Chapter 2
Description of the Working Field

Computing miniaturization and smart devices change manufacturing. Virtualizations and atomization of resources uncover novel manufacturing principles. Virtual representations of units, processes and resources enforce unaccustomed network properties with strategic impact and irrefutable implications on manufacturing. Eventually, many manufacturing setups might have to be reconsidered in total. Mechanisms from distributed automation, already engaging interacting intelligent manufacturing units and decentralized planning and decision procedures illustrate important effects of this irreversible shift of focus towards collaboration and interoperability. Important ICT developments are telecommunication driven and discussed under different chapters, as Internet of things, Ubiquitous Computing, Cyber Physical Systems, Smart Objects or comparable terminology. The subsequent service approaches for informatising and virtualising manufacturing units and processes propagate a number of powerful and fascinating devices, ready for implementation. Properties, which had been found for distributed automation, now reappear for Manufacturing in total, so the upcoming set ups can be mirrored to the experiences and the findings there.

Distributed Manufacturing, as understood here, is a manufacturing network, whose functionality and performance is independent of the physical distance between the involved systems, units and elements. This includes logical and spatial dispersed units, which cooperate and communicate over processes and networks on order to achieve manufacturing functions (Kuehnle 2010). Evidently, the resulting set of loosely coupled, autonomously acting manufacturing units is subject to principles and modes of complex structures, which are unaccustomed and more general, compared to what is known from automation systems and manufacturing set ups (Kuehnle 2012).

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2.1 Relevant ICT Thrusts

Intensive researches on the converging fields of telecommunications, computer science and engineering have brought vast progress. Miniaturised, smart, highly mobile, multi-functional electronic devices with enormous computation power offering ubiquitous, uninterrupted, and embedded capabilities are already in use in daily life (Adelstein et al. 2005). In consequence, ICT will be inevitably shaking up the entire manufacturing environment in a next phase. Some important IT developments, as cyber physical worlds, have already provoked intensive reactions in the industrialised world; not only on company levels but on national and international levels as well (Open China ICT 2013). More brilliant innovations e.g. the machine to machine (M2M) communication or body area networks (BAN) are about to rapidly diffuse with radical and disruptive consequences for manufacturing. Their potential can impossibly be ignored by manufacturing companies, as these ICT achievements have already proven to be extremely advantageous and utmost efficient in various other sectors (healthcare, mobility); undoubtedly they broadly find their ways into the manufacturing world.

Some years ago, an object virtualization method has emerged, known as Cyber-Physical System (CPS, DCPS if distributed) (NIST 2011; Sztipanovits 2007; Wolf 2009; Lee 2008), meaning the integration of computing systems with physical processes and physical environments. Initial motivation behind the notion of CPS is the need to design and produce reliable and sustainable computing systems that work in harmony with their surroundings (Ptolemy 2013). Components are networked at every scale and computing is deeply embedded into every physical component, possibly even into materials (Sztipanovits et al. 2012; Derler et al. 2012). Incorporating cyber physical systems into manufacturing environments has brought up the terminology of Cyber Physical Production Systems (CPPS), which is e.g. strongly propagated in the national funding scheme Industry 4.0 in Germany; some advocates even highlight the CPPS context as a fourth industrial revolution (Monostori 2014). CPPS is expected to break up the monolithic functional automation hierarchy into virtualized distributed networked nodes that are more difficult to handle. Cyber Physical Robotics covering industrial robots, tools, sensors, actuators with individual virtual representations of their abilities, constraints and properties, called Cyber-Physical-Devices (CPD) represent Cyber-Physical-Robot-Cells (CPRC) (Michniewicz and Reinhart 2014). When using CPPS (VDI/VDE 2013), components could adapt themselves automatically to the other components, which inevitably changes the way these CPS-enabled components are to be designed and manufactured. Therefore, manufacturers see reasons for totally rethinking industry and industrial production to take the full advantages of CPPS (VDI/VDE 2013).

