Digital solutions for bespoke apparel achieving mass customization in as service business models

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ABSTRACT – REZUMAT

Digital solutions for bespoke apparel achieving mass customization in as service business models

The Information and Communications Technology sector may be organized into individual technologies or solutions. Theoretical literature review argues digitalization technologies make up enterprise architecture and shape business processes or business models. It also shows contemporary business models market solutions for a given value or impact, rather than sell individual technologies per se. Empirical data confirms enterprise architecture is the market for system integration. Market data shows the market leader is Software AG. The goal of this article is to build a theory with an emerging case example of more technologically and business model sophisticated solutions than the theoretical and market benchmark. The methodology is a dual case study on important market players, Siemens and PTC. The standalone cases allow for similar solutions which cannot be otherwise tested or validated. Reference is also paid to other market players within the article. The empirical data analysis is compared to acceptable benchmarks, theoretical literature review and the enterprise architecture market leader Software AG. Findings show emerging technologies add capability maturity levels to accepted system integration. Network business models with a quantifiable and provable customer value proposition: bespoke or personalized products, reasonable cost per item, and zero inventory achieve the vision of mass customization. The business models are enabled by the highest level of digitalization capability maturity, not considered in the status quo literature review and at the leading enterprise architect. They place the textile industry at the forefront of technological innovation and extended reality-based marketing.

Keywords: *bespoke products, enterprise architecture, platform business models, as a service business models*

Soluții digitale pentru îmbrăcăminte la comandă care realizează personalizarea în masă în modele de afaceri ca serviciu

Sectorul Tehnologiei Informației și Comunicațiilor poate fi organizat în tehnologii sau soluții individualizate. Din analiza literaturii teoretice rezultă că tehnologiile de digitalizare formează arhitectura întreprinderii și modelează procesele de afaceri sau modelele de afaceri. De asemenea, prezintă modele de afaceri contemporane despre comercializarea soluțiilor de piață pentru o anumită valoare sau impact, mai degrabă decât despre vânzarea tehnologiilor individuale în sine. Datele empirice confirmă că arhitectura întreprinderii este piața pentru integrarea sistemică. Datele de piață arată că liderul de piață este Software AG. Scopul acestui articol este de a construi o teorie cu un exemplu de caz emergent de soluții mai sofisticate din punct de vedere al tehnologiei și modelelor de afaceri decât standardul teoretic și cel al pieței. Metodologia este un studiu de caz dublu pe jucători importanți de pe piață, Siemens și PTC. Cazurile independente permit soluții similare care nu pot fi testate sau validate altfel. În articol se face referire și la alți jucători de pe piață. Analiza datelor empirice este comparată cu benchmark-uri acceptabile, revizuirea literaturii teoretice și liderul de piață al arhitecturii de întreprindere Software AG. Constatările arată că tehnologiile emergente adaugă niveluri de maturitate a capabilității de integrare sistemică acceptată. Modelele de afaceri sunt în rețea, cu propunerea valorii cuantificabilă și demonstrabilă pentru clienți: produse la comandă sau personalizate, cost rezonabil pe articol, inventar zero. Astfel se realizează viziunea personalizării în masă. Modelele de afaceri sunt activate de cel mai înalt nivel de maturitate a capacității de digitalizare, care nu este încă inclus în recenzia literaturii teoretice general acceptate și nici în oferta de referință a leaderului pieței arhitecturii informaționale. Ei plasează industria textilă în fruntea inovației tehnologice și a marketingului bazat pe tehnologiile numite realitate extinsă.

Cuvinte-cheie: *produse la comandă, arhitectura întreprinderii, modele de afaceri tip platformă, modele de afaceri ca serviciu*

INTRODUCTION

Digitalization and digital transformation may be defined as the impact of a mix of technologies on businesses, industries, and society. Capability maturity indices are used to conceptualize digital transformation and the technologies, and other resources grouped in capability maturity levels which describe solution architecture. Literature review shows capability maturity indices are tied to the levels of value which they create, capture and deliver. Advanced digital business models involve marketing solutions rather than selling products; the value created, captured and delivered by solutions is computed during the marketing process. Stipulated in customer contracts and guaranteed to the customer. Integrated solutions with defined input, output, outcome and impact may be defined via as a service business model. The following article tackles several new technologies, extended reality ER and generative artificial intelligence networks GANs, which advance the scholarly and market reference of leading system integration and enterprise architecture. Within enterprise architecture, platform business models achieve mass customization and the customer value proposition of personalized products mass-produced at standard cost. Late in 2021, Facebook and Microsoft [1–3] launched the Metaverse, where virtual reality VR and augmented reality AR will be used for leisure, learning, work, and omnichannel commerce, beginning with the fashion industry. Market analysts like IDC [2, 3] argue that extended reality ER, that is VR, AR or mixed reality MR are the latest trend in omnichannel commerce and favours highly personalized products as new use cases. The textile industry has already noted the implementation of Information and Communication Technologies ICT [4]. These technologies include those who analyse the pattern of the human body measurements enabling clothing design [5, 6]. These body measurements are used for customized apparel [7]. Bespoke apparel has long been an objective in the textile industry, and in 2022 technologies have been integrated into designated solutions by major ICT vendors. The vendors create the solution and customer value proposition. The goal of this article is to create a complex causal loop diagram of the solution and enterprise architecture that creates bespoke products and advances the literature for digital solutions with a theory-building case study. The methodology is an explanatory, systems-based, theory-building and instrumental case study. It uses a complex causal loop diagram which is the conclusion of empirical data and is presented upfront in figure 1.

