Software Technology

Digital Transformation

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This instalment of the Software Technology department discusses how the digital transformation is affecting software technology and the software industry.

Digital Transformation (DX) is about adopting disruptive technologies to increase productivity, value creation, and the social welfare. Many national governments, multilateral organizations, and industry associations have produced strategic-foresight studies to ground their long-term policies. By proposing the implementation of public policies regarding DX, such groups expect to achieve the goals listed in Table 1.

DX is forecasted to have high annual growth and fast penetration [1-3]. But there are barriers slowing its dissemination, such inadequate or overly heterogeneous company structures or cultures, the lack of DX strategies and ROI (return on investment) visibility, and even the perception of cannibalization of existing businesses (the "innovator's dilemma" [4]). External barriers also exist, such as the lack of recognition of how DX will benefit all of society, a shortage of skills and a qualified labor force, lacking or insufficient infrastructure, missing or inadequate regulation and consumer protection, and poor access to funding, particularly for small and medium businesses.

Table 1 – Digital Transformation Goals

Perspective	Objective
Social	Foster the development of a more innovative and collaborative culture in industry and society
	Change the education system to provide new skills and future orientation to persons so that they can achieve excellence in digital work and society
	Create and maintain digital communication infra-structures and ensure their governance, accessibility, quality of service and affordability
	Strengthen digital data protection, transparency, autonomy and trust
	Improve the accessibility and quality of digital services offered to the population
Economic	Implement new and innovative business models
	Increase income generation, productivity and value addition in economy
	Improve the regulatory framework and technical standards

The Industry Perspective on DX

Industry is moving to adopt holistic business models, completely redesign products and services, and establish closer interactions with suppliers and long-term partnerships with customers [5,6] The widespread implementation of DX will profoundly affect the industry business environment—for example, by providing better value-chain integration and new-market exploitation, with competitive-advantage gains.

DX is driven by a flood of software technologies. Embedded electronics such as microdevices with sensors and actuators connected through the IoT facilitate ubiquity. Data analytics, cloud storage and services, convergent interactivity and cognition, augmented reality with visualization and simulation, pattern recognition, machine learning, and AI are facilitating a convergence of IT and embedded systems [2,5]. Underlying these, we've identified enabling methods, techniques, and tools, such as agile development for flexible systems, blockchains and Hyperledger to ensure security and trust in distributed transactions, and microservices and open APIs supporting software architectures.

Let's look at automotive technologies, where digitization is ramping up fast. A modern car incorporates 50 to 120 embedded microcontrollers and is connected over various external interfaces to a variety of cloud and infotainment technologies. Onboard software is in the range of hundreds of millions of lines of code (MLOC) and is still growing exponentially. Automotive software product lines and variants are some of the largest and most complex in industry. It's said that the automobile is rapidly becoming a "computer on wheels."

Automotive original-equipment manufacturers (OEMs) are equipping next-generation production processes and vehicles with connected embedded sensors and actuators to obtain better intelligence and control. They adapt information and communication technology workflows from their IT systems to each car. Vertical integration is attained by ensuring that product-lifecycle-management systems, enterprise-resource-planning systems, production-planning-and-control systems, and manufacturing-execution systems work in coordination with capital goods on plant floors. Concerning horizontal integration, vehicle parts are delivered with RFID tags to guarantee production traceability.

OEMs work with suppliers that have the same focus, to ensure that the acquired parts come with self- or distance-monitoring facilities. Examples include highly interconnected electronic control units (ECUs) from companies such as Bosch, Continental, Denso and ZF, mechatronic systems from Aptiv, Magna, Mahle and Schaeffler and Head units and infotainment from companies such as Harman, Valeo, Panasonic and Visteon. In factories, robots from ABB, Denso, Kuka and Yaskawa assemble complete vehicles from parts with exact monitoring and logging of e.g. screw-load-torque to ensure compliance with production and safety standards. All software is individually configured for each single car by modern IT systems, both in production and after sales with over-the-air (OTA) upgrades. These movements toward a digital automobile world have already rationalized costs and investments. For example, according to David Powels, former CEO of Volkswagen's Latin American operations, in the three-year period ending in 2016, the group obtained 30 percent productivity gains in some factories with focus on digital process and competencies. [7].

