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Advanced design-driven approaches for an Industry 4.0 framework: The human-centred dimension of the digital industrial revolution

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Abstract
There are many ways to name the transformation linked to the digital economy: Industry 4.0, Convergence, Digital Revolution. In this contribution I try to systematize the role of design in this transformation. So, alongside the enabling technologies we support the centrality and innovative potential activators of approaches that are driven by contemporary cultures design. The contribution provides a map of the playing field for this transformation by highlighting the dual and simultaneous ongoing transformation and the connections between technology and design practices. The work ends with a detailed list of potential that can be activated using integrations between enabling and activating approach technologies.

Keywords: advanced design, Industry 4.0, digital revolution, information and communication technologies.

The Industry 4.0 phenomenon[1]

Contemporary economic literature maintains that the process of substantial and pervasive change in the general features of the advanced capitalist production model started a few years ago (Holzhauser and Schalla, 2016). After the revolution generated by the intensive use of the movement of water and steam, after the revolution supported by the discovery and intensive use of electricity and, finally, after the revolution generated by Fordism, the production chain and the scientification of industrial production (classical industry), economists describe the moment we are now living as a "digital tsunami" (Bergami, 2016). For this reason the context in which we are operating is called the fourth industrial revolution, and particularly with respect to the strategic industrial plan launched at the beginning of this decade in Germany, this impetuous and substantial rethinking of production processes can be summarised under the title Industry 4.0.

The origin of this process is attributable to the situation in which a high number of technologies, due to various factors, have simultaneously become cost effective, minimally invasive and quantitatively widespread. We call them "enabling" technologies, in the sense that it is thanks to an integrated and simultaneous use of some of these technologies that the production process acquires highly innovative features and change is enabled. According to estimates by Gartner, over the coming years the objects connected digitally to manufacturers through built-in sensors will grow from 4.9 billion in 2015, to over 6.3 in 2016, reaching 20.7 billion in 2020. Already today the advanced economies in Europe are measured in terms of the degree of absorption of this revolution through an indicator called DESI (Digital Economy and Society Index) that highlights, for example, that there already exists a large gap between the needs and availability of business operators able to deal with this kind of challenge: operators that are able to understand the effects, scope, speed and use both in the production system and in society.[2]

The emphasis that dominates the contemporary narrative of these events makes frequent use of terms like "factory of the future", "automated factory", "additive manufacturing". These terms place the emphasis on an aspect that by itself is not sufficient to explain the extent that this process is having on the global industrial production system. And consequently on our everyday lives. First of all, we must focus our attention on a vast field of exploration. We must not focus solely on the factory as a building in which manufacturing takes place, nor on the single dimension of the network that links the company and the set of suppliers of materials, components, products and services that make up the supply chain. We can say that between the producer and the supply chain important and substantial changes are taking place, but concentrating

[1] The name was given by the German Government to the plan of development for the country's manufacturing industry as a function of the digital revolution. Common synonyms are digital revolution and the fourth industrial revolution.
[2] In the first stage of development of this substantial transformation, in addition to a large number of experts with vertical automation skills pertaining to networks, sensors, computers, data security, etc., it is very important to be aware of the lack of designers capable of playing a conscious role of mediator between the market and production.

