partners primarily addresses the consolidation of transports, i.e., combining shipments from different consignors in one transport. Organisational and technical models for building 'trustworthy networks' are being developed and tested in pilot projects for this purpose. The AOELIX[54] project is developing a concept for and testing an IT platform that integrates existing logistics information systems, thereby enabling the development of comprehensive IT solutions for logistics applications.

Many experts also see blockchains as an enabling technology for logistics management platforms. The main argument is that Smart Contracts constitute a distributed infrastructure that makes digital information on transactions forgery-proof and transparent for all without the need for a trusted third party.[55] The ports of Antwerp and Rotterdam announced that they will test blockchain technologies, and the Maersk shipping company together with Microsoft already carried out a blockchain pilot project for ship insurance. However, there are some very challenging research questions in terms of detail: How is the very complex process of mining the new blocks in the blockchain to be designed? How can it be ensured that confidential information contained in the blockchain is not visible to all partners in the system despite its transparency? Such questions are also addressed in the BMBF's new guideline titled 'Zivile Sicherheit – Kritische Strukturen und Prozesse in Produktion und Logistik' (Civil security – critical structures and processes in production and logistics).[56]

5.5 Projects of the logistics cluster

The progress achieved by the supported iSLT.NET and SaSCh projects since the beginning of the PAiCE technology programme is presented on the following pages.

47 www.project-islt.net (retrieved 21 December 2017).
48 www.sasch-projekt.de (retrieved 21 December 2017).
49 www.projekte.fir.de/add2log (retrieved 21 December 2017).
50 www.geschaeftsmodelle-i40.de (retrieved 21 December 2017).
51 www.bmbf.de/de/innovationen-fuer-die-produktion-dienstleistung-und-arbeit-von-morgen-599.html (retrieved 21 December 2017).
52 www.industrialdataspace.org (retrieved 21 December 2017).
53 www.nextrust-project.eu (retrieved 21 December 2017).
54 www.aeolix.eu/ (retrieved 21 December 2017).
55 Niels Hackius and Moritz Pertersen: Blockchain in Logistics and Supply Chain: Trick or Treat?, in: Carlos Jahn et al.,ed. Digitalization in Supply Chain Management and Logistics (= Proceedings of the Hamburg International Conference of Logistics, 23), 2017.
56 www.bmbf.de/foerderungen/bekanntmachung-1402.html (retrieved 21 December 2017).

iSLT.NET

Company-spanning network for smart, modular special load carriers

Brief description

iSLT.NET is designing, implementing and evaluating a network for smart, modular special load carriers. A company-spanning, interconnected IT and communication infrastructure is being created in order to achieve greater transparency for the logistics process. New business models for using load carriers are also being developed. Reconfigurability of the containers is leading to innovative operator models, such as pooling or pay-per-use.

www.project-islt.net

Current developments from the project

The iSLT.NET project was officially launched in February 2017. The specifications for the planned network of modular special load carriers have now been completed (see Fig. 32). Requirements for services, the load carrier and its modularity, the sensors and the IT infrastructure were documented in this context. Furthermore, application partners Dräxlmaier and BMW defined the reference application scenario for the prototype implementation and evaluation of the iSLT (intelligent special load carrier). Based on this, the entire supply chain of the special load carrier from development, production, use and management of the companies involved was mapped and the resultant costs were presented in a lifecycle calculation. One result is that the acquisition costs of a load carrier amount to just around one sixth of the total lifecycle costs over a period of seven years.

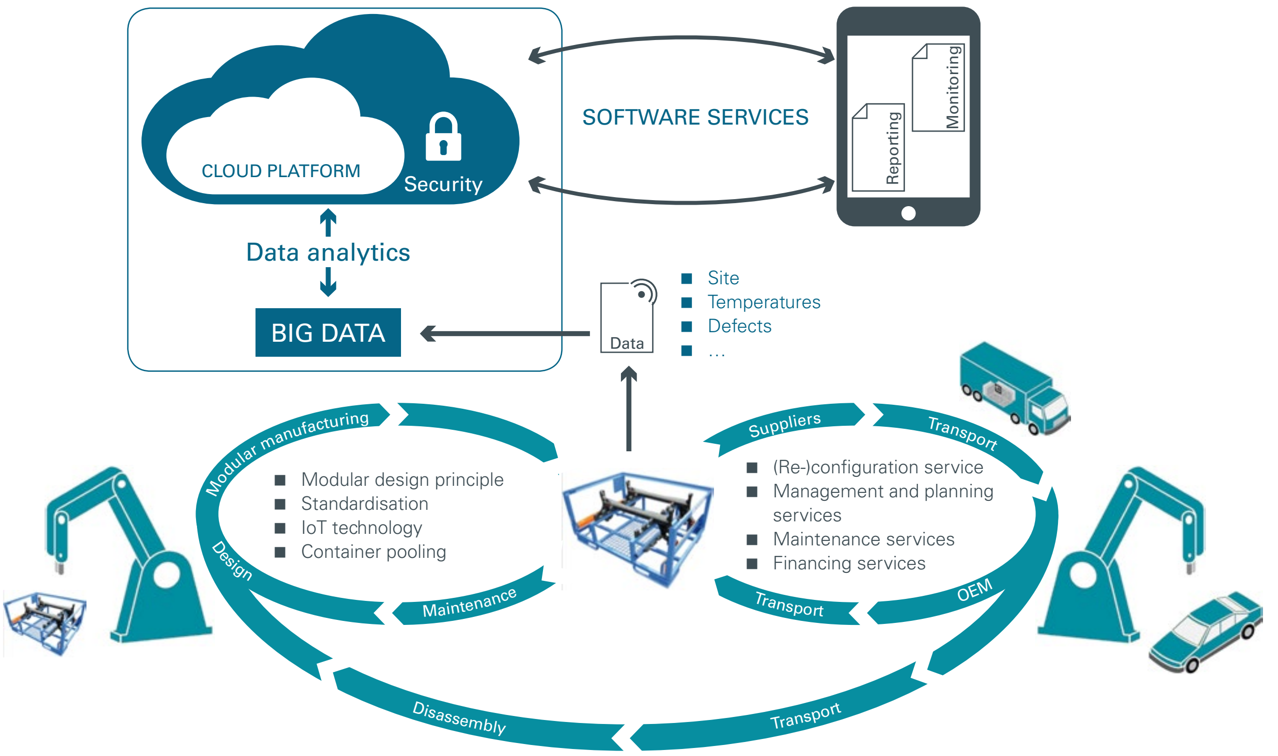

Fig. 32: Structure of the iSLT.NET platform (source: iSLT.NET)

In a next step, the benefit of using an iSLT is to then be evaluated in qualitative terms. Moreover, elements that can be influenced in the lifecycle analysis will be calculated according to the target costing principle. The business model of container manufacturer Gebhardt Logistic Solutions was analysed in order to subsequently realign it over the entire project term and to transform it from a model for a product supplier into a model for a service provider. The realignment of the business model was based, amongst other things, on services that were developed. It was found that 13 out of a total of 22 services are in fact relevant for the application partners and that these would be used within the framework of a new business model. In a next step, these will be translated into concrete service concepts and elaborated in the form of target processes.

Acceptance is scheduled for early 2018 for critical topics that are crucial for the success of the future business model, such as the development of modularity concepts for load carriers. The sensors will also be selected in early 2018. Existing technologies that fulfil the requirements documented in the specifications include, for instance, telematics, LPWAN, WiFi/WLAN and Bluetooth. In some cases, testing of the above-mentioned technologies is already underway or planned. The steering committee of the project partners will decide on the final acceptance of the respective milestones and the selection of the sensors and/or the modularity concept.

In March 2017, the iSLT.NET project was presented at the Logimat logistics fair in Stuttgart. In November 2017, the project and, more importantly, the change in business model were presented at the Digital Day in Fulda. In December 2017, the iSLT project published first results in the Zeitschrift für wirtschaftlichen Fabrikbetrieb ZWF journal.