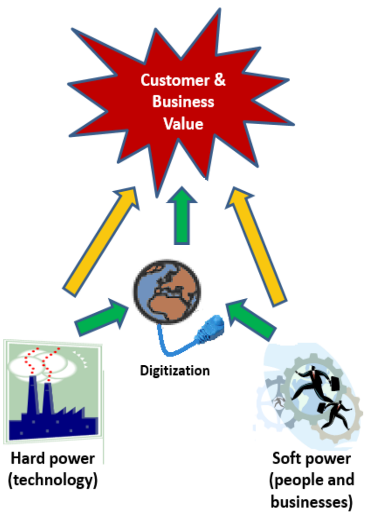

Figure 1: Digital Transformation is a convergence of hard and soft forces and movements from which additional value emerges.

Other industries are following fast toward DX. Vivo, a company in the Spanish Telefonica group, is adopting the agile-squad model and open innovation as the bases of its DX implementation. The company developed a social software robot called Vivi, which helps customers formulate requests. Ten million sessions have already been opened, and 94 percent of them have been solved in an automated way.

Hospital Samaritano and Hospital Sírio-Libanês, two leading São Paulo institutions, have consistently invested in DX to improve the patient experience and operational performance. Both keep integrated secure electronic health records of patients, which are used in procedures, treatments, prevention, and healthcare planning and decisions.

DX Impacts

DX has been a source of continuous entrepreneurship and business dynamism, particularly in technology-intensive industries. These companies have reorganized themselves to operate simultaneously in two distinct modes. The standard mode keeps traditional businesses and operations running, while a disruptive mode seeks additional opportunities to exploit new markets and innovate in technologies, processes, products, or services. Figure 1 illustrates that value is now created not only in traditional ways (the yellow arrows) but also through digitization (the green arrows).

Software technology today is both the driver and effect of disruption. The market leaders are ahead of their competitors because they develop and commercialize new technologies to address customers' future performance needs. However, these companies don't want to cannibalize their current cash cows. So, they're rarely in the forefront of commercializing new technologies that don't initially meet the needs of mainstream customers and that appeal to only small or emerging markets.

So, disruptive companies explore the occupation gaps left by the market leaders. This is a source of innovation and market change, which Clayton Christensen illustrated using price and performance data from the hard-disk-drive industry [4].

We performed a systematic classification of the DX technology offerings; Table 2 presents some details. Although we haven't compiled quantitative evidence of the disruptions caused by the analyzed hardware technologies, Organisation for Economic Co-operation and Development studies have recognized that robots, 3D printing, and connected devices have disrupted productivity in their respective markets [1,2,5]

Likewise, some of the software technologies we studied have been disruptive, but this is due only to their strategic significance, resulting from their penetration, adoption, and perceived value in distinct market segments vis-à-vis the initial markets. Finally, the remaining software technologies we studied can't be considered disruptive because they haven't obtained value recognition outside their initial markets (and therefore aren't included in Table 2). We structured our findings in the form of a knowledge map [6,8], but here we presented just some branches in textual, pictorial, and tabular form. We hope this compilation will help software engineering (SE) practitioners and researchers develop and implement DX.

The Mutual Influence of the DX and SE Disciplines

With software being key to any DX, mutual influences between DX and SE must exist. But DX disruptions due to SE innovations might emerge at any time and are almost impossible to predict. So, we can only speculate about the implications for SE.

To perform initial verification and validation of our ideas, we organized a debate panel during the 2016 IEEE

Requirements Engineering Conference [5]. During the panel, researchers and practitioners discussed the impact and relationship of requirements engineering and DX in industry and research institutions. The panelists came from companies such as Intel (US), Nokia (Finland), Denso (Japan), Civic (China), and CI&T (Brazil).

