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Engineering Leadership and Sustainable Smart Manufacturing: Literature Review with Focus on Contemporary Era (2000-2020)

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Abstract: This study aims to explore the effective engineering leadership competencies and understanding engineering leaders' role in achieving sustainable smart manufacturing (SSM) with focus on contemporary era (2000-2020). There will be an attempt to provide better understanding of the definition of engineering leadership and its importance in the future in the light of Industry 4.0. Besides, it intends to explore the main leadership competencies that engineers need to balance and achieve TBL sustainability and explore the common challenges and obstacles. Using the literature review approach, the study is based on a multidisciplinary approach that combines three different disciplines, namely engineering leadership, sustainability leadership and leadership 4.0. The study's novelty lays in merging all these different leadership approaches together in one study. The study showed that most engineering leadership research focused on entry-level engineers to equip them with essential non-technical skills. in the majority of the engineering leadership studies related to population size, no general agreement of what engineering leadership is, use of different leadership models, and investigation of different leadership levels, sectors, and geographical areas because most of the studies have been conducted in Canada and the USA. The study also showed that sustainability is one of the fundamental goals of Industry 4.0. Although smart SM and Industry 4.0 have drawn the interest of the science community and industry in recent years, attempts to analyse the state of the art of these two emerging paradigms still lack in the literature. The situational, transformational, transactional, and authentic leadership styles appeared more than others in the reviewed studies. Finally, the results of the study will help industry to recruit effective leaders and improve leadership programme development. It will boost the engineering curriculum to prepare future engineers with the required leadership competencies required by the industry to overcome obstacles during the new industrial revolution.

Keywords: Leadership, Engineering Leadership, Sustainable Manufacturing (SM), Industry 4.0, Leadership 4.0.

القيادة الهندسية في ضل الاستدامة والثورة الصناعية الرابعة: مراجعة أدبية

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المستخلص: هدفت هذه الدراسة إلى استكشاف كفاءات القيادة الهندسية الفعالة وفهم دور القادة الهندسيين في تحقيق التصنيع الذكي المستدام. كما تقدم الدراسة محاولة لتقديم فهم أفضل لتعريف القيادة الهندسية وأهميتها في المستقبل في ضوء الثورة الصناعية الرابعة وذلك في العصر الحديث (الفترة مبين 2000 و2020). إلى جانب ذلك، ركزت الدراسة على استكشاف الكفاءات القيادية الرئيسية التي يحتاجها المهندسون لتحقيق التوازن وتحقيق الاستدامة واستكشاف التحديات والعقبات المشتركة. وتستند الدراسة، التي تعتبر من ضمن دراسات المراجعة الأدبية، إلى نهج متعدد التخصصات يجمع بين ثلاثة تخصصات مختلفة، وهي القيادة الهندسية وقيادة الاستدامة والقيادة في ظل الثورة الصناعية الرابعة. وتكمن حداثة الدراسة في دمج كل مناهج القيادة المختلفة هذه

معًا في دراسة واحدة. أظهرت الدراسة أن معظم أبحاث القيادة الهندسية ركزت على المهندسين المبتدئين لتزويدهم بالمهارات الأساسية غير الفنية. في غالبية دراسات القيادة الهندسية المتعلقة بحجم السكان، لا يوجد اتفاق عام حول ماهية القيادة الهندسية، واستخدام نماذج القيادة المختلفة، والتحقيق في مستويات القيادة والقطاعات والمناطق الجغرافية المختلفة لأن معظم الدراسات أجريت في كندا والولايات المتحدة الأمريكية. أظهرت الدراسة أيضًا أن الاستدامة هي أحد الأهداف الأساسية للصناعة 4.0. على الرغم من أن التصنيع الذكي المستدام والثورة الصناعية الرابعة قد جذبا اهتمام مجتمع العلوم والصناعة في السنوات الأخيرة، إلا أن محاولات تحليل حالة الفن في هذين النموذجين الناشئين لا تزال تفتقر إلى الأدبيات. ظهرت أنماط القيادة الظرفية والتحويلية والمعاملاتية والحقيقية أكثر من غيرها في الدراسات التي تمت مراجعتها. أخيرًا، ستساعد نتائج الدراسة الصناعة على توظيف قادة فعالين وتحسين تطوير برامج القيادة. سيعزز المنهج الهندسي لإعداد المهندسين المستقبليين بالكفاءات القيادية المطلوبة التي تتطلبها الصناعة للتغلب على العقبات خلال الثورة الصناعية الجديدة.