The dependent variable is the customer value proposition created, captured and delivered: bespoke (or personalized or individualized) apparel available in mass at standard cost. The independent variables are all the elements of enterprise architecture as they are integrated into the elements of the business model canvas.

Findings show several benefits. Empirical data advances the leading proposal for enterprise architecture with technologies that enrich all processes (research and development, customer relationship management, supply chain management). This gives the article its theory-building value. Empirical data illustrates the functionality of the as a service business models used to architect these integrated solutions and thereby brings fresh examples to recent theories. Solutions which include ER provide the first products for the Metaverse, launched in 2021. These are argued here as having significant benefits compared to other products; the value created, captured

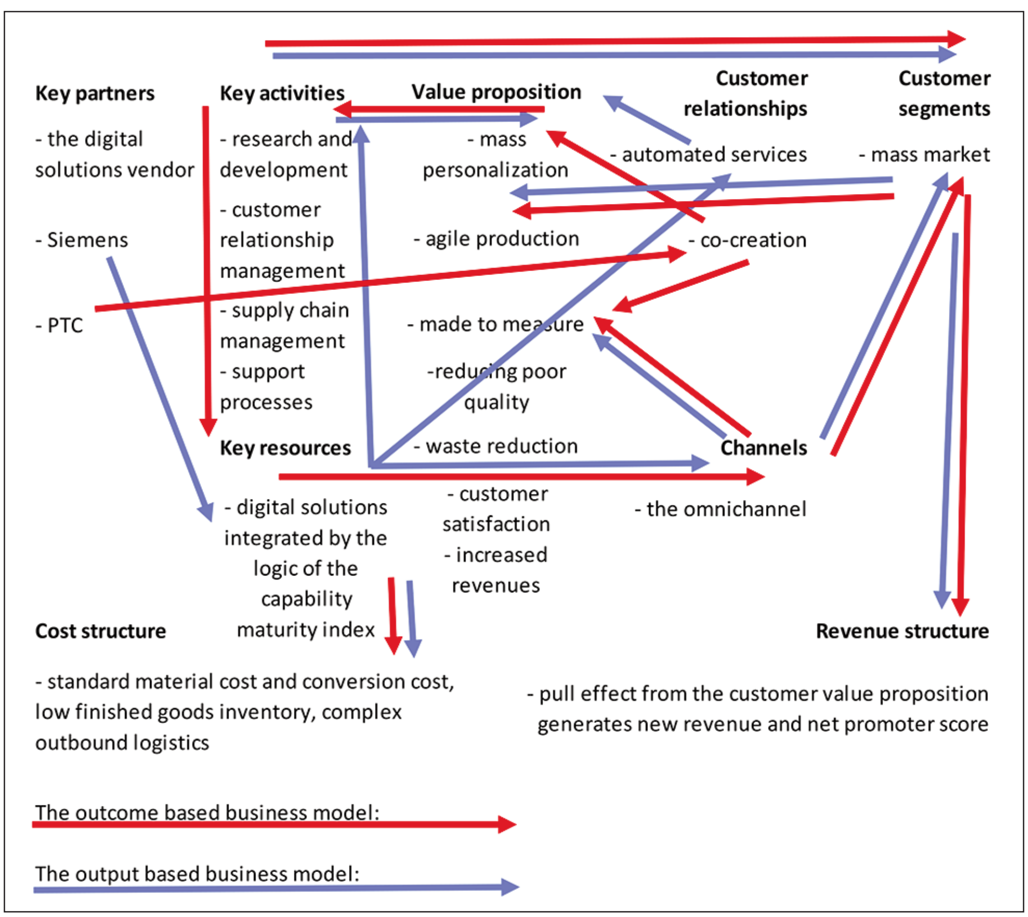

Fig. 1. Complex causal loop diagram based on the elements of the business model canvas

and delivered for customers should motivate buying and loyalty. There are strong limits to the approach: the case study needs extensive references, yet cannot demonstrate the validity of the assertions about technology, which belong to vendors. To mitigate this shortcoming, four case studies have been used in parallel and compared to the others. Findings from all four sources show personalized products are recently emerging solutions that integrate technologies, which technologies are consistent at all vendors and include ER as a marketing interface. Furthermore, the case study is extensive, uniting several topics that normally belong in individual articles with clear demonstrations.

LITERATURE REVIEW

The digital transformation journey is typically represented by a maturity index, a management tool that represents future digital transformation scenarios alongside capability maturity stages in a progressive manner. Each stage summarizes the organizational dimensions of digital transformation capability and provides a scale-based assessment of the level that they have reached to date. Digital maturity indices are used as an assessment and control tool to manage the digital transformation process. Acatech, the Industry 4.0 working group, provides the most important maturity index [8, 9]. In it, the *stages* of digital transformation capability maturity include computerization, connectivity, visibility, transparency, predictive capability, and adaptability. The *dimensions* of digital transformation capability maturity include resources, information systems, organizational structure, and culture. The digital transformation capability maturity index begins with rigid value chains supported by automation-hierarchy business information systems and progresses to flexible value networks supported by distributed digital networks [9–11]. Horizontal integration across the entire value creation network describes "…the cross-company and company-internal intelligent cross-linking and digitalization of value creation modules throughout the value chain of a product life cycle and between value chains of adjoining product life cycles…" [9]. The new vision interlinks smart factories with smart supply chains, which are integrated and driven by customer order [12–15]. In the most common vision, mass customization, the customer order is individualized in the batch size of one. As the customer places the order on the Internet, all supply chain activities are scheduled to meet this demand. The cost of producing individual units matches the standard cost. Manufacturing is conceived to be agile. By 2020, Industry 4.0 technologies are progressively united into solutions that match specified value drivers by the Industry 4.0 capability maturity index (figure 2) [8]. The index means that mature technologies can only be used in combination with less mature technologies. It also involves specified value drivers matching each capability maturity level, where agility is the main key performance indicator. The new business models are to have great customer pull, while maintaining reasonable cost, for example, standard cost, and scalable quantities which can be mass.

