

# How to Adapt Information Technology Innovations to Industrial Design and Manufacturing to Benefit Maximally from Them

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*IT developments come at a dazzling pace. Industry feels having no option but to keep up. All too often, in hindsight, conclusions are that IT innovation might have been better exploited if ... This paper surveys IT trends and seeks to assess their impact on industrial design and manufacturing in the near term future of 5 to 20 years from now. This paper assumes that IT technology is leading and design and manufacturing follow. To that extent, this paper discusses what complementary technology the industry should develop in order to prepare, and to benefit optimally from these IT trends. It presents a joint academic-industry research framework to settle, with the aim to attain collective innovation.*

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## 1 INTRODUCTION

Among experts, there is a firm belief that in the near future, around 2030, say, only two IT-environments will prevail: a personal environment descended from the current office suite and a 'professional', technical application environment. The personal suite is the one almost everyone will share, no matter what position. It supports personal and business communication in all its extents, and for many basically clerical jobs (lawyers, accountants, journalists, and the like) this environment will contain everything needed. It will consist of small modular pieces of software, distributable across multiple small smart devices, such as handhelds and able to set up communications with intelligent environments such as cars, offices, shops, traffic systems, home, etc. It will tailor itself, slowly fading out what is not used and strengthening what is used frequently and intensively. Smart content management features will remember what has been written before and recognize semantic intentions and reasoning pattern. Documents will no longer flow around organizations, but in contrast, amendment rights and certificates will, managed by online collaborative content management tools. Roaming documents are available worldwide. We will no longer key in every single word: we organize our thoughts, findings and messages and a smart mind mapping tool turns them into plain English.

A second 'professional' environment will be available, with which all kinds of virtual worlds can be crafted: landscapes, buildings, urban and rural patterns, water, crowds, avatars, noise, smells, etc. Geographical information models and virtual and real urban and rural environments are the common denominator. Location and time snapshots can be assigned knowledge and documented and scenarios and scenes that live somewhere in a virtual world can be shared with others in a variety of forms. Behavior can be restricted to follow verified patterns, as well as patterns mentally possible but physically impossible. Smart natural-like pervasive substances and materials interact with the human controlled smart environments, not only in the virtual world, but also in the real physical world.

Designers do no longer *design* our artifacts they organize knowledge and information for us, so that we ourselves can decide on details and behavior. Fed by snapshots, mental maps, fuzzily matched shapes, or whatever representation, a first impression of a new product can be presented to potential customers. Customers can take part in further conceptualization and its equipment with intelligent behavior. Designers can verify and validate customer use cases by querying collected knowledge smart objects have acquired about their own functioning. Although acting autonomously, pervasive products remain supervised through

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world-wide clouds of near field communication networks and continuously obey adapting their function to customer habits and preferences.

Future scenarios like the above have been delineated by many *futurists*. Pondering on the near term [51], medium term [3], and far future [45] and [12] is inspiring<sup>1</sup>. It may help us in finding consensus on development paths to open up, in targeting development resources, and in uncovering obstacles. It is the domain of *epistemological research* [40], [44] and [45]. Institutional thinking about the future is by no means new: the World Futures Studies Federation was established some forty years ago and is still very active today. Indeed, today, the need to foresee and anticipate future is more compelling than ever. Epistemic research seeks to present *argued projections* on the future, not fantasies. In this paper, we will not dwell on epistemic research any further, but we will use it as a *teaser* showing the power and potential of interdisciplinary thinking about a world we can help shaping ourselves.

At the end of the day, however, technology is needed to materialize *desired* futures. This paper surveys brewing IT trends inducing the ‘2030’ scenarios and surveys what the impact is on industrial design and manufacturing in the near term future of 5-20 years from now. This paper assumes that IT technology is leading and design and manufacturing follow. This has been the case for the last three decades and there is no reason to believe this will change in the near term future. Of particular interest and central to the discussion inhere is how industry can adapt to unrolling IT trends so as to benefit optimally. Supporting technological development may have to be initiated and adopted

by the industry. This paper will seek to find out how to identify these ‘missing’ technological developments. Cost and financing are left out of the discussion. Not because these aspects have no impact or play no role (on the contrary) but primarily because this paper focuses on technology.

This paper is organized as follows. Section 2 discusses the current state, as a starting point for the discourse into the future. It discusses generic IT and more specific industrial IT and business developments. Next, section 3 presents a ‘missing’ technology inventory; section 4 frames future research developments in a framework providing conditions and controls to foster developments. This section also prospects the potential and merits technical risks. The paper is concluded by section 5, presenting conclusions and further suggestions.

## 2 CURRENT STATE OF IT

### 2.1 Current State in Generic IT

In this topic, we refer to information technology not specifically targeting to engineering, as *generic IT* (Fig. 1). Generic IT is notoriously ‘dynamic’ and in many respects, “technology drives applications”. The need for alignment of business and IT processes is widely perceived as a necessary condition to increase efficiency and utilization of IT technology at the strategic level [9]. The following trends are observed.

#### *Generic IT split up*

Generic IT tends to fall apart into two main fields:

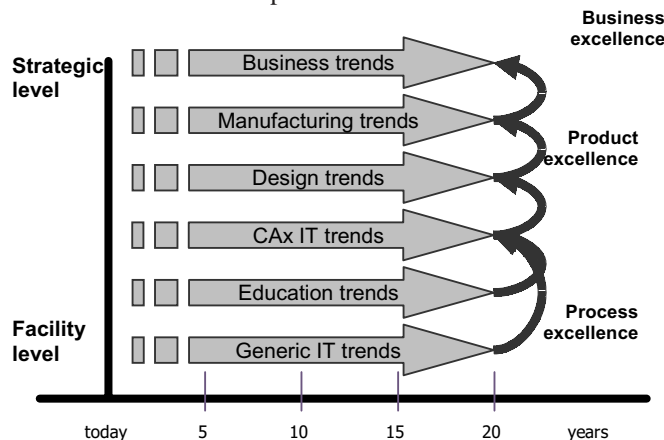


Fig. 1. Various trends and their technology-driven causal-loop upward interactions

<sup>1</sup> Which does not mean that it foresees only positive prospects; e.g. [51] and [45]

- generic IT as a generic *facility service*;
- generic IT as *part of product design*.

IT as a facility service tends to become a commodity like fresh water and electrical power. On the near-to-medium long term, IT service departments will gradually be replaced by a service contract with some remote provider. IT as a facility will no longer be a competitive instrument, just a *conditio sine qua non*.

On the other hand, we have IT as an integral part of the product design: IT as a *product enabler*<sup>2</sup>. This IT will further stand out in its capacity of enabling the design of highly competitive products [10] and [51] and processes to craft such products. Future design will show logic and intelligence programming and autonomy constraining on a much more intense scale. Like with robotics, self-learning and group intelligence will be exploited, to create smart collectives, bounded and directed by designers. Correspondingly, manufacturing will grow into fitting logic and function and setting smart object evolutionary learning in motion. Nano-layers, sheets and films and fibers in construction composite materials store and process probed data from the environment.

#### *Rapid advances in near field communication*

Advances in near field communication (NFC), support and are supported by the advent of *pervasive smart products* and environments [2] and [51]. Products (consumer and professional alike) are endowed with logic and NFC, with significant consequences for design, ownership and use. Familiar current examples are PDA's, cellular



Fig. 2. *Autonomous AGV's (automated guided vehicles) in the Rotterdam Port ECT sea container yard, operational for almost two decades now [source: www.ECT.nl].*

phones, digital cameras, video and audio devices, barcode scanners, smart cards and labels, laser-equipped handheld measurement devices, hospital beds, AGV's (automated guided vehicles, Fig. 2), but many more are still to come.