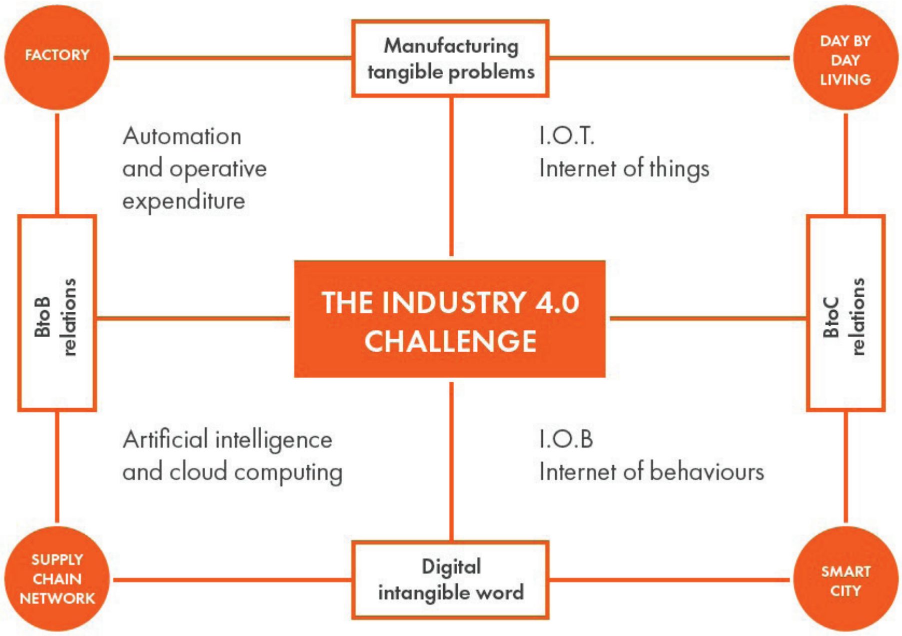

Figure 1. The model represents the "playing field" of the ongoing fourth industrial revolution (Celaschi, Padula).

our attention on the B2B aspect of the question does not sufficiently encompass the scope of the matter.[3]

Figure 1 illustrates what I propose be used from this point onwards to define the so-called "playing field" of the phenomenon we are talking about. We can easily identify a chart of four quadrants separated by Cartesian axes, which becomes useful to read as if they were divided by a central wall (vertical axis) into two playing fields that the previous classic production system considered separate and fairly independent: the B2B field (Business to Business, or anything that happens between producers and suppliers) and the B2C field (Business to Client, or everything that happens from the manufacture of a good until the good arrives at its final destination).

Traditional models of production have so far supported the existence of a barrier that professionally separated the technical-design-production dimension from the commercial-communication-design-marketing-distribution dimension. The first dimension was understood to be an internal activity (of the engineers), which takes place predominantly in the factory or in the relationships between suppliers and the manufacturer. The second was understood to be an area manned by experts in finance, management, design and communication, substantially external to the production environment and focused on the markets, disturbing as little as possible the concentration of those who are busy with production.

Figure 1 highlights four extremes. The two extremes of the vertical axis represent the first challenge, according to which the material dimension (manufacturing) and the intangible dimension (digital) must be combined. This is the easier challenge to understand and perhaps to be implemented because it is still strongly tied to concrete investments in machinery and production services that traditionally represent a share of capital that is easily understood and quantifiable in corporate balance sheets. On the other hand, the extremes on the opposite sides of the horizontal axis are the two worlds of production and the market that up until now have basically lived separately in the big house of the classic industrial production system.[4]

Enabling technologies

In the past few years circumstances have generated an interesting situation in which a number of innovative technologies have become available at low prices and with levels of complexity that are sufficiently manageable. We are talking about technologies with which we now have considerable global experience, researched for a few decades and that for 15-20 years have been used, even industrially, in some especially innovative and particular production sectors (military aeronautics, advanced medicine, nuclear research, etc.).

There are other technologies that, added to these main ones, burst onto the scene with very affordable costs and low levels of complexity: georeferencing users through GPS technology is the most specific example.

[3] The focus of this contribution and the first objective of the discourse developed herein is that the movement taking place is simultaneously composed of a vertical transformation (between digital and physical manufacturing) and a horizontal transformation (between industrial relationships and lifestyle and consumption relationships or behaviours). The revolution will lead to a great need for intermediation between these four systems that until now have not been able to communicate effectively with each other.

[4] Investments in human resources (education, research, integration, mediation) should be regarded as fundamental for both the challenges of this important transformation, however the increased scope of this investment must allow the company to eliminate the wall that currently divides the B2B dimension from the B2C dimension.

Chart 1. The chart systematises the primary and most common families of so-called enabling technologies.

