What has Industry 4.0 got to do with us? A review of the Literature

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Abstract

This article presents an exhaustive review of the literature relevant to Industry 4.0 (I.4.0) and Smart Factories (SFs). In this review, a landscape of I.4.0 principles is plotted in the form of a mind map, Definitions explored, background and components investigated, from this a pyramid framework is constructed. This pyramid will assist in identifying the major themes of this I.4.0 concept and help provide specific gaps for further research. A meta-analytic approach (qualitative literature review method) was taken. The paper highlights contradictions and similarities in the form of a table of current research presented in the field of SFs. Successful frameworks such as *"Aluminium In*dustry 4.0*"*, *"*SmartFactoryKL*"* as a model for I.4.0, and game changing case studies such as Exxon Mobil, Proctor and Gamble and Tata Motors are explored. Finally the paper discusses the gaps in knowledge, specifically into the area of what I.4.0 means for developing contexts. The pyramid framework is presented in the recommendations section as a tool for analysis and evaluation. Results reveal that a possible scalable solution is needed for developing contexts. Implications of the literature survey are that an optimal tool of assessment for I.4.0 is needed. This can be along the lines of a matrix, rubric, or checklist for companies to measure practically where they stand when measured against the I.4.0 movement. Future research directions could focus on a more empirical study such as a future concept facility design with the concepts of I.4.0 and SFs.

Keywords
Industry 4.0, Literature survey, Pyramid Frameworks, Major Concepts, Smart Factory, I.4.0 Mind Map

1. Introduction
The topic of Industry 4.0 (I.4.0) is no longer just a buzzword in the field of Industrial Engineering. Although this started as a push to increase the productivity in the manufacturing of the German Federal government, Kagermann et al. (2013) [1] have now started a chain reaction of events that has set alight the engineering and ICT world forever. Recently, researchers and industry from America's term of the Industrial Internet of Things (Kiel, 2017) [2], to China's "Made in China 2025" goal (Li, 2017) [3], to Smart Malaysia (Bahrin et al., 2016) [4], to Virtual Singapore (NRF, 2018) [5], and even locally to the NDP 2030 in RSA (NPC, 2011) [6], have shown an increased interest. One of the most significant current discussions revolves around how we are ushering in this new envisioned Industrial Revolution. Change is being planned, created and lived in right this minute and we need to get on this freight train before we are steamrolled by it. A substantial amount of literature exists currently on the definition and designation of Industry 4.0, considering the term's short lifespan. The first serious discussions and analyses worldwide of I.4.0 appear to have emerged during the years 2015 and 2016, when many tried to describe, name and clearly quantify by

means of technologies what the concept is and its potential capabilities (Drath & Horch, 2014; Veza et al., 2015; Jazdi, 2014; Wan et al., 2015) [7], [8], [9] [10].

As to the origin of the name, briefly, the German expression "Industrie 4.0" was first published in November 2011 by Kagermann et al. (2013) [1], and later translated to English and termed I.4.0 [1]. This presents the final report of the working group as a comprehensive national strategic document stating the group's vision of outcomes and progression of I.4.0 for Germany. This dossier consists of all the role players and sectors needed for collaboration to make this future vision a reality. Hermann et al. (2016) [11] expanded on this work, gave it a defined area within which to work, and aimed to create design criteria for other researchers to follow in developing the concept. According to them [11], the increasing integration of the Internet, and connectivity into the industrial value chain, has set the foundation for the next industrial revolution.

This paper is organized as follows: Research methodology, including some search and data-gathering strategies, followed by the literature survey results and analysis which are then presented under numerous subheadings, commencing with the history of the Industrial Revolutions. Some critical discussion is made thereafter, whereby a framework is presented and conclusions are made, with further research recommendations being given.

2. Research Methodology

The following is a description of the researcher's method while undertaking the literature survey. A systematic and structured approach was undertaken with Randolph's Guide (2009) [12] as a method to log and track the themes and main concepts of other researchers in the field. First, key focus characteristics had to be identified for this particular study and defined for the literature survey. Goals, perspectives, and organization of data and coverage were essential to clarify from the start. Criteria for inclusion and exclusion were defined and these, along with the key research questions, were what guided the research. The following criteria were applied:

Evidence to be included

- Abstract or title contains any of the keywords searched, namely: Industrie 4.0 or Industry 4.0, Fourth Industrial Revolution, Smart Factory, or Smart Manufacturing and Intelligent manufacturing systems.
- The similarity of the abstract to the topic Industry 4.0 or Smart Factory is high.
- The author is an expert in the field determined by the H-score rating, and the above criteria apply.

Evidence which will be excluded from this survey

- Abstract or title has no relevance to the major theme of the study.
- Topic not similar or relevant to research questions or topic of the research.
- The author is not an expert in the field determined by the H-score rating unless the high relevance to topic criteria is met as above.

A similarly structured process and a systematic approach are seen by in the work of Kiel (2017) [2] and Adereyi et al. (2017) [13] in their survey of the field in the literature studies done. **Figure 1** demonstrates my own set of methods used, based on these two methodologies.

As a starting point and to determine authors and articles with a high impact in the field, this survey made use of Harzing's h-index as a metric. The use of a high quality and quantity output indicate that the researcher is of high repute and the research material gathered will be credible. Harzing's "Publish or Perish" software analysis tool was used to determine the H-Score of all the high-impact researchers in the field relating to the topics of Robotics and Intelligent manufacturing. The decision to use this filtering mechanism was to keep the survey objective and non-biased. Examples are demonstrated in **Figure 2** and **Figure 3** of the tabular representation of the search and data-gathering strategies of all the authors and names considered for the review. All authors and publications were chosen from their H-score rating value, listed from highest to lowest, and only the top five authors and top five published books were chosen. The top five journals and top five articles were also selected. To reach a point of sufficient saturation, 25 top articles were chosen by the snowball method.

The analysis of the data was done on an Excel™ spreadsheet. Once criteria for inclusion had been met, the spreadsheet was used to catalogue the author details and reference source. The abstracts and summarized conclusions, as well as recommendations for further research, were compiled. The researcher then identified concepts and themes under which concepts of similar natures were clustered together. The final spreadsheet consisting of 63 article outputs (12

were removed according to process chart decisions) was surveyed from across 14 different journal publications. These data were compared by contrasting viewpoints against each other and also in comparison with those of the preliminary research questions stated above. By using this approach, which is also illustrated in the process diagram. the survey achieved increased quality, rigor and comprehensiveness.

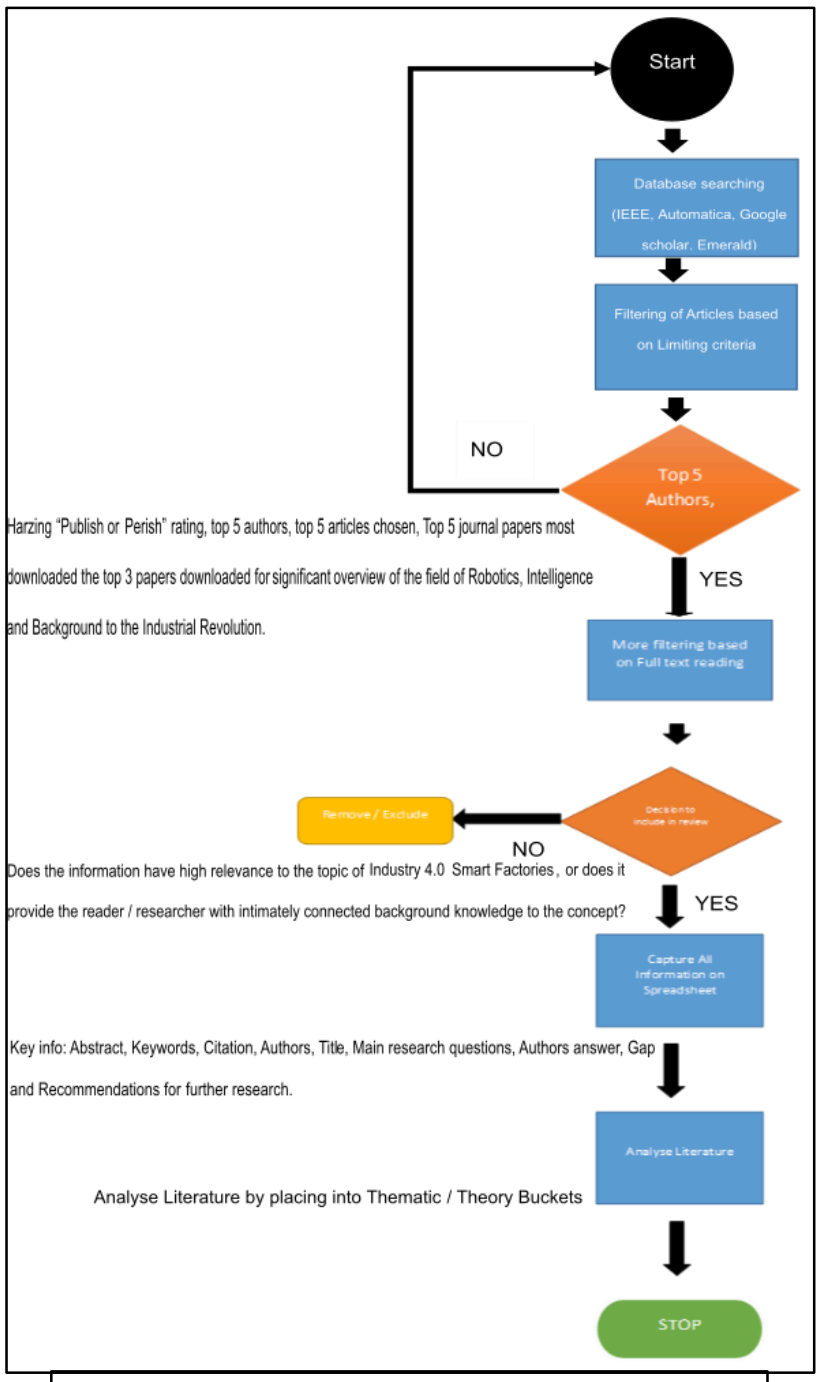

Figure 1: Literature search process chart

Source: Own illustration based on Adereyi et al. (2017) [13]

2.1. Aim, Scope, Goal, Questions

The objective of the present work is to review in detail the I.4.0 landscape, trying to get to the heart of the concept. Within the literature, this author will try to find knowledge gaps in the field and therefore give recommendations as to which future directions one may take. The scope of this study was to find out how I.4.0 and SF elements can be implemented and applied into a specific agri-processing environment. This is the goal of the review, to seek out the current knowledge and explore potential unanswered questions in the field; to enhance understanding so as to define all the elements so that the researcher may know and understand the path ahead and behind; and illuminate other avenues which are unexplored.