الكلمات المفتاحية: القيادة، القيادة الهندسية، التصنيع المستدام، الثورة الصناعية الرابعة، القيادة

I. Background.

The current global challenges — such as population growth, poverty, resources dearth due to high consumption, and climate change — require strong leadership to solve them. Engineers, as problem solvers, should take part in resolving those issues. Sustainability is the global trend to preserve the economy, environment and social parameters, and engineers should drive their technologies towards sustainability to maintain the triple bottom line (TBL): people, profit, and the planet. Nowadays, sustainability is regarded as a necessity, not a choice; the only other option to sustainable business is unsustainable business. Hence, sustainability should be ahead of the curve in the theoretical and practical fields of engineering. The transition to a sustainable industry is vital for organizations to seize future opportunities and satisfy global trends. Organizations have to ensure they are ready to sustain their activities for the benefit of companies, societies, and the environment. The increased awareness among end-users, especially in the developed world, will force the industry to align its strategic goals with the TBL of sustainability. Thus, sustainability can be viewed as the ultimate goal of the Industry 4.0 revolution. As we are on the cusp of the new industrial revolution (Industry 4.0), engineers should lead this transformation towards sustainability. To do so, they must demonstrate strong leadership skills that ensure the effective implementation of Industry 4.0 technologies for the sake of sustainability (Xu et al., 2018).

One of the essential skills that engineers need is leadership, which will allow them to employ their knowledge in the field and lead the industry into a sustainable future. In fact, the current lack of leadership in industrial digitalization (industrial revolution 4.0) is being viewed by many academic and professional bodies as the main reason behind the slow pace of implementing Industry 4.0 technologies effectively. Since industrial digitalization relies on technological engineering, engineering leadership could be a solution to fill the leadership gap. Therefore, understanding engineering leadership and its role in Industry 4.0 is indispensable. However, there are many challenges and obstacles that may prevent engineers from doing their job properly. Thus, engineers as leaders should be flexible in dealing with these issues. It is essential to empower the leadership role of engineers in order to for them to be able to lead the industrial revolution 4.0, through exploring the obstacles that engineering leadership may encounter and proposing solutions (Sanders, Elangeswaran & Wulfsberg, 2016)

The main focus of the study will be on exploring the effective engineering leadership competencies and understanding engineering leaders' role in achieving sustainable smart manufacturing (SSM). There will be an attempt to provide better understanding of the definition of engineering leadership and its importance in the future in the light of Industry 4.0. Also, the aim will be to learn about the main leadership competencies that engineers need to balance and achieve TBL sustainability. Moreover, the common challenges and obstacles will be explored.

II. Leadership:

Engineers efficiently use scientific knowledge and creative thinking to solve problems and potentially facilitate people's lives. Industrial revolutions and technological advancements are among the top engineering accomplishments that have contributed to the flourishing of civilisations. However, engineers have not always received the credit they deserve; instead, they have been blamed for the advent of various global issues, including the global warming phenomena that are believed to be a result of the industrial revolutions. It is believed that engineers have focused solely on productivity, regardless of its environmental issues. The whole world is encountering many challenges to survival which demand that engineers effectively demonstrate more than its technical skills. The performance of engineers should be considered as the environment and community as well as production. Engineering should be viewed as an ongoing learning process that must respond and adapt to the surrounding environmental changes. Therefore, engineers' proficiency should not be isolated, technically and cognitively, from global changes. They must engage themselves practically in multidisciplinary and cultural tasks that will help them develop new skills. Leadership competencies are one of the critical success skills for engineers in the future .