Enabling technology	Characteristics	Application examples
Collaborative robotics	Industrial automation has begun to employ machines that cooperate with man. This collaboration generally takes one of two forms: (1) machines that assist and facilitate the handling of physical objects by reducing the effort of man without subtracting sensitivity and accuracy; (2) machines that learn from their errors and are therefore able to function progressively better, managing their own development.	The so-called learning machines are already used in a countless number of cases in which the machine must interface with an unknown user that requires customised performance of the machine itself. The machine approaches the user, and based on some initial reactions adapts its behaviour.
Augmented & virtual reality	These are technologies that allow the operator to have an augmented perception of objects. A digital model and reality can thus be integrated, offering viewpoints of the activity under way.	There are for example complex operating machines that are made with many overlapping components that can jam and that require human intervention to be reset. In this case, the operator equipped with stereoscopic vision glasses can have the illusion of physically entering the machine with his or her body to the point of standing in front of the layer that has malfunctioned, all without removing any of the machine's casings. For example, Boeing and Accenture have developed a manual system for installation of aircraft interiors by equipping assemblers with a device like this that shows the operator the finished interior of the aircraft while the components are being assembled. In this way the operator can make sure in real time that the work being done is accurate and appropriate for the project.
Additive manufacturing	The next step in the creation of digital mathematical models of physical objects in 3D is sending this information to a machine that produces the object by adding material as if it were mouldable clay. These production systems can be developed using both polymeric materials and metals, and are facilitated by reverse engineering that allows for the three-dimensional analysis of a 3D object to send the order to duplicate it to an additive manufacturing machine.	This technology has two main paths of use: The first is professional, producing parts or components that need to be tested without first having to manufacture an entire series of moulds and other needed support products. The second is more amateur, taking the name of "maker" and using so-called FabLabs to learn how to make structured artefacts for models or for use in simple, real applications.
Cloud manufacturing	Today it is possible to create a digital and virtual model of the production process and entrust it to an external repository in the Cloud. Each relationship and computerised transmission of information between one machine and another, between the different parts of a machine, between one production line and another, between the manufacturer and its network of suppliers is governed through this remote Cloud system that encompasses the entire supply chain process, allowing each node to have access only to the information for which it was authorised. The digital model of the production process is critical for simulating process changes without first having to implement them, allowing for the calculation of the pros and cons of each possible variation.	This technology breaks down the physical barrier between the factory and the manufacturing district, giving the information the opportunity to travel in real time to every corner of the network of suppliers and return to the centre allowing for an immediate overall governance of each step, before it happens and visible to multiple interacting entities. For example, the entire food distribution chain can be managed on a global level in the Cloud, processing orders related to the quantities purchased by the customer of any POS (point of sale) in the world and then automatically managing restocking based on experience with seasonal climate, calendar of holidays, the correlation between symbiotic products (bread and jam).
Big data & advanced analytics	Through sensors placed on products or service touch points it is possible to collect information in real time on the reaction and on the relationship between user and product, as with any entity that has influenced the distribution value chain. All these data arrive in the company which can then analyse their meaning and extract information useful for production.	For example, every online reader of a newspaper with his reading style guides the journalists and the direction of the newspaper that, thanks to the camera positioned on the PC and miniaturized eye tracking, can figure out not only how many seconds the reader has spent on any news item, but also what the eyes have focused on and the user's concentration on each quadrant of the screen, allowing for an assessment of the effects of each component of the news item.

Chart 1. Continuation.

Enabling technology	Characteristics	Application examples
Industrial internet of things	It is precisely the sensors mentioned in the above line through which a series of predefined information can be analysed with respect to the life of the product and its relationship with the user. IOT Internet of things is therefore the technology that allows the boosting of information flow to and from the user and that destroys the barrier between B2B and B2C.	Sensors placed on the seats of an airplane allow the cockpit to know how many people are awake, how many are reading, how many are sleeping or working, and how to offer precise and tailored services to meet the needs of each. Medicine packaging can control the dose and the schedule of use, prevent abuse where the fingerprint on the package is not the one recorded by the purchaser, provide automatic replenishment based on consumption.

The revolution under way is the result of the real possibility of using all these technologies simultaneously to achieve both the optimisation of productive investments in the factory or in the factory supply system,[5] as well as in knocking down barriers between manufacturing and digital spaces (vertical dimension of Figure 1) and the removal of the barrier between the two left quadrants (production) and those on the right (the market), both in the personal and individual dimension and in that of communities and cities (smart cities). The total and systematic use of these technologies is now called IOB Internet of Behaviours. This label in fact represents the more complex and current situation of the fourth industrial revolution in which the real-time behaviours of consumers or users themselves, individually or collectively, govern production and its quantitative and temporal or qualitative response. In short, a sort of Big Brother that depending on where the control is based can allow for the total command of the manufacturing processes – wherever they are physically located – by the citizen, as well as the absolute control of the behaviour of citizens by the production system, wherever they might be.

Activating approaches

Parallel to the availability of enabling technologies, the cultures of manufacturing organisations have evolved and meshed with the cultures of design, humanities and disciplines based on creativity. The exclusive reliance on traditional engineering is no longer sufficient, it is urgent to combine knowledge from different branches of disciplines and create platforms for sharing cultural approaches.