The main guiding research questions were:

1. What is this new phenomenon termed Industry 4.0?
2. What does a Smart Factory look like and what technologies does it include?
3. How can we harness the potential of the concept of I4.0 for Africa and SA manufacturing firms?

The motivation behind the study is to expand and explore the knowledge of I.4.0 and SFs concept. The motivating factors of the study would be to increase the growth potential of I.4.0 projects and output around the themes. This is possible by understanding and mastering the current knowledge of the field in order to advance the descriptive and exploratory knowledge of the SF theories in terms of South African perspective. The scope of the study will be focused on the SF and not the other components of I.4.0. The contribution of this literature survey is that the resulting outcomes can be capitalised and used in the author's dissertation.

2.2. Search and data-gathering strategies

Top Rated Authors on Industry 4.0 (English) & Smart Manufacturing According to Harzing Publish or Perish rating system

Name of Author	H-Index
Michael E. Porter*	134
Bicchi, Antonio	54
Thomas Edgar	49
J. Edward Colgate	44
Michael A Peshkin	39
Wolfgang Wahlster	34
James S. Albus	33
Klaus Schwab*	29
Davis, Jim	24
Wolfram Jost	18
Michael Sarli	18
Henning Kagermann	16
Heinrich Arnold	15
Leveling, J.	15
Ioan Dumitrache	12
Thomas Bauernhansl	10
Siegfried Dais	9
Johannes Helbig	7
Stephanie S. Shipp	7
Manfred Wittenstein	6
Reinhold Achatz	6
Otto, B.	6
Priyavrat Thareja	5
Siegfried Russwurm	4
Jung, Kiwook	4
John Bernaden	3
Louhez, Alain	2
Edelbrock, M.	2
Stephan Fische	0
Heinz Derenbach	0
Klaus Träger	0
Rachuri, Dr. Sudarsan	0
Mckewen, Ellen	0
Joan Jacinto	0
James Porter	0

Key:	
	German Industry 4.0 focus work group
	Author removed from search for potential political affiliations or business affiliations
	Traditional researcher or academic

Figure 2: Top-rated authors

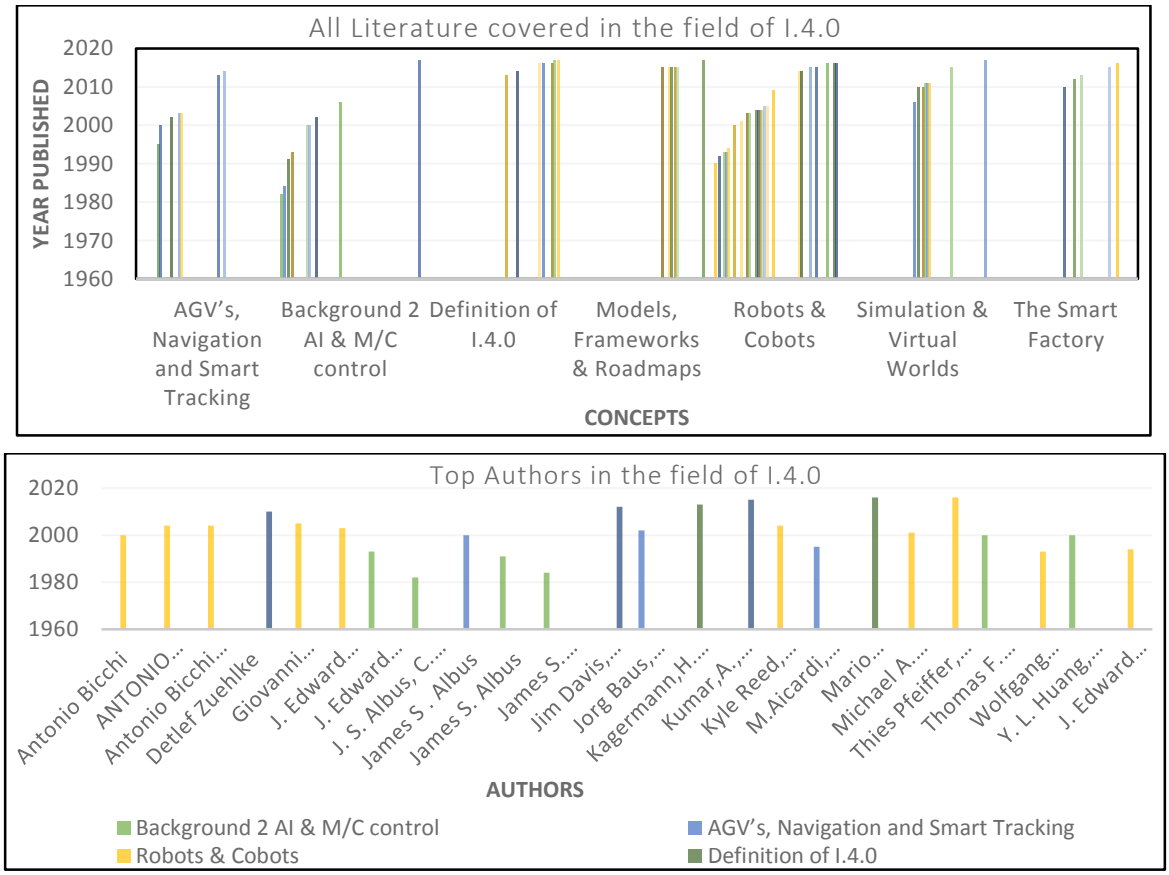

Figure 3: Pivot chart of authors, year published and categorization

3. Literature Survey Results and Analysis

The final literature survey comprised of 63 articles was analyzed and categorized into seven main concepts or areas for review. These concepts can be seen in **Figure 3** above in the Key section of the Chart. They are: Concept 1:

Background to Artificial Intelligence and Machine Control; Concept 2: Definition of I.4.0; Concept 3: The Smart Factory; Concept 4 AGVs, Navigation and Smart Tracking; Concept 5: Robots & Cobots; Concept 6: Models, Frameworks and Roadmaps; and Concept 7: Simulation and Virtual Worlds. The presentation of the results begins below with the history, and each concept is outlined in more detail, displaying the most significant insights and perspectives.

3.1. The History of the Industrial Revolutions

At this point in the report, it is of great importance that the reader understands the background of Industry 4.0, also known as the Fourth Industrial Revolution (Burmeister et al., 2016) [13]. The First revolution began with the introduction of steam- and water-powered mechanical manufacturing processes. An example of this is when the first mechanical loom was introduced, classified in **Figure 4** below as 'mechanization'. The Second revolution was brought about when electricity-powered mass-production lines based on the division of labour came into operation. The first production lines were introduced in 1870 in Cincinnati slaughterhouses and **Figure 4** classifies the era as one of electrification. The Third Industrial Revolution was sparked in the 1970s after the first programmable logic controller (PLC), Modicon 084, unit had been installed in 1969. Broadly labelled digitization and automization, the use of IT and electronics allowed further automation of manufacturing, and as a result, increased productivity was seen. A rich background of support literature arose in the fields of robotics and systems engineering (Haskins, 2006) [14], cybernetics and computer control systems for automated facilities (Albus et al., 1984) [15], (Edgar et al., 2000) [16], (Albus et al., 1982) [17] and (Colgate et al., 1993) [18], the control of robotic arms. Furthermore, this background is built upon ideas from the area of machine artificial intelligence (Albus, 1991) [19], to machine learning (Bengio et al., 2013) [20], (Buczak & Guven., 2016) [22], Akusok et al., 2015) [23], computer vision (Rao, 2013) [23], pattern analysis systems (Shen et al., 1993) [24], and real-time monitoring of machines (Na et al., 2017) [25]. The advances in the fields of computer science networks, robotics and control, machine pattern recognition and behaviour analysis and real-time modelling for system monitoring and control all supported the development of the I.4.0 concept. The argument and pursuit of I.4.0 as an interconnected network and system working together autonomously in collaboration with each other as well as the intervention of humans to assist them in performing their task better could be made only because of the already rapid advancement of research in these areas, as mentioned above. A most familiar quote comes to mind here which is attributed to Newton (1675) [26]: "If I have seen further, it is by standing on the shoulders of Giants." This brings us to today where the Fourth industrial revolution is gaining momentum by the introduction of cyber-physical systems, the Internet of Things and smart factories all working in collaboration to enhance manufacturing processes by means of connection and collaboration. As time progresses along the horizontal plane of **Figure 4**, it can clearly be seen that the complexity has increased similarly. If the trajectory continues we face exponentially complex systems in manufacturing as well as in our day-to-day lives.