Developing modern leadership is significant for sustainable development and overcoming global challenges. Digital transformation is changing business and personal life as well in a profoundly and sustainable manner. The Industry 4.0 revolution and the introduction of the SM approach are two substantial developments that significantly impact all aspects of consumption and production in the twenty-first century (Abubakr et al., 2020). The increasing interconnection in modern society between technology, economy, and society boosts engineers' opportunities to exercise leadership (Salmani & Taatian, 2011). The 2028 Vision for Mechanical Engineering report, the book Fundamental Competencies for the 21st Century Engineer, the Accreditation Board for Engineering and Technology (ABET), and the report The Engineers of 2020 highlighted that future engineer need leadership competencies and should be aware of non-technical factors that affect their work such as economic, social, environmental, cultural and ethical (Paul, Sen, & Wyatt, 2018). The changes lead to engineers' need to develop non-technical skills to shine in the digital and sustainable economy era.

II.1 Leadership Theories Timeline

There is a contradiction between leaders who are potentially born or made. Thus, Farr and Brazil (2009) believe that leaders are born with different abilities, but some can effectively develop leadership competencies.

Figure (1) Leadership approaches evolving by industrial revolutions (Kelly, 2019, p. 14)

There are extensive leadership timelines; however, Kelly (2019, pp. 7—10) summarised the four major leadership schools over time linked to the industrial revolution (Figure 1) as follows:

1- Behaviourism was developed in the 1940s that innate and predetermined behavioural. However, it is the opposite of the 19th - and early- 20th -century theories, where the great man theory by Thomas Carlyle and trait theory of personality by Allport and Stagner were dominant. The environment and external factors potentially condition it; the notions behind behaviourism are knowledge and experience.

2- Cognitivism was developed in the 1950s believed that behaviour is developed through inner reasoning. According to cognitive leadership, ideas, intellect, intuition, experience, and other cognitive skills are essential variables in leadership success.

3- Constructivism was developed in the 1960s believed that leadership is an evolving process associated with the world around us and affected by cognitive and social activities. Albert Bandura's Social Learning Theory (1977) explains how cognitive and environmental factors influence people's behaviour. However, it noted that in theory, the context is a significant factor. However, using a personal computer can learn (cognitive) and social contact through social media, but this will not make a person a leader.

4- Connectivists theory states that knowledge acquisition is not only a mental process but also available in networks. George Siemens (2004), who coined the term "connectivism", argues that learning theory in the digital age is different from behaviourism, cognitivism, and constructivism, as they are pre-internet learning theories. The main principles of connectivism are that learning can be found in diverse opinions, different sources of information and networks, machines, and the capacity to know. Multidisciplinary analysis, continuous learning, accuracy, and decision making is a learning process. However, Stephen Downes (2007) says that connectivism is a social activity, not a knowledge transferring or building approach. He adds that connectivist leaders do not prioritise ideas and innovation.

The prevailing leadership theories and approaches (Mallette, 2005; Holness, 2019) are defined by being:

- **Great man/trait approach:** Leaders are born with intrinsic leadership traits.
- **Skills approach:** Leadership can be learned, and the three areas of skills needed are technical, human, and conceptual.
- **Behavioural approach:** Leaders can be made and are not born; leaders demonstrate different behaviours such as autocratic, democratic, laissez-faire, bureaucratic and charismatic.
- **Style approach:** It is considered behavioural. Leaders can be ranked on two dimensions, concern for results (task) or people (relationships). Blake Mouton’s managerial grid model provides five different styles in these two dimensions.
- **Contingency approach:** This approach focuses on matching leaders to the demands of a specific condition. It added a significant element, which is the environmental factors. Leaders are ranked on three dimensions based on leader-member relations, task structure, or position/power.
- **Situational approach:** Leaders change their leadership style (directing, coaching, supporting, and delegating) according to the group's situation.
- **Transactional approach:** A transaction between a leader and the followers is made to establish a common interest relationship, where the leader is focused on supervision and control to enhance performance. It is a carrot-and-stick motivation approach through an organization’s reward-and-punishment system. Some consider it a part of the style approach, while others classify it under the power and influence category.
- **Transformational approach:** It is a part of power and influence, where the transformation of people is made through inspiration, leader charisma, trust relationships building, engagement, clear purpose, flexible rules, and a high sense of belonging.
- **Team approach:** It focuses on forming teams and can involve both shared and distributed leadership. The team's leader supports them by monitoring and assessing the situation and determining the appropriate course of action.
- **Psychodynamic approach:** Leaders who can understand their followers’ emotional responses may change employee behaviour.