Consortium

GEBHARDT Logistic Solutions GmbH (consortium leader), Dräxlmaier Industrial Solutions GmbH, BMW Group, Fraunhofer ISS Center for Applied Research on Supply Chain Services SCS, Landshut University of Applied Sciences – Chair for Production Management and Logistics, TU München – Chair for Materials Handling, Material Flow, Logistics

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SaSCh

Digital services for interconnected supply chains

Brief description

The SaSCh project is developing a system for a smart, interconnected supply chain which consistently collects data with quality and condition relevance. Mobile and stationary sensors are also used. Based on the data collected, digital services are provided for the companies involved, so that they can identify transport problems at an early stage and provide assistance. The aim is to achieve lean and robust supply chains without special transports, rework, production downtimes and product recalls.

www.sasch-projekt.de

Current developments from the project

The requirements were analysed and specifications drawn up for the application scenarios in order to develop the SaSCh concept of an agile supply chain. The scenarios cover quality assurance in production and sensor-monitored road and sea transport of parts to a car factory in the US (see Fig. 33). The analyses and specifications included the inclusion of the processes in the scenarios, an analysis of weak points in order to identify quality risks and the development of a catalogue of measures. Fields of action and system requirements were identified on this basis. Furthermore, the partners began to further refine the EPCIS standard which forms the basis for SaSCh. Among other things, they developed a concept for using the EPCIS standard to exchange sensor and quality data. For this purpose, the EPCIS acquisition interfaces and the information obtained were described in EPCIS XML structures. A work request for global standardisation for exchanging sensor and quality data was also developed. The development of the sensor system is based on a specifically developed system design for sensor-based object monitoring in the supply chain. The basis is a new, small and cost-effective sensor which will not only measure temperature and shock, but also humidity. The infrastructure in the form of a sensor-gateway system was tested and first measured values were generated. Cross-country trips and an intercontinental trip to the US were carried out for this purpose. The development of image recognition methods for quality evaluation focuses on checking the correct number of products on trays. For this purpose, the partners tested different 3D camera models, with low-priced models from the consumer products sector also proving to be generally suitable.

Furthermore, the development and software implementation of digital services is also underway. The identification of digital services has been completed, and an architecture model for developing digital services has been set up. The partners also addressed the development of business models against the background of legal issues, exploitation opportunities and public relations work. A model demonstrator is under development or under construction. The EPCIS-based exchange of sensor data was published in the 'Industrie 4.0 Management' journal. The project was presented in a paper on 'Digital services for designing agile supply chains' at the Logistics Day.

The presentation of the SaSCh project with the model demonstrator is scheduled for Hannover Messe in April 2018. By autumn 2018, development of the sensor systems will be completed and the integration and validation of the system components developed will begin. Digital services are scheduled for completion by the end of 2018, and the project will be completed by the end of 2019 when the remaining work packages are completed.

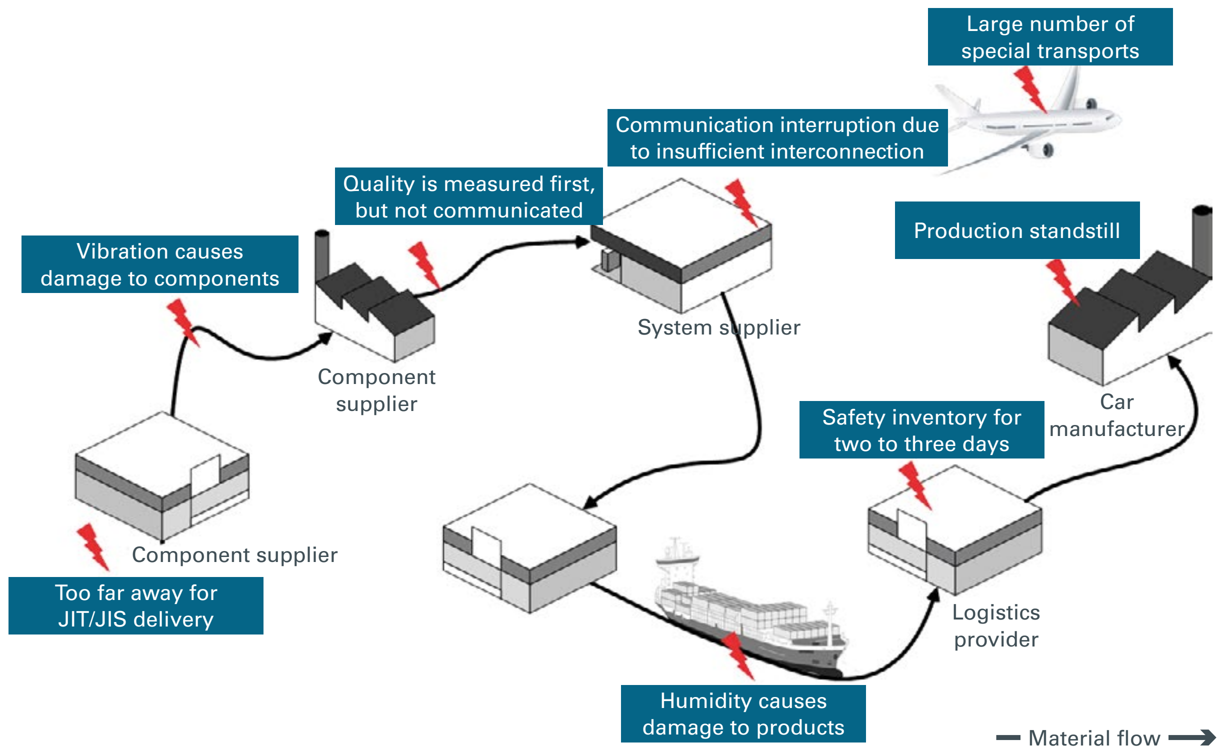

Fig. 33: Tracking a component transport in the SaSCh project (source: SaSCh)

Consortium

queo GmbH (consortium leader), BIBA - Bremer Institut für Produktion und Logistik GmbH GmbH, BLG INDUSTRIELOGISTIK GmbH & Co. KG, GS1 Germany GmbH, Robert Bosch GmbH

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6 The Communication cluster

System architectures for industrial communication

6.1 Market analysis

Industrial communication is a segment of the market for automation systems, i.e. for products and services that can be used to control technical systems in production, logistics, power generation and supply as well as transport largely without human intervention. Automation technology is one of the strengths of the German economy. In 2016, German companies in the electrical and electronic industry generated sales of EUR 40.9 billion with automation systems (excluding electric drives), with exports accounting for 71 percent of this figure.[57]

Just like the entire plant and mechanical engineering sector, the automation industry is medium-sized; large suppliers such as Siemens are the exception. However, increasing horizontal and vertical interconnection of production and logistics systems in Industry 4.0 is creating new products and services for industrial communication, and new competitors are entering the market. The market for industrial communication essentially comprises three areas, the first one being the established market for network devices and components. The other areas are telecommunication services and the relatively new cloud-based systems for more far-reaching value-added services. The companies positioning themselves in the latter two segments now tend to be from the ICT industry rather than the automation sector.

6.1.1 Networks

Devices and components for industrial communication are traditionally offered by system providers for turnkey automation solutions, such as Siemens, ABB and Rockwell Automation, but also by a large number of medium-sized companies. Similar to other communication systems too, technical standards have an important role to play. The market for the older network systems (‘field buses’) is dominated by manufacturers of so-called programmable logic controllers (PLCs) which are used to monitor and control machines or systems (see Fig. 34). The large PLC manufacturers prefer a fieldbus standard which they are supporting strongly. These include, for instance, Profibus for Siemens, Modbus for Schneider Electric (France), ControlNet for Rockwell Automation (US) and CC-Link for Mitsubishi (Japan). For some years now, however, communication systems have also been increasingly used based on the very common Ethernet standards for IT networks and which are adapted to the special requirements of industry, for instance, with regard to robustness and guaranteed message runtimes (‘Industrial Ethernet’). As with fieldbuses, a variety of industry standards developed in this case too, which were then often further developed by PLC manufacturers on the basis of existing fieldbus standards, such as Profinet as a further development of Profibus. Even if the majority of all machines and systems still communicate via fieldbuses, experts expect that Ethernet systems will prevail in the long term. They offer better technical features, such as the available bandwidth, and are also compatible with common network technologies.[58] This opens up the market for new device manufacturers. In the important sub-segment for so-called Managed Industrial Ethernet Switches[59], Cisco, as one of the leading manufacturers of network systems, has now assumed an important role, joining the group of existing suppliers of automation systems, such as Siemens, Beckhoff, Rockwell Automation and Schneider Electric.[60]

57 ZVEI: Elektroindustrie in Zahlen, 2017. This includes switchgear, industrial controls, measuring systems and process automation.
58 Michael Volz: Trends in der industriellen Kommunikation, in: Polyscoope 8, 2016.
59 Switch: A component to connect different devices to form a network.
60 Technavio: Global Managed Industrial Ethernet Switches Market 2017–2021, 2016.