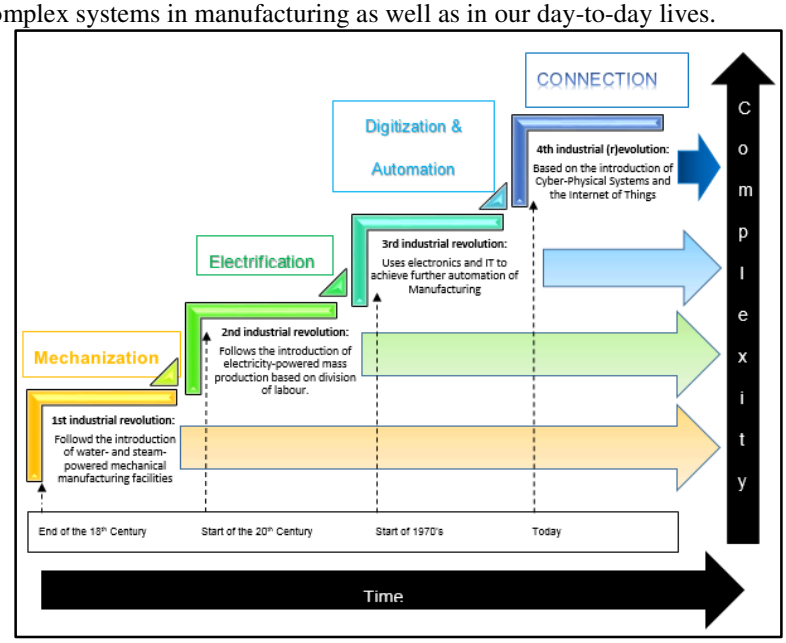

Figure 4: Overview of Industrial Revolutions

Source: Own illustration based on Kagermann et al. (2013) [1]

The term or phrase "I.4.0" incites much debate and argument as no standard definition has been generally accepted in the workplace. Kiel (2017) [2]states that this I.4.0 concept is internationally referred to as the "Industrial Internet of Things". Here the author performs a literature review of 82 publications on what we know about I.4.0 and what future economic benefit can be gleaned from this research development area. In this article, Kiel gives a succinct definition of the concept as a "new paradigm of digitized and connected industrial value creation, assumed to yield extensive industry-spanning opportunities". This sentiment is echoed in Wan et al. (2015) [10], when the authors report on I.4.0 as being an enabling technology for the transformation of the manufacturing sector. It is simply the progression of technology that will make the traditional production process better in the future to come. The main question driving the researchers here was how to make this concept a reality today and what tools are currently available to make that vision come true, concluding that we are not as far off as we think. In counterargument to this, Drath and Horch (2014) [7] are of the opinion that I.4.0 is still in the future. However, I.4.0 is a phenomenon that will come inevitably, whether we want it or not. This is similar to the consumer world, which was confronted with the Internet in the early 1990s, leading to an unpredictable world of online shops, auctions, Internet banking, online brokerage, and video streaming. The fourth wave of industrial engineering is well on its way, whether by revolution or evolution is an argument in philosophy. Today's fast-paced rise in technology and consumer-focused growth strategies has propelled manufacturing systems to become faster, more automated and better connected with the aid of computers and able to serve more customers than ever before. This says nothing of global competition in the manufacturing sector, which is becoming fiercer and fiercer.

3.2. What is I.4.0?

The mind map constructed in **Figure 5** is a graphical representation highlighting the article of Hermann et al. (2016) [11], giving some brief definitions and stating the four components of Industry 4.0: Cyber-Physical Systems (CPS); the Internet of Things (IoT); the Internet of Services; and finally, Smart Factories (SF). The mind map links the aspects together in an illustrative manner. Six design principles are also mentioned (virtualization, real-time capability, decentralization, modularity, service orientation, and interoperability) which will be used as design criteria and will help identify I.4.0 environments and to assist in the implementation thereof.

Let us now give some attention to the individual components which were identified by both Kagermann (2013) and Kiel (2017) [1], [2]. They are the components CPS and IoT respectively. Gunes et al. (2014) [27] describe CPS as a broad range of complex, multidisciplinary, physically-aware next-generation engineering systems that integrate embedded computing technologies (the cyber part) into the physical world. In order to define and understand CPS more precisely, the author presents a detailed survey of the related work, discussing the origin of CPS, its relation to other research fields, prevalent concepts, and practical applications. Furthermore, this article enumerates an extensive set of technical challenges and uses specific applications to elaborate and provide insight into each specific concept. CPS has a very diverse application. For this reason, it is pervasive in almost every industry. spanning different markets. Li et al., (2015) [28] describe the IoT as the next generation of the Internet, where physical things can be accessed and identified through the Internet. The authors confirm that it can radically change businesses models and how we generate wealth in the future. Firms today can take advantage of IoT at intra- and inter-organizational levels, creating competitive products which will result in more profitability, greener business models, optimized resources, and real-time information processing. These two areas of research working in combination and collaborating together form the basis of SF concept. CPS and IoT are research topics in their own rights, and to limit the scope, we will be looking only at Smart Factories and humans in coordination to produce a particular product or service known as the SF concept. This will be delved into more deeply in the next section of this literature review. This research will focus on the examination of the SF. In the researcher's opinion, it has the potential for the biggest impact on the world. It is believed and assumed that research done in this field will be the most beneficial for the workforce, industry, and government as it has the potential to change the face of manufacturing. This will have major impacts on the GDP, which will, in turn, translate to the biggest increase in the profit of the country and businesses.

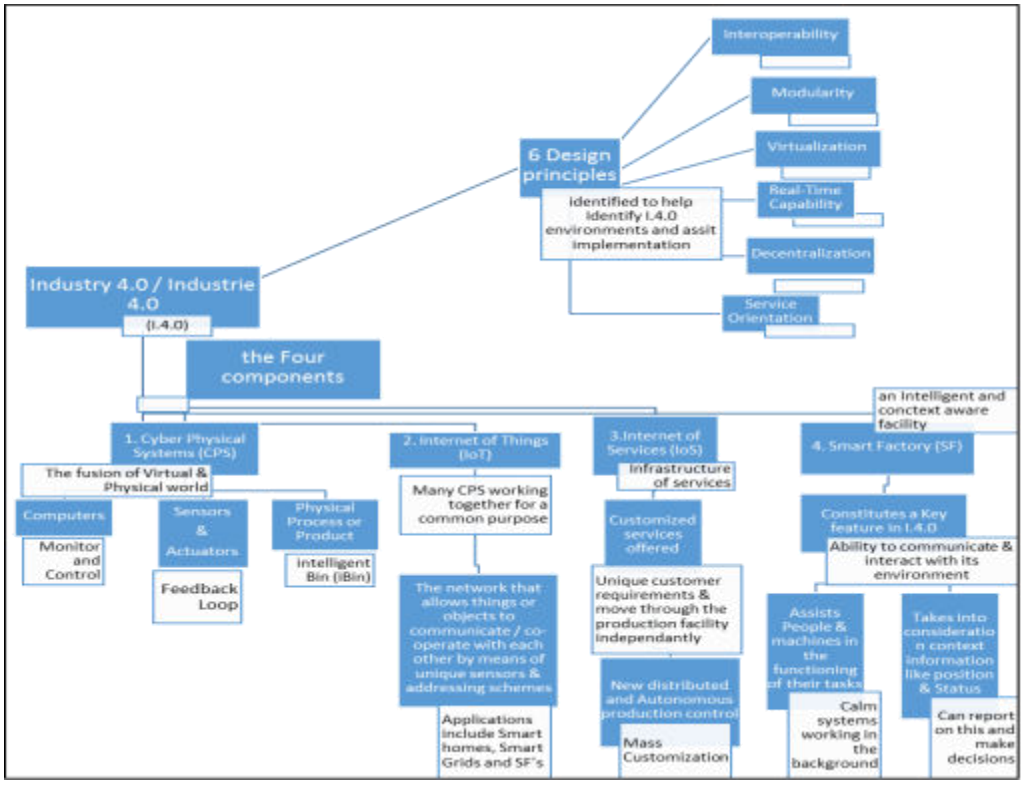

Figure 5: Personal mind map of I.4.0 key components

Source: Own illustration based on Hermann et al. (2016) [11]

3.2.1. Let's talk about the Robots

It may be considered a broad proposition but it's not a stretch to believe that most people believe that robots are coming to take over our jobs and our futures. This heading will outline the literature surveyed in the relationships between humans and robots. Works include Bicchi (2000), Bicchi and Kumar (2004), Albu-Schaffer et al. (2009), Okamura (2004), Colgate and Brown (1994) and Peshkin et al. (2001) [29]–[34], who look specifically at Collaborative robotics (Cobots) and the use of these advanced machines in work environments as assistors. The second topic found in this subheading is that of robotic interfaces, sensors, and controls. This literature looks at work that specifically delves into the area of robotic interfaces and how humans react and respond to them. This is described as a new robot architecture: the Cobot. Cobots are intended for direct physical interaction with a human operator. The Cobot can create smooth, strong virtual surfaces and other haptic effects within a shared human/Cobot workspace (Peshkin et al., 2001) [34]. Arms, hands and end effectors, robotic grasping and the literature thereon – Bicchhi and Tonietti (2004) [35] look at different possible approaches for dealing with the problem of achieving the best performance of robotic arms, hands and end effectors, under the condition that safety is guaranteed. This is relevant for all robotics applications when introducing humans into the surrounding spaces, although in this particular work, Bicchi and Kumar (2004) [30] exhaustively survey the field of robotic grasping and the work that has been done in this area over the last two decades, with a slight bias toward the development of the theoretical framework and analytical results in this area. In the work of Tonietti et al. (2005) [36], the authors conclude the design and control of actuators for machines and robots physically interacting with humans, implementing criteria established in the previous work in 2004 on optimal mechanical-control co-design for intrinsically safe, yet performing machines.

Albu-Schaffer et al. (2009) [31] further expand on this thinking by supplying the information that lightweight robots (LWRs) with torque sensing in each joint and promise a consistent approach for using these sensors for manipulation in human environments. An integrated mechatronic design approach for LWR is presented and the authors propose that sensor technology, like the integrated joint torque sensors and link-side potentiometers, in addition to the common motor position sensors, allow for the implementation of safety features which go far beyond the state-of-the-art in industrial robotics and facilitate the opening of new markets such as medical applications or future service robotics scenarios. Potential industrial application fields are fast automatic assembly as well as manufacturing activities done

in cooperation with humans (in effect, industrial robot assistants). Okamura (2004) [32] displays a medical application of human and robotic collaboration when he adds that robot-assisted surgery enhances the ability of surgeons to perform minimally invasive procedures by scaling down motions and adding additional degrees of freedom to instrument tips. Thousands of general, urologic, and cardiac surgical procedures are now performed worldwide with robotic surgical systems. Despite these successes, progress in this field is limited by an unresolved problem: the lack of haptic (force and tactile) feedback to the user. Current research at the Johns Hopkins University Haptics Laboratory and elsewhere seeks to correct this problem by providing the physician with feedback indicating the amount of force applied by the robot. This requires the integration of haptic sensors into the instruments used by surgical robots, as well as methods for displaying haptic information to the human operator. Colgate and Brown (1994) [33] look at a similar issue here and answer the question of what the factors are affecting the dynamic range of haptic displays. To summarize, this paragraph looks at the current literature available on collaborative robotics and similar kinds of projects which are under way in order to provide substantial evidence for the case of safe and productive human and robot collaboration in the SF concept. Cobots are signalled as the robots of the future in that they will become the safe and productive assistants to the human worker of the future.