Parallel to CPS (USA), Computer scientist had come up with the Internet of Things (IoT) in the context of ERA (EU). IoT technologies are already applied for accessing and for connecting manufacturing resources. CPS and IoT cannot be clearly differentiated since both concepts have been driven forward in parallel,

although they have always been closely related (CERP-IoT 2009). The IoT can be considered a part of the future internet and be envisioned as a dynamic global network infrastructure with self-configuring capabilities, where physical and virtual objects have identities, physical attributes and virtual personalities; they use intelligent interfaces and they are online connected via information networks.[1] IoT is of vital interest to manufacturing, where the "thing" may typically be the product itself, the equipment, the transportation means, etc.

Triggered by the option of adding more data to any object, we are witnessing the upcoming of a large IoT, where each object has his proper identity (e.g. Eguchi and Thompson 2011); we shall experience smart worlds full of Smart Objects (SO) (Kortuem et al. 2010). A Smart Object (SO) is an autonomous physical and digital object augmented with sensing, processing, and network capabilities.[2] In contrast to RFID tags, SOs carry chunks of application logic that let them make sense of their local situation and interact with human users; coupled with software agent technology however, RFID can transform everyday objects into smart objects as well (Chan et al. 2012). Thus, smart objects and all the developments around are widely discussed as being of highest relevance for manufacturing, as RFIDs are already applied as solution components since years.

Additionally, pervasive computing has migrated from desktops to micro devices, and embedded computing is increasingly integrated into various kinds of objects. Significant progresses have been made in many domains, such as machine-to-machine (M2M) communications using wireless sensor networks (WSNs), as ZigBee[3] and wireless body area networks (WBAN) (Chen et al. 2011). Key achievements refer to easy communication among computers, embedded processors, smart sensors, smart actuators, and mobile terminal devices, without or with limited human intervention (Wan et al. 2012). The rationale behind M2M communication is to generate more autonomous and intelligent applications by networking and interconnecting machines. According to European Telecommunications

[1]Technologies for realizing IoT devices have already been around for years, and have been standardized by the IETF, starting from the lower layers of the stack and moving up. Today, we have IPv6 as a foundation running over links such as those found in mobile networks (2G, 3G and LTE) as well as low power local area sensor networks such as IEEE 802.15.4/6LoWPAN and EPICS. The implementation can be based on multiple agent languages and platforms (JADE, JADEX, LEAP, MAPS) on heterogeneous computing systems (computers, smartphones, sensor nodes).

[2]In 2008, an open group of companies launched the IPSO Alliance to promote the use of Internet Protocol (IP) in networks of "smart objects" (http://www.ipv6forum.com/index.php.) As different definitions of IoT do currently exist, for manufacturing purposes it is useful to refer to IoT as a loosely coupled and decentralized system of smart objects (SOs), which are autonomous physical/digital objects augmented with sensing/actuating, positioning, processing, and networking capabilities.

[3]ZigBee Home Automation is the industry leading global standard helping to create smarter homes that enhance comfort, convenience, security and energy management for the consumer. It appears to be the technology of choice for world-leading service providers, installers and retailers, http://www.zigbee.org/.

Standards Institute (ETSI), standardization plays an indispensable role in long term development of the M2M technology,[4] too. The five elements' structure, as proposed by ETSI, results in three interlinked domains, formed by an M2M area network and M2M gateway, communication network domain and 3G (Lu et al. 2011). A specific Industrial Internet has been brought up by GE (2012), which refers to the convergence of intelligent devices, intelligent networks and intelligent decisions. Industrial Internet is creating the very foundation, needed to make smart manufacturing possible by bringing together brilliant machines, analytics and scalable software platforms to enable nearly instant person-to-person (P2P), person-to-machine (P2M resp. HMI), and machine-to-machine (M2M) communication (Wan et al. 2013).