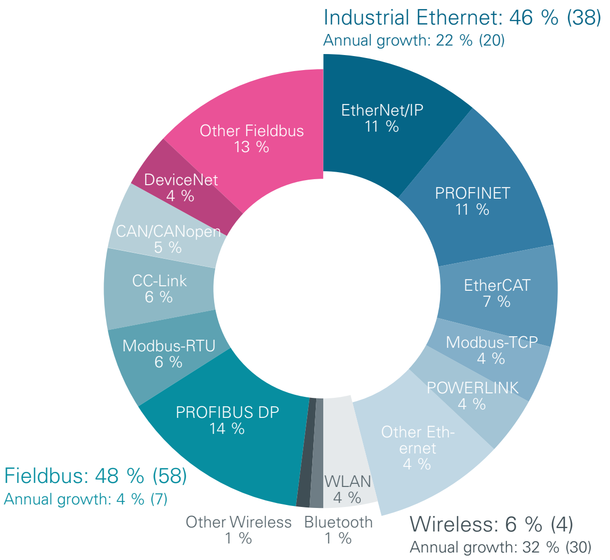

Fig. 34: Market shares of industrial networks (diagram by the authors, data according to Volz 2016[62])

6.1.2 Telecommunication services

Wired systems offered by telecommunications companies are still used today to connect different production and logistics system locations. However, suppliers are under high price pressure and sales have been declining continuously for years, even though data volumes have been increasing (also continuously) for years. This also applies to the corporate customer business which currently totals EUR 21.4 billion in Germany and accounts for around 36 percent of the total market for fixed-net and mobile communications in Germany.[61]

The obstacles hindering site-spanning Industry 4.0 applications are Germany's broadband connectivity which, at best, corresponds to the average performance of other industrialised countries as well as the evident supply gaps in rural areas.[62] Many experts blame Deutsche Telekom's continued dominant role as a former monopolist for the insufficient fibre optic network coverage.[63]

However, it is foreseeable that machines and systems will not only communicate via wired networks. Radio-based communication is often easier and cheaper to implement. Mobile machines, such as driverless transport vehicles or non-stationary service robots, cannot be connected to a network cable anyway. This means that further players will enter the market. This applies to providers of technical solutions for near-field communication via standards, such as WLAN, Bluetooth or Zigbee, who will also increasingly offer products for industrial users.

Mobile radio, however, is even more important. The use of data messages via mobile radio networks is already common practice in wide-ranging logistics applications. But mobile radio is also often a meaningful alternative in production facilities and factory premises because it is not necessary to install a separate structure for WLAN access points or similar solutions. In view of stiff price pressure, many telecommunications companies see M2M (machine-to-machine) communication as an important new business field. This is all the more valid as the current definition of the new 5G mobile communications standard allows the special requirements of industrial users to be taken into account from the very beginning. This is a particularly important aspect because many industrial users are still sceptical about mobile radio and have concerns regarding its availability.[64]

Estimates suggest that the global telecommunications market for M2M will increase to EUR 35 billion by 2019 (2015: EUR 19.4 billion). Besides the market for data communications (2019: EUR 35 billion), markets for the corresponding communications modules (2019: EUR 5.1 billion) and for software and services (2019: EUR 15.1 billion) are also growing.[65] Here too, suppliers tend to come from the telecommunications rather than the automation systems industry.

61 Dia62log Consult, VATM: 19. TK-Marktanalyse Deutschland 2017, 2017.
62 See the Broadband Atlas (Breitbandatlas) issued by the Federal Ministry of Transport and Digital Infrastructure (BMVI): www.breitbandatlas.de.
63 Bernd Beckert: Ausbaustrategien für Breitbandnetze in Europa. Was kann Deutschland vom Ausland lernen?, Bertelsmann Stiftung, 2017.
64 Michaela Rothhöft: Marktstudie Industrielle Kommunikation, Herner, 2017.
65 IDATE: DigiWorld Yearbook, Montpellier, 2016. Up-to-date figures for the German market are not available.

One obstacle to the development of this market could be concerns on the part of industrial users about becoming too dependent on a mobile network provider. They specifically want to control the network management systems on their own premises, either to connect new devices or to adapt network coverage to their own needs. It remains to be seen whether the new 5G standard will take this into account.

6.1.3 Cloud-based platforms for the Industrial Internet of Things

Cloud-based platforms for the Industrial Internet of Things (IIoT) have been increasingly entering the market since around 2014. These platforms typically offer two basic functions: Functions for consolidating and analysing data generated in large interconnected production or logistics applications and functions for controlling processes within the networks. In addition to established automation equipment suppliers, such as Siemens, Bosch and General Electric, companies from the IT industry, including SAP, IBM, Microsoft and Amazon, are also active in this area.[66]

However, the market is not yet consolidated: The platforms still differ strongly in terms of their functions, and the systems have so far only been used in individual and pilot projects. Furthermore, new players have also been entering the market, such as the ADAMOS joint venture, which was only founded in 2017 and is supported by mechanical engineering companies including DMG Mori, Dürr and Carl Zeiss Jena and Software AG and promises a manufacturer-independent approach for an IIoT platform.[67] Market estimates, for instance, sales of EUR 10.1 billion for IIoT platforms in the manufacturing industry in Germany,[68] are therefore currently pure speculation.

6.2 Start-up environment

Most start-ups in the industrial communications sector naturally offer either hardware or software products that can be developed and produced with comparatively limited effort, whilst the provision of telecommunications services is reserved for large and established telecommunications companies due to the very high infrastructure costs involved.

New companies developing hardware for IT networks are based almost entirely in the US (without differentiation in terms of hardware for industrial and other applications). In 2016, for example, all 17 publicly known financing rounds in this segment went to 14 companies from the United States (see Fig. 35). EUR 244 million was invested. In a long-term comparison of 435 investments in network hardware companies between 1997 and 2017, the US also dominates the country comparison, accounting for a share of 84 percent. This is hardly surprising given the continuing dominant role of the United States in the IT industry.

The situation is also similar for start-ups working on the upcoming 5G mobile communications standard and which are therefore very close to the hardware sector. Compared to five US companies financed in 2016, only two European companies (UK, France) and one Turkish company received financing while the investments in US companies totalling EUR 31 million by far outweigh those in the other companies. This relatively small investment sum shows that most investors consider 5G-specific start-ups to be a niche sector and

66 A first overview of the platforms available on the market can be found at: www.mandsconsulting.com/industrial-iot-platform-comparison/.
67 www.de.adamos.com (retrieved 9 January 2018).
68 Deloitte: Industrielles Internet der Dinge und die Rolle von Telekommunikationsunternehmen. Hype oder vernetzte Revolution?, 2016.