How humans relate to, interact with and control machinery in a factory has a large impact on the working conditions and environment of the factory. A study done showed how a major impact of trust was built on the robotic interface (Weiss et al., 2016) [37]. Other elements such as fear of and intimidation by robots had a negative psychological effect on the human operators. This design area must carefully be considered when looking at factories of the future. Designing and developing a successful user interface for Cobots is discussed so that the human is centred in the design process for controlling and monitoring the functions of the robot in the system.

In Colgate et al. (2003) [38], scholars elaborated on Intelligent Assist Devices (IADs) in industrial applications, that review subsequently defined IADs as computer-controlled tools that enable production workers to lift, move and position payloads quickly, accurately, and safely. Several examples of industrial applications are given, illustrating typical configurations and functionality, including strength amplification and virtual surfaces. The concept of human intent sensing is introduced and discussed, as are IAD safety and control considerations. IADs are increasingly being used around the world to assist industrial workers in highly specialized assembly environments such as those found in automotive manufacturing. Adoption is also beginning in other traditional material handling environments including the appliance, aerospace, converting, electronics, food, furniture, glass, packaging, printing, pharmaceutical, sheet metal, textile and warehousing industries worldwide. In short, the authors predict the technology will continue evolving to the point where intuitive human-machine interaction is no longer a novelty; rather, it will become a necessity.

The following year, Reed et al. (2004) [39] performed initial studies on Human-robot-human interaction, human-human interaction, and haptic interaction and discussed this within Fitts's Law, which is often used in human–computer interaction and ergonomics. The study explored how two people physically cooperate, compromise, and guide one another, through force and motion, and how machine-generated forces and motions can enter into the human–human physical conversation in the case of physiotherapy. This study is of importance to future designers as often two people must work together physically on a common force and motion, applied either directly to one another's tasks, such as lifting and positioning of a workpiece, or, in the case of the model experimental system, turning a two-handled crank. Such tasks involve communication between the people, mediated by the task kinematics and dynamics: each person feels forces and motions produced by the other and derives some meaning from them. Tasks may include a degree of competition: the two people may not have exactly the same goal in mind and must negotiate a compromise.

More recent studies by Weiss et al. (2016) [37] look at this area from an I.4.0 perspective, looking into the first applications of robot teaching in an existing industry environment (Pfeiffer et al., 2016) [40], and utilizing empowering interfaces in order for workers to become empowered to understand, monitor, and control the automated processes of I.4.0 environments. Technical advances in control and communication create infrastructures that handle more and more tasks automatically. As a result, the complexity of today's and future technical systems are hidden from the user. These advances, however, come with distinct challenges for user interface design. Addressing these design challenges requires a full integration of user-centred design (UCD) processes into the development process. Discussions on flexible but powerful methods for usability and user experience engineering are made in the context of I.4.0.

Pfeiffer et al. (2016) [41] report on three case studies on the usability and acceptance of an industrial robotic prototype in the context of human-robot cooperation. The three case studies were conducted in the framework of a two-year

project named AssistMe, which aims at developing different means of interaction for programming and using collaborative robots in a user-centred manner. Together with two industrial partners and a technological partner, two different application scenarios were implemented and studied with an off-the-shelf robotic system. The operators worked with the robotic prototype in laboratory conditions, in a factory context, and in an automotive assembly line. The results show that close human–robot cooperation in the industrial context needs adaptive pacing mechanisms in order to avoid a change of working routines for the operators, and that an off-the-shelf robotic system is still limited in terms of usability and acceptance. The touch panel, which is needed for controlling the robot, had a negative impact on the overall user experience. It created a further intermediate layer between the user, the robot, and the workpiece and potentially leading to a decrease in productivity. Finally, the fear of the worker of being replaced by an improved robotic system was regularly expressed and adds an additional anthropocentric dimension to the discussion of human-robot cooperation, SF, and the upcoming I.4.0.

To give a final analysis to the human–robotic interaction subheading, the following is understood from the literature. The cooperative approach would help with easing the transition of working with a new robotic system and to increase its overall user experience. Further research and field tests are needed in order to get a deeper understanding and improvement of shortcomings. Increased sight and recognition of Cobots will be needed in order to measure the persons' movements and waiting positions, which may improve the factor of perceived safety, as well as rest positions. Furthermore, all workers will likely be afraid of being replaced by this or similar robotic systems in the near future. This anthropomorphism in a factory dimension of human–robot cooperation was also revealed in related research by Stadler et al. (2013) [41], which also suggests that hybrid robots (combining a social- and tool-like appearance and behavioural elements) will be potentially preferred by naive users in the industrial context in the future.

3.2.2. AGVs, Navigation, Smart Tracking and Contextually-aware Spaces

Automated Guided Vehicles (AGVs) are self-driving vehicles that have the capability to perceive the surrounding environment and navigate without human intervention (Jo et al., 2013) [42]. For this concept to work within the context-aware environment requires constant communication with other vehicles and automated machinery components, as well as humans within the factory of the future. However, Baus et al. (2002) [43] work towards a resource–adaptive mobile navigation system that can be used indoors and outside to determine locations and with the help of cellular phone signal towers investigate how pedestrians and traffic can adapt and detect changing environments. Aicardi et al. (1995) [44] have developed a closed-loop steering system for a unicycle with simple Lyapunov theory, leading to simple closed-loop control and path following but with a strong suggestion of extension towards complex car-like or articulated vehicles such as forklifts.

Machines are now able to track and perceive objects and identify their identities with radio frequency identification (RFID) tags (Schabus & Scholz, 2015) [45]. Smart Bins are supplied with RFID tags which provide unique identities so that separate and similar products can be grouped and allocated. Navigation and tracking of movement and alerts can be sent if pre-set alarms are triggered. This allows an increase in quality of the supply chain for asset tracking and inventory purposes. Logistics and planning are improved as marketers and depots know much more detail about the location of products and can provide more information if required to satisfy customers orders and needs before the requests come up.

Kernel-based object tracking (Comaniciu et al., 2003) [46] suggest that to improve awareness of products and machinery you insert low-level vision and recognition even if items do not contain these requirements, thus building upon the concept of spatial and contextual awareness of things. Certain instructions can be given in case this happens, such as linking instructions to the AGV Forklift to determine the item's Smart ID and making a decision according to the system of where it is intended to go, then moving it autonomously to that point. Human collaboration is needed here now to manage the inventory levels and stock control instead of only driving the forklift. Unknown locations, incorrect inventory levels and human accidents in driving can be a thing of the past. Contextually-aware buildings are also known as Smart Buildings and with the help of sensors and actuators can provide utilities such as water, lights, and ventilation when and where they are needed (Kreitlein et al., 2015) [47]. This concept is gaining traction not only in factories but service sectors as reduction of resource consumption is aimed at by analysing and learning from other workspaces and places. Workplaces all around the globe are going greener in a bid to help climate change and also to try to eliminate wasteful expenses. Health and safety aspects of factory spaces can also be utilized by the contextually-aware facility in the form of incident detection and the identification of unsafe working conditions if standard operating procedures are being deviated, such as the lockout procedure. High-impact areas, danger zones, or high-noise zones can also be monitored and controlled more closely.

3.3. SFs at the centre of the next industrial revolution

In this chapter the definition of an SF is analysed, and we examine what some of the components look like and where they fit in with this research study. The chapter will also include more analysis on those elements found within a typical SF. Davis et al. (2015) [48] introduce and expand upon the elements of Smart Manufacturing. Smart Manufacturing, according to Davis et al. (2015) [48], is the "dramatically intensified and pervasive application of networked information-based technologies throughout the manufacturing and supply chain enterprise". At the heart of manufacturing is the Smart Factory. This paper demonstrates examples of "Game-changing Facilities" which have the following characteristics:

- Exxon Mobil use integration of information infrastructure across units globally and real-time capability to increase the ability to plan and schedule.
- Procter and Gamble use "supercomputing" to model complex problems while avoiding the need for expensive mock-ups or experimentation.
- Tata Motors built a Factory with the ability to mass produce customised products, and they are able to trace and track every part in case of a recall. This will have the ability to connect with Smart grids when the technique becomes common use.
- Shougang "Sustainable" Steel Factory has the ability to recycle 99.5 % of its solid waste and 98% of its water.

Davis et al. (2015) [48] also point towards the factories being excellent examples of future models to use in a definition of the term. These characteristics resonate closely with the six design elements of the smart factory outlined in Hermann et al. (2016) [11] (see **Figure 6** below in support of the argument that the authors listed in the table find many commonalities and consistent characteristics). Some of the current technologies and elements typically found within an SF are considered, and there is an analysis of the literature covering the SF concept and the key characteristics. The connecting technical threads are real-time information synchronization, decentralized units, virtualization in the form of design, integrated performance metrics, and modular, in that the resources can be recycled and re-utilized.

The SF concept has taken centre stage in many case studies, as seen by the six articles reviewed. The articles represented and cited in the coming paragraphs seek to define the concept in its totality. Kang et al. (2016) [49] derived SF from the term "smart manufacturing". In the article, the "Smart" tag is discerned and analysed from past evidence, present findings, and future directions. The author's main conclusions were that the concept was simply aimed to improve competitiveness through the convergence of cutting-edge ICT technologies. Another by-product was to secure growth in GDP, increase job employee numbers, and involve many more aspects of the manufacturing sector. With this in mind, it can be concluded that when viewed from these three authors' perspectives, the SF concept is really a collection of the latest technologies working together and separately, as a whole system of elements trying to increase the overall effectiveness of the factory or organisation. A research paper documenting this collection of technologies working together was found in the form of a test-bed case of a digital factory. The SmartFactoryKL was developed from the vision of the future work. It aims to create viable and testable option for companies to test such prototype designs of facilities for future implementation. Zuehlke (2010) and Weyer et al. (2015) [50], [51] also expand on the idea by outlining standards and lessons learnt in the process of creating SmartFactoryKL which is a unique multi-vendor and highly modular production system as a sample reference for Industry 4.0. SmartFactoryKL started as a research project but has subsequently also had very successful vendor case analysis at actual production manufacturing integration and modularity in actual working environments in Germany. This test case has sought to design around and solve all six of the design aspects outlined by Hermann et al. (2016) [11], as stated above. Below is a pictorial illustration of the case. Radziwon et al. (2014) [52] also explored the SF concept, and unlike many of their fellow researchers, they argue against the blanket vision of the term, stating that it is insufficient for further development. The authors are of the opinion that scholars are unsure whether it is a concept, a technology, an approach, or even a paradigm. As there is much debate surrounding the term, and after much consideration, the author proposes his own definition of the SF.