The first stage of digital maturity is computerization, that is, connecting Product Lifecycle Management PLM software and adjacent modules to Enterprise Resource Planning ERP functions, such as Customer Relationship Management CRM and Supply Chain Management SCM. Together, they form the business information system infrastructure, shape business activities and business processes, and form operating models [10, 11].

In the second stage of the digital transformation of capabilities, these business systems are placed in the cloud [5, 6, 15, 16]. The next three stages involve [3] sensors that send information to the cloud, generating big data [1] that analytics technology can mine for patterns [5, 6, 16, 17]. These are descriptive, diagnostic and predictive analytics. One definition of the

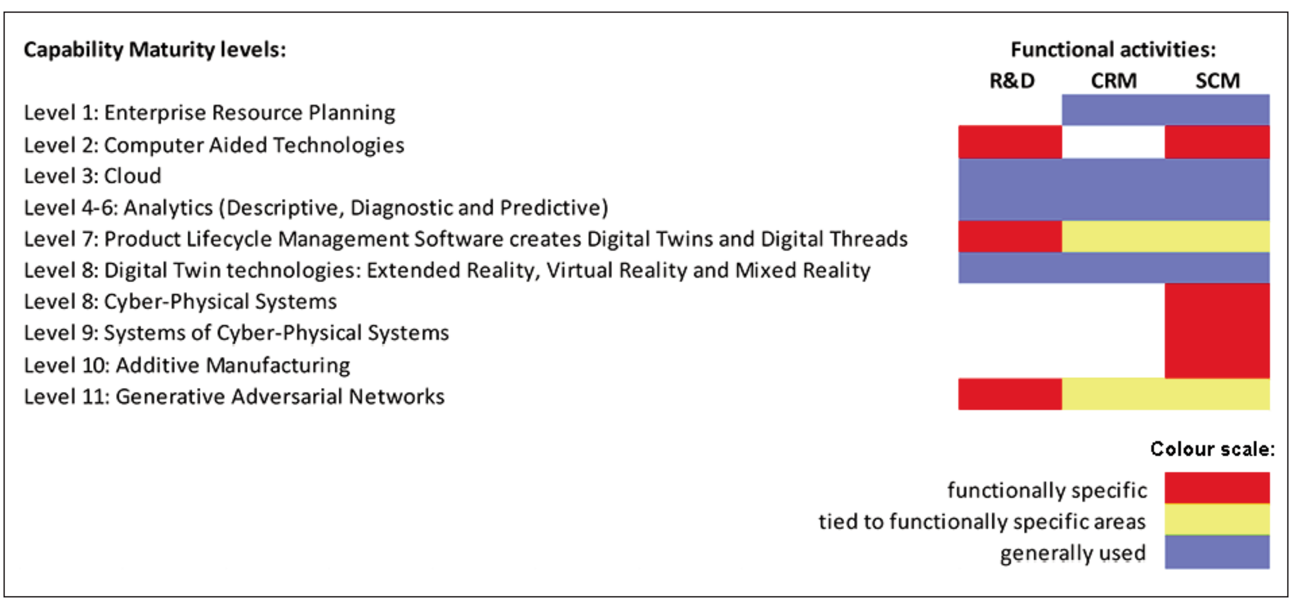

Fig. 2. Technologies and business processes in the Industry 4.0 capability maturity index

digital twin is essentially a software model that uses sensor data to mirror a machine or series of processes within a business to provide a deeper understanding and reveal which changes will lead to better performance [5, 6, 16, 17]. These technologies upgrade the enterprise resource planning ERP-based architecture [17–19].

The first process to be digitalized is PLM software, based on the preceding stages of digital transformation capability maturity. In 2003, Daum [11] defined PLM as activities including market research, collecting customer feedback, technological research, prototyping, initial customer tests, business planning, go or no-go decisions, development/implementation, market and business development, beta testing, pilot testing, and release. The digital twin, a concept introduced by Grieves in 2003, directly relates to PLM software because the digital twin is an indistinguishable virtual copy of a physical product [18], and PLM software is defined as the virtualization of the physical world as a combination of physical products in real space, virtual products in cyberspace, and data and information that tie the virtual and real products together. Uniting several digital twins generates the digital thread, and the digital twin and digital thread are subject to the ISO/TC 184 standard [20, 21]. PLM software comprises two main types of programs: product design (producing the bill of materials) and production planning (producing the routing or bill of the process) [22]. Innovative PLM systems now fully enable the transmission of the digital twin of product design and production manufacturing, in a digital thread, to the manufacturing execution stage [18–21]. PLM systems transmit product design (i.e., material content) and production planning (i.e., machine minutes and labour minutes) to operations [19, 20], thus creating the digital thread [18–21]. In 2022, PLM is implemented on cloud platforms, and the information in the digital twin may be shared within the enterprise and with suppliers, open innovation partners, retailers, and customers [22].