*Bluetooth, WiFi, RFID*-based handhelds invade our cars, homes, offices, shops and factories. Inter-communication can make products *smart*, i.e., capable of autonomously performing a tasks according to predefined logic and depending on input data sampled from the environment, alone and in collectives. Smart products are aware of each others' presence, within predefined range and capable of exchanging data and services, unilaterally, bilaterally or through Internet. To do so, they must share some *protocol*, for instance Bluetooth or WiFi, both belonging to the IEEE 802-family of protocols. Smart products can also *negotiate* to collectively perform a task. To learn of each others features, a *catalogue* is usually exchanged as a first step in the negotiation protocol. Many smart products are *reconfigurable*, i.e., their service catalogue is not fixed for life, but can be updated life long. That is not to say that smart object can adopt just any behavior and any task they happened to learn: designers will have to limit the room for self-learning and bound *polymorphism*. They will have to balance object functions they would like to attribute to the designed object with services obtainable from neighboring objects, encountered during usage.

Nanotechnology is advancing rapidly. But even today considerable intelligence can be compressed in less than 1 mm<sup>3</sup> of material, so for designers this brings up new challenges and opportunities to design low cost disposable micro-devices and logic-endowed consumer products. To construct such species of objects, smart materials are needed, in the form of foils, varnishes, embedded composites, micro-connectors, and molecular frameworks. Apart from state-capturing, chargeable/ dischargeable materials, embeddable *logic wiring* will be needed, manufactured and assembled at an industrial scale.

For manufacturing, this invokes new lithographic processes, new gluing and surface mounting techniques, nano- and vaporizing techniques, logic initializing processes, but also new protection foils, *malware* protection, electromagnetic 'clean rooms' etc. More and more, construction materials will be organic, like *bio-*

<sup>2</sup> The term enabler is also used in other meanings, e.g. [4], but in this paper exclusively used in the sense of a precondition to product functions and features.

*sensors, bio-tracers, etc.* stable under the right environmental conditions, and bio-degrading when out of conditions.

### *Computer-to-computer web services*

Web Services are SOAP/XML-based data and services that can be exchanged between computers. The SOAP protocol exchanges data and services request messages in the form of a self-describing XML text file. Services can be registered (published) for public use in a UDDI file on Internet, a Universal Discovery Description Discovery and Integration registry, and the invocation of the service (input, output description) is specified in an accompanying WSDL file, a Web Service Description Language file. The idea of public web services is to anonymously and publicly offer a generic service that others can use. Web services need not be public, but can also be restricted to use within a supply chain for instance. British Petroleum, for instance, deals with over 1500 suppliers [27] alone. The UDDI commonly has a white pages part, a yellow pages part and a green pages part, describing the taxonomy and the category of the offered service and where to get access. A UDDI file enables discovery of the service on Internet, describing the identity of the publishing party and where to get access, the WSDL file describes definitions, types, bindings, services, messages, etc.

Perhaps the most important feature of web services is that they allow computers to talk to computers directly (no human intervention), invoking operations on the receiving computer, by sending it a SOAP/XML request message. This paves the way for a new type of interoperability. Unlike a tight coupling like sharing a distributed object framework like CORBA, (D)COM, ADO, or Java RMI, web services lead to loosely coupled (file-based and off-line rather than runtime and online) interoperability. In combination with its self-description capacity, and well-designed adaptive business processes behind [39], operations and data sharing can remain relatively stable. Compared to traditional forms of neutral file-based exchange (STEP, ISO16926, etc.), web services seem to have a number of advantages, but the “lingua franca of the business internet” (Bill Gates, 2000) also shares a few drawbacks. To illustrate this, envision the exchange of design data:

- Being loosely coupled, the exchange of model data in an XML file spawns a new offline copy of the model to a remote application (Fig. 3). This may give rise to subsequent change management and release management problems. These problems do not occur when sharing objects within a distributed object framework. Such objects are modified real-time, online, and typically have transaction locking mechanisms;
- Upon exchange, data, including references to other objects and operations, have to be spelled out explicitly, in contrast to distributed object frameworks. Frequently, data transformations are necessary between sender and receiver;
- The extent of self-description is limited in practice when not based on a shared model (like STEP) or taxonomy/ontology;
- The ability to exchange design intent and to get semantics across is severely limited. The use of ontology may help, but everything beyond simple well-contained data remains difficult;
- Exchanging large models leads to verbose text files. Today, XML files can be stored (e.g. as a BLOB) in XML- and other databases, but nonetheless, this remains a problem. Inline compression may partly remedy this.

SBVR, Open Management Group’s Semantics of Business Vocabulary and Business Rules (see [<http://www.OMG.org/>]) may help to define semantics down from the business level. XPDL and BPEL4WS are languages that support business process alignment [37]. XSLT, fuelled with appropriate templates can assist in intermediate data (format) transformations. Web services are capable of running over various protocols, but are almost exclusively run on top of HTTP for security reasons. They are no solution to

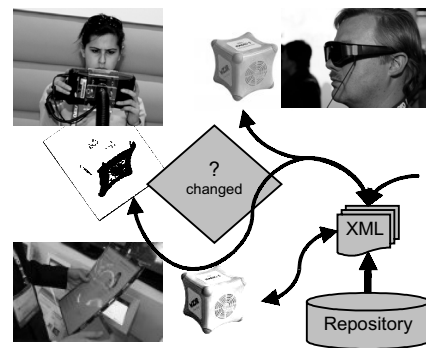


Fig. 3. *With all XML files around; are we all looking at the same model version?*

the need for secured exchange of information. This general problem is often remedied by the use of VPN (Virtual Private Network), certificates and/or secure peer-to-peer socket connections. In addition, web services based modifications to the data can be accompanied by an audit trail, to keep track of modification records.

Web services are expected to have more impact on manufacturing than on design. Web services may be used for intelligent and autonomous e-procurement systems of catalogue parts (bearings, shims or stop nuts, for instance), stock balancing systems across supply chains, for 24/7 order tracking, customer care, QA, etc. but also for scheduling milling capacity with a supplier, recruiting contractors from a personnel hub on Internet, etc. As far as design is concerned, web services are expected to be primarily applied to exchange product data (PDM-data).

#### *Dispersion of storage*

The storage and management of massive amounts of distributed data, still growing at a rate of tens of percents a year, across networked volatile media, is a complex problem. It is not uncommon for a company to have terabytes of data nowadays, e.g. [25]. With increasing design variants, more demanding PDM/PLM procedures, e.g. Katzenbach in [16], this trend has an evidently negative impact on its controllability. Conditions for appropriate intellectual property protection and security are also negatively affected. Not the mere amount of data, but the dispersion makes handling a challenge. Distributed design leads to a serious data and release synchronization problem that only can be solved by adequate change and configuration control, using CVS-like and Source Forge-like

environments. The next generation change and configuration control software will have to be real time, online up- and downstream synchronizing, distributed, and must be able to present change *consequences* and *possible response scenarios* to designers.

With the advent of pervasive smart objects and environments, streaming data to central stores is no longer an option. In the near term future, data will live within smart objects and stay there. Objects will process data to knowledge on their own performance and functioning in a pre-designed manner. Upon request, objects report knowledge back to designers and other professionals with adequate access rights. Data and also knowledge lives only as long as the object lives, so knowledge must be transmitted before the end-of-lifetime. This requires adequate estimating methods to determine end-of-lifetime design and estimation; Xing et al, in [29].

Internet, *qualitate qua*, permits for 'lazy' forms of storage: not everything of interest needs to reside in our own database. All it takes is the storage of a hyperlink, pointing to a source location (URL) on Internet. *That is in fact Internet by its very nature*. The problem is that we cannot inflict any form of data management on data we do not own. On the other hand, copying in all external data invokes another problem: when the information is modified by the owner, we miss the changes; we look at an obsolete copy. There is the tradeoff. Data management standards and agreements may help to remedy the remote data management problem (hyperlinked data), update alerts and automated updates (e.g. through web services) may solve the latter old-copy-in-own-database problem.

The introduction of 'base registrations' may cut the storage and exchange of data tremendously. Basic data, regularly shared among applications, may be stored in a single, shared base registration, to prevent every single database from having to do so itself. Personal data, car data, electronic and mechanical part data, compliance data, consumer data, real estate data, drug data, etc. lend themselves to some extent for this type of registration (Fig. 4). An appropriate form of data sharing and interoperability is required for this type of storage. The idea of base registration is not new, but as of yet industrial uptake and exploitation is limited.