> *"A Smart Factory is a manufacturing solution that provides such flexible and adaptive production* processes that will solve problems arising on a production facility with dynamic and rapidly changing boundary conditions in a world of increasing complexity. This special solution could, on the one hand, be related to automation, understood as a combination of software, hardware and/or mechanics, which should lead to optimization of manufacturing resulting in a reduction of unnecessary labour and waste of resource. On the other hand, it could be seen in a perspective of collaboration between different

industrial and nonindustrial partners, where the smartness comes from forming a dynamic organization."

Comparative table on the definitions and main components of the Smart Factory							
Author Name	Zuehlke	Weyer *et al*	Kumar *et al*	Kang *et al*	Radziwon *et al*	Kiel, D.	Davis *et al*
Quote	"But the future must become LEAN - not only in organisation, but also in planning, and technology! We must edvelop technologies which allow us to speed up planning and setup, to adapt to rapid changes"	"I.4.0 is a synonym for the transformation of todays factories into smart factories, which are intended to adress and overcome the current challenges of shorter product lifecycles, highly customized products and stiff global competition. " -	"Smart manufacturing addresses this challenge through pervasive adoption of cost-effective infrastructure for integration of manufacturing intelligence in real time across an entire production line.	"Industry 4.0 or Smart Manufacturing is the fourth industrial revolution" - It is a new paradigm and convergence of cutting edge ICT and manufacturing technologies.	"Scholars are unsure wheather it's a concept, technology, approach or Paradigm" we use this pervasive and all encumpassing "smart"tag to everything with a CPU - Radziwon	"...recommendations are mostly general, highly aggregated, and difficult to grasp. Specific and tangible actions that need to be taken to accelerate the realization of the IIoT are essential."	"Game-changing technologies continue to set new standards for the way manufacturing companies innovate, create, source, manage and deliver their products."
Year Published	2010	2016	2014	2016	2014	2015	2012
Perspective (Origin of Thinking)	Mark Weiser's Vision of a future world - Ubiquitous Factory	German Industrie 4.0 - Towards a Standardized SF	Case Study - Chemical Industry	To evaluate past, present and future findings of 3 countries who have strong government initiatives to see Smart Manufacturing a reality.	U- Factory, Wireless comm. Infrastructure (SFKL), Glocalized (from supply chain view)	Management / Business view - Economic perspective	From the Smart Manufacturing origin
For what purpose are they used (Intention)	SmartFactoryKL initiative is a Test bed / prototype for future factory technologies	able to apply one standard implementation to all factories across different companies across diferent industries - One standard to rule them all	The aim is to demonstrate a feasable initial proof-of-concept.	To Identify Key system structure and key technologies that are driving the Smart Manufacturing concept forward	The aim is to understand the different visions of the concept	Supports managerial practitioners in understanding the IIoT and its inevitable effects on industrial companies by presenting insights into strategic management in the era of digitized and connected industrial value creation and capture.	Game Changing Examples
Common Design Parameters	Modular, Lean, decentralized structures, self organising, decoupling processes, allow re-use of components, developed technologies for human operators	Highly Modular Production Systems, Multi-Vendor system, Virtual, Decentralized, Real time, Plug and Produce	Using Comutational Fluid Dynamics CFD analysis, to give real time production results for instant feedback on the production line.	They have the following Sub technologies / Infrastructure: CPS IoT 3D Printing Big Data Cloud Computing Smart Sensors Smart Energy Hologram	Flexible, Adaptive,	orders Self Guided, Extensively penetratve, Autonomous Network and machine set-ups, Ability to reschedule production on their own if an error is predicted. "smart factories" are in control of complexity and less vulnerable to losses of production.	- Intergration of information infrastructure across units globally & Real Time capability '- uses "super computing" '- Factory with the ability to mass produce customised products. Ability to connect with Smart grids '- "Sustainable" Steel Factory - Ability to recycle 99.5 % of its solid waste and 98% of its water.

Figure 6: Tabular representation of the different perspectives on SF

Source: Own illustration

3.4. Industry-specific frameworks

This paragraph seeks to discover from the literature a global implication of I.4.0 by trying to understand if other scholars are determining the impact of I.4.0 and SF in their own regions. The evidence presented below in the literature motivates that scholars have begun to explore and study this phenomenon, as it affects their specific manufacturing sector. Veza et al. (2015) [8] expand on the analysis of the current state of Croatian manufacturing industry with regard to Industry 4.0, showing that Croatia is far away from Industry 4.0. Bahrin et al. (2016) [4], however, take a slightly different approach, stating that it is a journey towards that eventual goal in the future. His view is that productivity can increase through various I.4.0 effects in Malaysia. Demonstration of a positivist mentality that the automation and robotic industry have the potential to lead Malaysia towards Industry 4.0 through key initiatives by government and industry players working together. In the article, the author goes into detail about who the main drivers and instigators of the trend need to be, as well as organisations and partners who can use this as a replication model in their own context. A specific case study in the South African perspective has not yet been found in the literature. This leaves a gap in the field for potential researchers to explore, design and develop such cases. A special report published by Deloitte (2016) [53] on trying to ascertain "Is Africa ready for a digital transformation?" looks generally at various companies in the automotive and manufacturing sectors on the merging of real and virtual worlds, trying to gauge where South Africa as a nation stands with regards to the I.4.0 announcement. This report leaves the door open to much discussion from a research perspective as well as some uncertainty from the industry sectors which seek to learn and understand this new development happening globally.

Such an industry-specific framework approach is demonstrated by Coa et al. (2015) [54]. This study takes into consideration production processes, equipment technology, advanced sensing, IoT, data analytics, intelligent management, and control, trying to implement a novel idea in the form of a framework for the aluminium industry.

The "Aluminium Industry 4.0" is a unique production-mode framework implementation strategy (Coa et al., 2015). Smart manufacturing (Kumar et al., 2015) [55] addresses this challenge through the pervasive adoption of cost-effective infrastructure for integration of manufacturing intelligence in real time across an entire production line. The authors present a case study within the chemical industry, in which the aim is to demonstrate a feasible initial proof-of-concept for a smart manufacturing system. Using Computational Fluid Dynamics (CFD) analysis, to give real-time production results for instant feedback on the production line allowed for greater integration of process data and advanced high-fidelity models, which facilitated a real-time decision support system using enterprise-wide integration of data management and analysis tools. This example is an integrated framework that relies on the use of sensors, for distributed-parameter control of a hydrogen production testbed all at a fairly low cost. These two novel framework approaches present merit for building a case to propose an industry-specific model for any given industry, even within the chemical manufacturing sector, into which the paper presents a future look at small-scale and agile manufacturing units. These agile units aim to be more connected, creating a connection between the smaller units, their internal suppliers and the customers, in order to meet the rapidly changing needs of the market (Van Kranenburg et al., 2012) [56]. The authors attempt to the look at current trends of I.4.0 and try to project a sustainable and competitive future for the chemical manufacturing industry. These very same sentiments can be applied with agri-processing in mind, creating many small-scale and connected agile units to create a connection potential that would be a step towards I.4.0 and the rapidly changing needs of the market.

Smart dairy farming is brought into play by Grogan (2012) [57]. This article shows a brief indication of the innovative nature with which one farm has taken the automation of its processing, introducing with success automated milking, smart feeding, and a smart barn environment. With the assistance of sensors, cameras, lasers and RFID ear tags, these tools aid in the intelligent monitoring system on the DeLaval farm. This case gives a very relevant look and motivation for the changes being seen in the agriculture sector. Another study outlines the olive farming in central Namibia, looking at the impact of technology integration in the farming of cash crops and olive farming in particular. The study advocated that growth and innovation happen in all sectors of the market. The study examined the presented factors that contributed to the success and or failures (Matengu & Ashekele, 2010) [58]. A case was developed using technological applications and cooperation on product development. The farmer was found to be instrumental in applying many innovative and simple technological ideas and relating them to the personalized nature of his farm. He did not rely on external factors to push him to innovate and make his farming process more efficient and interconnected; he was simply seeking to improve productivity and quality control. Some of the factors of his successful implementation were:

- Acquiring knowledge for a business plan, production, processing and marketing (real-time monitoring of important business data).
- Innovation in management and production style (decentralizing the customer focus).
- Innovation in research and development (autonomous and virtual connections).

Matengu and Ashekele (2010) [58] conclude that there has been little work done on factors that promote this integration of modern technology. The farmer's innovative mindset approach saw the potential to develop further technological success stories in the agriculture sector. The economic benefit of this innovative approach has not been calculated or suggested by the researcher, but despite that, one can make inferences in saying that many thousands of rands have been saved by the implementation of this technique and the use of technological networks and devices. One other industry-specific framework is described by Dlodlo (2015) [59], who examines the rural needs in Zambia and South Africa, and how IoT can help alleviate some of the challenges by injecting productivity and growth into the sector. The researcher constructs a broad application of IoT in the Agriculture sector. Unfortunately, few studies have been carried out on the application of the framework, so an empirical study would do well to develop these concepts.