In the next stage, manufacturing execution and SCM are digitally transformed. For these functions, artificial intelligence AI and autonomy are needed to reach the level of full cyber-physical systems CPSs [22–25], which can make autonomous, highly complex decisions for themselves and the chain of systems they are embedded in [23–26]. In the smart factory, CPSs collaboratively decide the manufacturing schedule. If the entire supply chain is based on CPSs, the internet-based customer order will determine the full supply chain scheduling. Previous research has addressed the relevance of digital twin-based EA for CPSs [27–36]. Digital transformation moves the automation hierarchy to the digitalized distributed network [7, 8, 21, 24, 25, 36, 37]. It enables new products, such as smart connected products [38]. In other words, rigid value chains are replaced with flexible value networks [39], which may become the next critical competitive advantage in the global fashion industry. Scholarly research has identified several Internet of Things architecture models, including Reference Architecture Model Industry 4.0, Industrial Internet Consortium Open Architecture, IIC Security Framework, and OpenFog Reference Architecture [40]. In 2019, Pasqual et al. [40] developed a digital twin-based EA that creates platform business models.

Going beyond the Industry 4.0 capability maturity model, a complementary technological innovation is additive manufacturing AM, in which the manufacturing process is designed as a distributed network rather than an automation pyramid. Digital twin-based EA facilitates AM applications [40–44], so a need has emerged to accelerate further efforts to develop and standardize a digital thread for AM [45]. Following the framework of the IIC, systematic efforts should be made to identify, assemble, test, and promote best practices to hasten the development of an AM digital thread. Research and support from industry, government, and academic partners worldwide can contribute to the development of prototypes and ensure the digital collation, processing, and storage of information, leading to informed, effective decision-making. Rather than be operated by traditional computer-aided manufacturing, AM is now managed by CPSs.

Other technologies have recently emerged that shape the customer experience. In line with [13], CRM aligns lead generation, customer engagement, closing, after-sales service, and ongoing customer service. In the age of pull business models, the customer experience is enriched by other technologies that rely on digital twins and AI. Digital twin technology supports AR, in which digital information, such as 3D CAD models or data captured by sensors or calculated by IT systems, is placed in the context of a real-world environment [8]. This is where digital twin technologies become more sophisticated and encompass ER, AR, VR and MR.

Furthermore, generative AI is used to support collaborative co-creation [46, 47]. In 2014, Goodfellow et al. [47, 48] proposed a generative model called the generative adversarial network (GAN), comprising a generator and a discriminator. The generator is responsible for producing samples and the discriminator for determining the authenticity of samples. Because the goal of each side is to defeat the other, the model that optimizes itself is continuously modified, and, after the final training, the generator can produce a nearly real sample through any input. The goal of a generative model is to study a collection of training examples and discover the probability distribution that generated them, and GANs [47] are an AI algorithm designed to solve the generative modelling problem. They are subsequently able to generate more examples from the estimated probability distribution. Generative models based on deep learning are common, but GANs are among the more successful generative models (especially in terms of their ability to generate realistic high-resolution images). GANs [46–50] provide a way to discover deep representations without extensively annotated training data. To achieve this, backpropagation signals are derived through a competitive process involving a pair of networks [51]. The goal of GANs is to estimate the potential distribution of real data samples and generate new samples from that distribution. GANs [51, 52] have been widely studied due to their enormous potential for applications. These applications include the fashion industry, typically in creating new apparel [52–54].

As the capability maturity index shows, digital technologies are hosted as software as a service on cloud platforms as a service. Theoretical literature review shows that, in business-to-business markets, business models move from selling products to providing services. Business models may mean selling individual products. As a service business models, however, involve tailoring integrated solutions to customers' needs. As a service business models additionally specify the key performance indicators created, captured and delivered by the solutions [55–58]. These performance indicators range from availability to return on capital employed [55–58]. In as a service business model, the customer value created and delivered by the solution is calculated by the vendor, stipulated in customer contracts and guaranteed to be achieved at the customer business by the vendor. Typically, computations treat the purchase cost and investment and compute the return on the investment given by key performance indicators above a hurdle rate. Thereby, commercial agreements interact with the realm of management accounting [59]. The new, as a service business models involve all these elements: integrated solutions and the business value they create, capture and deliver. From a technological perspective, this moves from individual technologies to system integration. From a business perspective, this involves close cooperation between the vendor and the buyer.

EMPIRICAL DATA ANALYSIS

Methodology

The standard methodology looks at a dependent variable and a simple formula of one or several independent variables in several stances. The article parts from a theoretical literature review, where several concepts are treated in individual articles with logical connections that may be inferred but missing in scholarly literature. Business practices however show a holistic approach that requires a new methodology to be researched to be consistent with the most recent trends in the ICT sector: as a service business model, meaning integrated solutions and customer value proposition. The methodology of this article looks at complex relationships between many independent variables outside formulae. This is motivated by the complexity of as a service business models, which part from selling individual products to integrating solutions and the customer value proposition they create, capture and deliver. The methodology will have to weigh in complexity, in the form of the number of variables and logical relationships induced. In this systems approach, mass-produced bespoke products at low cost are the customer value proposition and the dependent variable. The independent variables explain the dependent variable and refer to technologies converging into solutions and business activities that shape business processes and other elements of the business model canvas. The numerous independent variables require a systems approach, an actualization of the Peter Senge systems approach to business and complex business loops. A causal loop diagram may be created to represent the causal relationships between the various elements of the system, as in figure 1. The causal loop diagram has two stances, the output-based business model (shown in blue) and the outcome-based business model (shown in yellow). Two main vendors are considered in their solutions for bespoke products: Siemens and PTC. These technologies are studied at two ICT vendors: Siemens and PTC. They are compared between themselves, highlighting the similarities and differences. The case study refers to the market-leading enterprise architecture at Software AG [60], the systems integration of Industry 4.0 technologies into business processes and business models. The solutions for bespoke products are compared to this. Furthermore, PTC and Siemens are compared to IDC (market analyst) and Oracle (ICT vendor). The data in the multiple case study is available on the Internet. It comes from a wide variety of sources that have been searched systematically by keywords and match the technologies in the solution, their names, maturity indices, bespoke products, and personalized products. Vendors provide clear statements about the technologies integrated into these business solutions, which are referenced to as an argument. The variables considered in the empirical data analysis cover all the elements of the business model canvas, as in figure 1. They form interdependent systems. At Siemens, technologies shape activities and customer value propositions in output-based as a service business models. This means the solution is pre-architected for business customers and the business model solutions will create, capture and deliver business value to be stipulated in contracts. At PTC, the outcome-based business model is used, meaning customer value requirements and demands initiate the vendor's design of the integrated solutions which are to create, capture and deliver the desired value. This forms two logical connections between the dependent and the independent variables. These connections may be reciprocal when the choice of business value drives the co-creation of the solution architecture to meet these customer demands. Both business models integrate all elements of the business model canvas. A large number of variables and the complex, changing relationships amongst them however pose serious limitations to evidencing this research fully, although arguments do exist.