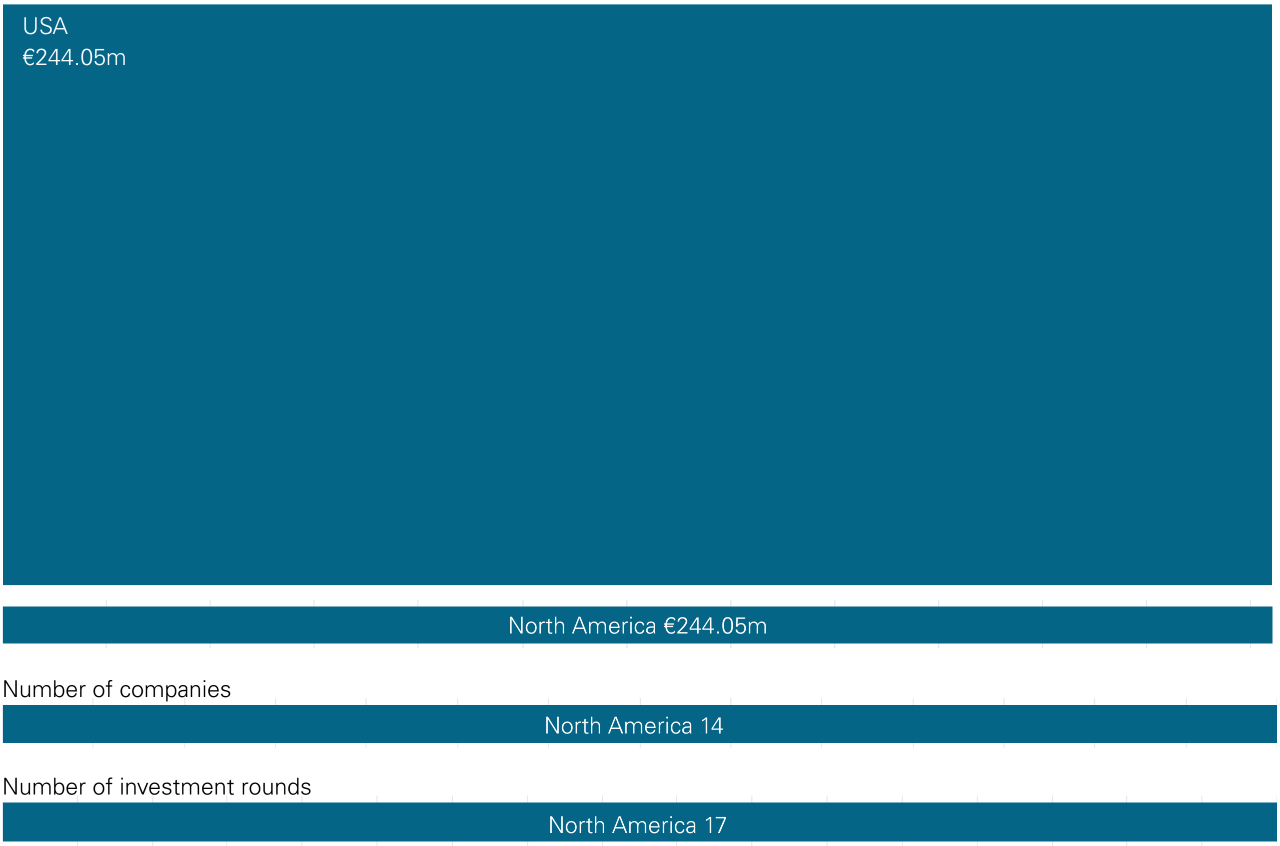

Fig. 35: Investment sums in companies in the area of network hardware in 2016 (diagram by the authors, data from www.crunchbase.com)

rather expect existing companies will embark on 5G technologies in the course of regular product development.

A somewhat different picture exists with regard to financing for companies working on network security, mostly software-based (see Fig. 36). Although the US also dominated this field in 2016, there were also investments in other countries, i.e., Israel, the UK, Switzerland, Japan, China and Germany. Two of the three German start-ups in this list work on cloud systems (Viprinet, Secucloud) and the other one with mobile applications (Appvisory). The total investment volume amounted to EUR 1.5 billion and was thus well above the financing amounts for network hardware and 5G. This reflects the central importance of IT security for the Industrial Internet of Things and the expectation that start-ups can – or even must – set new impulses in the market because established companies are acting too slowly.

On the other hand, not much activity can be seen in the field of financing start-up companies offering cloud-based platforms for the Industrial Internet of Things. In 2016, there were only two small investments totalling EUR 299,000 in Swedish supplier Evothings (mobile application platform) and South Korean ulalaLAB (IIoT platform).[69] The reason for the weak commitment on the part of investors is likely to be that large, financially strong

69 Source: Crunchbase. Query: (iiot OR „industrial internet of things" OR automation) AND (platform OR saas).

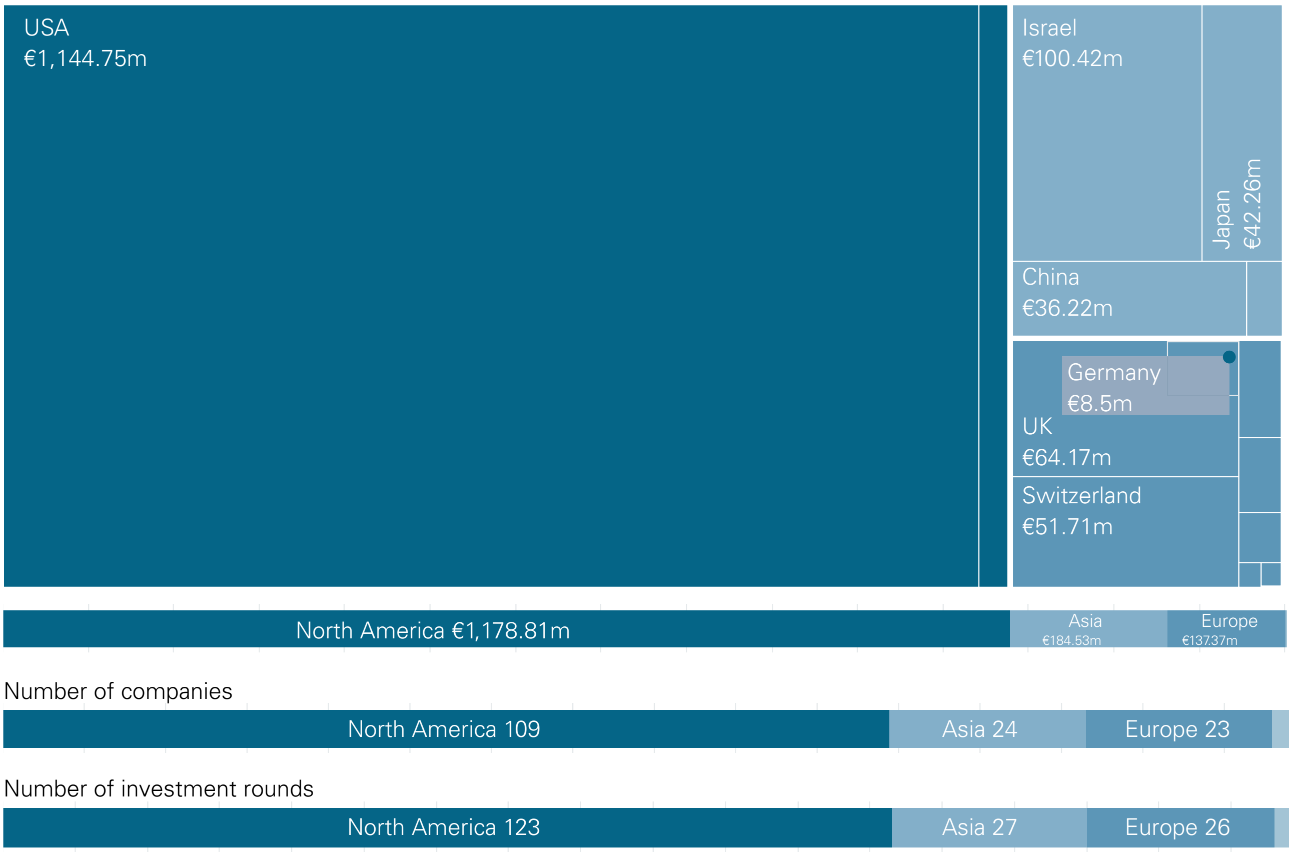

Fig. 36: Investment sums in companies in the area of network security in 2016 (diagram by the authors, data from www.crunchbase.com)

players from the automation technology and IT sectors are already active in this segment and start-ups have only limited chances of establishing themselves successfully here.