Another common misconception is that robotics and automation of a sector will stop or slow job creation. This is especially a large factor when we specifically refer to South Africa. Traditionally, the agriculture sector is a big employer (613 000 direct employees in 2013 recorded by the [60]). If the workers in the agricultural services, food manufacturing and trade are included, agricultural and agriculturally related employment (including all workers involved at packing facilities and cold stores) represent 9 percent of national employment, which accounts for 1.216 million in June 2013 [61]. However, in an article written by Doyle et al. (2016) [62], the authors give evidence, from the USA, that shows an increase in manufacturing labour from 1996 to 2014:"Today's robotics offer manufacturers improvements in efficiency that are driving up profits and employment." The article goes on to describe how these new jobs improve skills of employees for the future with a higher quality of work and better compensation. Other benefits and jobs being created are in the servicing and installation of this new machinery. A further contribution to

the argument of development for growth in agriculture is the National Development Plan (NDP) 2030 (NPC, 2011) [6] which highlights the need to increase productivity and competitiveness in this sector. As a broad strategic framework plan towards 2030, the NDP was created in 2011 to guide the business, private and public sectors to a greater South Africa: "To accelerate progress, deepen democracy and build a more inclusive society, South Africa must translate political emancipation into economic well-being for all. It is up to all South Africans to fix the future, starting today." NDP 2030 (NPC, 2011:24) [6]. The NDP was framed within development and strategy to grow the economy of South Africa. The areas of interest for this research which will link closely are as follows: 15 areas were established where the reduction of unemployment; there was improved quality of education and training; and the state had increased capacity to play a developmental and transformative approach.
Listed here are some of the needs/ targets in agriculture:

- The use of digital communications has changed society in ways that are not yet fully understood. It is clear, however, that young people have embraced the new media, and this represents a potentially powerful means of fostering social inclusion. Increasing economy and employment.
- Realize a food trade surplus, with one-third produced by small-scale farmers or households.
- There has to be infrastructure development.
- We need an inclusive and integrated rural economy such as agriculture, and expanding commercial agriculture.
- This research aims to align with the government plan to increase education, training and innovation within it.
- Aim for sustainability and resilience.
- Identify other potential partners in the agri-processing value chain to support smallholding development.

3.5. Simulation and the Power of the Virtual World

Very little in the way of instructions on how to build our brave interconnected world is given, but some inferences can be made by this study. It will be through the art of simulation. This case can be argued and analysed from the perspective of a simulation model. Simulation allows a replication of the current state and a capability to stress test future findings. Simulations that are more robust can be done in order to quantify the benefits at larger meso and macro levels. This model can be utilised for the start of the implementation of real-world cases of I.4.0 and SF concepts in SA. Grieves (2014) [63] takes the view of the building of models for the future development of SF concept. The method he advocates includes the use of software that generates a 3D design of the product, from a "Product Lifecycle Management" (PLM) approach. This software allows collaboration of design builds, for parts and manufacturing processing, and simulation. This paper introduces the concept of a "Virtual Twin" as a 3D virtual representation of real life. Focusing on this, real to virtual connection will improve productivity and uniformity of production and ensure the highest quality products. The model is currently limited, as connection synchronization is not always done well. In spite of this, it is a great tool for SF 3D-model generation and design. All three of the companies discussed below could provide large organizations with PLM solutions which suit their needs and levels of desired integration. A detailed evaluation of the different software solutions can be seen in Wu et al. (2017) [63], which highlights the benefits and pitfalls for each of the major three as well as some other software in the market at the time, in this paper on digital design and manufacturing for the cloud.

3.5.1. Autodesk PLM 360

Autodesk PLM 360 is a system which simplifies and makes more effective the management of processes, projects, and people by automating key tasks and delivering accurate and timely information to the right people. Autodesk PLM 360 is cloud-based, so users have immediate access to the data they need for their operations anytime and anywhere. Developed by US-based software company Autodesk, it is a computer-aided design application for creating 3D digital prototypes used in the design, visualization and simulation of products. It uses ShapeManager, their proprietary geometric modelling kernel. It provides a direct competitor to Dassault's "CATIA" and Siemens "Solid Edge" (AutoDesk., 2017) [64].

3.5.2. Siemens –Nx

Siemens PLM Software (formerly UGS) is a computer software company specializing in 3D & 2D Product Lifecycle Management (PLM) software. It is used, among other tasks, for Design (parametric and direct solid/surface modelling). It is also useful for Engineering analysis (static; dynamic; electromagnetic; thermal, using the finite element method; and fluid, using the finite volume method), and for Manufacturing finished design by using included

machining modules. Technomatix is a manufacturing and factory planning suite within Siemens PLM (Siemens, 2017) [65].

3.5.3. Dassault Systems –Catia

Dassault Systèmes, "The 3DEXPERIENCE Company", is a French multinational software company that develops the 3D design, 3D digital mock-up, and PLM software. SOLIDWORKS is a solid modelling computer-aided design (CAD) and computer-aided engineering (CAE) program that runs on Microsoft Windows. According to the publisher, over two million engineers and designers at more than 165 000 companies were using SolidWorks as of 2013. CATIA & DELMIA is a Global Industrial Operations software that specializes in digital manufacturing and manufacturing simulation. Its goal is to enable manufacturers in any industry to plan, manage, and optimize their global industrial operations efficiently (Dassault Systems, 2017) [66].

PLM thinking really gains momentum when speaking of its capabilities and Virtual Factories Framework, which is a concept by Saccol et al. (2010) [67], whose work speaks of a holistic, scalable and extensible factory. The idea of the factory as a comprehensive object or "product" to be innovated and improved upon is given life here. The integration of virtual environments as a tool to support design and management of all factory performance matrices and entities is possible with this program. The envisaged design solution offered is aimed at real-case factories with the aid of simulation and 3D-modelling software.

4. Discussion

As this last step, the final literature sample was compared, critically reflected, and discussed. Hence, a comprehensive overview of the knowledge regarding I.4.0 research can be given. By doing so, under-represented research topics can be revealed indicating a potential need for further studies.

The overall theme of I.4.0 is thinking of Digital Connection. People are able to communicate about work issues in Brazil with colleagues who have the solution to their problems in China, while the Angolans listen in and know which signs to look for in order to avoid disaster. Machines have the ability to communicate service repair times to fellow machines so that the parts are re-routed and a mechanic is messaged. Humans and robots work collaboratively with one purpose or goal. So far, this thinking has been only applied theory and dreams, and it does sound slightly utopian.

Design and development research seeks to create knowledge grounded in data systematically derived from practice. It provides a way to test the theory, validates practice, and establishes new procedures, techniques, and tools based on a systematic analysis of specific cases (Ross et al, 2007) [68]. The use of models (Jadhav et al., 2015; Ortmann, 2005; Ghonaim et al., 2011; Weeks & Du Plessis, 2011) [61], [69]–[71], Frameworks (Schaffers et al., 2011; Letaba et al., 2014; Chatterjee & Kar, 2015) [72]–[74] and Benchmarks (Kreitlein et al., 2015; Kruger & Hancke, 2014) [47], [75] is gaining traction among researchers when developing roadmaps and guidelines for future implementation of new technology and innovative concepts.

Represented in **Figure 7** is a triangle of the analysis of the concepts, placed in logical order for the author and reader to understand. A triangle is used as the concepts build on one another and frame it in the same way as understanding the different levels and layers is needed to make us understand the concepts and their interrelationships. At the bottom, we have the Background of AI and Machine control, from there Concept 2 is the definition of I.4.0 and its four components: CPS, IoT, IoS, and SFs. Concept 3 delves further into the SF its actual technologies and six design principles: virtual, interoperable, modular, real-time capable, decentralized and service-orientated. Concepts 4 and 5 are AGVs, Navigation and Contextually-aware spaces alongside Robotic interfaces and Cobots. They are placed together in one level as they represent the enabling technologies which can be integrated within and operate outside the SF environment. Following that is Concept 6: the Framework, Models or Roadmaps level, used in order to highlight that there have been and are many ideas that others have used and proposed which provide the general level of scaffolding strategy used. Points can be marked and plotted for oneself along this I.4.0 journey. However, we now get to a gap where scalable solutions for developing contexts or even SMEs find themselves. There seems to be no answer as to how to negotiate the gap or tool to transverse the chasm into the world of Best in Class and Robotic Integration. It is assumed that most want this solution but can't attain it. This gap can be closed with the assistance of simulations and the Virtual design world (Concept 7) alongside a Tool for assessing and evaluating the current status of the organization or party. This will take you from where you may find yourself using a set of possible dimensions, recommended here by the author as People, Technologies, Costs, and Productivity, in order to take them to the top of

the pyramid, which can be classified as a Benchmark Standard for their particular industry. This includes the best practices and success cases for others to follow.