Integrated business process management solutions for bespoke apparel

Capability maturity indices and the capability maturity levels in solution architecture

Newly emerging technologies enable end-to-end solutions for bespoke products, which means predefined product design that is adapted to the volumetric requirements of each customer, which are size or measurement. Market analyst IDC rates personalized products as a newly emerging use case with a notable future in omnichannel commerce or digital marketing [2, 3, 61, 62]. Both Siemens and PTC use digital maturity indices to show the progressive integration of technologies into solutions [63–66]. The index means technologies are integrated progressively into solutions, where each progressive step requires the completion of its predecessors. The indices are highly similar [63–66]: the first level of digital maturity is given by the cloud; the second level of digital maturity is given by analytics; the third level of digital maturity is given by digital twins, AR, VR, MR and the digital thread they create; artificial intelligence advances and reaches CPSs; finally AM and blockchain add on. PTC [65] offers a collaboration between PTC, Blacksmith International and Henderson Sewing Machine to create the Intelligent Apparel Manufacturing Platform. Both Siemens and PTC refer to their solutions for bespoke products or intelligent apparel as integrated solutions comprising several convergent technologies. This shifts the focus on solutions and their system integration rather than stand-alone products and technologies. The solutions are cumulated in the progressive order of the capability maturity index (figure 3).

Service business models and the role of solutions and key performance indicators therein

The as a service business model begins with identifying the key value drivers or key performance indicators that shape the integrated solutions. Both Siemens and PTC proceed this way. Siemens advertises a new end-to-end solution for mass-manufactured bespoke products at low cost [67–70]. At PTC, the solution is marketed with clear quantified benefits [71]: mass personalization; agile production; made-to-measure; reducing poor quality; waste reduction; customer satisfaction; increased revenues. The benefits are intended to create a customer pull that attracts and retains a high number of customers while