Ubiquitous Computing (UC), too, has been upgrading objects to smart objects, which can provide customers with new services that could not have been imagined before, because of the steady connection between the real-world objects and the intelligence of information systems. UC denotes another version of a world of smart objects, i.e. physical items whose physical shape and function are being extended by digital components (Langheinrich et al. 2000). UC cannot be considered a proper technology or classified as new functionality, rather a set of functions, which as a sum creates novel computing (Satyanarayanan 2002). Miniaturizations of computer technology provides for smallest processors and sensors for integration into more and more everyday objects, outdating accustomed computing equipment. People will communicate directly with their clothes, watches or pens, and they communicate with each other and with other people's items (Ferguson 2002), surely amazing features with striking relevance for manufacturing.

Cloud computing is a novel model for enabling ubiquitous on-demand network access to a network of computing resources that can be instantly accessed and released with little effort or third party interaction (NIST 2011). A cloud is a parallel and distributed computing net, composed of a set of interconnected computers, presented as one unified computing resource, made available according to service-level agreements (Buyya et al. 2008). Cloud architecture may provide users with options of configurable, virtualized production networks, based on models like federated factories or software-as-a-service applications (Meier et al. 2010). Virtualisations of resources and fast interconnections open up companies

[4]The applications of M2M communications extraordinarily depend on many technologies across multiple industries. The technical standardizations for M2M are proceeding in 3GPP, IEEE, TIA, and ETSI. The ETSI drafting standards for information and communications technologies consider an M2M network as a five-part structure http://www.etsi.org/website/homepage.aspx.

(1) Devices, usually are embedded in a smart device to reply to requests or send data.
(2) Gateway, acts as an entrance to another network. It provides device inter-working and inter-connection.
(3) M2M area network, furnishes connection between all kinds of intelligent devices and gateways.
(4) Communication networks, achieve connections between gateways and applications.
(5) Applications and services pass data through various application services and are used by the specific business-processing engines. Software agents analyze data, take action and report data.

in general, and manufacturing areas in particular, to new services and services' architecture, i.e. cloud hardware-as-a-service (HaaS), cloud software-as-a service (SaaS), cloud platform-as-a-service (PaaS), and cloud infrastructure-as-a-service (IaaS). Virtualized computing resources allow, e.g. combined with RFID, Big Data storage and flow. Cloud ERP and Cloud CRM are already available. Online monitoring and positioning of all products and resources enable tracking and fixing issues in real time, allowing companies to instantly improve all attributes of the manufacturing process. With these technologies, the real-time enterprise (RTE) is approaching.

Moreover, a number of researchers already propagate to specify Cloud Computing into Cloud Manufacturing CM, e.g. (Yang 2010), as a new mode of networked intelligent manufacturing, which is service-oriented and highly efficient. CM pushes the development of the concept of Cloud Computing into manufacturing and may become a networked manufacturing mode with quickest responses to market demand, enhanced competitiveness and facilitated collaborative manufacturing (Zhang et al. 2010). Furthermore, Resource Cloud Encapsulation (RCE) of soft and hard manufacturing resources and resource sharing are projected as services for further resource virtualization in CM (Ming and Chunyang 2013). In IoT and CPS, technologies are already widely in use for accessing and connecting physical manufacturing resources. In RCE, all physical manufacturing resources are seen as fully transferred into logical services; based on complete resource virtualization, RCE technology constructs large-scale virtual manufacturing resource pools that can be directly used for interacting and feedback control of manufacturing. RCE is supposed to largely reduce the coupling between physical resource and manufacturing application by the transferring physical resources into logical resources and virtual CM services with instant utilization, high agility, high security and high reliability. In addition, resource pooling and virtualization enable even more sophisticated solutions under Cloud-Based Design and Manufacturing (CBDM). It is a type of parallel and distributed system consisting of a collection of inter-connected physical and virtualized service pools of design and manufacturing resources (Wu et al. 2012) leading to new perceptions of manufacturing.

