

Setting the Hook – The Digital Transformation from a Manufacturing Point of View and what it Really Means

Completed Research

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Abstract

The digital transformation is gaining momentum. During February 2019, Google has received twenty-five times as many search requests for "digital transformation" as five years earlier. This inflationary upsurge is accompanied by an ever-increasing blurring of the context the term is supposed to address as well as of the definition itself. In this paper, we tackle that problem from a manufacturing point of view by conducting a systematic literature review. As a result, we present an industry-tailored three-layer definition for the phenomenon. Furthermore, we identify 30 technological concepts that are considered as digital transformation-related in that context. Divided into eleven clusters, we embed them into a framework outlining the digital transformation in the manufacturing environment.

Keywords

Digital transformation, digitalization, digitization, literature review.

Introduction

In 2019, the digital transformation is ubiquitous. The term has made it into the headlines of newspapers, web pages and practitioner conferences at a remarkable pace and is becoming a priority for both managers and politicians (Legner et al. 2017; Riedl et al. 2017). A brief look into Google Trends helps to quantify this perception (Siliverstovs and Wochner 2018): During February 2019, Google has received roughly twenty-five times as many search requests for "digital transformation" as in February 2014, whereas for connected terms like "technological progress" the numbers have stayed quite constant.

Unfortunately, when reading (scientific) publications on that topic, two controversial things strike the eye. First, there is no clear or universal definition of the terms used to address the phenomenon, namely "digital transformation", "digitalization" or "digitization" (Legner et al. 2017; Mertens et al. 2017; Mertens and Wiener 2018; Riedl et al. 2017). Second, there is no general understanding of the spectrum this term is supposed to cover. A screening by Mertens et al. (2017) has produced a list of over 2,500 different terms including the letter sequence "digital" in recent scientific literature and financial press, covering almost all facets of the modern social and economic life. A large part thereof appears rather obscure and/or intentionally made up to attract attention or create an impression of innovativeness.

This lack of a common theoretical fundament makes it impossible to ensure cumulative and sustainable knowledge creation (Sparrowe and Mayer 2011). It has therefore led to an extensive discussion among highly rewarded information systems (IS) researchers on the definition and the scope of the digital transformation (Legner et al. 2017; Mertens et al. 2017; Mertens and Wiener 2018; Riedl et al. 2017).

Taking on these two controversies in a combined fashion, we would like to contribute to that fundamental discussion by conducting an exhaustive literature review. As digital transformation-labeled publications are skyrocketing since 2014 (Mertens and Wiener 2018) with over 8,000 published journal articles, conference papers and even more non-scientific works, this is only workable by focusing on one specific subset. We therefore limit ourselves to the industrial sector that contributes the largest part of the value added in the

Western world according to the International Standard Industrial Classification (ISIC) (OECD 2015), i.e. the manufacturing industry. We seek to answer the following two research questions:

R1: How are the terms “digital transformation”, “digitalization” and “digitization” defined in the manufacturing context?

R2: What technological concepts and domains are subsumed under those terms in the manufacturing environment?

The rest of this paper is organized as follows: We first describe our methodological approach for the systematic literature review in Section 2. Afterwards, we present our results on the definition of the digital transformation (Section 3) and the different themes and technologies covered by it (Section 4). We will conclude our paper with a discussion of the resulting implications for research and practice.

Methodology

From a methodological point of view, we follow the approach of Webster and Watson (2002), as it provides the most suitable search strategy for theory-based reviews like this (Paré et al. 2015). After identifying the relevant publications through a database search, this preliminary list is extended by an additional backward and forward search. Searching backward means that the citations and reference lists of the identified publications are screened to recognize further relevant sources which were not covered by the database search. In a forward search one uses a web-based database to identify articles citing the key articles found in the previous steps and include them, too, if necessary (Webster and Watson 2002).

As they have typically been peer-reviewed before publication, journal articles and conference proceedings are commonly regarded as the two scientific formats which ensure the highest level of content quality (vom Brocke et al. 2009; Webster and Watson 2002). Consequently, we limit ourselves to those two formats. We use Scopus for our screening. Scopus is the world’s largest abstract and citation database, which means that it does not host the research articles itself but lists the publicly available parts like authors, title, abstracts, key words and publication data. It is therefore not primarily intended to give access to research papers (as most scientific databases are, e.g. ABI/Inform or ScienceDirect) but to provide an exhaustive overview over what has been published in almost all scientific fields, including medicine, social sciences, engineering, business, economics and several more. With specific regard to IS research, it covers a very wide spectrum of journals and conferences, including the complete Senior Scholars’ Basket of Journals, the whole ranking published by Lowry et al. (2004) and 302 of 312 sources that are ranked as A+, A or B in the VHB Jourqual 3 Ranking. This makes Scopus the ideal tool for comprehensive literature reviews not just for IS but for all social and technological research areas and reduces the risk of individual mistakes while comparing and mapping data sets from several different databases.