6.3 State of the art

Communication systems are essentially dependent on common technical standards. The state of the art is therefore directly reflected by current industry standards and norms. This applies to both the basic level of wired communications and radio communications as well as the real system architectures.

In the case of wired communications, the previous serial field buses are being increasingly replaced by systems that are more or less based on the Ethernet standard as the common standard for IT networks. However, Ethernet itself does not meet the special requirements of industrial applications. It lacks, for instance, the deterministic message runtimes that are necessary for realtime control of machines and systems. The standards must hence be modified in order to actually achieve 'realtime Ethernet'. Depending on the required message cycle times, different classes of realtime Ethernet methods and standards have emerged that are sometimes no longer compatible with original Ethernet standards. Although mature solutions have been available for years, development in this field is far from over; work is underway, for example, on processes with less runtime fluctuations or with improved IT security protection.[70]

Adapting common standards for wireless communication to industrial requirements is even more demanding. This is particularly true since most of these methods rely on the use of the freely usable ISM[71] frequency bands and thus compete with other applications that also use these bands. Common methods, such as WLAN or Bluetooth, are also extended accordingly in radio communications in order to achieve deterministic runtimes and a high degree of robustness. These systems are already in use in certain application areas with less demanding requirements (process control, sensor networks, connection to ERP systems). However, the processes are not yet suitable for controlling machines or assets where requirements for realtime and robustness are very demanding.[72]

OPC-UA (Open Platform Communications Unified Architecture) is currently the predominant approach for the architecture of systems for industrial communications and has become generally accepted in Europe in recent years. Its sponsor is the OPC Foundation, an industrial consortium of companies from the automation and IT sectors. OPC-UA is an open standard architecture that enables consistent communications from the ERP system right through to machine control. The data is also semantically annotated in order to support the integration of third-party systems. The OPC-UA Time Sensitive Network (TSN) communication protocol integrates current realtime Ethernet standards and enables realtime communications within the given technical limits.[73] For the specification and a reference implementation of OPC-UA, the German Federal Office for Information Security (BSI) conducted an IT security analysis which demonstrated the absence of systematic errors. OPC-UA is regarded as a central communication technology for Industry 4.0, especially by German machine builders and automation system suppliers, because machines with controllers from different manufacturers can be easily coordinated in one system.

Besides this vertical approach focused on industrial production, many other architectural models are currently available that instead claim to provide a uniform technical structure for the Internet of Things which extends horizontally across all application areas. Like OPC-UA, they are also based on basic Internet protocols, such as TCP/IP, HTTP, etc. The most important representatives include oneM2M, which is supported by the telecommunications industry, the Data Distribution Service (DDS) of the IT industry-based Object Management Group and the Web of Things of the W3C Internet standardisation committee.

The oneM2M consortium defines standards for M2M communication and includes representatives of standardisation organisations, forums and companies from the telecommunications industry. In contrast to OPC-UA, oneM2M is designed to be application-neutral. The declared aim is to cover areas as diverse as transport, healthcare, home automation and industrial production. Initial pilot projects are specifically working on the issue of interconnecting urban infrastructures (smart city).[74]

70 Martin Wollschläger, Thilo Sauter and Jürgen Jasperneite: The Future of Industrial Communication. Automation Networks in the Era of the Internet of Things and Industry 4.0, in: IEEE Industrial Electronics Magazine, 11 (2017).
71 ISM: Industrial, Scientific, Medical.
72 Andreas Frotzscher et al.: Requirements and current solutions of wireless communication in industrial automation, in: Proc. 2014 IEEE International Conference on Communications Workshops (ICC), 2014.
73 www.opcfoundation.org (retrieved 12 January 2018).
74 www.onem2m.org (retrieved 12 January 2018).

The DDS (data distribution service) standard architecture from the Object Management Group (OMG) has up to now primarily addressed the exchange of data in large, massively distributed systems in the financial sector, the energy industry and air traffic control. The OMG is a standardisation organisation that is supported mainly by the IT industry in the US. Since 2014, the OMG has also managed the business of the predominantly US-based Industrial Internet Consortium (IIC) and since then has also positioned DDS as a solution for industrial communication architectures. The architecture supports the exchange of data in realtime communication systems based on a publish/subscribe messaging architecture model.[75]

The W3C standardization committee, which is known for its web standards, such as HTML or XML, bundles standards and architectural principles for implementing an Internet of Things under the term 'Web of Things'. The approach is based on established web technologies that are independent of the individual underlying communication protocols. Similar to websites in the classic World Wide Web, the individual physical 'things' are to be accessed via unique identifiers (Uniform Resource Identifier, URI) and controlled via functions described in meta information. With the Web of Things, the W3C also addresses a wide range of applications, including home automation, office IT, healthcare and medicine, but also smart cities, energy, trade and factory automation.[76]

So far, none of these general architectural approaches has achieved a dominant position in the Internet of Things. Practical differences are rather small, especially because all models, including OPC-UA, are based on basic standards or at least able to integrate these basic standards, such as HTTPS (Hypertext Transfer Protocol Secure) for secure communications or MQTT (Message Queuing Telemetry Transport) for exchanging M2M messages in unreliable networks.

6.4 R&D developments

Many research projects currently focus on the further development of communication technologies for industrial applications. The future 5G mobile radio standard has a central role to play here since wireless communications are indispensable in many application scenarios and today's mobile radio standards meet the requirements of industrial networks to a very limited extent only.

Network management is at the heart of many projects. They are often based on concepts for software defined networks, i.e., central software-based control of network components, and network virtualisation, i.e. abstraction of the technical management of a network from its physical components. With so-called network slices, a central concept for industrial communication then builds on this. A slice bundles virtual network resources which can now be offered as a service package with the service qualities, such as runtimes and bandwidths, required for the respective application. Dynamic allocation procedures ensure that the slices automatically adapt to the requirements of the applications.

Another fundamental question is currently the distribution of computing power in the

75 www.portals.omg.org/dds (retrieved 12 January 2018).
76 www.w3.org/WoT (retrieved 12 January 2018).

system. A few years ago, centralised cloud computing architectures dominated the landscape. However, centralised storage and management of production and company-specific data did not turn out to be the ideal concept in many situations. Companies run a high risk when their production processes depend heavily on the availability of a centralised cloud infrastructure. Furthermore, requirements for data throughput, bandwidth, realtime communications and IT security in industrial communications are increasing, so that central cloud systems are also proving to be a technical bottleneck in other respects.

The edge computing model therefore provides distributed communication nodes (edges) which can be used locally for time-critical calculations and which exist either in addition to or instead of a central cloud communication unit for data storage and processing. This relieves the central cloud instance, and sensitive process data does not reach the outside world, but instead remains within the company where it is processed locally. This not only increases technical efficiency, but also eliminates concerns regarding the protection of internal company data.

Telecommunications equipment supplier Cisco coined the term 'fog computing' for this distributed concept. The Open Fog Consortium, an industry consortium initiated by Cisco, is currently working on a corresponding reference architecture. The Open Fog Consortium includes hardware manufacturers, such as Cisco, Dell and Intel, cloud computing providers, such as Microsoft, as well as research institutions from the US, China and Europe. In 2016, the consortium and OPC-UA already agreed to co-operate in order to coordinate their standardisation work.[77]

In Germany, 5G – Industrial Internet, 5G – Tactile Internet, and Reliable Wireless Communication in Industry programmes of the Federal Ministry of Education and Research are addressing these research topics. These three programmes currently involve 19 research and development projects, including the following major projects:

The 5G-NetMobil project is developing an infrastructure for interconnected driving and platooning of vehicles.[78] The TACNET project is developing concepts for managing radio connections both for internal company use and across company borders on the basis of cloud computing technologies with a special focus on IT security.[79] SiNSeWa is conducting research into communication infrastructures for maintenance networks in aircraft and railway systems.[80] The ParSec project is developing efficient, hardware-based cryptographic procedures.[81] The HiFlecs project is developing an industrial radio system for realtime control applications with the possibility of integrating legacy systems.[82] One very important project is FIND which is exploring new approaches for managing complex communication systems based on network slicing. The FIND consortium plans to develop a reference architecture model for 5G communication technologies based on its flexible network management concepts.[83]

77 www.openfogconsortium.org (retrieved 9 January 2018).
78 www.forschung-it-sicherheit-kommunikationssysteme.de/projekte/5g-netmobil (retrieved 9 January 2018).
79 www.tacnet40.de (retrieved 9 January 2018).
80 www.ip45g.de/projekte/sinsewa (retrieved 9 January 2018).
81 www.parsec-projekt.de (retrieved 9 January 2018).
82 www.forschung-it-sicherheit-kommunikationssysteme.de/projekte/hiflecs (retrieved 9 January 2018).
83 www.forschung-it-sicherheit-kommunikationssysteme.de/projekte/find (retrieved 9 January 2018).