The role of advanced design

Cultures and design practices are therefore at the centre of the digital revolution. All the approaches mentioned above are urgent and important and must fully enter into the culture of the companies that intend to benefit from this digital revolution, and the same goes for the enabling technologies. The difference is that the technologies are being provided to manufacturers as a service by major global players (multinational specialised corporations) and therefore in the future will tend to be outsourced as was done with hardware and software of the first information revolution. The same will not occur for activator approaches, however. From 2007 to 2017 IBM increased the number of designers it employs from 320 to more than 1700, and at the same time it all but abandoned hardware production.

In this process of activator approaches we believe that there is a tip of the iceberg consisting in the approach that has a task of driver with regard to the others, making it possible to operate in advance. We can describe Advanced Design (ADD) as a crossroads of four conditions:

- Project tension with respect to future scenarios rather than the market of tomorrow morning.
- The study of extreme situations and sectors very different from those in which one usually operates in order to extract ideas and stimuli that are innovative and not supported by incremental reasoning.
- The attitude of continuous innovation necessary to meet the now unattainable speed of needs that requires time for project development that is irreconcilable with research times that are necessarily continuous (shelf innovation approach).
- Lack of buyer, in ADD, because it is unlikely that a customer will have expectations other than those requested by the end customer, imagination is not a priority and the stress of short-term results in corporate balance sheets mandates short-range views and briefs that are very close to reality.

The Industry 4.0 paradigm definitely involves the processes of anticipating, where it is not the signals of responses received and processed with respect to the responses of the contemporary market that can generate value, if anything to the contrary it is the ability to operate in a disruptive manner that generates solutions that can be courageously explained and communicated to the final customer.

[5] The main advantages that the use of these enabling technologies in the B2B dimension provide are: greater production flexibility, higher production speeds, greater productivity in terms of volumes produced, better quality, greater overall competitiveness.

Chart 2. The chart summarises and compares the approaches to innovation that we call enabling in the sense that technology alone cannot meet the challenge of this transformation.

Approach	Characteristics	Consequences
Vertical and horizontal integration of the information	Using IIOT, Industrial Internet of Things, the product, the machine that manipulates it and the system of suppliers upstream and downstream of the production process interact and interfere, exchanging information useful for the improvement of the process itself. This is called vertical integration of information and is largely entrusted in the future to the so-called "Cloudification" of the production process. At the same time, thanks to the sensors assigned to the goods and integrated therein, it is possible for the production dimension to send information to the user's space and in exchange receive information in real time, generating the so-called Big Data that through Analytics are then processed to transform information into knowledge.	The goods and services are no longer born just once and for all in the manufacturer's head, but rather are born and evolve continuously through the reprocessing of the information that returns from the consumer or user. Consumers become "Continuous users".
Open source research	The competitive advantage generated by the secrecy of knowledge and its exclusive protection is outweighed by the advantage of sharing information openly and having a large number of brains working together on the simultaneous and integrated solution to problems, especially where different disciplines must integrate horizontally to generate new knowledge. Furthermore, with the reassessment of secrecy it becomes necessary to adopt innovation within organisations to make the assessment of its progress and results measurable and part of a collective effort.	The speed of innovation is growing impetuously, there is a need for a different system of remuneration of knowledge and intelligence no longer based on royalties, as innovation platforms require continuous design.
System design	An awareness of limited resources and their high cost of reproduction require the adoption of secondary raw material reuse processes (the scrap of one process must become the input of another until their total energy has been exhausted). This is also called circular economy and is feasible both in the physical and intangible dimensions (time, for example).	Only space that has already been urbanised can be urbanised again, or at most transform an urbanised area into a natural space in exchange for new urbanisable space elsewhere. Each displacement of material becomes an obvious cost that must be weighed, and thus are formed local economies with aggregated production chains of producers that coexist exploiting each other's scrap.
Participative design	The recognised value of a single creative demiurge – the omnipotent artist who with his taste/style/knowledge informs the product by imposing a distinctive value – will collapse. This kind of value is in competition with the value shared with the user, who wants to be seen as co-author of the product and intends to participate in the supply chain by producing value that will be utilised in a distinctive manner.	Processes sharing creative identity must be designed, capable of listening and sharing information and enabling creativity in those who are unable or not professional.
Internet of behaviours	The set of all the enabling technologies used simultaneously generates this effect: user behaviour is monitored and designed as it continuously evolves, and the producer does not abandon the product at the time of purchase but through it enters the individual user's life (home, car) or collective life (smart city), massively influencing the individual at all times.	Design is carried out in the opposite direction, starting with the behaviour of the consumer and based on that adapting the production process in real time to react sufficiently and conveniently to the behaviour of the individual or collective. The relationships between entities can be triggered and monitored in real time.
Human-centred design	Any production process, even those traditionally more B2B and far from a relationship with the user at the end of the product life cycle (for example, the oil & gas industry, the extraction of minerals, steel rolling, industrial maritime transport, etc.), must deal with the user whether it be an operator or the final recipient. Man at the centre of the project is the slogan most accredited for learning how to include and use the person and his/her biological body as a parameter of validation of the production process and his/her ability to produce value or damage.	Integrated disciplines like neuroscience put us in a position of imagining and carrying out modifications in the person. The person becomes the product.