We use the terms “digital transformation”, “digitalization”, “digitization”, “digitalisation” and “digitisation”. We connect them with the “OR” operator and limit the search to the titles, abstracts and keywords of the respective articles. Since the hype has started in 2014 (Mertens and Wiener 2018), we limit our analysis to this year and the following ones until the end of 2018.

That search query results in over 8,000 results. Therefore, it is inevitable to integrate a further filtering step to ensure an appropriate level of content quality (vom Brocke et al. 2009). As not only the IS community is increasingly engaging in research on the digital transformation, we do not want to limit ourselves strictly to IS journals and conferences. This eliminates the already mentioned IS-only options of the Senior Scholars’ Basket of Journals or the ranking published by Lowry et al. (2004). Instead, we limit it to journals and conference proceedings that are ranked as A+, A or B in the more widely spread VHB Jourqual 3 Ranking. This means that 302 renowned international scholarly journals or conference proceedings in the fields of business, economics, engineering, information technology (IT) and IS are used as potential sources for our review, including backward and forward search.

The resulting search query leads to a list of 227 scientific publications which match the chosen requirements. As we limit our research to the manufacturing sector, we have to manually identify all articles which lack a connection to that specific environment. Due to the broad search approach, many of them deal with topics in the healthcare and retail sector or with social, legal or other implications (Laumer et al. 2015; Laumer et al. 2017). These are excluded which leads to a list of 31 publications that are analyzed in depth.

Searching backward and forward reveals another nine publications so that we ultimately rely on 40 works dealing with various questions around the digital transformation in manufacturing.

Defining the Digital Transformation

Taking a closer look at these publications from a literal point of view, five out of the 40 articles stick solely to the term digitization, seven to digitalization and four to digital transformation. 15 works use two of these terms as equivalents and leave out the third. Seven other publications use all three terms as synonyms. The works of Arnold et al. (2016) and Brynjolfsson and Mitchell (2017), which were found in the backward search, do not use any of these terms but “digital” in various constellations.

Ultimately, they contentwise all address the same phenomenon. Furthermore, only one article pays regard to this lack of wording precision. Mocker and Fonstad (2017) do this by including a second sentence into their defining footnote saying “We refer to digitisation to mean the application of digital technologies to transform how business is being conducted. We do not distinguish it from the term digitalisation.” In the other works not a single word about this vagueness can be found.

When it comes to defining these terms, few of the revised publications render real assistance. In only nine out of 40 an explicit definition can be found (Coreynen et al. 2017; Denner et al. 2018; Echterfeld and Gausmeier 2018; Heavin and Power 2018; Lenka et al. 2017; Loebbecke and Picot 2015; Mocker and Fonstad 2017; Nwankpa and Roumani 2016; Piccinini et al. 2015). These nine are collected in Table 1.

Source	Definition
Coreynen et al. 2017	“Digitization refers to the increasing use of digital technologies for connecting people, systems, companies, products and services.”
Denner et al. 2018	“As the impact of digitalization is boosted by the fast emergence of digital technologies (Mattern et al. 2012), digitalization can be defined as the adoption of digital technologies to improve or disrupt business models, business processes as well as products and services (Gartner 2016).”
Echterfeld and Gausmeier 2018	“Digitisation is basically a broad and multifaceted term that drives innovations in manifold ways [...].
Heavin and Power 2018	“Digital transformation is defined as ‘the use of technology to radically improve performance or reach of enterprises’ (Westerman, Bonnet, & McAfee, 2014). Westerman et al. (2014) note that ‘executives are digitally transforming three key areas of their enterprises: customer experience, operational processes and business models’.”
Lenka et al. 2017	“The industrial management literature defines the digitalization of manufacturing as the phenomenon of intelligent connected machines that information and digital technologies power (Lerch & Gotsch, 2015; Parida et al., 2015).”
Loebbecke and Picot 2015	“Digitization originally describes the conversion of analog to digital information and processes in a technical sense (Negroponte, 1995). We, however, are primarily interested in changes of established patterns caused by the digital transformation and complementary innovations in our economy and society.”
Mocker and Fonstad 2017	“We refer to digitization to mean the application of digital technologies to transform how business is being conducted. We do not distinguish it from the term digitalization.”
Nwankpa and Roumani 2016	“Within an enterprise, digital transformation is defined as an organizational shift to big data, analytics, cloud, mobile and social media platforms.”
Piccinini et al. 2015	“We witness how advancements in digital technology are reshaping a wide range of activities in society at large, which we may refer to in short as digital transformation.”