The IC4F (Industrial Communication for Factories) project, funded by the German Federal Ministry of Economics and Energy (BMWi), is much more application-oriented than the previously mentioned projects, bringing together numerous companies from the telecommunications and automation sectors as well as research institutions. This project will test its results in several use cases.

The European Commission also finances a number of projects investigating 5G technologies in different market segments. Two projects have just started:[84]

> The 5G-RANGE project addresses 5G network coverage in rural areas. Within the scope of 5G-RANGE, an infrastructure for mobile radio networks will be created which will enable profitable business models for operators even in sparsely populated areas.
> The NECOS project is working on the concept of a Lightweight Slice Defined Cloud which virtualises all available network resources and thereby creates a high level of flexibility for the dynamic compilation (orchestration) of these resources. NECOS is implementing slice-as-a-service as a new business model for telecommunications providers.

84 www.cordis.europa.eu/project/rcn/212224_en.html (retrieved 9 January 2018).

6.5 Project of the communication cluster

The progress achieved by the IC4F funding project since the start of the PAiCE technology programme is presented on the following pages.

IC4F

Kit for a trusted industrial communication and computing infrastructure

Brief description

IC4F aims to develop secure, robust and realtime communication solutions for the processing industry. The project will develop an open and domain-spanning reference architecture and a technology kit for an integrated communication and computing infrastructure for industrial communications and data processing. Modular extension for new applications and communication technologies is also possible. Selected application scenarios/use cases will be implemented as prototypes.

www.ic4f.de

Current developments from the project

The analysis of industrial applications from the IC4F user group was successfully carried out and relevant applications for implementing the reference architecture were classified and documented. Applications include a massive factory sensor network, secure remote access and highly reliable realtime machine control. In May 2017, the first IC4F user forum took place at Bosch GmbH in Renningen near Stuttgart with over 60 participants from over 30 companies and scientific institutions from the fields of information and communication as well as automation technology. Meanwhile, more than ten associated partners are contributing to the development of the use cases. The analysis and documentation of internal and external use cases have been largely completed. The second IC4F user forum will take place in March 2018 at Siemens in Munich.

Work has begun on the reference architecture and the technology modules (see Fig. 37). Demonstrators are being prepared and the acquisition or reservation of radio licenses is currently being clarified. Initial specifications are available for the sub-projects of access technologies, communication and computing infrastructure, application layer and security for the reference architecture.

In close cooperation with companies from the German Electrical and Electronic Manufacturers' Association (ZVEI), partners from the IC4F project have successfully incorporated basic applications for the 'Factory of the Future' in the report on the definition of communication requirements (3GPP TR 22.804) of the 3GPP standardisation organisation. These are crucial for Germany's manufacturing industry and have now set an international trend.[85] Furthermore, several aspects concerning Industry 4.0 and RAMI 4.0 were contributed to TR-0018 'Industrial Domain Enablement' in the oneM2M standardisation committee[86]. The project results were also contributed to WG 1 'Reference architectures, standards and standardisation' of the Industry 4.0 platform, in this case under the 'management shell' topic, and WG 3 'Security of interconnected systems'. Talks are underway with the German Institute for Standardization (DIN) in order to identify suitable standards for the horizontal and vertical interfaces of the framework architecture.

85 3GPP: Technical Report 22.804. Study on Communication for Automation in Vertical domains (CAV). Draft, 15.3.2017 (https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3187, retrieved 5 March 2018).

86 oneM2M is a standardisation organisation in the telecommunications industry which develops technical specifications for communication between machines (M2M).

IC4F will be present at BMWi's booth in hall 2 at the Hannover Messe and will hold a workshop on IT security concepts and communication architectures for Industry 4.0 on 24 April 2018. A whitepaper on the IC4F reference architecture will also be published at Hannover Messe, taking the application cases into account. The results to date were also published in three scientific peer-reviewed publications on Industry 4.0, situation-based access control, automated provisioning and deployment of services and IoT applications.

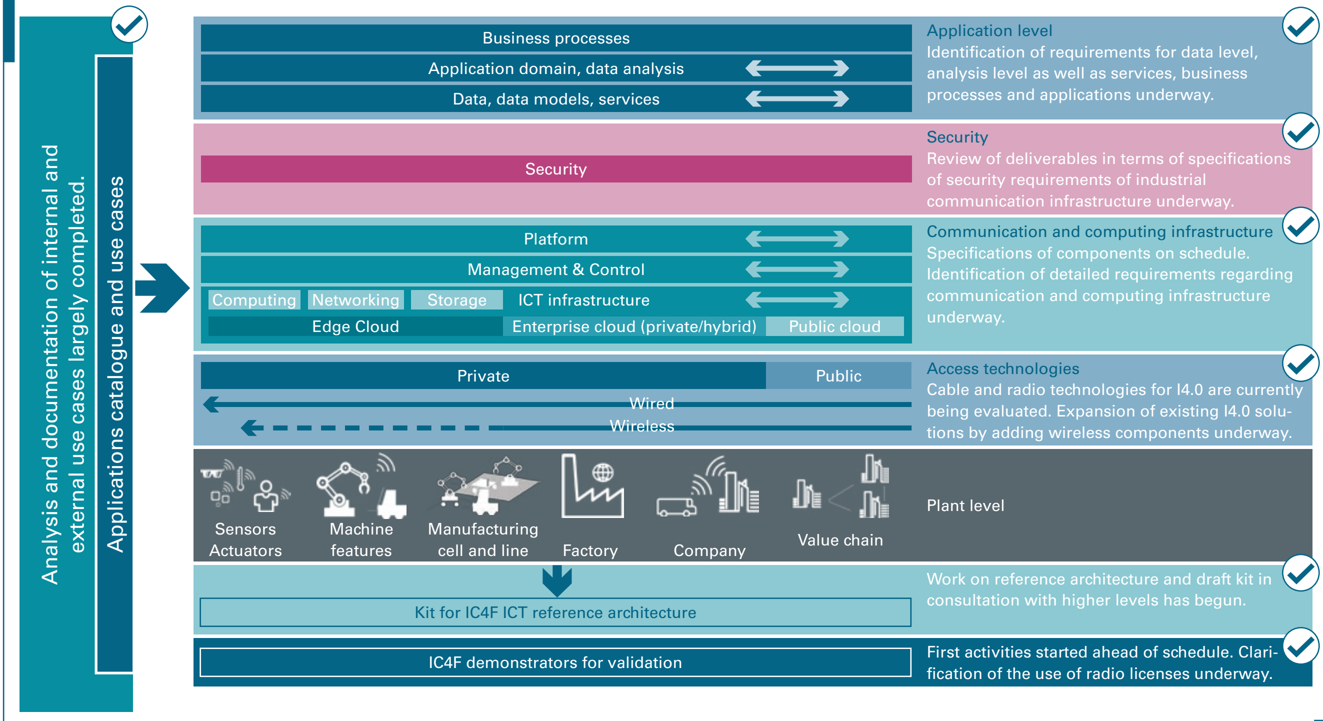

Fig. 37: Structure of the IC4F project (source: IC4F)

Consortium

Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute HHI (consortium leader), Fraunhofer Institute for Integrated Circuits IIS, Robert Bosch GmbH, Deutsche Telekom AG, Gesellschaft für Produktionssysteme GmbH, brown-iposs GmbH, MAG IAS GmbH, Nokia, rt-solutions.de GmbH, Schindler Fenster + Fassaden GmbH, Siemens AG, STILL GmbH, TU Berlin, TU Kaiserslautern, University of Stuttgart

Associated partners in the user forum

ITQ GmbH, Samson KT Electronic GmbH, Schmalz, Benteler, TE Connectivity, Arena2036, HMS, Komsa; Seele, Labs Network Industrie 4.0, BSH Hausgeräte GmbH, Carl Zeiss, Dürr Systems AG

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7 Scientific assistance

In March 2017, scientific assistance to PAiCE began working under the leadership of the Institute for Innovation and Technology (iit) at VDI/VDE Innovation + Technik GmbH. Partners of iit are the German Institute for Standardization e. V. (DIN), Prof. Dr.-jur. Susanne Beck, Law Faculty of Leibniz Universität Hannover, HK2 Rechtsanwälte, Verband der Elektrotechnik Elektronik und Informationstechnik e. V. (VDE) and the LoeschHundLiepold Kommunikation GmbH (LHLK) communications agency.