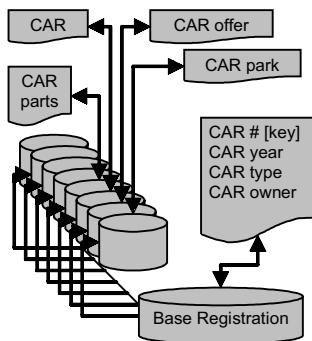


Fig. 4. *Concept of a base registration*

*Desktop operating system vanishes*

The operating system gradually disappears from the desktop. Configuration management costs (almost exclusively software) gave rise to a trend towards ‘thin clients’, blade server-based clients and fully web-enabled software at the desktop. Server-side virtualization further accelerates this development. Eventually, software applications are believed to become dominantly or even fully networked and roaming, running in their own adaptable run time container. Current thin clients (mostly booting an embedded XP), web interfaces and software as a service trends (SaaS) can be seen as precursors. For industrial design offices, this trend doesn’t need to have severe consequences, or may even have a positive (cost reduction) impact. It may help to synchronize software platforms across supply chains as well as design office – shop floor alignment. This trend may further help to circumvent the software application lock-in problem, making the use of software best-fitting-the-purpose feasible on an occasional basis.

*Geo-mapped information*

For many of us the Google homepage is the access point to Internet. Tomorrow’s access point to Internet will be a ‘home location’ on Google Earth or Virtual Earth. Information on internet will become attached to a location, assigned to a building, a street, a local event, a restaurant, a memorial statue, a stationary camera, etc. Not just

geo-information per se, but all information and the map environment is not just for navigating the world map itself, it is also an overlay over internet [8]. Pointing with a mouse will be replaced by (a stream of) location data from a handheld device, a car, an avatar, an Internet access point, or a Bluetooth parrot.

This will drastically change the way information is added and retrieved from Internet and how knowledge will be organized. It is expected to also reflect on the design of real world objects. Virtually any object designed in the near term future will be exchanging directly or indirectly information with the Internet continuously. Long after it left the workshop floor where it was manufactured, it can still be reached through internet across the globe. It will be capable of scheduling its own maintenance, for instance, and report on its own performance. During its lifetime, it can serve as an agent, returning useful usage data records to the designer.

The introduction of virtual worlds is accompanied by the advent of an entire generation of emerging urban- and rural simulation approaches [8] and [28]. Servicing and servicing coverage is a central theme in this work. Today, authors assume single-step service-to-client types of servicing, like in telecom, in the near term future, servicing will be cloud-based and multi-step: not every object needs to have access to the correct time, for instance, as long as at least one object in a cloud has and is programmed to share this service with other cloud members.

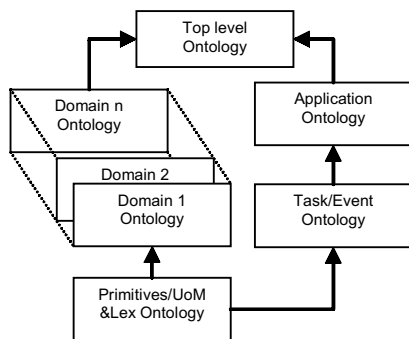


Fig. 5. Simple ontology framework, modified after [24]

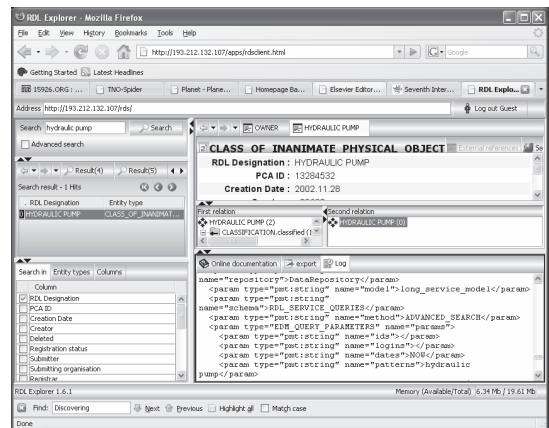


Fig. 6. The ISO 15926 data model and the Reference Data System containing the Reference Data Libraries. Here the data of the object Hydraulic Pump. Source: <http://15926.org/>

## Software suite re-bundling

Software deployed in personal environments tends to cluster in a single suite. See the Introduction. Particularly if present industry standards can be swapped for open standards, multiple such suites may appear. This trend has no specific fundamental implications, neither for design nor manufacturing. All other software re-bundles in a second (SOAP/) XML-based environment: the professional suite. Like with office suites, where the market welcomed OpenOffice.org, inspired by Sun Microsystems, Inc. genuine interoperability will appear sooner or later and professional environments will follow. Professionals want to be able to use such suites on their home infrastructures and in mobile computing, companies want them, governmental bodies may demand them, and open consortia will develop them. In the future, electronic PDM/PLM dossiers may be sent off to the customers, too. At present, it is customary to distribute separate 'viewers' (e.g. Acrobat Reader for reading PDF), but this will fade out. Software as part of the provider's portfolio will change dramatically. Software 'seats' will become no more than attractors for something much more valuable: knowledge and excellence centers, providing niche strategies and best practice solutions.

As of yet, neither ISO 10303 (STEP) nor ISO 15926, brought a fundamental *omni-potent* solution to the general data exchange problem. STEP "will go XML" and as far as ISO 15926 (POSC/Caesar) is concerned: the ultimate goal is to develop a general purpose computer interpretable framework providing a single solution for the industry at large. Domain specific RDL's (Reference Data Library),

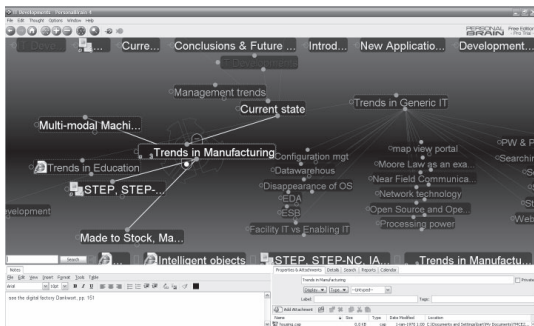


Fig. 7. Example mind map. Thoughts are represented by boxes and associated by arcs. Attributes and objects can be attached.

e.g. for construction, ship building, mechanical engineering, process industry, E&P, etc. together with a common grammar and generic data model, may constitute a framework conquering ground up till now reserved for ISO 10303 (STEP). Refer to Figure 6. Recall that ISO 10303-221 (AP 221) and ISO 15926 are entangled.

The use of ontology may be woven in and that what's happening. Generally, domain ontology (Fig. 5) matures most naturally, like with object-oriented technology. On top of that, domain ontology, like domain object classes, may be better re-usable than application-based ontology. What holds true for a domain ontology also holds for low level ontology, lexicons, definitions, generic data formats etc. [23]. The real touchstone will be the cross-discipline application and upper level-ontology [6].

Integrated professional geo-mapped applications are to arrive soon (a Google avatar API or even more innovative?). Integration with design data may not be immediate, but will ultimately be the case. In manufacturing, shop floor-ERP might be one of the first areas to show uptake. The lack of genuine interoperability is one of the biggest technological challenges at the moment, for which basic low-level IT technology exists, but present data and knowledge modeling techniques at the semantic level fall short.

## Mind mapping

Mind mapping is the expression of thoughts and free associations between them, in a diagramming style called a *mind map* (Fig. 7). Mind mapping provides great freedom in expressing thoughts, without obstructive formalisms. Mind mapping will become image-based and eventually emotion-based, expressions-based, etc. Finally, mind maps will become personal and computer-interpreted. The impact of mind mapping is thus expected to stretch far beyond generic IT, more so when combined with artificial intelligence and ontology. It can help bridging the gap of designers and non-technical customers. Mind mapping can also serve as a personal way of organizing information. Impact on design and on manufacturing will be enormous.