Table 1. Explicit Definitions Addressing the Digital Transformation Phenomenon

All together, they are far away from homogeneity, reaching from the very vague statements by Piccinini et al. (2015) (“advancements in digital technology are reshaping a wide range of activities in society at large, which we may refer to in short as digital transformation”) and Loebbecke and Picot (2015) (“changes of established patterns [...] in our economy and society”) to the highly specific definition of Nwankpa and Roumani (2016). They explain the digital transformation as an “organizational shift to big data, analytics, cloud, mobile and social media platforms.” The other six definitions lie somewhere in between.

After all, it is impossible to quickly synthesize a universal version from the explicit definitions by just referring to the respective statements as they can be found in Table 1. This can only be done by looking deeper into the content and searching for implicit definitions. A common element in all articles is that the practice of taking something that used to be physical or analog and transforming it to be primarily digital makes up the core of the digital transformation (or digitization/digitalization process, respectively). Obviously, differences exist regarding the question which “somethings” can be counted as inductive for this process and which cannot. This becomes particularly clear when, for example, the statements of Nwankpa and Roumani (2016) and Piccinini et al. (2015) are compared.

Considering that, three different main views on how far the process reaches can be identified, two of which seem to be primarily relevant for today’s researchers and practitioners. The remaining one is the technical definition which is stressed by Loebbecke and Picot (2015) (and heavily supported by Legner et al. (2017) within the current debate). They limit “digitization” in its “originally (...) technical sense” to the conversion of analog to digital signals in order to decouple information from physical carriers and simplify its transmission. However, as they focus on digitally-induced changes of societal and economic patterns rather than their underlying technological foundations, they not use it as a stand-alone definition for their research paper. They rather mention it to draw a comprehensive picture of the whole subject area including its origins. They therefore start to refer to the term “digital transformation” as soon as they move away from the analog-binary-conversion to the societal and economic impacts in the further course of their work. In the other 39 works the technical definition is not mentioned at all.

Between the two remaining approaches, setting clear boundaries is more difficult. They differ about the question whether the digital transformation leads to changes in the business model of the respective company or not. In 28 of the 40 revised publications the digital transformation is understood as a holistic phenomenon, reaching from modifications in production processes over shifts in the way people and/or machines collaborate to extensive changes in the business models of the affected companies. On the other side, there is not a single word about business model implications in the remaining twelve articles which rather focus on the increased level of automation and interoperability enabled by various digital innovations. This outcome is in line with the results from the screening of Mertens et al. (2017) which they table within the current discussion within the IS community. Therefore, after our review we can conclude that the manufacturing sector does not constitute an exception compared to other industries.

Furthermore, we can infer that, as only Mocker and Fonstad (2017) and Loebbecke and Picot (2015) get in touch with the issue of differentiation, the vast majority of scientists and practitioners use the terms digitization, digitalization and digital transformation as synonyms.

Hence, answering our first research question (R1), we can note that the following three definition approaches can be derived from the manufacturing-related literature on the digital transformation:

Definition 1 (technical sense, mentioned in one out of 40): The term digitization labels the conversion of analog to digital signals.

Definition 2 (narrower sense, used by twelve out of 40): The terms digitization, digitalization and digital transformation label the practice of taking objects that used to be analog (or physical) to some extent and transforming them to be primarily digital in order to increase the degree of automation and interoperability.

Definition 3 (broader sense, used by 28 out of 40): The terms digitization, digitalization and digital transformation label the practice of taking objects that used to be analog (or physical) to some extent and transforming them to be primarily digital with inherent effects on the business models of the affected companies.

Delimiting the Digital Transformation

Besides the confusion about the general definition of the phenomenon and the correlated terms, there is no general understanding about which technological concepts or domains (or buzzwords) belong to it and which do not (Denner et al. 2018; Mertens et al. 2017). Again, we try to close that gap by evaluating and synthesizing the opinions of various distinguished scientists and practitioners which have been published in the leading scientific formats in the last five years. Based on our analysis of the identified literature, we try to bring in some structure into that topic by introducing our framework which is outlining the digital transformation from a manufacturing point of view (cf. Figure 1).