The tasks of scientific assistance are to interconnect projects with other national and international initiatives, address cross-cutting topics in specialist groups, studies and events, monitor projects, and to support the exploitation of project results, standardisation and the transfer of results.

7.1 News from the expert groups

Cooperative Business Models Group

Systematic as well as tried-and-tested procedures and methods help to ensure the structured development of new business models. The predecessor programme, AUTONOMIK for Industry 4.0, focused on the exchange of experience for the structured development of business models from the generation of ideas to practical implementation. Methods and instruments, opportunities and risks, promising business model patterns and opportunities to expand or renew existing business models were discussed. The result was a guide titled 'Neue Wertschöpfungsketten und Geschäftsmodelle in Industrie 4.0' (New value chains and business models in Industry 4.0)[87]. This guide provides orientation and support for companies that are planning to develop new business models within the framework of the implementation of Industry 4.0 and wish to use new ways of value creation in order to sustainably strengthen their market position. Besides the best-known and widely used general methods for business model development, the guide describes the specific methods focused on Industry 4.0 and the instruments developed in the GEMINI[88] project.

The PAiCE projects are addressing the topic of collaborative business models or directly implementing cooperative platform projects with a larger number of partners. However, when it comes to developing complex business models or platform ecosystems with the participation of various actors, previously known methods for developing linear business models have their limits. Based on the results of the AUTONOMICS for Industry 4.0 technology programme, PAiCE scientific assistance focuses on experience, solutions and methods for joint development of cooperative business models with different partners as well as on the consideration of different market participants with the following questions:

- What are the challenges, opportunities, framework conditions and solutions when developing and implementing new cooperative business models where partners from different stages of the value chain work together in a structured manner?
- What kind of expertise and experience in developing and implementing cooperative business models can the experts from the projects contribute to the work by the specialist groups?
- How can cooperative approaches be implemented? What are the possible roles for individual partners and which partner can generate added value with which contribution?

87 Begleitforschung AUTONOMIK für Industrie 4.0: Leitfaden Band 6. Neue Wertschöpfungsketten und Geschäftsmodelle in Industrie 4.0, BMWi, 2016. Available online at: www.digitale-technologien.de/DT/Redaktion/DE/Downloads/Publikation/Autonomik-leitfaden%206.pdf?__blob=publicationFile&v=4 (retrieved 9 January 2018).

88 Geschäftsmodelle für Industrie 4.0: www.geschaeftsmodelle-i40.de (retrieved 9 January 2018).

- What kind of expertise and experience with new technologies are of cross-project importance for cooperative business models?
- Which methods for developing cooperative business models are available, which experiences have been made with their application and what advantages, disadvantages and limitations do the respective methods have?
- What impact do cooperative/platform-based business models have on the competitive situation, what is the role of network and scale effects in the successful implementation of platform-based business models in industry and how important are openness and trust in the platform in this context?

During the first workshop in Berlin, experts were informed about the cross-cutting issue and exchanged views on the issues and challenges arising from the projects. This provided a good insight into the problems and issues of the individual projects as well as into what remained left for further group work. Participants generally showed great interest in exchanging first-time user experience from the different projects in order to generate learning effects. The following topics met with particularly strong interest:

- Experience with models for partner participation and the development of a common language and culture as well as common standards in order to make cooperative business models work
- Experience and solutions for developing open source business models

Further group work will be continued as follows:

- Presentation and testing of different methods for business model development in specialist group workshops
- Presentation of the various challenges and the respective approaches to solutions that arise during the term of the projects and within the framework of the work of the specialist groups
- Publication of examples and general best practices for developing and implementing cooperative/platform-based business models

The 'Law' expert group

The work of the 'Law' expert group is based on the results of the previous AUTONOMIC for Industry 4.0 programme to overcome legal challenges. At the beginning of the expert group's work, the project partners were introduced to the results of the preliminary work, for instance, in the study[89] titled 'AUTONOMIK: Recht in der industriellen Fertigung' and the guideline[90] titled 'Rechtliche Orientierung für digitale Wertschöpfung'. The guide also describes the legal reference architecture for Industry 4.0 (Ju-RAMI) as a reference model so that legal laypersons can also assess which areas of law are affected in their projects for digitising production. In addition, the articles in the book 'Robotics, Autonomics, and the Law'[91] – another result of the scientific assistance of the predecessor programme – form a good basis for the work by the expert group.

89 Begleitforschung AUTONOMIK für Industrie 4.0: Juristische Herausforderungen für digitale Wertschöpfung. Strukturierte Lösungswege für KMU, BMWI, 2016. Available online at: www.digitale-technologien.de/DT/Redaktion/DE/Kurzmeldungen/Aktuelles/2016/2016-04-26_Recht%20in%20der%20industriellen%20Fertigung.html (retrieved 9 January 2018).

90 Begleitforschung AUTONOMIK für Industrie 4.0: Leitfaden Band 3. Rechtliche Orientierung für digitale Wertschöpfung, BMWi, 2016. Available online at: www.digitale-technologien.de/DT/Redaktion/DE/Downloads/Publikation/Autonomik-leitfaden3.html (retrieved 9 January 2018).

91 Eric Hilgendorf and Uwe Seidel: Robotics, Autonomics, and the Law, 2017. Available online at: www.nomos-shop.de/Hilgendorf-Seidel-Robotics-Autonomics-Law/productview.aspx?product=29896 (retrieved 9 January 2018).

The project partners in the 'Law' expert group addressed the following key challenges through the experts involved (Prof. Beck and Mr Bartels):

- Data protection/IT security law, contract law, copyright law
- Legal challenges in the use of collaborative systems in industry

The requirements of the new EU-wide General Data Protection Regulation call for new strategies for modelling law-compliant data processing in collaboration systems and a consistent guarantee of compliance with IT security guidelines. The company representatives are aware of the fact that this must lead to solutions like privacy-by-design, which require a new way of thinking and clearly defined rights of use. The discussion specifically focussed on the legal assessment of the tradability of industrial data (with and without a personal reference). Also of particular interest are the practical rules to be applied with regard to data access rights as well as data use and evaluation where the technical discussion will be deepened within the scope of PAiCE. The safeguarding of copyright claims is also considered to be an essential issue. Uncertainties exist with regard to appropriate procedures for the collection and allocation of machine and industry data.

Liability issues were discussed especially with a focus on the legal protection of open source developments or damage caused by design errors. Key legal issues include, for instance, the following questions: 'Who is to be held liable in the case of defective open source software which may even have been published in an 'unfinished' state? and 'How to prove in which step of the production process an error occurred?', Answers must be found to these questions. Ambiguity also exists with regard to the distinction between rights of use and copyright, whilst 3D printing, for instance, also raises the need for clarification with regard to the original and forgery issue. This specifically leads to the question of license management options.