All cloud solutions enable to dynamically adapt in order to satisfy unpredictable or unexpected demand; manufacturing clouds support scalability to a certain level, e.g. for manufacturing units, general purpose equipment, and standard components for machining. Given that the cloud is a huge shared service pool of design and manufacturing resources, consumers may easily find some dedicated tools and equipment for specific products in the manufacturing cloud that can satisfy their requirements (Wu et al. 2013).

Public clouds are handled by external providers, and the data of various clients may be mixed in factories, servers or CPUs of the cloud.

Private clouds are internally driven and represent a good choice for companies that need high data protection.

Hybrid clouds combine the models of public and private clouds. They may be the key to acquiring an external supply in scaled form and under demand;

however, these clouds add the complexity of determining how to allocate tasks and processes across these different environments (Macia-Perez et al. 2012).

The sum of the ICT progresses, as outlined above, gives plenty of reasons to revisit key portions of our current manufacturing thinking and to justify revising manufacturing from its basics with the aim of setting up a comprehensive framework, which fully captures distributed manufacturing from a consolidated starting point.

2.2 Revisiting Manufacturing Fundamentals

Since its gradual rise from craftsmanship towards industrial structures, manufacturing has made an amazing pathway through history and time. Especially since the late 80s and the beginning of multiple scientific endeavours, manufacturing has undergone quite a number of fascinating developments, as mass production or mass customisation and with lean manufacturing and fractal factory concepts even revolutionary phases. However, what is to come with distributed manufacturing now has every potential to exceed all imagination. An upcoming smart manufacturing world, fully consisting of intelligent, acting, sensing, negotiating and deciding items and units might reach beyond all conceptual capacity; communicating technology objects and parts will orchestrate fragmented and atomised processes and value chains. Manufacturing industries are highlighted by abilities of perfectly mastering long transformation sequences for efficient value creation by implementing the highest degrees of organisation. Other than everyday use smart objects, as smart phones, smart manufacturing units aim at coherent harmonised process chains in the sense of deliberate sequences of transformation, which self-configure and self-optimise, recognised as additional challenges for CPS (Lee et al. 2015).

Currently, much work is on the way generating concepts on how new developments and achievements from information and communication technology may be synthesised best with classical industrial processes. All efforts to achieve more efficient and more flexible production processes seem to be restricted to approaches for men-machine and machine to machine communication and networking of products and machines on the basis of more or less given processes only. However, considering all impacts on the technology domains concerned as well as their possible melting, the backlash on existing processes and overall business models itself may be breathtaking. Just the logical hierarchy of processes and tasks will remain, whereas the physical hierarchy of technological set ups will steadily dissolve. Highly competitive value chains and successful business models will be jeopardised or even be quickly outdated by new versatile ways of putting processes together and playing the game of in- and outsourcing with partners, service providers and expert communities.

Fundamental changes change fundamentals! Therefore, a most rudimentary description of manufacturing as being

- transformation of material by adding
- energy and
- information

into higher valued output is useful to be recalled for identifying and resetting tipping points, which might be ahead.

A short glance at the field of materials reveals: there have been amazing progresses directly impacting most manufacturing transformation technology, process design and all logic behind. E.g. the introduction of plastics, fibre materials and sophisticated metals are already impressive examples and there is certainly much more to come! Novel manufacturing technologies, as additive manufacturing, allow shifting quite a number of manufacturing activities into the design process of a part or a product. Even very sophisticated one-piece products may be manufactured decentralised and rapidly anywhere and anytime, and even the design may be done using collaborative design tools in a distributed way. Embedding IT (nano-) devices into material and parts will make them smarter, and will once more reshape value chains and redesign business models over time. Again, labour division between suppliers, manufacturers, service providers and customers is reset. In distributed manufacturing, all materials and parts may be IT integrated by pervasive computing, by data information codes, by transponder or by other (nano-) devices. Moreover, all materials and objects may be localised and tracked. DNA code-like coining may include all information about the past and the future of the material, part or product.