- **Inspirational approach:** This approach identified four qualities for an inspired leader: they selectively show their weaknesses, they rely on intuition, manage with empathy, and they know what is unique about themselves.
- **Servant approach:** The main roles are the leader's main focus, leading by example, and creating a positive culture. The leader encourages collaboration, trust, foresight, listening, and the ethical use of power and empowerment. However, it is a slow process that requires time.

There are many other leadership approaches, such as swarm, magnetic, authentic, adaptive and collaborative moreover, the different leadership approaches and models are an endless effort. As was discussed earlier, every different leadership approach has its strengths and weaknesses. No leader has all characteristics, and it is impossible and frustrating to try to be everything to be an effective leader. However, Dulewicz and Higgs (2016) reviewed leadership theories and observed that most of the competencies fall into three categories: intellectual (IQ), managerial (MQ), and emotional and social (EQ).

II.2 Leadership and Business:

The field of leadership is gaining considerable attention due to the rapid changes and emergence of new megatrends. Many studies revealed a significant shortage of leaders who can operate in a digital environment. It is asserted that there is a need for profound research to understand leadership competencies, roles, and challenges (Rossini et al., 2019). Niedermeier (2016) study shows that 70% of participant's assert that the Industry 4.0 context would change the leadership (Helming et al., 2019). According to MIT research based on interviewing more than 1,000 business leaders from 27 diverse sectors and sizes in 131 different countries, the majority believed that digital transformation affects its business. However, 70% declared they lack leadership, workforce skills, and an agile operating structure (Yücebalkan, 2018). A World Economic Forum report described a $100 trillion market for both business and society through the implementation of Industry 4.0 technologies; however, lack of effective leadership is considered the main factor in preventing the UK from digitalising the manufacturing sector (BEIS, 2017).

Moreover, business sustainability is another challenge that should be considered to avoid the inequality and poverty that appeared as an implication of the previous technological explosion. Further, Oxford Economics 2016 surveyed more than 4,000 persons from 21 nations in different sectors. The result shows that millennials who were born before 1980 comprise the bulk of the workforce. More than 20% of leaders show a big divergence in perception when contrasted with the former generation (Yücebalkan, 2018). a survey by Johnson Controls Global Workplace Solutions (2010) shows that 96% of 18–45-year-olds value working in environmentally friendly workplaces. As evidence of the new skills requirements, an MIT and Deloitte job survey reveals that 90% of the interviewed participants, including executives and managers, affirm the importance of updating skills annually to perform in the digital world

(Guzmán et al., 2020). Leaders play a key role in business success; however, digitalization, sustainability, new generations' perception, and global challenges demand a non-traditional leadership approach and new competencies.

II.3 Leadership Competencies:

There are general competencies required for general success in life and specific competencies required for particular tasks. In the engineering context, "technical skills" or "hard skills" and "non-technical skills" or "soft skills" are widely used (NAE, 2004). Bartram's (2005) Great Eight Universal Competency Framework emphasises the necessity of recognising the context, and Boyatzis's (1982) Model of Effective Job Performance highlights the importance of an individual's understanding of the Organizational environment for success (Meredith Handley, 2017, p. 11). The multi-dimensional approach combines two different ideas, the behavioural and functional approaches, and considers social and management competencies important for accomplishing goals. (Prifti et al., 2017). The coincides exactly with Boyatzis's model, where effective job performance consists of three competencies: individual, job, and Organizational environment. To be clear and precise, in this research, the researcher defines competency as "the observed and measured behavioural and functional KSA abilities to achieve desired goals in a certain context".