The participants agreed that software technologies at the core of DX disruptions have been around for some time. These technologies have caused disruptions because of:

- early or timely value delivery (agile methods),
- usage at larger scales (APIs, microservices, and IPv6),
- applications in new domains (3D modeling and printing, control software, and blockchains), and
- unpredicted technology combinations (cognitive computing, which combines computer vision, voice recognition, natural-language processing, and machine learning).

So, DX has not led to the development of radically new software technologies. Instead, it has given rise to new software technology applications, owing to the additional requirements that must be satisfied.

Technological solutions' complexity and scale have increased substantially, leading to software systems with many MLOC, usually binding together old and new, in-house and third-party developments. However, the industry objectives for DX—an improved customer experience and operational excellence—have placed time to market, quality, and affordability at the forefront. So, practical DX problems have become tractable with software only with effective development management, reusability, and requirements-engineering methods, techniques, and tools.

The SE branches we've described have many interfaces, which deal with unproven metrics, hard complexity bottlenecks, and imprecise artifacts. The human factor is central to addressing these issues, but the required key competences for problem solving, managing complexity, and dealing with high abstraction levels are often lacking or insufficient.

DX requires software engineers to organize their work efficiently, act on their own initiative, have excellent communication skills, and successfully perform tasks involving emotion, intuition, creativity, judgment, trust, empathy, and ethics [2].

At higher organizational levels, SE managers are expected to change their mind-sets and abandon command and control, moving to more leadership-oriented, risk-taking, and mistake-tolerant approaches. Corporate leaders need to motivate, direct, support, and inspire their autonomous teams, while learning along with them. They must be prepared to face business environments in which hyperawareness, informed decision making, and fast execution rule.

How can people obtain such skills? DX challenges traditional SE education systems to change their methods and content to a digitally transformed reality. Apart from the classroom and learning-by-doing approaches, continuous, just-in-time, and innovative learning methods—such as massive open online courses, gamification, and simulation—will be increasingly demanded.

To meet DX demands, SE will transform completely, leading to changes in how SE education treats human factors. In this new scenario, human resources will be extremely valuable, possibly becoming more important than the underlying technologies.

DX today is the megatrend across industries. However, DX is challenging because it demands a new set of competences, combining embedded-systems development with IT and cybersecurity. Software thus is the cornerstone of DX. In its convergence of classic IT with embedded-systems engineering, DX will completely reshape the landscape of software technologies and processes. (For more on DX and systems engineering, see the sidebar.)

With industry, home, healthcare, and automotive applications being major drivers, IT will converge with embedded systems such as the IoT and Industry 4.0. At the same time, embedded industries will evolve toward IT with cloud solutions and dynamic over-the-air upgrades. Critical industries such as the automotive industry involve practically all the quality requirements, such as safety, cybersecurity, usability, performance, and adaptability. The underlying software components cover anything from embedded real-time firmware to complex secured cloud solutions. Failure to meet any of those quality requirements results in expensive callback actions and legal lawsuits. These challenges will soon reach across industries.

DX is opening the doors for technology innovation, new business models, and cross-industry collaboration. The future is arriving while some are just running in their hamster wheels. Thus, we should be cautious, along the lines of what technology strategist Herman Kahn already observed several decades ago: "Everybody can learn from the past. Today it's important to learn from the future." [9].

Acknowledgements

The assumptions, views, and opinions in this article are solely the authors' and don't necessarily reflect the official policy, strategy, or position of any Brazilian government entity.