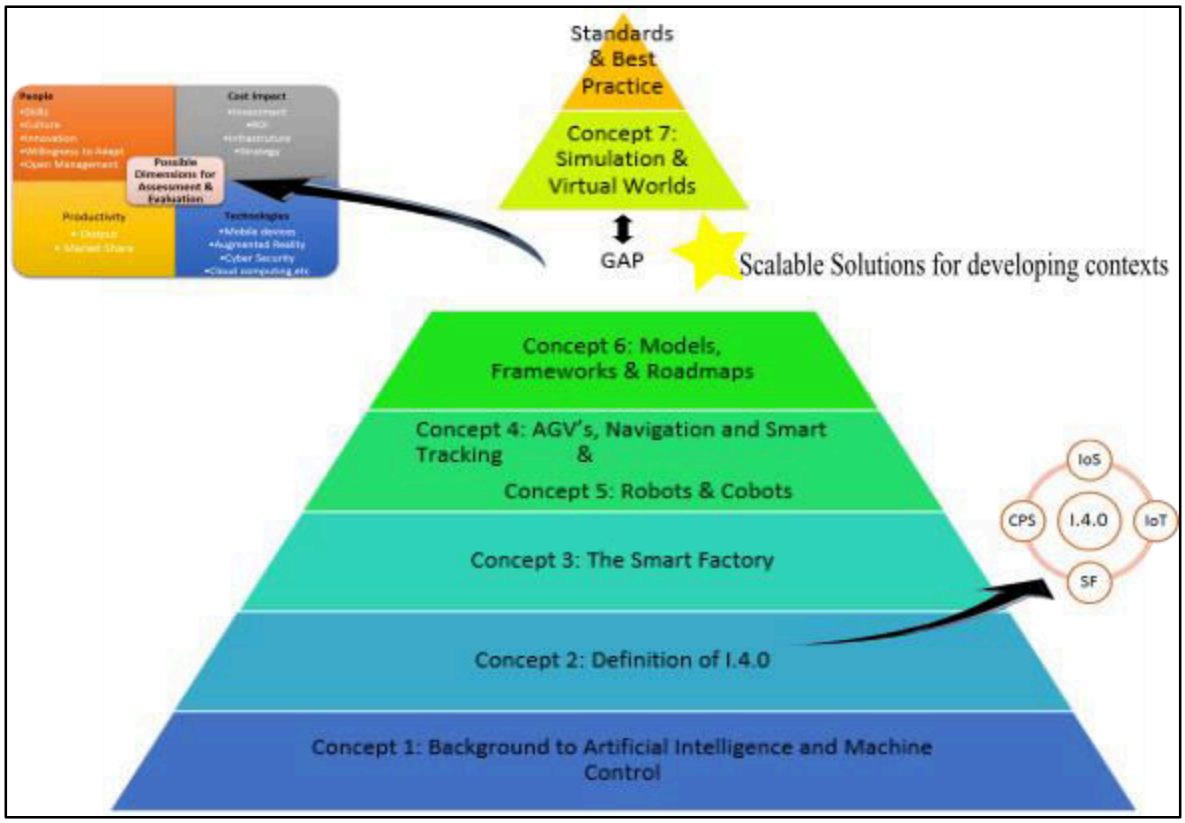

Figure 7: Pyramid analysis of the literature survey

5. Conclusion

This study has reviewed the definition and designation of I.4.0. It has also delved further into SFs. As has been noted in the results above, an SF has been defined as a collection of the latest technologies working together and separately as a whole system of elements trying to increase the overall effectiveness of the factory. The features that are desirable for the smart factory would relate to being flexible and reconfigurable, low cost, adaptive or transformable, agile and lean. The different elements thereof were explored, such as, AGVs, Navigation, Smart ID, Sensing and Location, as well as Smart Buildings, which are contextually-aware spaces. Another area discussed was the collaborative robots or Cobots, which are intended for direct physical interaction with a human operator. The thinking behind this is that SFs of the future will have humans and robots working together collaboratively without fear or intimidation and with safety to produce many more outputs than previously thought possible. The literature has looked at what work has been done in developing countries and what can be done in those contexts to apply these principles to the current case study. The literature has devoted a section to the Models, Frameworks and Benchmark generation prevalent in research today in order to implement and give guidelines as to the procedures firms can take in order to see the success of new ideas. The literature has highlighted specific examples within agri-processing environments which have implemented SF concepts into their current manufacturing processes with some success. The literature has suggested software capable of designing a 3D-model in order to implement a benchmark SF concept. This study has not expanded on the other key components of I.4.0 such as IoT and IoS. A further study investigating their impacts on the landscape would be interesting. More work will need to be done to develop those concepts further. The choice would be to focus on what the author believes is the central aspect of I.4.0, namely SF.

From a theoretical standpoint, this paper suggests a pyramid framework to assess their current state. Possible further studies need to be done to determine the optimal tool of assessment. This can be along the lines of a matrix, rubric, or checklist for companies to measure practically where they stand when measured against the I.4.0 model. The author

believes with the tool of assessment it can provide developing context industries the means to evaluate the current status of the business and the steps it needs to take in order to get to progress to I.4.0. Some potentials will always exist to improve productivity and increase the quality of customer service and products alike. But is it too good to be true? This paper fails to gain some practical applications and success stories found, as few studies examine the South African context. Some empirical studies are therefore suggested, as there is no basis for these productivity claims without reliable evidence on the part of the researcher. This research has thrown up many questions and theories that need further investigation. More empirical information on the descriptions and indicators on practical SFs in South Africa would establish a greater degree of accuracy on this matter of debate. In order to move this debate forward, this paper suggests a better understanding of the KPIs of the current manufacturing firms and how they would assess and rate these so-called "SFs", and how a model for implementation needs to be developed.

6. References

[1] H. Kagermann, W. Wahlster, and J. Helbig, "Recommendations for implementing the strategic initiative INDUSTRIE 4.0 - Final report of the Industrie 4.0 Working Group," Frankfurt/Main, 2013.

[2] D. Kiel, "What do we know about 'Industry 4.0' so far ?," in Proceedings of the International Association for Management of Technology Conference, 2017, no. Vol 26, pp. 0–22.

[3] L. Li, "Technological Forecasting & Social Change China's manufacturing locus in 2025: With a comparison of " Made-in-China," Technol. Forecast. Soc. Chang., no. February, pp. 0–1, 2017.

[4] M. A. K. Bahrin, F. Othman, N. H. N. Azli, and M. F. Talib, "Industry 4.0 : A review on industrial automation and robotic," J. Teknol. (Sciences Eng., vol. 78, no. June, pp. 6–13, 2016.

[5] NRF, "Virtual Singapore," Government of Singapore, 2018. [Online]. Available: https://www.nrf.gov.sg/programmes/virtual-singapore. [Accessed: 27-Mar-2018].

[6] National Planning Commision, "National Development Plan 2030, Our Future-make it work," 2011.

[7] R. Drath and A. Horch, "Industrie 4.0: Hit or Hype?," IEEE INDUSTRIAL ELECTRONICS MAGAZINE, no. June, pp. 56–58, 2014.

[8] I. Veza, M. Mladineo, and I. Peko, "Analysis of the current state of Croatian Manufacturing industry with regard to Industry 4.0," in 15th INTERNATIONAL SCIENTIFIC CONFERENCE ON PRODUCTION ENGINEERING –CIM2015, 2015.

[9] N. Jazdi, "Cyber physical systems in the context of Industry 4.0," in Proceedings of 2014 IEEE International Conference on Automation, Quality and Testing, Robotics, AQTR 2014, 2014.

[10] J. Wan, H. Cai, and K. Zhou, "Industrie 4.0 : Enabling Technologies," in 2015 International Conference on Intelligent Computing and Internet of Things (IC1T), 2015, pp. 135–140.

[11] M. Hermann, T. Pentek, and B. Otto, "Design Principles for Industrie 4 . 0 Scenarios," in 49th Hawaii International Conference on System Sciences, 2016, pp. 3928–3937.

[12] M. K. Adeyeri, K. Mpofu, and T. Adenuga Olukorede, "Integration of agent technology into manufacturing enterprise: A review and platform for industry 4.0," in Proceedings of the International Conference on Industrial Engineering and Operations Management, 2015.

[13] F. T. Burmeister, C., Lüttgens, D., and Piller, "Business Model Innovation for Industrie 4.0: Why the 'Industrial Internet' Mandates a New Perspective on Innovation," Die Unternehmung, vol. 70, no. 2, pp. 124–152, 2016.

[14] INCOSE, Systems engineering handbook, Version 3. Seattle, WA: Systems Engineering Handbook, 2006.

[15] J. S. Albus, A. J. Barbera, M. L. Fitzgerald, E. Kent, C. McLean, H. McCain, H. Bloom, L. Haynes, C. Furlani, E. Barkmeyer, M. Mitchell, H. Scott, D. Bloomquist, and R. Kilmer, "A CONTROL SYSTEM FOR AN AUTOMATED MANUFACTURING RESEARCH FACLITY," in Robots 8 Conference and Exposition, 1984, pp. 1–18.

[16] T. F. Edgar, S. W. Butler, W. J. Campbell, C. Pfei, C. Bode, S. B. Hwang, K. S. Balakrishnan, and J. Hahn, "Automatic control in microelectronics manufacturing :," Automatica, vol. 36, pp. 1567–1603, 2000.

[17] J. S. Albus, C. R. McLean, A. J. Barbera, and M. L. Fitzgerald, "AN ARCHITECTURE FOR REAL -TIME SENSORY - INTERACTIVE CONTROL OF ROBOTS IN A MANUFACTRING FACILITY," IFAC Inf. Control Probl. Manuf. Technol., 1982.

[18] J. E. Colgate, P. E. Grafing, M. C. Stanley, and G. Schenkel, "IMPLEMENTATION OF STIFF VIRTUAL WALLS IN FORCE-REFLECTING INTERFACES," IEEE, pp. 202–208, 1993.

[19] J. S. Albus, "A Theory of Intelligent Machine Systems," in IEEE / RSJ International Workshop on Intelligent Robots and Systems, 1991, no. 91, pp. 3–9.

[20] Y. Bengio, A. Courville, and P. Vincent, "Representation Learning : A Review and New Perspectives," IEEE Trans. Pattern Anal. Mach. Intell., vol. 35, no. 8, pp. 1798–1828, 2013.