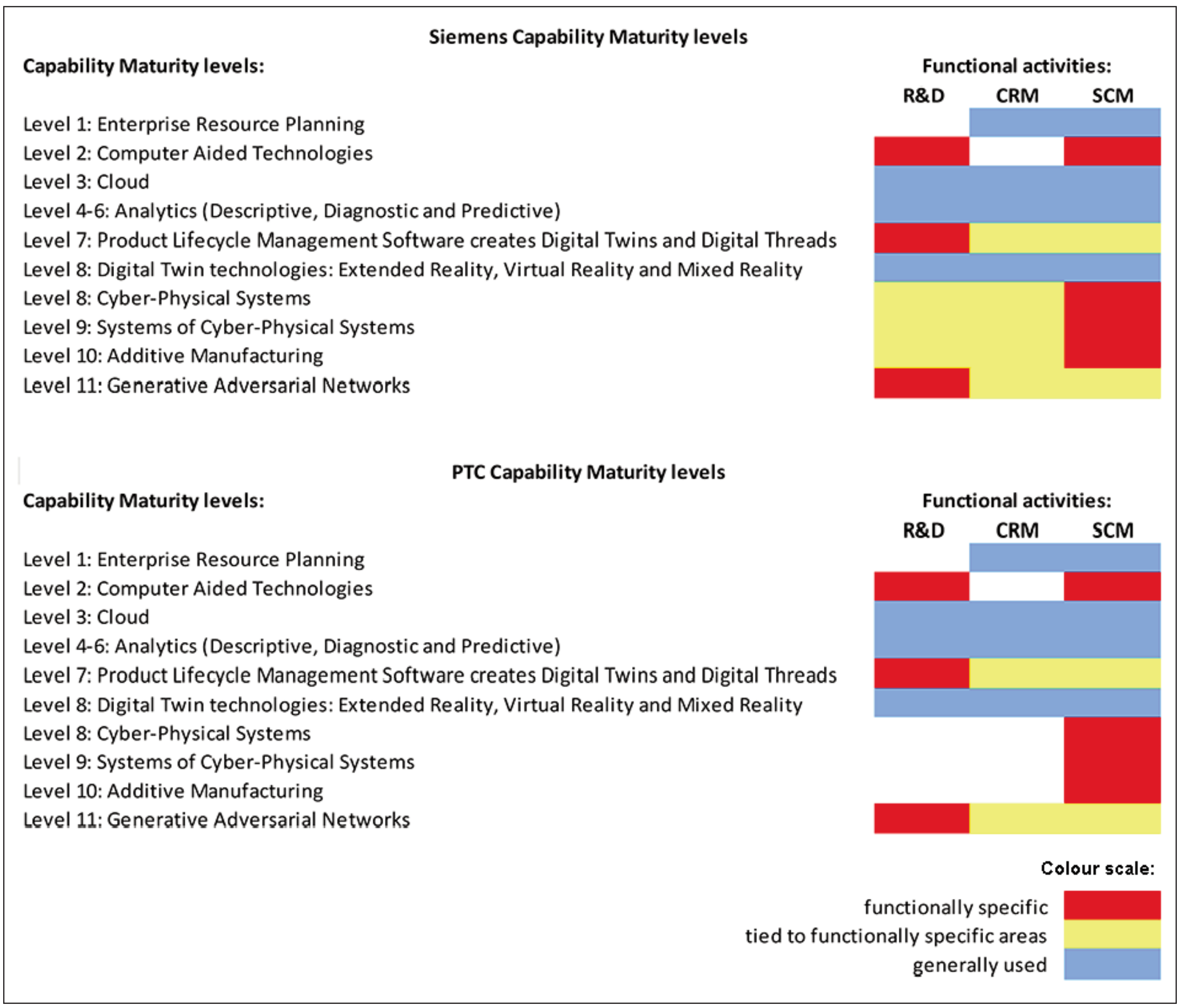

Fig. 3. Technologies and business processes in the Siemens and PTC capability maturity index

maintaining efficiency and assuring agile production. Customer pull indicators are mass personalization; made to measure; customer satisfaction; increased revenues. Mass personalization means: "younger consumers, especially millennials, want personalized products rather than mass-marketed products that don't reflect their individuality". Made to measure involves: "What comes to mind when you think of making a garment specific to an individual? Most people think of a seamstress or tailor, but today, an apparel company can do just that. Because of the Internet of Things, store managers, designers, and developers communicate in real-time, so orders with measurements specific to one consumer can be made and delivered without interrupting the entire supply chain". Customer satisfaction may be understood as: "When an apparel company can provide quality products at a good price while offering immediate delivery, customer satisfaction increases. Not only will they be satisfied, but they are much more likely to remain your customer for life". Increased revenues are driven by: "providing the right garments to the right consumers, you will increase customer loyalty, retail contracts, and market share". Efficiency indicators are: reducing poor quality and reducing waste. Reducing poor quality signifies: "The cost of poor-quality falls between 5 and 30% of total revenue. With Industry 4.0, poor-quality garments can be a thing of the past. Smart Factories will now have access to real-time quality data, and information sharing that tracks processes, machines, and people. Because of this, apparel companies can increase the speed of improvement and decrease the cost of quality". Reducing waste entails: "Prior to Industry 4.0, the fashion industry process that started with a fashion show in Paris and ended on a production line could take two years or more. When finally produced, many of these clothing trends do not sell well, leading to thousands of pounds of waste. According to the Fashion Industry Waste Statistics, the clothing industry is the largest world polluter next to oil. With real-time feedback, companies can now change their garments to meet consumer needs with little waste". Besides customer intimacy and operational efficiency, the integrated solution will guarantee agile production. Agile production is defined as: "Industry 4.0 lets apparel companies visualize the apparel process from design to production and automated processes allow multiple product lines. This means that an apparel company can still produce a mass-marketed permanent collection while offering smaller capsule and limited edition collections without sacrificing quality". Both Siemens and PTC create a blend that delivers personalization at low cost and in mass capacity. Both corporations advertise and guarantee these benefits to customers in the event their solutions are purchased. Both have global service units to assist customers in computing return on their investment (purchases). At Siemens Financial Services, 2800 tackles the issue of customer return on investment amongst others [72]. At PTC, 1400 employees address the same issue and help compute the customer return on investment [73]. This is done via key value drivers or key performance indicators that shape the investment. Solutions are architected with the goal of creating, capturing and delivering business value. At Siemens, the pre-architected solutions create customer value in the form of key performance indicators. At PTC, outcome requirements drive the co-created solution architecture for the textile customer.

The digital technology solutions at Siemens, PTC, Oracle, Accenture, and Software AG, the business processes they underpin and their relation to value stipulations in as a service contracts

The first business activities in the business model are research and development and involve PLM and GANs. This stage is not included in the reference enterprise architecture at Software AG [59], but both Siemens and PTC offer extensive solutions for it. It is also included in the solutions for highly personalized products at IDC [2, 3, 61, 62]. These solutions are placed in the Cloud and encompass PLM for product design and production planning and GAN to adapt this product design to requirements and constraints. At Siemens, the implicated PLM systems are Simcenter, NX and Teamcenter [74–76]. Siemens' innovation strategy is the digital thread [64], which integrates digital twins across the product lifecycle and extended enterprise. In 2015, Siemens' smart innovation strategy aims to create products that vary (such as in their size parameters) in response to customer input. A digital collaboration platform is used for AM [77], whose functions are based on the digital twins of product, production, and performance [77]. AM can print any given product design, but adapting the product design to customer volumetric requirements is achieved via GANs [78, 79]. In the future, Siemens intends to use these technologies for completely new forms of customer experience with autonomous functions in which generative design is combined with AI in Simultenigence [80, 81]. PTC has a similar research and development solution, where PLM is placed in the cloud and combined with GANs. These stages are achieved by the Internet of Things platform Thingworks and the PLM software solution Flex PLM together. At PTC, the standard PLM solution for all markets is Windchill [82–84]. Flex PLM is a designated PLM Software for the retail, footwear and apparel industry [83]. PTC argues the retail, footwear, and apparel product development process is fundamentally different from that of discrete manufacturing, which has driven the development of traditional PLM [83]. PLM is complemented by GAN PTC Creo [85–90]. PTC [89] offers a generic design for a set of alternatives which engineers can refine and explore to produce the best design that fits requirements. These requirements may be volumetric requirements. In their turn, in the textile industry, these are the customer measurements that the textiles need to compare to, typically the size. Furthermore, PTC Creo is a generative design solution that allows users to input their requirements and constraints for the product to be designed and then manufactured via AM [91].