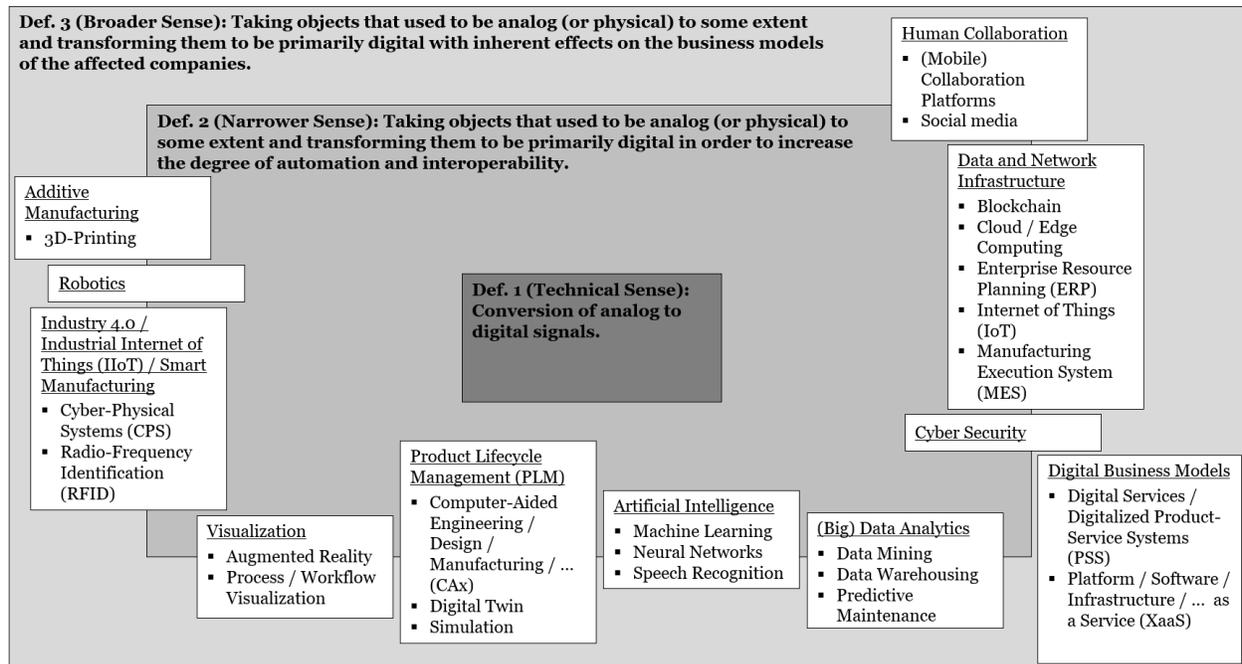


Figure 1. Framework for the Digital Transformation in the Manufacturing Sector

The three grey filled frames mark the definitory boundaries in between which the various technological clusters or domains (in the white boxes) lie. This means that all mentioned concepts are covered by the third definition, whereas not a single concept is covered by solely relying on the first definition. For the clusters lying on the boundaries between two frames the exact position needs to be considered as it is proportional to the number of authors who have located that specific topic in one or the other definitory field. This means, for example, that 60% of the cluster “Additive Manufacturing” lie within the outer frame as 60% (or 3 out of 5) of the publications mentioning the related technologies connect possible business model changes to these technologies. At the same time, 40% of the cluster lie within the medium frame as 40% of the authors don’t envision (or at least don’t write about) the possibility of business model effects caused by the adoption.

The framework therefore renders two very helpful services: On the one hand, it clusters the numerous buzzwords and technologies that can be found in the literature to draw a neatly arranged picture of what facets belong to the digital transformation. On the other hand, it provides an overview over how profound the transforming effects connected to these technologies can be in terms of how business is conducted (Mocker and Fonstad 2017).

The framework is supported by Table 2 which summarizes the whole literature review numerically. The first two columns represent the clustering already included in figure 1. In the third column, the number of publications, in which the respective technological concept is mentioned, is listed. In the fourth column, this number is split into how many of these articles follow the second or the third definition approach, whereas in the last column these references are listed explicitly.