## Agent, ontology based knowledge management

The research fields knowledge management, ontology, and multi-agent technology

tend to overlap more and more [4], [7], [19], [41] and [43]. Organizing, classifying and inferring knowledge is expected to become a principle field of research in the near future. Further to this [42] relate this to individual and organizational learning. Here too, the impact on design will be enormous. Many design tasks, particularly in the conceptual phase, benefit strongly from knowledge. Personalized use cases, queried from smart objects, may support design. The design process is expected to become more 'rich' and 'soft' information can be merged more easily.

Similarly, agent technology has also profound impact on manufacturing, in production process data gathering. Agents, pieces of software programmed to be autonomously crawling and pruning the Internet in search of targeted data and information, map their collected data and information through ontological schemes into a knowledge framework. Agents are nowadays equipped with latest Artificial Intelligence. Multi-agent technology (MAS) allows for collective, self-coordinating acting, outperforming humans in simple and moderately complex tasks [50].

*Open standards, platforms and consortia*

The trend to open platforms will further support interoperability at a global scale. Open standards force dominant technology providers to reconsider their technology and beyond a critical industry uptake as more open platforms enter the market, this process is expected to accelerate. Counteracting movements are also seen, for instance in the US where business models, algorithms, and living entities can be patented, leading to what is discussed as "open science" versus "private science" in [14]. The impact on design, more in particular on the design CAx tool suite and on data exchange in manufacturing are great.

**2.2 Current State in Design**

In recent years design activities have intensified, expanded, become more flexible, geographically dispersed, become a team performance, under increasing time pressure,

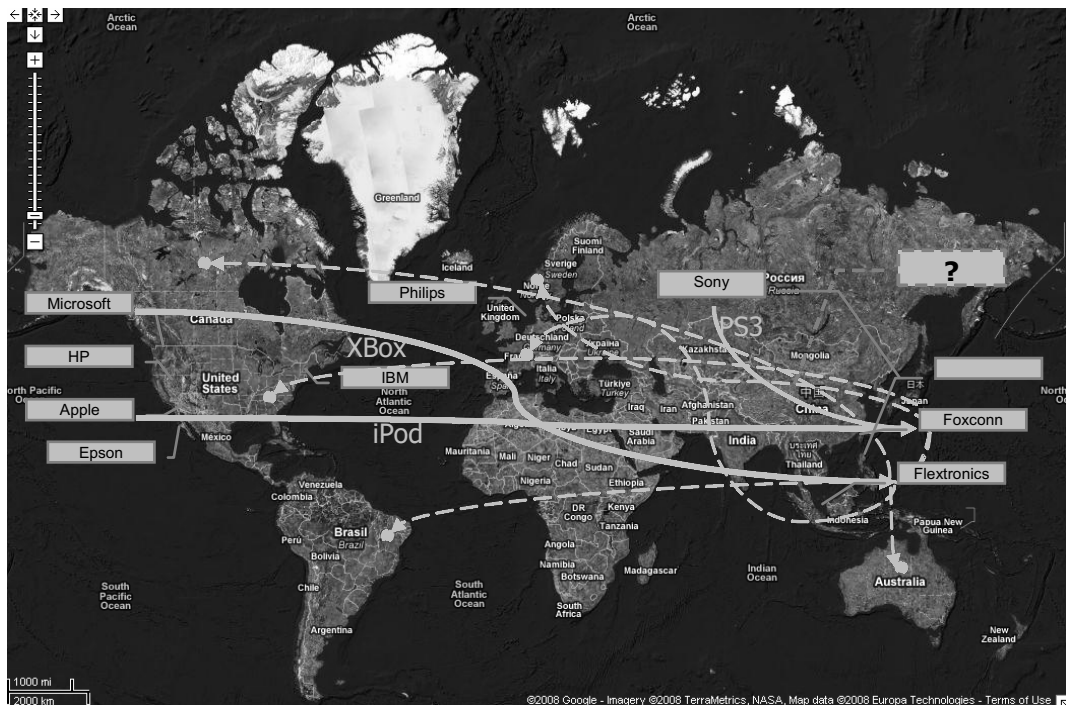


Fig. 8. Design anywhere-build anywhere in consumer electronics: consumers purchase and pay to OEM's (HP, IBM, SONY, etc.), who forward (solid lines) an order-to-build to manufacturers (Flextronics, Foxconn, etc), who ship to customers worldwide (dashed lines). Headquarter locations may change in the near term future; however, the DA-BA principle is not expected to disappear soon.



holistic, global and inter-cultural. Design can be subdivided in a number of stages, in various ways, according to various criteria. Here, we are not going to enter that discussion. See for instance Fujita and Kikuchi, and Clement et al. in [29]. At the early stages of design, emphasis is on conceptual ideas requiring a large degree of (mental and technical) freedom. During the global and detailed (component) design, more formal and interoperating tools and techniques are needed. Data volumes explode and detailed knowledge communication spreads across the supply chain. Data and release management and communication are becoming dominant factors. Cost estimation and production planning is at hand.

Beside the traditional waterfall like design process, more and more evolutionary approaches are now in use. Some of them are spiral-like, spawning evolving prototype-to-mature model versions after each development cycle, Clement et al. in [29]. Others involve the (possibly unskilled) customer, [24]. Some are co-designed, usually at part or component level, using online collaborative design environments, that can have an inter-regional, international or inter-cultural setting, Katzenbach et al. in [15]. Some target at (configurable) product family design rather than a single product [43], some target *make-to-stock* production, some *make-to-order* and some deal with *compliance* restrictions. Major IT-related trends are as follows.

#### *Design anywhere – build anywhere*

Cheap communications led to design anywhere-build (make, produce, manufacture) anywhere schemes, e.g. Marais and Ehlers in [29]. For repetitive design or manufacturing tasks, potential partners, contractors, etc. can even be recruited online, e.g. Klamann in [15].

A clear example is the spreading across the globe of Consumer Electronics OEM's, like HP and Sony, and the actual manufacturers, like Flextronics and Foxconn. See Figure 8. In earlier days, manufacturers just built as specified; nowadays they co-design and even deliver ready-to-re-label electronic equipment to OEM's. The design of high-end equipment, such as iPod-s and Xbox-es, however, is still typically done by OEM's themselves. In future strategic alliances, partners are expected to bundle their collective knowledge, object lifecycle long.

#### *Mass customization and e-consumer services*

Mass customization (MC) is the ability for customers to adapt products and services to personal needs and preferences at (approximately) mass production price and delivery conditions. MC thus seeks to match the production efficiency of mass production with the flexibility and added customer value of customization. MC is however more than just providing the customer with a few optional features in an order form. It is the precious interplay between marketing, design and manufacturing staff in the entire supply chain on the one hand and customers on the other hand. Mass customization is now rapidly becoming common practice, not only for relatively simple goods, such as eyeglasses [46], also for more expensive products like cars [34]. The need for *consumer intelligence* is coming up strongly, Seelmann-Eggebert and Schenk in [29] and [22], [24], [32] and [33] and is expected to be one of the decisive competitive capacities in the near future. This includes knowledge on production machines and processes [38].

#### *Design to be broken down for manufacturing*

As a result, for a flexible and adaptive manufacturing process, design needs to be parameterized and/or *broken down* in a basic part of more or less standard components that can be produced make-to-stock (or commissioned to a supplier), and a customized finishing, to be conducted at delivery time in a make-to-order atmosphere or even at installation at the customers site [19] and [43].

Time and form postponement [46] and unifying and serializing operation principles [21] will have to be envisioned and anticipated during design. Furthermore, designers will have to assemble and maintain catalogs of more or less standardized components customers can assemble their preferred product configuration from.

#### *Expanding CAx tool suite*

CAx environments contain a growing number of tools, for sketching, RE-tools, feature recognition and feature description, soft computing, fuzzy design, augmented reality rendering and photo-realistic visualization, Siadmok and Cooper,

and Woksepp and Tullberg in [29]. CAD-CAPP pre-production coupling has been introduced, like geometric dimensioning and tolerance tools, and QA-support, Roller et al. in [29] and Katzenbach et al. in [16].