Operational activities comprise CRM and SCM processes and successful research and development. IDC [2, 3, 61, 62] markets use cases about digital marketing that is based on ER. The future of digital marketing and omnichannel commerce also includes personalized products [61, 62, 72, 73]. At Software AG [60] reference enterprise architecture, CRM processes are called “market to cash” and comprise digital twins and augmented sales bots. The end-to-end solution overarches all technologies and shapes all business activities needed to market bespoke products, for example, the helmet [70]. The digital twin in CRM activities is preceded by technologies which shape it according to customer requirements. At Siemens [67], CRM activities involve, in this order: generating the digital twin or scan of the customer’s head, via mobile phone, augmented reality, a mobile phone application, a 30,000 point cloud of the customer’s head; ordering the product online, via the company website; matching the design of the product to the volumetric requirements of the customer’s head to obtain a customized helmet. The bespoke helmet is a pioneer product enabled by Siemens for its customers, who will be the producers of the helmet. Other bespoke products also emerge from bespoke spectacles, and bespoke shoes [67–70]. At PTC, Vuforia is the solution for AR [92–99]. This may involve several interface technologies: Vuforia Instruct via tablets, Vuforia Expert Capture via special glasses, Vuforia Studio also via special glasses, Vuforia Engine via mobile phone, Vuforia Chalk via a tablet, and Vuforia Spatial Toolbox. AR may be used for manufacturing solutions, service solutions, and sales and marketing solutions. In sales and marketing solutions, Vuforia Ventana is ascertained to transform the marketing function. AR is “an interactive experience that combines computer-generated perceptual overlays on real-world physical objects or environments with digitally presented information”. The solution is intended for build-to-order and configurable products, whose design is decided by the customer. Via the Visual Line Collaboration App, users can access all product-relevant data from one source, including data in ERP and e-commerce systems [100]. A similar ER Cloud comes from Oracle as a new form of marketing or CRM. This will allow people to collaborate in gaming, design, marketing, and commerce [101–103]. The architecture of Oracle Cloud comprises several layers: visual browser, Internet of Things, sensors, beacons, edge computing, AR cloud (point cloud, data storage, web services), the aesthetic layer (computer vision, image and remote sensing, cameras, facial recognition), the functional layer (visualization, mapping and analysis, localization), and the intelligence layer (artificial intelligence, object detection, spatial pattern detection, predictive modelling, clustering).

SCM management involves manufacturing and supplying the customer order, which comes in the form of the digital twin. In the reference enterprise architecture at Software AG [60], SCM involves processes demand to operate (CPSs, logistics cobots) and source to pay (3D printing, digital rights). At IDC [2, 3, 61, 62], personalized products may be 3D printed or managed via ERP. At Siemens, the digital twin is 3D printed exactly as per the customer order in several manufacturing stages; then it is shipped to the customer [67]. Siemens claims the manufacturing activities may be scaled from 1000 units to 70,000 units without difficulty. The product will be of measurable high quality and low cost. At the Intelligent Apparel Manufacturing Platform [103–105], a collaboration between PTC, Blacksmith International and Henderson Sewing Machine, PTC complements its Internet of Things platform Thingworks, Product Lifecycle Management software solution Flex PLM with automated sewing machines that are upgraded to Industry 4.0. Blacksmith International brings manufacturing level Industry 4.0. A smart factory uses Industry 4.0 technology, such as robotics, AI, the Internet of Things, and analytics. The pattern of the product will be 3D printed. Conventional textile manufacturing methods will be used to cut and sew textiles giving any design and any fabric. At Oracle, the ER cloud is intended to be used together with 3D printing machines in a joint venture with Xerox [101, 102]. This aims to make new types of products possible. Siemens notes that the combination of technologies enables new products and new production processes [106]. In traditional manufacturing, activities are sequenced as stages of engineering, manufacturing, and storage. With the AM network, the process steps change to engineering, distribution, manufacturing, and tracking [100, 101, 107–111]. The AM network connects part buyers via the cloud with part suppliers, machine vendors, materials vendors, software vendors, and engineering consultants [100, 107, 111]. The process steps [80, 81, 86, 87, 100, 108–111] include requirements, generative design, adaption, performance validation, manufacturing validation, pre-processing, 3D printing, part finishing, and quality control. These processes create an AM network, which may involve customer co-creation. Thus, Siemens creates AM digital transformation centres. This pioneering solution is intended to be followed by many in the future.

AT Siemens and PTC, GANs are used to adapt predefined apparel design to customer volumetric requirements. Accenture [112] offers a more sophisticated marketing interface for the apparel industry, where customers combine existing product designs into new product designs. This gives new dimensions to co-creation. Accenture technology is not known to be integrated into a full solution.

On the PTC website, there are four approaches to exploring customer offerings: selling products, technologies, pre-architected solutions or architecting solutions based on key performance indicators [113]. PTC Creo is used together with other technologies for a special type of textiles, and space suits [114]. Other technologies in textiles target the digital transformation of traditional fibres into integrated technol-