Cluster	Assigned Tech. Concepts	# of Ref.	Definition Split 2/3	Sources
Additive Manufacturing	3D-Printing	5	2/3	Bienhaus 2017; Coreynen et al. 2017; Dalenogare et al. 2018; Denner et al. 2018; Srai et al. 2016
Artificial Intelligence	Machine Learning	2	1/1	Brynjolfsson and Mitchell 2017; Heavin and Power 2018
	Neural Networks	1	1/0	Brynjolfsson and Mitchell 2017
	No Specification	2	2/0	Arntz et al. 2017; Kusiak 2017
	Speech Recognition	1	0/1	Heavin and Power 2018
(Big) Data Analytics	Data Mining	4	1/3	Kusiak 2017; Loebbecke and Picot 2015; Oztemel and Gursev 2018; Shuradze et al. 2018
	Data Warehousing	1	1/0	Shuradze et al. 2018
	No Specification	8	3/5	Andersson and Jonsson 2018; Bienhaus 2017; Bilgeri and Wortmann 2017; Dalenogare et al. 2018; Denner et al. 2018; Nwankpa and Roumani 2016; Sebastian et al. 2017; Srai et al. 2016
	Predictive Maintenance	6	3/3	Bokrantz et al. 2017; Dremel et al. 2017; Echterfeld and Gausmeier 2018; Kusiak 2017; Lenka et al. 2017; Subramaniyan et al. 2018
Cyber Security	No Specification	3	2/1	Bienhaus 2017; Kagermann et al. 2013; Kusiak 2017
Data & Network Infrastructure	Blockchain	1	1/0	Denner et al. 2018
	Cloud / Edge	7	3/4	Bilgeri and Wortmann 2017; Dalenogare et al. 2018; Denner et al. 2018; Du et al. 2016; Kusiak 2017; Lenka et al. 2017; Mocker and Fonstad 2017
	ERP	6	3/3	Du et al. 2016; Lasi et al. 2014; Loebbecke and Picot 2015; Oztemel and Gursev 2018; Sebastian et al. 2017; Srai et al. 2016
	IoT	11	4/7	Bienhaus 2017; Bilgeri and Wortmann 2017; Denner et al. 2018; Du et al. 2016; Heavin and Power 2018; Kagermann et al. 2013; Kusiak 2017; Loebbecke and Picot 2015; Oztemel and Gursev 2018; Sebastian et al. 2017; Srai et al. 2016
	MES	3	2/1	Dalenogare et al. 2018; Lasi et al. 2014; Subramaniyan et al. 2018
Digital Business Models	Digital Services / Digitalized PSS	8	0/8	Bilgeri and Wortmann 2017; Chester Goduscheit and Faillant 2018; Coreynen et al. 2017; Dalenogare et al. 2018; Herterich et al. 2016; Lerch and Gotsch 2015; Sebastian et al. 2017; Zheng et al. 2018
	XaaS	1	0/1	Sebastian et al. 2017
Human Collaboration	(Mobile) Collaboration Platforms	5	1/4	Denner et al. 2018; Hildebrandt et al. 2015; Mocker and Fonstad 2017; Nwankpa and Roumani 2016; Sebastian et al. 2017
	Social media	3	1/2	Denner et al. 2018; Nwankpa and Roumani 2016; Sebastian et al. 2017

Table 2. Literature Review Results

Cluster	Assigned Tech. Concepts	# of Ref.	Definition Split 2/3	Sources
Industry 4.0 / IIoT / Smart Manufacturing	CPS	10	4/6	Bienhaus 2017; Bokrantz et al. 2017; Dalenogare et al. 2018; Kagermann et al. 2013; Kusiak 2017; Lasi et al. 2014; Müller et al. 2018; Oztemel and Gursev 2018; Richter et al. 2018; Srai et al. 2016
	No Specification	2	1/1	Echterfeld and Gausmeier 2018; Subramaniyan et al. 2018
	RFID	5	1/4	Dalenogare et al. 2018; Kagermann et al. 2013; Lasi et al. 2014; Müller et al. 2018; Srai et al. 2016
PLM	CAx	2	1/1	Dalenogare et al. 2018; Mauerhoefer et al. 2017
	Digital Twin	2	1/1	Bienhaus 2017; Zheng et al. 2018
	Simulation	5	3/2	Bienhaus 2017; Dalenogare et al. 2018; Kusiak 2017; Lenka et al. 2017; Oztemel and Gursev 2018
Robotics	No Specification	4	2/2	Arntz et al. 2017; Bienhaus 2017; Echterfeld and Gausmeier 2018; Oztemel and Gursev 2018
Visualization	Augmented Reality	2	1/1	Bienhaus 2017; Oztemel and Gursev 2018
	Process / Workflow Visualization	3	1/2	Coreynen et al. 2017; Mocker and Fonstad 2017; Shuradze et al. 2018

Table 2. Literature Review Results (continued)

Discussion

Our study contains various outcomes for theory and practice which we will discuss briefly in the following.