### *Compliance*

Compliance has become a major issue, to be supported by tools, with online data submission for approval, in parallel to the evolving design, e.g. Calder and Sivaloganathan in [29].

The above trends do not specifically zoom in on important trends in the domain of product data management (PDM) and product life cycle management (PLM). Within a context of mass customization the building up of a solid electronic personalized product dossier is critical for future support, maintenance, amendments, and end-of-life strategy. All these trends are noteworthy, but do not pose IT-problems not yet addressed.

### **2.3 Current State in Manufacturing**

Over the past decade, manufacturers have replaced their traditional *make-to-stock* production by a *make-to-order* production strategy, in order to respond to the growing demand for mass customized consumer goods and services. Successful implementation of these inherently dynamic processes requires thorough knowledge of the (potential) customer, as stated. The better knowledge of who customers are, where they are, what they want and when they want it, the easier the mastering of the varying design, production, delivery and custom service process. The major challenge is to design e-consumer services and customer decision support systems (CDSS) that allow for the entrance of a *new group of customers*, typically the ones that do not yet have the affinity and the technical background knowledge [24]. Consultative and cross-selling will navigate potential customer through a sheer endless virtual shop. Strategic *bundling* of complementary and *perceived value enhancing* products in product suites should also comfort novice e-customers.

Customer knowledge across the entire supply chain is expected to become decisive factor [13]. Apart from what customers want *beforehand*, at the time of purchase, it is also vital to have a thorough understanding of how they *really* use the

product afterwards and determining their satisfaction.

Most workers in this field proposed solutions based on the idea to postpone the moment of delivery, often called *time postponement*, or the moment of differentiation of the product into a variant, called *form postponement*, and push it as far downstream as possible [46]. Form postponement may take even the form of assembly at the customer site. Su et al. point out that above a certain production floor, time postponement is more effective for larger numbers of products and higher interest cost. Form postponement is less vulnerable for disturbances, such as a late component arrival. In practice manufacturers tend to follow a mixed small series-large series production scheme, often mixing make-to-stock (e.g. standard components) and make-to-order strategies [13]. IT-related manufacturing trends are as follows.

### *Pull production in a digital factory*

Manufacturers adopt a *pull production* mixed make-to-order and make-to-stock adaptive 'digital factory' model, Schneider in [16] and [47] and [49].

### *Consumer and production data dispersion*

The dispersion of customer and production data down the supply chain has come down as far as the level of cellular production units. The data exchange demands that comes with it not only give rise to change and release management problems and intellectual property concerns [14], Klamann in [15], it also brings up the interoperability problems and alignment issues discussed earlier [39] and [41] and Katzenbach in [15].

### *A need for responsiveness*

There is an increasing need for responsiveness to commonly just-in-time arriving consumer and production data. Not only logistics itself must be just-in-time, also data accompanying it. In n-tier supply chains, early global production and delivery schedules are commonly refined and updated up to the deadline, with only small tolerances allowable.

### *Production adaptation data stream*

Adaptive production requires a constant stream of resource, performance and quality-related

data as well as maintenance and reconfiguration planning data. The difference with traditional organization of production is that scheduling maintenance is not 'invariant', as production configuration changes from hour to hour. Production line swaps must be planned machine-by-machine, cell-by-cell etc. [47] and Novak in [29].

## 2.4 Current State in Business

Whereas the eighties are often associated with quality, and the nineties with business process re-engineering (BPR), the years 2000 are associated with responsiveness (or: agility); e.g. [30]. This requires strategic thinking up to the level of board members. Various workers have analyzed business at a strategic level. Bergeron et al. [9] discuss the relationship of strategy, structure and technology. They found that this relationship is a strong determinant for the performance of the company, at a given contribution of IT technology. Results are in agreement with results found in [13] and in [17] and [48]. At Board level, the introduction, application and management of IT technology can be split into two different principle challenges:

1. Applying "off-the-shelf" IT for the regular business *processes*. ERP, CRM and office suites fall into this category. Managing this type of IT in conjunction with BPR is not believed to be optimal yet [10] and [48]. This has been referred to as IT applied as a facility service, in this paper;
2. Applying functional IT Technology as essential aspect of the company's *product or product development process*, in this paper denoted as *enabling IT*. Board members are not always capable of overseeing the underlying product technology at the level of strategic business planning [10].

Increasingly, board members have to handle applications and mergers. Integration of information infrastructures (i.e. IT as a facility service) of merging companies is generally seen as the key to a successful merge. A supportive framework for mergers has been proposed in [35]. Also see [5]. No study was found on IT as an enabler in relationship to acquisition and mergers. Only a single global IT relevant trend will be listed here: the need for process alignment and regular evaluation of the company's strategy, so as to prepare for and respond to external and internal change. This includes an increasing need for codes-of-conduct, governance etc. [48].

## 2.5 Current State in Education

CAX education in earlier days came with the applications and access to them [15]. Gradually, in the seventies and eighties, education in IT and CAX entered the academic curriculum of engineers and designers. CAX education for business people, for legal workers and for business administration is still sparse. Education in future sciences is more apt than ever, e.g. [44]. Future outlooks on futurist studies on IT-related developments were not found in literature.

Dankwort underlines the virtualization of design: the trend of product design to be represented in virtual structures and models, almost exclusively. Indeed, the role of drawings, mock-ups, paper models, etc. vanishes. Nonetheless: sketches remain a preferred way to represent conceptual car designs, and rapid prototyping is still a very active field of research; Tovey resp. Campbell in [29]. Moreover, many workers proposed *virtual analogs* of the former clay, wood and paper models.

By virtue of e-learning, education penetrates more and more rural areas, developing countries, etc. [1], [11], [28], [31] and [42]. Lin in [36] also stipulates that teaching people lacking technical background in information technology is regarded as an important but difficult challenge for the future. Most workers (e.g. Mokyr, Fountain) subdivide IT expertise in knowledge to *design*, to *own* and to *use* IT. According to literature, the barrier to own and use IT technology is sufficiently low for most people to benefit from IT technology. In the US for instance, women represent only 28% of the "designers" of IT technology but make up the majority of IT users, with some 57% [20].

Educating in CAX-technology has to respond to the demands of ever more professional and job profiles [15] and will be taking place partly in the universities, partly in the industry. Apart from IT-aspects, also product engineering, CAD- and FEA-related technology and a wealth of other aspects are involved. Many workers stress the importance to 'human factors'.

## 3 WHAT WE NEED FOR THE FUTURE

### 3.1 Methods and Approach

In this section, an analysis will be made of 'missing' technology, supporting technology

needed for the industry to adapt for the IT-trends signaled. This can be both engineering technology and auxiliary IT technology. Next, we determine what scientific knowledge is needed and in which form this is to be delivered. An  $\Omega$ - $\lambda$ -diagram, Figure 10 [40] frames this. This section starts, however, with an inventory of technology inspirers, actors and supporters roles, and typical technology development cycle times, building stones in our framework.

### 3.2 Definitions and Terminology

In the following, by *organizational entity*, we mean a company, enterprise, governmental body, academic institution or any other entity capable of inspiring, acting or supporting<sup>3</sup> a technological development. A *precondition* is an essential development condition that needs to be met for the development to be successfully conducted. *Cycle times* are elapsed times, durations, of technological developments. An *inspirer* is an organizational entity initiating, demanding, enforcing or otherwise causing technology development to happen. An *actor* is a conducting, acting organizational entity, designing, developing, realizing the technological development, or part of it. A *supporter* is a promoter, advocate, stakeholder (other than a shareholder), user, or otherwise in favor of the newly developed technology, prior to, during or after development. A distinction made at the company level is between technology *providers* and technology *consumers*, each of which groups are further subdivided in *dominant* providers and *following* providers and dominant and following consumers, respectively, Table 1. Dominance may also come from a *collective* or a *community*.