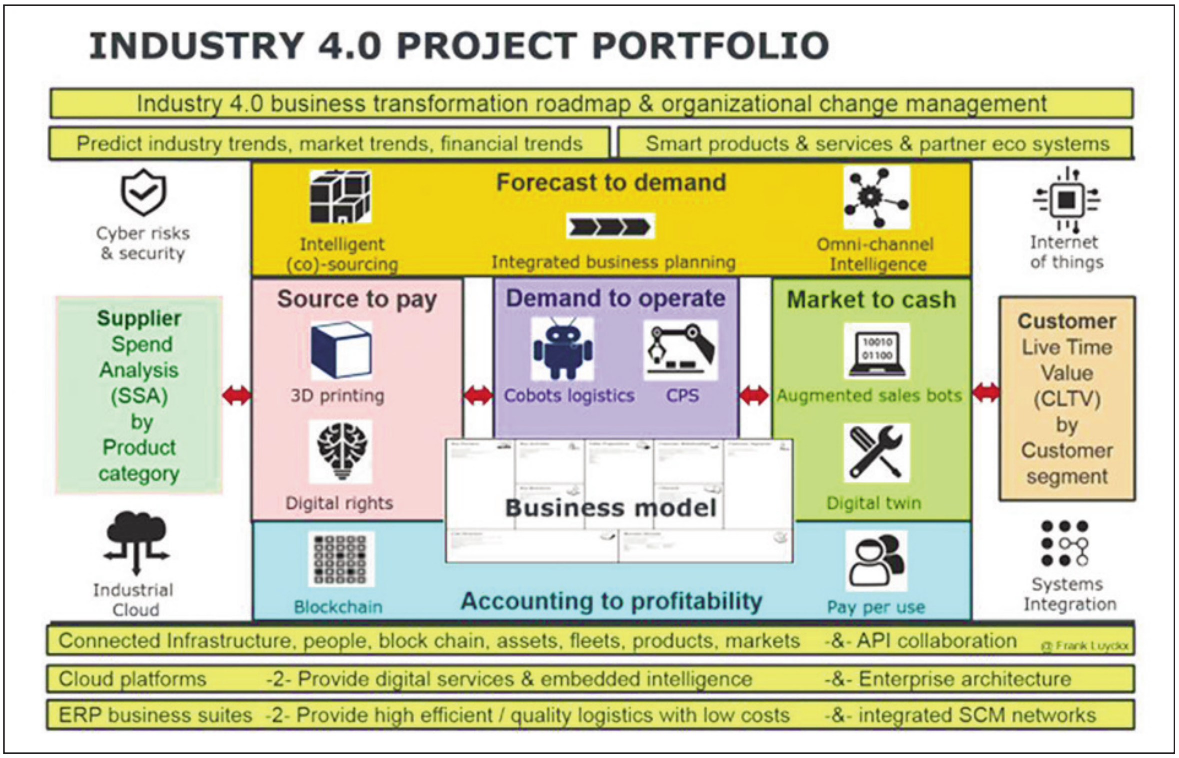

Fig. 4. Enterprise architecture according to the market leader [60]

ogy systems for consumer and military use [115]. The solution involves other, unconventional technologies: the integration of semiconductors, smart yarns and other networked devices or systems. The value drivers are innovations in energy storage and conversion; temperature regulation; health monitoring; colour-changing garments (figure 4).

Enterprise architecture at Software AG [60] involves digital technologies that are placed in the cloud and integrated into new business processes triggered by the customer order in the entire supply chain: market to cash, demand to operate, and source to pay. Market to cash is catered by digital twins and augmented sales bots. Demand to operate is managed by cyber-physical systems and logistics cobots. Source-to-pay processes are conducted by 3D printers and digital rights. Support processes involve finance and strategy and oversee operational customer relationship management and supply chain management.

CONCLUSIONS

This article is extensive and addresses a plethora of topics. Scientific literature review writes about capability maturity models and the progressive integration of the capability maturity levels therein. The levels of the capability maturity index show the progressive integration of technologies and the business processes they underpin into solutions. When this integration is complete, the concept of enterprise architecture describes the overview. Distinct literature review refers to as a service business models, where the object of the trade agreement is not an individual product, but a bundle of products and services integrated into solutions. Articles are focused on individual topics and the ties in between are scarcely explored. However, empirical data shows that as a service business models and enterprise architecture may be closely connected. The article methodology is an explanatory systemic case study. It tackles two as a service business models, where bespoke products are the customer value proposition: the output business model, where solutions are pre-architected along with their output, and the outcome business model, where solutions are co-created based on outcome agreements. Empirical data analysis reveals and illustrates the pattern in figure 2. There are complex causal loops between the elements of the business model canvas, as in the causal loop diagram. Customers may choose from existing solutions or co-create solutions based on value requirements; value is important as it provides the business rationale for customers to purchase/invest in these solutions. By comparing the solution architecture to the literature review, it shows the elements of the Industry 4.0 capability maturity model are used and the same goes for the additional technologies added on top as recently emerging. These solutions may span all business processes, shape all elements of business models (including the customer value proposition) and be integrated into a novel enterprise architecture concept.

The levels of sophistication of these solutions differ at Siemens, PTC, Oracle or Accenture. However, the comparison of the literature review and the market leader in enterprise architecture reveals the reference level of enterprise architecture used and elaborated. The similarities between the four empirical cases, literature review and market leader enterprise architecture show the most advanced technologies are systems integrated realistically and credibly. The add-on of ER and GAN technologies by the two highlighted solution providers shows the solution for bespoke products is more technologically advanced than the market leader and enabled by new commercial realities such as the Metaverse. ER marketing interface makes it possible for customers to get a 3D look at the apparel as it suits their size. At IDC, they may try it virtually. Unlike the staple enterprise architecture, these recently emerging technologies make bespoke products possible online. The research will impact customers who use these solutions or competing solutions. There are strong limitations to this approach in the sense of using the space and scope of an article; demonstrating vendor assertions. New research opportunities may be created by new products, services and solutions for ER interfaces, such as the Metaverse; of them, bespoke products for couture or haute couture stances may be included; integrated solutions have synergetic capabilities that may differ strongly from stand-alone technologies and, as such, deserve further research.

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