First, by neither defining the three terms “digital transformation”, “digitalization” and “digitization” nor ensuring at least a common understanding, the (IS) research community has made life hard for itself (Legner et al. 2017; Mertens et al. 2017; Mertens and Wiener 2018; Riedl et al. 2017). This lack of a common fundament makes it hard to recognize commonalities and to identify possible synergies. To counteract this problem, we suggest a three-fold definition specifically tailored towards the manufacturing industry, which is based on 40 high-quality scientific studies in that field. This definition clearly determines the three terms and puts them into context among each other.

Second, there are controversies within the IS community about whether the digital transformation is a new and disruptive development or just a new label for things that have already been discussed and researched in the past (Baiyere et al. 2017; Legner et al. 2017; Mertens et al. 2017; Mertens and Wiener 2018; Riedl et al. 2017). The numerical results of our literature review, presented in Table 2, contribute to that. Noticeable is that with ERP a technology that has already been discussed heavily in the literature over 20 years ago (Koh et al. 2008) has been mentioned quite frequently. The same applies for cloud or edge computing or digital services, as they have already been discussed to a considerable extent before the digitalization hype has started in 2014. On the other side, it is evident that very young concepts like Blockchain, a term that has not been mentioned in literature before 2015 (Risius and Spohrer 2017), or digital twins have received little attention from the scientific community so far. These numbers suggest that a significant part of the publications labeled with digital transformation, digitalization or digitization do not contain new or disruptive elements but rather present “old wine in new bottles” (Baiyere et al. 2017). Regardless of the question whether this is done intentionally or not, it bears the danger of redundant research endeavors and the non-consideration of previous projects and results (Mertens and Wiener 2018). It is now up to the IS community to build bridges between older research projects and their outcomes and the current ones as to prevent a break in the IS research time axis.

Our third implication, and closely connected to the second point, deals with the repeatedly asked question within the same discussion on how the IS discipline can edge its way towards a standardized nomenclature of digitalization-related concepts. Our review clearly shows that there is little common understanding between the various authors using the terms digital transformation, digitalization and digitization. This applies to both the definition and differentiation of the three terms as well as the spectrum they are supposed to cover. Hence, our review supports the call by Mertens and Wiener (2018) that the IS community requires a sustainable nomenclature. We suggest our three-layer definition as a basis for further discussions.

Beside these contributions, by their very nature, our review and its results cannot be understood as conclusive and are therefore limited by several factors. First, our scope lies on the manufacturing environment and leaves out other considerable sectors like healthcare or retail. Second, our limitation to journals and conference proceedings that are ranked as A+, A or B in the VHB Jourqual 3 ranking could lead to the neglect of relevant works of appreciable quality that have not been published in one of these formats. Ultimately, associated topics might be left out as the authors did not classify them as digital transformation-related and thus they were not covered by the search string.

Conclusion

The digital transformation is a popular but controversial topic right now. Since 2014 the number of publications and formats that carry this title has soared into the air. Unfortunately, this topic lacks a common and sustainable theoretical fundament which defines and delimits the terms, the correlated concepts as well as the context they are supposed to cover. Reacting to that, René Riedl and colleagues have started a discussion in 2017 on how the IS discipline can find a way towards a common nomenclature (Legner et al. 2017; Mertens et al. 2017; Mertens and Wiener 2018; Riedl et al. 2017). This paper contributes to that that debate by conducting a systematic literature review focused on the digital transformation within the manufacturing sector. We suggest a three-layer definition for the three terms and the phenomenon they are supposed to address, specifically tailored towards that industry.

Furthermore, the review reveals 30 technological concepts which are mentioned by authors that have labeled their works with one of these three terms in the past. We sort them into eleven domains and embed them into a comprehensive framework which outlines the digital transformation in that specific environment. Our results further suggest that many of the publications labeled with digital transformation, digitalization or digitization do not contain new or disruptive elements but rather present “old wine in new bottles” (Baiyere et al. 2017). We therefore support the call of Mertens and Wiener (2018) for a common and lasting nomenclature within the IS discipline to prevent redundant research endeavors and the non-consideration of previous results in the future.

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