### 3.3 Inspirers Actors and Supporters

In Table 1, inspirers ('I') are primarily projected among dominant technology providers and consumers. In the near term future, we foresee a removal of dominant industrial standards and more open standards, a development that already started, Section 2. Neither individual technology providers nor individual technology consumers are believed to be in a position to enforce a breakthrough alone, and as the table suggests, inspiring technological developments is a joint effort. Follower technology consumers can support,

<sup>3</sup> Since cost and financing are no primary topic in this paper, financing is not encompassed here either, but of course does play an important role in this regard.

Table 1. *Roles and where to recruit*

	Technology Consumers <b>Dominant</b>	Technology Consumers <b>Followers</b>
Technology Providers <b>Dominant</b>	I, A, S	S, a
Technology Providers <b>Followers</b>	S, a	S

and likewise, following technology providers can take part. Of course dominant parties can also choose to support, rather than adopting an inspiring role. Acting is primarily up to dominant providers (capital 'A'), particularly for 'kernel' CAX-technology, but contributions may come from specialized SME (small to medium enterprises) or from active participation by smaller consumers that co-develop (lowercase 'a').

### 3.4 Cycle Times

Development life cycle times for generic IT technology development vary from approx. 2 (e.g., Moore's law, Java Packages, ...) up to 20 years (e.g., Java, XML, radio protocols, ...). Dankwort in [15] shows that typical cycle times for CAX technological developments vary from 10 up to well in excess of 20 years. Development life cycles are frequently terminated prematurely, at the birth of a competing new technology. This implies that in the time span of the near term future as set out in this paper (Fig. 9):

1. Running generic IT developments may on average be followed by at most 1 more complete development and part of a 2<sup>nd</sup> one;
2. Running CAX developments may on average be followed by at most 1 more development.

Reasoning is as follows. CAX developments take on average 15+ years and at time zero (now), running developments will have advanced halfway on average, taking another 7.5+ years to complete. The succeeding CAX technology will require another 15+ years on average to unroll. Assuming a small overlap of 10-20%, we see that in the near term time lap up to 2030, as set out in this paper, we may foresee running CAX developments to mature during the next couple of years and a next generation CAX developments to start, to mature roughly around 2030. Of course, in practice, developments form a more or less continuous

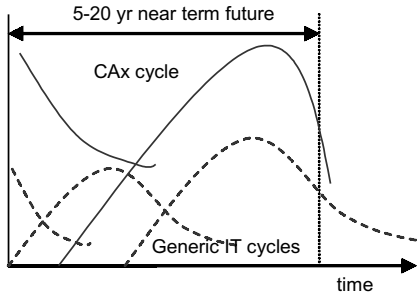


Fig. 9. Near term future with max. 1-2 generic IT development cycles (dashed lines) and approx. 1 CAx development cycle, at max.

spectrum over time, but our goal here is to *model* the room for a single research and development program we have in the near term future. Also, reasoning this way, we immediately see that CAx developments typically take twice as long to be completed compared to generic IT developments. Also, remark that the model in Figure 9 expresses the room to program developments, not the actual industrial uptake. For the main goal of this paper: to find out how to adapt for IT trends to benefit optimally from them in design and manufacturing, the model suffices.

### 3.5 Missing Technology Inventory

Having identified IT, design and manufacturing trends, we're now geared up to compile the 'missing' technology. This step comes down to collecting consequences of IT trends on design and manufacturing and defining possible actions and activities in response. For the research of this paper, this was organized using a brainstorm

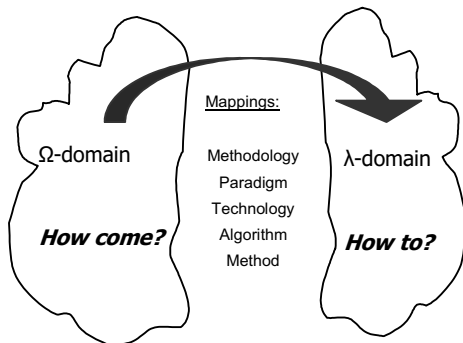


Fig. 10. Mapping between the  $\Omega$ - (how-come) – domain and the  $\lambda$ - (how to)-domain, linking the domain of fundamental (understanding) knowledge with applied (application) knowledge.

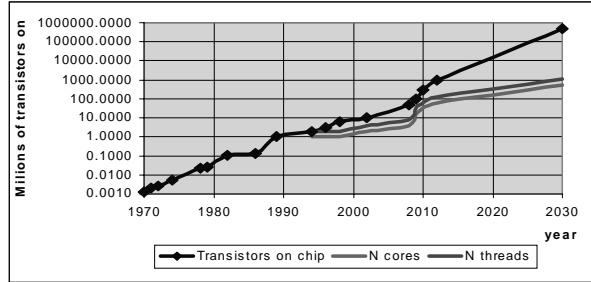


Fig. 11. Moore's law and the projected development of many-core processors

session. This resulted in a long list of which Table 2 only displays a part. Once this list has been compiled, the next question is: how to program and schedule research developments that deliver this 'missing' technology. This is the subject of the remainder of this section and of Section 4. Development cycles determine room that we have for such a program and the roles defined help to assign actions and roles to parties involved.

An example may illustrate this. For quite some years, the development of Intel CPU's (central processing units, the heart of a computer) and the development of Microsoft's operating systems are to some extent intermingled. On the one hand, exploiting hardware capabilities requires applications which require an operating system to run on and on the other hand operating system limitation are directly related to hardware limitations. Figure 11 displays the projected (source: Internet publications) development of Intel CPU's. Lower lines display the number of cores and threads. Moore's law predicts a doubling of transistors on chip every 18 to 24 months. Present generation CPU's have multiple kernels, giving rise to the term: *many-core* CPU's. Each core has its own resources and can carry out separate tasks. Intel turned to this strategy, mainly for technical reasons. The question is then: how to exploit many-core technology? A software counterpart might be to program using multi-threading programming techniques. A thread is a mini-process spawned by an application program that might typically be assigned to a single CPU-core.

With CPU's having up to tens of cores, programmers lack paradigms and methods to design programs making clever use of so many threads. In response, Microsoft and Intel established two University Parallel Computing Research

Centers to develop parallel computational algorithms and methods. This example shows a generic hardware IT trend, for which uptake is hindered because of missing technology. It also shows how coordinated response to program the development of the missing technology can take place *in parallel*, to have lifted the problem by the time such CPU's come to the market.

Not yet announced, but well conceivable, CAx vendors might launch a similar initiative to adapt their applications to multi-threading on many-cores. Real time online change and release management as formulated earlier, might in fact require multiple simultaneous threads running. The end goal of having such and advanced change and release management tools available might support the reaching of more strategic goals, such as cross supply chain mass customization support and adaptive manufacturing.

The Microsoft and Intel initiative (I) was timed looking at typical development cycle times (Fig. 9), as discussed above. The same (Fig. 9) says: CAx vendors should program their initiative now too.

Brainstorming on the above described IT trends and their impact on industrial design and manufacturing resulted in Table 2. The following remarks apply:

- Only inspirers are indicated in the table (rightmost column), actors and supporters have been left out, for clarity. They can be 'matched' following Table 1. Among LSE's (large scale enterprises), there is a desire to shift responsibilities and risk down the supply chain while increasing information and knowledge transfer upstream [26]. See for instance the example given in the Consumer Electronics industry (Fig. 8). This may affect the positioning of actors and inspirers;
- Designers generally fall into the category CAx consumers, being primarily actors or supporters;
- Legal, business administration, managerial etc. expertise is also needed in several developments.

Table 2 clearly calls for a map of multi-discipline development tracks, exploring new collective thinking patterns. The framework to develop in Section 4 will show this indeed. Stevenson, in [45] analyses *group thinking* emphasizing that to liberate from "converged epistemology of the group", *trans-epistemological* thinking is needed: the exchange of new, often

radical thoughts among scientists from various background.