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Table 2. Disruptive Technologies Adopted in DX Implementations

Technology type	Inherent nature and attributes	Disruption and significance	Early-adopter experience	Adopted technology	Ease of adoption	No. of alternatives	URLs
Collaborative equipment (drones and robots)	Hardware capable of limited interactivity with moving parts and remote or embedded controls having typical sensor or actuator functions in heavy industry, space, or military applications	Adoption of cognitive computing expanded this technology's applicability from routine tasks to those requiring adaptability or autonomy, enabling its commercial use in precision agriculture, logistics, consumable-product industries, and services.	Alibaba manages retail warehouses in China using teams of unmanned shelf-carrying robots, which load and unload at multifunctional workstations.	Quicktron self-charging robots with QR code readers, laser or LIDAR anti-collision sensors, adaptive routing, and Wi-Fi connectivity with back-end software	Hard	Few	http://translate.google.com/translate?js=n&sl=auto&tl=en&u=http://www.flashhold.com/page/16.htm
Additive manufacturing and 3D printing	3D object creation from digital models, using printer heads driven by software-controlled stepper motors, for polymerization, jetting, extrusion, fusion, lamination, or deposition	Advances in image processing, precision mechanics, and new materials decreased the price of printers and printed objects, making them accessible to businesses and consumers for rapid prototyping and small-scale or customizable production.	BioArchitects supplies FDA-certified 3D prostheses to customers in Brazil and the US, for training doctors and planning surgery procedures.	GE Arcam machines, which support additive high-power Electron Bean Melting production of titanium prostheses from CAD models generated using diagnostic-imaging exams	Hard	Very few	http://www.arcam.com/products/arcam-q10
IoT connected devices	Hardware with embedded digital electronics, software, and network connectivity enabling its unique identification, data collection, and data exchange	Implementation of IPv6 and reduced device costs enabled the massive dissemination of connected devices in machine-to-machine transactions and the IoT.	Volkswagen uses an IoT solution based on RFID tags to manage supply chain traceability in factories worldwide.	A Kathrein IoT distributed antenna system with customized software and standardized UHF RFID tags and transponders to ensure end-to-end order traceability	Hard	Some	https://www.kathrein-solutions.com/solutions/logistics
Agile development	Software development based on adaptive planning, evolutionary development, early delivery, and continuous improvement through collaboration of self-organizing cross-functional teams	Rapid-prototyping development evolved to widespread agile development owing to user involvement and rapid compliance with requirements, time-to-market reduction, and early value delivery.	Lloyds Bank adopted design thinking, agile methods, and a cloud-based microservice architecture to break down the transformation of 10 customer journeys, which paid back in three years.	IBM Bluemix, a hybrid cloud platform-as-a-service architecture, used to support Scrum and a minimum-viable-product development methodology	Medium	Very many	https://www.ibm.com/cloud-computing/bluemix
Blockchain or Hyperledger	Continuously growing lists of decentralized information blocks, linked and secured through cryptography, used in recording financial transactions between parties efficiently, verifiably, and permanently	This technology has been disseminated to many other application domains that require secure fault-tolerant event record management, such as the arts, law, accounting, commerce, and healthcare.	A blockchain open source platform has been used to manage things ranging from World Food Program vouchers for Syrian refugees to a collaborative decentralized news network.	The Ethereum blockchain app platform, a decentralized framework with programmable virtual-machine and peer-to-peer protocols for defining and running distributed secure transactions	Medium	Some	https://www.ethereum.org
Open APIs and microservices	APIs and distributed services allowing system architectures to be structured in modular and open configurations	This technology's use in developing enterprise application ecosystems out of business functionalities, with decoupled deployment and operation, maximizes value for money.	Equinix Cloud Exchange provides cross-cloud application integration and scalable services by using an open-API platform.	Google Apigee, a Java-based service platform to develop, deliver, manage, and analyze APIs via their proxies	Easy	Many	http://www.apigee.com
AI	A set of algorithmic tools for data analysis, representation, inference, deduction, and heuristics-based behavior	The coupling of AI to big data, cloud computing, natural-language processing, computer vision and voice recognition enabled scalable resolution of real problems in many application domains.	Telefonica launched its AURA AI service to help customers with any bureaucratic, communication, and interactive-content demand.	The Microsoft Bot Framework and LUIS, the respective IDE for creating and deploying software robots and natural-language-understanding integrated services	Easy	Many	https://dev.botframework.com https://www.luis.ai/home

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