There is an implicit agreement that competencies describe a person's capacity that includes KSA to respond effectively to complex requirements (Kipper et al., 2021). In technical environments, competencies refer to a person's fundamental traits about an effective performance leading to observed behaviours necessary to succeed across different position levels (Meredith Handley, 2017, pp. 9,14). According to the Oxford Dictionary, competency is the ability to do something successfully. The Organization for Economic Cooperation Development (OECD) (2002) definition is "the ability to successfully meet complex demands in a particular context" (Abdulwahed & Hasna, 2017). However, most authors agree with Hartle and believe that competency is a set of KSA (Łupicka & Grzybowska, 2018). Other models add "habits" to the KSA, becoming KSAH; however, habits will appear in attitudes and do not directly influence leaders. Rather, they are a way to develop one of the KSA.

II.4 Leadership in Context of Smart Manufacturing:

Businesses are struggling particularly in this period, owing to a shortage of effective leaders. Arguably, leadership development programmes lag behind the rapid changes in the environment. The speed of technological and social changes is faster than the speed of education. According to Tomaschitz (2019), social fear occurs when education runs behind technology and vice versa when education ahead of technology creates prosperity. This fear will generate resistance to adopting new technologies effectively. The research determines unavailability of the right effective skills due to lack of cooperation between industry and academia is one of the main challenges in the digital era. Ashkenas and Manville

(2018) emphasise that leadership competencies are derived from real experience and constant practices (Guzmán et al., 2020). Thus, bridging this gap by conducting more empirical studies is vital for a thriving and sustainable future.

Most leadership models, such as transformational and charismatic, focus mainly on leaders' characters, overlooking the Organizational context (Hind, Wilson, & Lenssen, 2009). Transformational leadership has failed to move beyond an aspiration, and in time the culture of transactional and coercive leadership has been pervasive (Kelly, 2019, p. 14). Some believe that transformational leadership is the most suitable leadership style for millennials in the age of Industry 4.0 since it inspires, develops, supports, and adapts to change. It is also suitable for a volatile business environment where creativity and innovation are key factors for Organizational success (Suyanto et al., 2019). An obvious example supporting the need to study competencies within a specific context is the contradictory results between different studies. For example, Kim et al. (2008) found that being sociable is not important for professional achievement, while Bartrum (2005) found that extroversion is correlated to job success (Meredith Handley, 2017, p. 15). There are various researches, and each research has its potential concepts; however, many authors agree that lack of progress in defining effective leadership competencies is related to lack of contextual studies since the effective performance competencies are associated with a certain context (Meredith Handley, 2017, pp. 4—9). In another example, research on women's leadership identified a distinct array of effective leadership competencies (Holness, 2019). The research declared that the effectiveness of the leadership approach varies depending on context.

III. Engineering Leadership:

Engineers play a significant role in modern civilisation and future prosperity. They have considerable strength to solve future challenges as they create new products, technologies that change the globe (Jantzer et al., 2020). Engineering is a creative process that improves the quality of people's lives (NAE, 2004). 'engineering' originates from the Latin *ingeniator*, and engineering will forever be synonymous with 'ingenuity'. Countries deem engineers to be the spirit behind productivity and boosting the economy and social life quality. For example, engineering contributed around 26% to the UK's GDP, and each engineering job secured another 1.74 jobs (RAEng, 2017). The USA believes that engineers are crucial to sustaining its global economic advantage (Farr & Brazil, 2009). However, changes in the environment demand that engineers acquire new skills. Engineers should innovatively apply technology, considering cultural differences and legal and economic constraints (RAEng, 2004, pp. 47—49). Tryggvason and Apelian (2006) show that the evolution of engineers' role across the previous two centuries was from professional engineer to scientific engineer to entrepreneurial engineer (Abdulwahed & Hasna, 2017, p. 13). The two important elements for an entrepreneur are innovation and creating social value. Thus, sustainable development and technological innovation are the most important areas for future engineers. According to The IEA (2013), "Engineering is an activity that is essential to meeting the needs of people, economic development and the provision of services to society in environmentally sound and sustainable lifecycle" (RAEng, 2014). All industrial revolutions' history and characteristics have two things: the role of engineers and disruptive change (Giannetti, 2021). The research argued that engineers lack social skills and overlook environmental impact, except the regulations (Fromel et al., 2019). Others believe that engineers value their social responsibility and the significance of their future contribution; however, they practice conflicted responsibility. Moreover, cost, quality, regulations, and stakeholders' and customers' satisfaction (Jantzer et al., 2020). Therefore, the balance between economic and social expectations is one of the major challenges for engineers and engineering leaders.