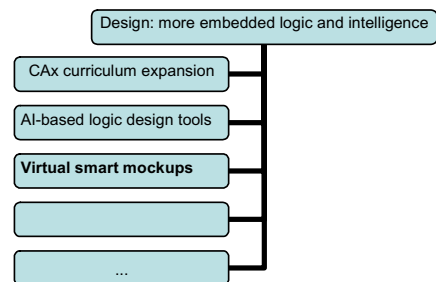
### 3.6 Linking Science and Technology

The rightmost column in Table 2 indicates whether any academic research is foreseen. Here, we adopt the  $\Omega$ - $\lambda$ -diagram technique (Fig. 10) interpreting the proposed notions in [40] with some freedom to make things work. The *propositional*  $\Omega$ -domain represents background science ("how come"), while *prescriptive* technique ("what/how to") is depicted in the  $\lambda$ -domain with a mapping in between.  $\Omega$ -knowledge is more fundamental,  $\lambda$ -knowledge more on application. Notice that science domains like IT, Design, Mechanical Engineering, etc. may both be represented in the  $\Omega$ - and the  $\lambda$ -domain, much like Chemistry can be fundamental and applied in the process industry.

Missing technology development (in response to IT trends) generally requires additional pieces of  $\Omega$ -knowledge from fundamental research, in order to assemble the complete  $\lambda$ -knowledge needed. The  $\Omega \rightarrow \lambda$  mapping can be through and in the form of collecting corollary knowledge, an established relationship ('a law'), a methodology, a paradigm, an algorithm, etc.; the *academic products*, say. The more recipe-like (how-to), the less likely, as how-to knowledge belongs to the  $\lambda$ -domain, but hard boundaries will not be proclaimed here.

Figure 12 shows the resulting  $\Omega$ - $\lambda$ -diagram of the missing technologies as in Table 2. Not all technologies and mappings have been entered, for readability. Relationships for three technological developments cases have been worked out in Figure 12.

Case 1: Initiative: *Virtual smart mock-ups*.



More autonomous and smart objects, implies for the design that designers will apply more embedded logic and intelligence in their designs. The diagram shows four possible actions

Table 2. *Inventory of missing technology*

IT trend	Impact	Initiative/response/action	Role and recruitment
Split up of IT	Design: More embedded logic and intelligence in design	1. CAx curriculum expansion 2. AI-based logic design tools 3. Virtual smart mockups 4. Mind mapping in design	I: academic institutions I: academic/ CAx providers I: academic/ CAx tech providers I: academic/ CAx consumers
	Manufacturing: fitting logic and function through form	5. Smart parts catalogue 6. Universal parts bus/ wireless	I: CAx consumers I: generic IT providers
Near Field Communication (NFC)	Design: low cost dispensable and disposable micro-devices	7. Biodegradable construction material for disposable micro devices	I: academic/ generic technology providers
	Miniaturization	8. Smart parts catalogue	I: CAx consumers
	Manufacturing: surface mounting and protection	9. Catalog complex logic hardware 10. protection foils (skin technology) 11. electromagnetic 'clean rooms'	I: generic IT providers I: academic/ CAx consumers I: academic/ CAx consumers/housing and construction
Web services	Manufacturing: web services for e-logistics and procurements of parts and for cross supply chain e-resource planning and management	12. standard for catalog part taxonomy	I: part suppliers/ academic
		13. automated part supplier procurement/ automated e-trading	I: generic IT providers
		14. advanced stock optimization	I: academic/ CAx consumers
		15. cross supply CAPP/optimization	I: CAx providers/consumers
		16. cross supply chain QC/QA	I: CAx providers/consumers
		17. cross supply chain e-ERP	I: generic IT providers
		18. database alliance technology	I: generic IT providers
		19. trust/ deontic/ normative intelligence	I: legal/ generic IT providers
		20. message certificate technology	I: legal/ generic IT providers
		21. intelligent data integrity, patch, version and release control systems	I: academic/generic IT providers
Scattering storage	Design: consistent design repository, PDM/PLM. Minimizing risk for IP violation	22. roaming configuration management	I: generic IT providers
		23. compliance roles and access rights	I: legal/ generic IT providers
		24. agent-based compliance V&V	I: legal/ generic IT providers
		25. distributed document management	I: generic IT providers
		26. IP encryption technology	I: academic/generic IT providers
		27. cross supply chain SOA/SaaS	I: generic IT providers
Vanishing OS	Design and Manufacturing: Synchronize application tools suite	28. pervasive product technology	I: academic/CAx consumers
		29. enhanced PLM (short/long life)	I: CAx providers/consumers
Geomapping paradigm	Design: adapt design paradigms for geomapping	30. self-organizing 'data rivers' and 'data precipitation' technology	I: academic/ generic IT providers
		31. product-middleware technology (protocols for reconfiguration, inter-communication)	I: academic/ generic IT providers
		32. product-as-an agent technology	I: academic/ CAx consumers
		33. product security (malware, etc.)	I: generic IT providers
		34. auto-service scheduling technology	I: CAx consumers
		35. reconfiguration technology	I: CAx consumers/ providers
Software re-bundling	Design: CAx tools suite re-bundling	36. enhanced PLM	I: CAx providers/consumers
		37. Generic interoperability technology at knowledge level	I: academic/ CAx providers
Mind mapping	Design: involvement non-experts	38. Shop floor-ERP	I: CAx providers
		39. easy associative specification language	I: academic/ CAx providers
Fusion of knowledge, ontology, and MAS	Design: more 'rich' and 'soft' information, preference scores, etc. in conceptual design	40. cognitive, non-verbal mental expression and association protocols	I: academic/ generic IT providers
		41. mind mapping e-consumer decision support systems	I: academic/ CAx consumers
		42. improved soft computing technology	I: academic/ CAx consumers
		43. new knowledge-intensive design paradigms	I: academic/ CAx consumers
Open standards	Design and Manufacturing:	44. Design agent technology	I: academic/ CAx consumers
		45. Supervising agent technology	I: CAx providers
		46. various open standards	I: academic/ generic IT providers/ CAx providers/ consumers

in response, brought up during the brainstorm session:

1. CAx curriculum expansion; teach student designers the principles and advanced skills of designing with embedded logic and intelligence;

2. Develop AI-based logic design tools for designers of customer products;

3. Create virtual smart mockups that virtualize smart products in the design stage, with which an adequate impressions and simulation can be

presented to designers;

4. Develop mind mapping methods for designers.

In this Case 1, we work out Virtual smart mockups in greater detail, as an example.

Basic question: how to program and schedule research such that we will have Virtual smart mockups at our disposal, within the next generation of CAx design tools? First of all, we will need a valid and complete system theoretical behavior model, so that research conclusions obtained from the Virtual smart mockup are representative for the real product being designed. That is: possible states (state space) must be identical and state transitions must be triggered by the same events and conditions and lead to the same stable state (possibly through identical non-stable states). This requires fundamental research from cybernetics and a fitting design CAx application in the applied domain. Observed product behavior (e.g. in response to environmental stimuli) needs to be verified and validated against this theoretical model, for which we need a validation protocol. So, in summary:

1. Cybernetics delivering a system theoretical finite state behavioral model plus a protocol for validation of the products behavior; Likewise, we find:
2. Humanoria delivering a paradigm to estimate the product behavioral model appreciation by consumers; is the product acting as human-expected?
3. Computer science delivering an algorithm to robustly mimic internal logic and to (re)play a simulated product behavior session in a behavior player;
4. Finally, Design and Engineering delivering a methodology to design and create the virtual mock-up.

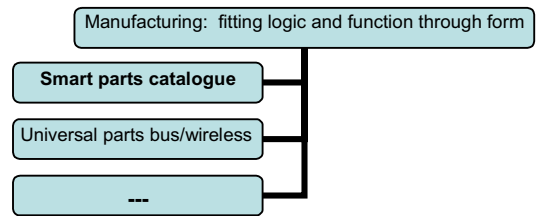
This somewhat simplified list of missing technologies already provides some interesting coordinated cross-discipline research and a development 'program'. Recall that the ultimate goal in this case was to prepare and benefit maximally from the generic IT trend of splitting up IT in IT facility services (not so relevant for designers) and pervasive embedded IT in smart objects (with great consequences for designers).