For this kind of smart distributed objects, enhanced by pervasive computing, the Internet of things, wireless connections and ubiquitous computing, adequate frameworks are still missing and therefore have to be provided. These frameworks should not only embrace all interactions between the manufacturing technology units, the materials and objects, but also interactions between the materials. E.g. after all respective parts already "know" that they will be joined in the final product, their communication capabilities can easily be used to speed up processes to the make value creation more efficient. Moreover, it should lay ground for identifying principles, methods and tools that establish efficient processes using smart materials.

For putting energy to manufacturing transformations, many additional ways have been paved since the early times of water mills and steam engines. A decisive breakthrough was most certainly the wide use of electrical power. Miniaturisation has enabled the self feeding progress in manufacturing technologies via ever-sophisticating transformations steps bringing up full-scale decentralisation of drives and actuators down to the tiniest subunits. Power storage technologies, as well as future options of energy transfer give novel opportunities to disperse, to decentralise and to distribute energy sources and energy plug-in points. Additionally, more options may be kept in mind, basing on wireless energy

transfer, smart energy grid, low consumption and efficiency optimised devices for self aware autonomous actions for a number of manufacturing applications.

Formerly, the use of information for executing originally pre-reflected, pre-cogitated transformation steps or respective tasks, was exclusively seen in the context of human intelligence and peoples knowledge, ICTs have come up to take over more and more steps for information processing and information input. Starting with simple NC machines, ICT has meanwhile grown up to the visibly dominating part in all manufacturing equipment. ICT abilities as well as its restrictions have decisive impact on how manufacturing transformation steps are defined, assigned and executed. More and larger transformation chains are taken over by ICT, entire value chains can be performed in full automation and around the clock, so even growing parts of human flexibility in executing tasks and processes will be taken over by modern manufacturing equipment.

Miniaturised distributed databases again allow more and different kinds of decentralisations, therefore, radical changes come about with a new manufacturing world, consisting of autonomous smart items (cyber physical production units, online smart objects or things). This is true for both, for the latest automation solutions as well as for manually driven processes, as technologies may be integrated to participate in this novel manufacturing world. The most prominent application, the distributed automation technology, sees smart manufacturing operations as being fully identified, monitored and controlled by computing and IP communication by sensors embedded in objects and structures of the physical environment. Moreover, distributed automation already provides powerful logic for coupling of sensors and actuators, via fieldbus, Service-Oriented Architectures for modelling of business processes, encapsulations of methods and applications, integration and invocation of services on independent platforms, and agent systems from artificial intelligence. In order to minimise complications with other networks, decentralised and intelligent components are enabled to run local decision processes on model-based descriptions. In automation, bringing in the information for the transformations steps is traditionally done by cascaded control, while time sliced ERP plans will be given down to be detailed on the MES level and executed by field control and plc devices. This entire set up is generally referred to as the automation pyramid, representing a monolithic construct for data transfer and processing.

Innovations in Distributed Manufacturing have brought in agent technology and multi-agent systems, simply dissolving this automation pyramid into autonomous units on the MES level (Kuehnle and Peschke 2007). What had been achieved was the successful introduction of the JAVA virtual machine on jini base for enabling machine controls to communicate via the Internet. This way of completely emulating controls for providing full internet compatibility by using a markup language had initially been seen critical. Today, this is the common approach; the initiated automation markup language AutomationML has been promoted by the authors to the IEC 62714 standard in 2014. Moreover, the ability to communicate via Internet does not only connect the controls online, it multiplies their functionalities by granting full access to a plethora of services that have come up around the Internet.