Rapid changes across the technology forced engineers to acquire new skills to perform effectively. Milisavljevic-Syed et al. (2020) affirm that engineers need new digital skills. It effectively cleared that there is a mismatch between the education and the qualifications desired by industry and that the workforce is only equipped to tackle challenges arising in previous times. Future professional engineers have to work in multidisciplinary and diverse teams that require non-technical competencies such as collaboration, communication, market and social understanding, business management, lifelong learning, resilience, leadership, high ethical standards, openness to change, and flexibility (RAEng, 2004, pp. 55—58).

Attributes of the engineer of 2020 are to have the ingenuity of Lillian Gilbreth, the problem-solving capabilities of Gordon Moore, the scientific insight of Albert Einstein, the creativity of Pablo Picasso, the determination of the Wright brothers, the leadership abilities of Bill Gates, the conscience of Eleanor Roosevelt, the vision of Martin Luther King, and the curiosity and wonder of our grandchildren (RAEng, 2004, p. 58).

Notwithstanding the lack of studies in the field, there is general agreement in the literature on the distinct engineering working environment, engineers' identity, and leadership perspective in the engineering context. However, there is no clear understanding and direction in the literature about engineering leadership's definition and roles. For example, "non-technical skills" and "leadership skills" are used interchangeably in engineering leadership. Further, it has been observed that there are four different understandings of "engineering leadership": how to be an engineer and leader, how to lead engineers, how to teach leadership in the engineering curriculum, and as a synonym of advancing technology. However, it has been noted that technical competencies are important in engineering leaders. Moreover, little agreement has been found on engineering leadership as a middle management role, where transformational and transactional leadership styles were deemed suitable for engineers. The real question is "engineering leadership" a fancy term, or has it a distinct field that differs from traditional leadership?

Despite the importance of the empirical study on engineering leadership, there are very limited studies. According to Lis and Veenstra (2012), practical experience is the main vehicle for understanding and obtaining engineering leadership. Further, the vast majority of research focused on non-technical skills for early-career engineers. The obvious reason is that the research field of engineering leadership is at an early stage and needs more profound investigation. Besides this, there is a wide gap between academia and industry regarding the developing engineering leadership competencies. In Saudi Arabia, research is extremely rare, and the existing result was surprisingly different from international studies where the cultural and other factors would influence. It is worth mentioning that there is no engineering leadership course developed by engineering colleges yet.

IV. Leadership 4.0:

Industry 4.0 technologies can achieve sustainable TBL in manufacturing. However, an effective smart manufacturing transformation requires a profound change in leadership practices (Jones et al., 2017), knowledge, skills, and attitude. Developing leaders is as important as developing new technologies. Organizations spend billions of dollars developing new technology and almost nothing developing new leaders (Phillips, 2018). Many authors believe that leadership research has continually evolved; however, more than at any other time, owing to technology and TBL sustainability, there are many calls for papers underlining the need to understand leadership in the digital era (Banks et al., 2019). Understanding leadership competencies in the digital age stimulates the development of leadership capacity and highlights the level of change leaders have to embrace (Junior, Cabral, Brinkhues, & Costa, 2020). Nevertheless, there is no consensus about the changes needed for Industry 4.0 .