Case 2: Initiative: *Smart parts catalogue*

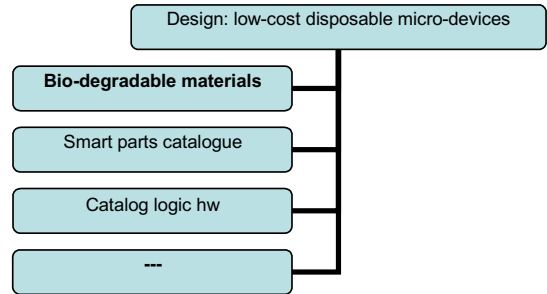
In a similar fashion, for manufacturing, more embedded logic leads to the demand (action)

for more standard smart components; a smart part catalogue and a way to wire them. See the diagram below. Missing technology inventory:

1. Design and Engineering delivering an ontology to create a smart part catalogue;
2. Computer sciences delivering a web services-based computer-to-computer e-procurement framework;
3. Business Administration delivering trading models, e-payment models, supply conditions, and trading trust standards.



Case 3: Initiative: *Bio-degradable disposable micro-device construction materials*



Missing technology inventory:

1. Ecology & Life Sciences delivering ecological knowledge on requirements such construction material should possess;
2. Chemistry, Physics & Mathematics delivering the composition of the basic substance for the material and the industrial process plant to compose the material on an industrial scale;
3. Computer Science delivering standards for computational conditions of the device (object) and environmental sensing characteristics needed;
4. Business Administration delivers an industrial business case.

Recall that in this case, the ultimate goal was to prepare and benefit from the generic IT trend of advancing NFC and pervasive computing in smart objects and environments, and the demand to design and manufacture disposable bio-degradable devices.



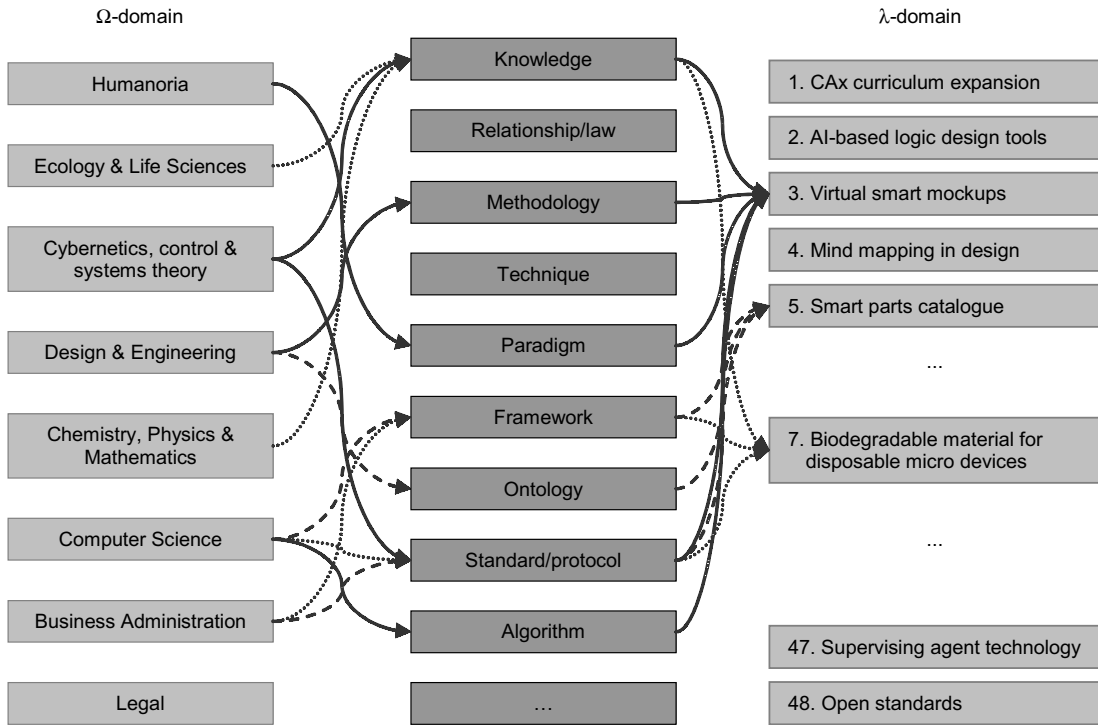


Fig. 12.  $\Omega$ - $\lambda$ -diagram of the missing technologies cases 1-3

Figure 12 commonly depicts the  $\Omega$ - $\lambda$ -diagram of the missing technologies of these three cases.

Per-discipline work packages can be taken from Figure 12 by zooming in on the arrows (flow of academic products) that leave each box in the  $\Omega$ -domain. Spelling out the whole  $\Omega$ -side yields the full research program.

#### 4 A DEVELOPMENT FRAMEWORK

Traditionally, academic and industry have their own disjoint development agendas. There are only few effective *knowledge generation chains*, the preferred solution. The key to successful interfacing between academic and applied research is in a painstakingly accurate and formal specification of the results to be delivered at the 'interface', i.e. in the central column in Figure 12. Figure 12 also shows interdependencies in the  $\Omega$ -knowledge developments.

Fundamental research is generally taking place at universities; technological institutes are generally equipped to conduct applied research. Of course, dominant technology producers and consumers may also have own facilities and

resources. Like in Table 2 and the following Figure 12, developments may be organized in work packages, assigning fundamental research parts to university, defining the output academic product and applying academic products in an evolutionary prototype application. EU Frameworks might be organized like that. The CERN-model also seems applicable.

Like in car manufacturing, where *concept cars* are prototype applications to explore and demonstrate the state of technology, concept products, services and environments might emerge, in response to driving IT trends. The knowledge generation chain should stretch out to demonstration projects in which technology and societal consequences can still provide feedback on the development process. Demonstration projects can to large extent (but not entirely) be virtualized.

#### 5 CONCLUSIONS

The impact of IT technology change in design and manufacturing is significant and driving, but can be adapted for. This can only be done within the near term future time span within a joint

academic-industry effort, in which dominant technology providers and consumer should fulfill an inspiring role. However, immersive technological innovation may threaten market positions of presently dominant technology providers and consumers alike. History reported enough examples of once dominant players no longer existing and only a collective innovation push may deliver the 2030 scenarios portrayed in this paper.

Academic engagement and enrollment might be in the form of an open, for instance CERN-like initiative. Supervision and management of those initiatives require careful thoughts and the right conditions, as we learnt from evaluations of large EU programs. Designers might take full advantages of new IT technology underway, but current design and engineering curricula need to be revised and enriched. Open standards may be both a means and goal.

A deployment of (genuine) interoperability is critical in the whole palette of developments. This is seen as the ultimate touchstone for trans-epistemological shaping of the future to occur. Purely technologically speaking, interoperability IT-technology at data level is already in place. The difficulties arise from semantics and different understandings of the precise meaning of data. At present, CAx technology providers don't always assign priority to interoperability issues. Moreover, CAx technology providers generally seek to optimize performance of their technology through advanced but proprietary storage schemes, each with its own internal representation. In addition to this, on the technology consumer side, OEM's, generally large scale enterprises at the top of the supply chain, should no longer negotiate the use of tools and application suites with their preferred suppliers, but adopt new, open technology.

The principle question is of course: how to capitalize on these opportunities? Not all 'IT progress' can be transformed into productivity increase and not all productivity increase is due to IT developments alone [18]. Industrial uptake is not immediate. Basically, however, IT has the potential to induce economic output growth [12]. Also, on a much smaller scale Claycomb et al. in [13] applying knowledge about the customer pays. Availability of the mere technology is generally not enough. Education and adaptive business strategies are preconditions for the technology to deliver its

full potential, plus a research and development horizon spanning across the near term future, overlooking current and next generation developments.

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