[21] A. L. Buczak and E. Guven, "A Survey of Data Mining and Machine Learning Methods for Cyber Security Intrusion Detection," IEEE Commun. Surv. Toutorials, vol. 18, no. 2, pp. 1153–1176, 2016.
[22] A. Akusok, Y. Miche, and A. Lendasse, "High-Performance Extreme Learning Machines : A Complete Toolbox for Big Data Applications," IEEE Access, vol. 3, pp. 1011–1025, 2015.
[23] U. Rao, "Design of automatic cotton picking robot with Machine vision using Image Processing algorithms," 2013 Int. Conf. Control. Autom. Robot. Embed. Syst., pp. 1–5, 2013.
[24] H. C. Shen, W. P. Yan, and G. E. Taylor, "Intelligent Sensory Decision-Making for Error Identification in Autonomous Robotic Systems," Int. Joumal Adv. Manuf. Technol., vol. 8, pp. 377–384, 1993.
[25] L. . Na, F. Gu, X. Yan-ling, Z. Hui, C. Shan-ben, and Z. Ju-jia, "Real-time monitoring of welding path in pulse metal-inert gas robotic welding using a dual-microphone array," Int. J. Adv. Manuf. Technol., vol. 90, pp. 2955–2968, 2017.
[26] I. Newton, "Letter from Sir Issac Newton to Robert Hooke," Historical Society of Pennyslvania, 1675. [Online]. Available: http://digitallibrary.hsp.org/index.php/Detail/Object/Show/object_id/9285. [Accessed: 07-Aug-2016].
[27] V. Gunes, S. Peter, T. Givargis, and F. Vahid, "A Survey on Concepts , Applications , and Challenges in Cyber-Physical Systems," in KSII TRANSACTIONS ON INTERNET AND INFORMATION SYSTEMS, 2014, pp. 134–159.
[28] S. Li, L. Da Xu, and S. Zhao, "The internet of things: a survey," Inf. Syst. Front., vol. 17, no. 2, 2015.
[29] A. Bicchi, "Hands for Dexterous Manipulation and Robust Grasping : A Difficult Road Toward Simplicity," IEEE Trans. Robot. Autom., vol. 16, no. 6, pp. 652–662, 2000.
[30] A. Bicchi and V. Kumar, "Robotic Grasping and Contact : A Review," IEEE Xplore, pp. 348–353, 2004.
[31] A. Albu-Schaffer, S. Haddadin, C. Ott, A. Stemmer, T. Wimbock, and G. Hirzinger, "The DLR lightweight robot : design and control concepts for robots in human environments," Ind. Robot An Int. J., vol. 34, no. 5, pp. 376–385, 2007.
[32] A. M. Okamura, "Methods for haptic feedback in teleoperated robot-assisted surgery," Ind. Robot An Int. J., vol. 31, no. 6, pp. 499–508, 2004.
[33] J. E. Colgate and J. M. Brown, "Factors Affecting the Z-Width of a Haptic Display," IEEE, pp. 3205–3210, 1994.
[34] M. A. Peshkin, J. E. Colgate, W. Wannasuphoprasit, C. A. Moore, R. B. Gillespie, and P. Akella, "Cobot Architecture," IEEE Trans. Robot. Autom., vol. 17, no. 4, pp. 377–390, 2001.
[35] A. Bicchhi and G. Tonietti, "Fast and 'Soft-Arm' Tactics," IEEE Robot. Autom. Mag., vol. 1, no. June, pp. 22–33, 2004.
[36] G. Tonietti, R. Schiavi, and A. Bicchi, "Design and Control of a Variable Stiffness Actuator for Safe and Fast Physical Human / Robot Interaction," in Proceedings of the 2005 IEEE International Conference on Robotics and Automation, 2005, no. April, pp. 1–6.
[37] A. Weiss, A. Huber, and M. Ikeda, "First Application of Robot Teaching in an Existing Industry 4.0 Environment : Does It Really Work ?," Societies, vol. 6, no. 20, pp. 1–21, 2016.
[38] J. E. Colgate, M. Peshkin, S. H. Klostermeyer, and A. P. Drive, "Intelligent Assist Devices in Industrial Applications : A Review," in Proceedings of the 2003 IEEE / RSJ International Conference on Intelligent Robots and Systems, 2003, no. October, pp. 2516–2521.
[39] K. Reed, M. Peshkin, J. E. Colgate, and J. Patton, "Initial Studies in Human-Robot-Human Interaction : Fitts ' Law for Two People," in Proceedings of the 2004 IEEE International Conference on Robotics and Automation, 2004, no. April, pp. 2333–2338.
[40] B. T. Pfeiffer, J. Hellmers, and E. Scho, "Empowering User Interfaces for Industrie 4.0," Proc. IEEE, vol. 104, no. 5, pp. 986–996, 2016.
[41] S. Stadler, A. Weiss, N. Mirnig, and M. Tscheligi, "Anthropomorphism in the factory - A paradigm change?," ACM/IEEE Int. Conf. Human-Robot Interact., pp. 231–232, 2013.
[42] K. Jo, J. Kim, D. Kim, C. Jang, and M. Sunwoo, "Development of Autonomous Car — Part I : Distributed System Architecture and Development Process," IEEE Trans. Ind. Electron., vol. 61, no. 12, pp. 7131–7140, 2014.
[43] J. Baus, A. Kruger, and W. Wahlster, "A Resource-Adaptive Mobile Navigation System org Baus Antonio Kr uger," in International Conference on Intelligent User Interfaces, 2002, pp. 15–22.
[44] M. Aicardi, G. Casalino, A. Bicchi, and A. Balestrino, "Closed Loop Steering of Unicycle-like Vehicles via Lyapunov Techniques," IEEE Robotics &Automation Magazine, no. March, Online, pp. 27–35, Mar-1995.
[45] S. Schabus and J. Scholz, "Geographic Information Science and Technology as key approach to unveil the potential of Industry 4.0 how location and time can support smart manufacturing," ICINCO 2015 - 12th Int.

Conf. Informatics Control. Autom. Robot. Proc., vol. 2, no. 2008, pp. 463–470, 2015.
[46] D. Comaniciu, V. Ramesh, and P. Meer, "Kernel-Based Object Tracking," IEEE Trans. Pattern Anal. Mach. Intell., vol. 25, no. 5, pp. 564–577, 2003.
[47] S. Kreitlein, A. Höft, S. Schwender, and J. Franke, "Green factories Bavaria: A network of distributed learning factories for energy efficient production," Procedia CIRP, vol. 32, no. Clf, 2015.
[48] J. Davis, T. Edgar, J. Porter, J. Bernaden, and M. Sarli, "Smart manufacturing , manufacturing intelligence and demand-dynamic performance," Comput. Chem. Eng., vol. 47, pp. 145–156, 2012.
[49] H. S. Kang, J. Y. Lee, S. Choi, H. Kim, J. H. Park, J. Y. Son, B. H. Kim, and S. Do Noh, "Smart Manufacturing : Past Research , Present Findings , and Future Directions," Int. J. Precis. Eng. Manuf. Technol., vol. 3, no. 1, pp. 111–128, 2016.
[50] D. Zuehlke, "SmartFactory—Towards a factory-of-things," Annu. Rev. Control, vol. 34, pp. 129–138, 2010.
[51] S. Weyer, M. Schmitt, M. Ohmer, D. Gorecky, S. Weyer, M. Schmitt, M. Ohmer, and D. Gorecky, "Towards Industry 4.0 -Standardization as the crucial challenge Towards Industry 4.0 - Standardization as the crucial challenge for highly modular, multi-vendor production systems," Int. Fed. Autom. Control. Online, vol. 48, no. 3, pp. 579–584, 2015.
[52] A. Radziwon, A. Bilberg, M. Bogers, and E. Skov, "The Smart Factory : Exploring Adaptive and Flexible Manufacturing Solutions," Procedia Eng., vol. 69, pp. 1184–1190, 2014.
[53] Deloitte, "Industry 4.0 Is Africa ready for digital transformation?," 2016.
[54] B. Coa, Z. Wang, H. Shi, and Y. Yin, "Research and Practice on Aluminum Industry 4.0," in Sixth International Conference on Intelligent Control and Information Processing, 2015, pp. 26–28.
[55] A. Kumar, M. Baldea, T. F. Edgar, and O. A. Ezekoye, "Smart Manufacturing Approach for Efficient Operation of Industrial Steam-Methane Reformers," Ind. Eng. Chem. Res., p. 4360−4370, 2015.
[56] Karin van Kranenburg, C. Sofra, D. Verdoes, and M. de Graaf, "Small-scale flexible plants - Towards a more agile and competitive EU chemical industry," Co. Whitepaper - TNO Sustain. Chem. Ind.
[57] A. Grogan, "Smart farming," Eng. Technol., vol. 7, no. 6, p. 38, 2012.
[58] K. K. Matengu and H. M. Ashekele, "Impact of technology integration on olive farming in central Namibia," *PICMET '10* - Portl. Int. Cent. Manag. Eng. Technol. Proc. - Technol. Manag. Glob. Econ. Growth, pp. 494–499, 2010.
[59] N. Dlodlo, "The Internet of Things in Agriculture for Sustainable Rural Development," no. April, 2015.
[60] DAFF, "Abstract of Agricultural Statistics 2016," Pretoria, 2016.
[61] F. G. Ortmann, "Modelling the South African fresh fruit export supply chain," Agric. Econ., no. December, p. 292, 2005.
[62] B. Doyle, A. Automation, and A. Arbor, "Do Robots Create Jobs ? The Data Says Yes ! Robots are changing the manufacturing dynamic in the United States and around the world Robots are an integral part of manufacturing ' s redemption Offshoring hit manufacturing hard , but is turning around," vol. 2016, pp. 69–73, 2016.
[63] M. Grieves, "Virtual Twin : Manufacturing Excellence through Virtual Factory Replication," Florida, 2014.
[64] AutoDesk, "AutoDesk," 2017. [Online]. Available: https://www.autodesk.com/. [Accessed: 31-Jul-2017].
[65] Siemans, "Siemens PLM.," Webpage, 2017. [Online]. Available: www.plm.automation.siemens.com/en/. [Accessed: 01-Jan-2017].
[66] Dassault Systems, "Delmia global industrial operations," 2016. [Online]. Available: https://www.3ds.com/products-services/delmia/. [Accessed: 28-Jul-2017].
[67] M. Saccol, P. Pedrazzoli, and W. Terkajl, "VFF : Virtual Factory Framework," in Proceedings of ICE - 16th International Conference on Concurrent Enterprising, 2010.
[68] S. M. Ross, G. R. Morrison, R. D. Hannafin, M. Young, J. Van Den Akker, W. Kuiper, R. C. Richey, and J. D. Klein, "Research Designs," in Handbook of Research on Educational Communications and Technology, Routledge, 2007, pp. 718–757.
[69] J. R. Jadhav, S. S. Mantha, and S. B. Rane, "Roadmap for Lean implementation in Indian automotive component manufacturing industry: comparative study of UNIDO Model and ISM Model," J. Ind. Eng. Int., vol. 11, no. 2, pp. 179–198, 2015.
[70] W. Ghonaim, H. Ghenniwa, and W. Shen, "Towards an agent oriented smart manufacturing system," Proc. 2011 15th Int. Conf. Comput. Support. Coop. Work Des. CSCWD 2011, pp. 636–642, 2011.
[71] R. Weeks and J. Du Plessis, "Servitization: Developing a business model to translate corporate strategy into strategic projects," *2011 Proc. PICMET '11 Technol. Manag. Energy Smart* World, pp. 1–10, 2011.
[72] H. Schaffers, N. Komninos, M. Pallot, and B. Trousse, "Smart Cities and the Future Internet : Towards Cooperation Frameworks for Open Innovation," J. Domingue al. Futur. Internet Assem., pp. 431–446, 2011.

[73] P. T. Letaba, M. W. Pretorius, and L. Pretorius, "The use of bibliometrics in the development of technology roadmaps: Planning for industrial impact of emerging technologies," 2014 Int. Conf. Eng. Technol. Innov. Eng. Responsible Innov. Prod. Serv. ICE 2014, 2014.
[74] S. Chatterjee and A. K. Kar, "Smart Cities in Developing Economies: A Literature Review and Policy Insights," Adv. Comput. Commun. Informatics (ICACCI), 2015 Int. Conf., pp. 2335–2340, 2015.
[75] C. P. Kruger and G. P. Hancke, "Benchmarking Internet of things devices," Proc. - 2014 12th IEEE Int. Conf. Ind. Informatics, INDIN 2014, pp. 611–616, 2014.

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