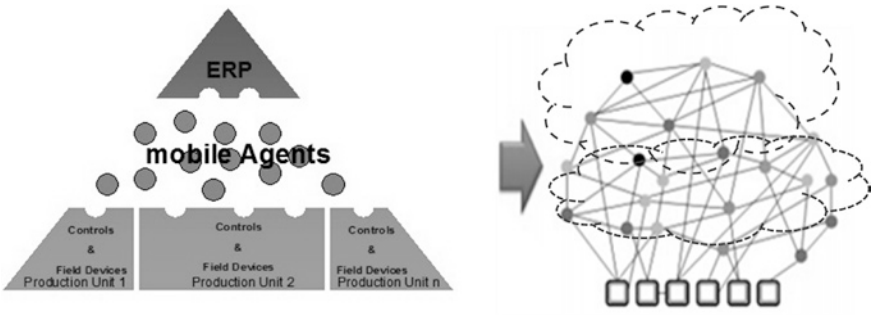


Fig. 2.1 Dissolution of the Pabadis automation pyramid into CPS with hybrid cloud based on fully decentralised automation according to VDI/VDE (2013)

The next wave of innovation, providing smart objects, cyber physical systems and Internet of things will further dissolve the automation pyramid on both, the ERP level and plc or field control levels (Fig. 2.1.). Eventually the structure to cope with will be a large set of cyber physical units and smart objects that are interrelated, online interconnected, self organising, self configuring and self optimising that may optionally be driven by service providers.

This upcoming fully distributed manufacturing world leaves an important issue unsolved: the fallen off hierarchy will have to be replaced by other structures. Smart distributed manufacturing setups, be it within one manufacturing site or in geographically dispersed multiple sites, and surely exhibit all necessary features for configuring manufacturing processes and tools for putting them together. However, their orchestration is profoundly influenced by the designs of production technology and manufacturing equipment, as all components are continuously online and communicate with huge networks of materials, equipment as well as humans. Most recently, we witness a growing and deepening convergence of manufacturing transformations steps with the materials involved and with the information technology units. Each of these domains includes comprehensive technology and systems components' bundles; almost any element may be imagined as being integrated with respective elements of all other domains offering a plethora of powerful additional options for distributed manufacturing. With RFID, smart objects, smart robot modules, micro power cells and smart materials we have only seen the starting points of an amazing take off.

On top of all these powerful innovations, wired and wireless connection and interoperability of all units, materials and energy sources once again give exponential networking combinations of all involved items. Miniaturisation increases abilities and lowers cost at the same time (Moore's law), telecommunication makes fully independent from locations, whilst at the same time allowing to precisely localising items. Traditionally all concentration and modelling efforts had been focused on plans, computerised procedures and numerical abstractions, now the novel identification and localisation capabilities suddenly provide fascinating

decision support via online monitoring, tracking, identifying and evaluating real-time data. They enable both; all plans and procedures may be instantly and concurrently matched with manufacturing realities by the full awareness of the whereabouts of all items and the states of all ongoing transformations as well as giving support to decision-making by quick trial and error corrections or iterations, quite different from habitual management thinking. Moreover, all options for Ambient Intelligence (Pallot et al. 2012) as well as Artificial Intelligence become highly available on the shopfloor anywhere and anytime.

The key trajectories as outlined all verify for manufacturing in total, what has been anticipated in a number of distributed automation applications already. Principles and attributes in distributed manufacturing set ups are fundamentally different from what we know so far. One time sequential planning with subsequent command and control is replaced by initial design, iterative adaptations, gradual approximations and evolving perceptions on the base of real-time data. Hierarchy levels exist purely logically, little relevant to organisation or planning horizons; they give decision support background with varying autonomy.

A courageous overall framework for Distributed Manufacturing is called for. Such framework will be provided in the subsequent chapter. Scientific progress here is definitely linked to intense interdisciplinary interaction within solid and consistent overall architecture. As multiple disciplines are involved, solid grounds are laid to scientific interchange instigating theory building and -extension for manufacturing in general as well as by introducing suitable generics in particular. Research work is presented, engaging a number of scientific domains with established theories, as complexity theory, social sciences and network management etc. The authors are convinced that the framework may also capture upcoming patterns of distributed manufacturing, which embrace converging new fields as are already visible, e.g. the nano-technology, neuro-technology or cognition sciences with strong impacts on manufacturing.

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