Chart 2. Continuation.

Approach	Characteristics	Consequences
Advanced design	It is no longer advantageous to innovate acting discontinuously and incrementally starting with a sequence of small changes in the product. It is necessary to act in parallel, developing long-term scenarios that include the company and its objective; perform research in fields far removed from the one in which the business normally operates (extreme design); generate continuous innovation platforms like shelf innovation; operate in the absence of the customer and of a brief by implementing problem finding activities.	The meta-products, the scenarios, the anticipation, studies of trends and weak signals become important B2B products for the innovator and generates employment in the intermediate stages of the creative and scientific-technological supply chain that produces semi-finished products for innovation.
Cyber physical system	It becomes essential to build digital models of the production process not only with regard to the manufacturing process but extended out to the market served. Complexity and interaction generate the need to predictively simulate and intercede in each operation so as to ensure sustainable system feedback.	First, you build the model of reality and work with that model, then with reality itself.

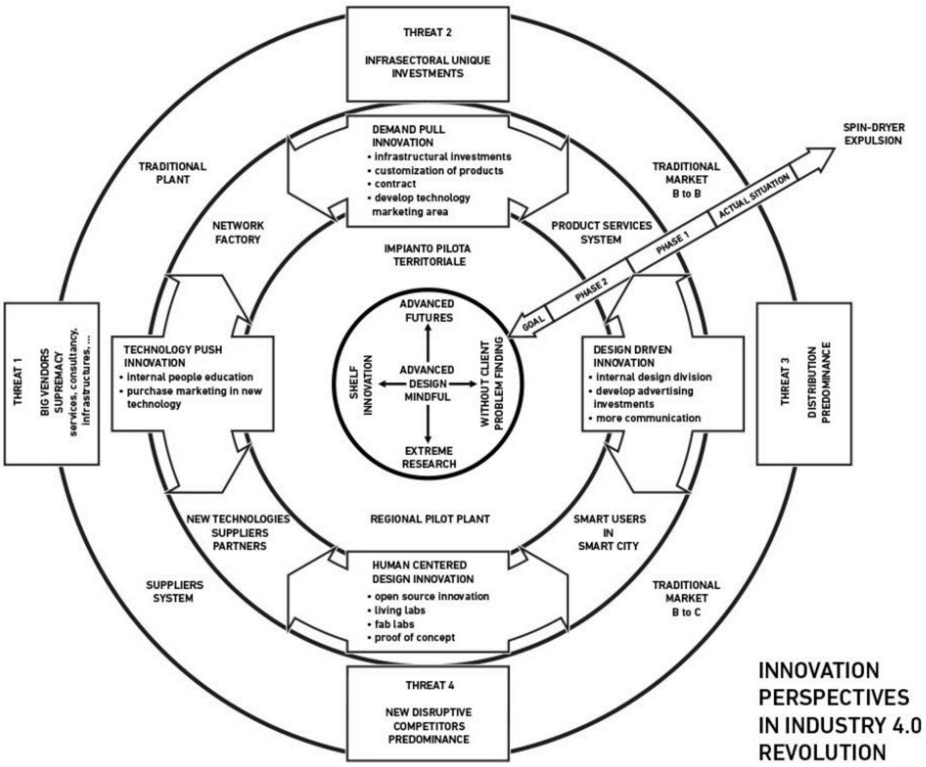

Figure 2. This model seeks to represent the dynamic dimension of innovation within a manufacturing region similar to those that characterise industry in Europe (Germany, Italy, France).