The experts and the scientific assistance team agreed on the following next steps for the further work by the expert group:

- Development of a survey methodology to survey the individual interests of the projects in the first quarter of 2018.
- The focus topics for the expert group work in 2018 should be identified on this basis.
- In 2018, a one-day event will be organised in order to determine the specific positions of the consortia and for a more in-depth discussion of the main topics chosen.
- During the further course of the year, webinars on special topics will be offered, such as copyright protection for additive production or data sovereignty of process data.
- Based on the results of the working group, the project partners will identify practical options for handling the expected legal challenges. Solutions to individual cases can be discussed and group-spanning results can be translated into guidelines.
- Preparation of a position paper summarising the main results for legal issues with relevance for PAiCE.

'Trustworthy architectures' expert group

The developments emerging in the PAiCE projects towards digitised, highly interconnected industry platforms are leading to new requirements for the underlying system architectures of industrial ICT systems. At the same time, a high level of functional and information security must be guaranteed in light of strong cross-company interconnections. Standardised interfaces are also required in order to guarantee comprehensive interoperability and, in some cases, the implementation of realtime characteristics.

Guidelines and best practice recommendations for designing, implementing and operating Industry 4.0 platforms and systems have been under development for several years. At an architecture level, the Reference Architecture Model Industry 4.0 (RAMI4.0) of the Industry 4.0[92] platform, the reference architecture model of the Industrial Data Space[93] and the Industrial Internet Reference Architecture (IIRA) of the Industrial Internet Consortium deserve special mention. An initial assessment and comparison of RAMI 4.0 and IIRA 1.7 were carried out within the framework of the AUTONOMICS for Industry 4.0 research programme together with projects, but also with experts from the Industry 4.0 platform.[94] RAMI 4.0[95] creates the structure of the Industry 4.0 domain and provides a common vocabulary that brings together the world of IT (Information Technologies) and OT (Operation Technologies). In contrast to RAMI 4.0, the Industrial Internet Consortium in the IIRA reference architecture model addresses not only production, but also other market segments, such as healthcare, power, smart cities and transport.[96] The IIRA 1.7 reference architecture model has been revised in the meantime. The previously abstract concepts and terminology have been summarised and concretised in the current IIRA 1.8 version. As a result of the comparison of the reference architecture models, RAMI 4.0 was found to provide a useful orientation and structuring approach for the areas of engineering, automation and production.

In their first meetings, the participants of the Expert Group on Trustworthy Architectures identified the following key challenges:

- There is a need for a clear process model (step model) in order to generate trust in the platforms. The process model should begin with the engineering of products and/or production plants and also include the ongoing production process – procurement, manufacture, marketing/sales, shipping/logistics, maintenance and customer support. The requirements from the perspective of all the stakeholders involved – end users, platform operators, component manufacturers, system integrators – must be recorded and taken into account in the process model. Since the development process of the individual components is distributed in a dynamic value creation network, traceability of the properties of the individual components in this structurally new value creation system must be guaranteed.
- General challenges for manufacturing companies continue to address topics, such as safety (functional safety), security (IT security), interoperability of interfaces and

92 'Reference Architectures, Standards and Standardisation' working group: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0). Eine Einführung, BMWI, 2016. Available online at: www.plattform-i40.de/I40/Redaktion/DE/Downloads/Publikation/rami40-eine-einfuehrung.html (retrieved 9 January 2018).

93 FhG: Reference Architecture Model for the Industrial Data Space, BMBF, 2017. Available online at: www.fraunhofer.de/content/dam/zv/de/Forschungsfelder/industrial-data-space/Industrial-Data-Space_Reference-Architecture-Model-2017.pdf (retrieved 9 January 2018).

94 Begleitforschung AUTONOMIK für Industrie 4.0: Softwarearchitekturen für Industrie 4.0 RAMI und IIRA aus Sicht der Projekte im Technologieprogramm AUTONOMIK für Industrie 4.0, BMWi, 2016. Available online at: www.digitale-technologien.de/DT/Redaktion/DE/Downloads/Publikation/autonomik-softwarearchitekturen%20studie.html (retrieved 9 January 2018).

95 ZVEI: Industrie 4.0: The Reference Architectural Model Industrie 4.0 (RAMI 4.0), 2015. Available online at: www.zvei.org/en/subjects/industry-4-0/the-reference-architectural-model-rami-40-and-the-industrie-40-component/ (retrieved 9 January 2018).

96 www.iiconsortium.org (retrieved 9 January 2018).

certification. However, a ‘safe & secure’ process for the collaborative development of hardware and software components must be redefined for the emerging digital platforms. Interfaces with service and component developers specifically require clear-cut rules, standards and process descriptions, but also control in order to create trust in the platforms.

The experts and the scientific assistance team have agreed on the following next steps for the expert group’s further work:

- Structuring of the topics discussed on the basis of value creation networks that arise in the platform-based solutions.
- Identification of cross-sectional components for functionalities, such as data exchange, interoperability tests, management of identity and privacy of platform participants and users.
- As a result, best-practice examples for communication architectures for Industry 4.0 will be identified against the background of IT and functional security issues and summarised in the form of a guideline.

Recent publications

Publications in 2017 and 2018:

Website: www.paice.de
Presentation of all projects as well as scientific assistance and their events and publications
Contact: Lynn Rohwer (LHLK), l.rohwer@lhlk.de

App: PAiCE
Available in the Google Play Store and Apple App Store
Presentation of all projects as well as scientific assistance and their events and publications
Internal communication platform for PAiCE projects and scientific assistance
Contact: Lynn Rohwer (LHLK), l.rohwer@lhlk.de

Program Brochure 'PAiCE – Digitale Technologien für die Wirtschaft'
Overview of the objectives of PAiCE projects and the work of scientific assistance

Short study 'Potenziale der Künstlichen Intelligenz in Industrie 4.0 in Deutschland'
Empirical Study on the value potential of artificial Intelligence for the German economy (April 2018)
Contact: Dr. Inessa Seifert, seifert@iit-berlin.de

Short study 'Open Engineering von Produkten – Chancen und Herausforderungen unternehmensübergreifender Kollaboration'
Case based study on the requirements and challenges of a cross-company and value chain collaborative engineering process
(Autumn 2018)
Contact: Dr. Matthias Künzel, kuenzel@iit-berlin.de

Short study 'Verantwortungsvolle Servicerobotik für Anwendungen im industriellen Arbeitsumfeld und in Dienstleistungsbereichen'
Toolbox for responsible technology design in the field of service robotics (autumn 2018)
Contact: Dr. Julian Stubbe, stubbe@iit-berlin.de

Events

Events in 2017 and 2018:

14 September 2017	Joint kick-off workshop of the three working groups on Law, Business Models and Trustworthy Architectures, Berlin Contact: Birgit Buchholz, buchholz@iit-berlin.de
2 November 2017	Synergy workshop of the Robotics Cluster in PAiCE; Stuttgart Contact: Dr. Steffen Wischmann, wischmann@iit-berlin.de
19 March 2018	Group workshops Smart Data Forum, Berlin Contact: Birgit Buchholz, buchholz@iit-berlin.de
24 April 2018	Workshop 'Blockchain in additive manufacturing (3D printing)' Hannover Messe 2018 Contact: Dr. Tom Kraus, kraus@iit-berlin.de
24 April 2018	Joint Workshop with IC4F 'IT security concepts and communication architectures for Industry 4.0' Hannover Messe 2018 Contact: Dr. Inessa Seifert, seifert@iit-berlin.de
23 to 27 April 2018	Exhibition of PAiCE projects at the joint BMWi booth Hannover Messe 2018 Contact: Lynn Rohwer (LHLK), l.rohwer@lhlk.de
29 May 2018	Group workshops Smart Data Forum, Berlin Contact: Birgit Buchholz, buchholz@iit-berlin.de
19 June 2018	Workshop 'Digital Platforms for Service Robotics' Automatica 2018, Munich Contact: Dr. Steffen Wischmann, wischmann@iit-berlin.de
26 to 29 June 2018	Joint booth of the PAiCE projects Automatica 2018, Munich Contact: Lynn Rohwer (LHLK), l.rohwer@lhlk.de

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