ADD is particularly indispensable in the management of the relationship between market and manufacturer, the traditional role of the designer's mediation in Industry 4.0 being inverted with respect to tradition: the designer is the person who, fully understanding the peculiarities of the new service-product, is better equipped than others to make it better understood and accepted by the final market.

Essentially the ADD approach not only offers a directorial capacity already accustomed to knocking down barriers between the physical and digital in the product/service, but also with respect to the ability to understand both the languages of production and those of use and consumption, i.e., versus the individual or aggregated user.

Conclusions

The revolution taking place in the global production system represented by the label fourth industrial revolution (Industry 4.0) places information at the centre of the process. The fact that information (its use and its posses-

Chart 3. Summary of the relationship and the contribution between disciplines and design practices, objectives and enabling technologies of the current digital revolution.

Objective	Technologies	Consequences for design
• Speed • Reduction in production costs • Customised lots of one	• Cad 2D.3D rendering digital modelling • CAE (fem etc.) • Additive production	Digital breaks down the division between production and design, and design cannot be done subsequent to the definition of a product's structure.
• Outcome certainty • Quality • Customisation • Interconnection with the supplier network	• Cloud • Digital modelling of the production system (cps) • Digital networks • IIOT	System design becomes protagonist allowing various actors at different levels of the chain to act on or control the progress of the design process (co-design and design 2.0).
• Predictive maintenance • Product servitisation (transition from product to service)	• IIOT • Sensors • Big data & analytics • Augmented reality	Digital connection between manufacturer and customer providing services. Service design becomes central to the creation of value.
• Disruptive innovation and generation of the collective product system (smart city) • Anticipation	• IOB • SENSORS • GPS • Big data & analytics • Digital modelling • Additive manufacturing	The barrier between B2B and B2C falls, design is the practice and knowledge that can mediate between the two worlds that today speak languages and assess information that are very different from each other.

sion) had become the key to the revolution had already been well understood within political systems and in the production of culture and scientific knowledge. *Data* are transformed into *information* and must be managed by each company to transform it into *knowledge*.[6] Today this factor has also become key to us and our daily behaviours and every instant of our lives. In parallel, information has become a good to be produced, together with supports that are of various kinds, physical or in the form of a service. UBER did not take vehicle traffic away from taxi companies in California, which prior to UBER generated gross sales of $40 million. Five years after the arrival of UBER, the market for transporting people in California has increased from $40 to $140 million: UBER created a transportation market that taxis could not develop and fulfil on their own. Information and its management create value and disrupt the traditional production sectors we are accustomed to.

We can therefore identify this as the philosophy underlying this radical transformation of production processes. There are secondary consequences that remain very important in the competition between systems, nations and companies (see Chart 3).

We can say that the limits that today's reality offers to the development of the fourth industrial revolution are mainly of three kinds:

- Infrastructure limits: possession of widespread high-speed networks are absolutely necessary for this development. We can say that the subject of enabling technologies co-exists with that of enabling infrastructure.
- Limits of network security and protection: using networks means entering a world that is less safe and more exposed than we know today. Any information not adequately protected is not only at risk but actually anyone can create false or damaging information and contaminate the foundations of the production project with incredible speed.
- Cultural limits: knowledge structures external to the firm (universities, research centres) are still too focused on single disciplines. The 4.0 phenomenon cannot be dealt with by any single discipline. The urgency of creating knowledge mediation and enabling projects to be influenced by multiple disciplines is urgent and cannot be procrastinated. To this must be added the traditional and ossified separation between the internal functions of a traditional company: production, design, sales, etc.

At each level of the complex production process required by this revolution age-old barriers are broken down between knowledge and practice. Urgently needed are mediation knowledge, common languages, co-design, integration of functions, redesign of business departments, rethinking the organisation around the function of the project, which can no longer be just a "hardware-centred" project typical of traditional industrial engineering: information-ICT-mechanical engineering-ICT are forced to work together and in turn break down traditional disciplinary barriers.

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[6] *Data* are the set of bits that technology produces, information is the possibility of transforming this data so that they can be understood and exchanged among multiple technologies and more and different actors of the production process. In the end, however, information is not transformed into *value* if the production organisation is not able to transform all this into a different and new knowledge to be managed, as occurs ubiquitously and in real time in the digital dimension.

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