Digital transformation means leading the digital transformation and the Organization in a digital environment (Klein, 2020). “Digital leadership is a combination of transformation leadership style and the use of digital technology (De Waal et al., 2016)”. Rudito and Sinaga (2017) define digital leadership as a “combination of digital competence and digital culture to drive the change and take the opportunity of digital technology” (Mihardjo, et al., 2019). El Sawy et al. (2016) describe digital leadership as thinking innovatively about corporate strategy, the business model, skill sets, working environment, mindsets, and the function of new technology. Miller (2018) refers to digital leadership to improve people’s lives and well-being by utilising technology (Yücebalkan, 2018). Asri and Darma (2020) show two different leadership definitions based on Sheninger (2014): “setting up direction, influencing others, and initiating sustainable changes through access to information, and building relationships to anticipate important changes for the success”. Oberer and Erkollar (2018) define it as “fast, cross-hierarchical, team-oriented, and cooperative with a strong focus on innovation”. There is divergence since each definition focuses on different dimensions, as discussed in the next paragraph.

Leading change requires leaders to focus on five strategic factors: put people first, inspire through a deep sense of purpose, enable people with the capability to succeed to achieve goals and go far, enable a culture of continuous learning, be an inclusive leader who builds an open debate environment, know what is missing, and give the people the credit leader deserve (Hemerling, 2016). In a recent book, Leadership in a Time of Continuous Technological Change, leading in the digital age needs an entrepreneurial mindset, diversity of perceptions, and adopting new values and working ways. The authors developed a tailored leadership model for digital transformational processes (Schwartz, 2020), where identity is the base, clarity is the heart, and emancipation, autonomy and capability are the tools. Additionally, agility and adaptability with a decentralised decision-making environment are important competencies for the digital era. Charles Darwin said, "It is not the strongest of the species that survives, nor the most intelligent that survives; it is the one that is most adaptable to change" (Milisavljevic-Syed et al., 2020). If leaders keep doing the same, the result will be the same. Dyer once said, "If you change the way you look at things, the things you look at change." Industry 4.0 is changing the current production paradigm, and manufacturing leaders have to change their way of thinking and managing business to exploit and drive the new industrial revolution to ensure SM. According to Jones et al. (2017), one important role of engineering leaders is to harness technological innovation to solve TBL sustainability conflicts effectively. Engineering leaders have to respond in a new way ¬¬to adapt to changes to achieve SSM successfully .

Another main driver of a new leadership approach is that Industry 4.0 blurs the boundaries between industries and countries, which requires leaders to lead beyond the edges. Thus, leaders have to be inclusive with a global mindset. A Deloitte report by Dillon and Bourke (2016) investigated inclusive leadership traits. The authors affirm that the context is changing now, which demands new leadership styles and competencies. The diversity in the market, customers, ideas, and talents compels leaders to think inclusively and acquire new competencies. The report surveyed more than 1,000 global leaders and conducted in-depth interviews with 15 leaders. It found six (Table 1) essential leadership traits for inclusive leaders: cognisance to avoid bias, curiosity because different ideas enable growth, courage to take risks, commitment and determination, collaboration, and having cultural intelligence (Dillon & Bourke, 2016).

Table (1) Inclusive leadership traits (Dillon & Bourke, 2016)

	1	2	3	4	5	6
Six traits	Commitment	Courage	Cognizance of bias	Curiosity	Cultural intelligence	Collaboration
15 elements	Personal values	Humility	Self-regulation	Openess	Drive	Empowerment
	Belief in the business case	Bravery	Fair play	Perspective-taking	Knowledge	Teaming
				Coping with ambiguity	Adaptability	Voice

V. Industry 4.0:

Technology and industry have a significant impact on all parts of people's life. Manufacturing is the main contributor to modern civilisation and is equally responsible for the current global challenges. Industrial revolutions have had a great positive influence on people's lives. However, despite the economic prosperity, environmental and social negative effects cannot be ignored. Technological innovation should tackle global issues; therefore, engineering practices must be integrated into sustainable technology (National Academy of Engineering, 2004). The need for disruptive change in manufacturing emerged first in Germany as the Industry 4.0 vision in 2011, followed by smart manufacturing initiatives by the Digital Manufacturing & Design Innovation Institute (DMDII) in the USA, the Made in China 2025 mission, Smart Industry in the Netherlands, and the Robot Revolution Initiative 5.0 in Japan (Milisavljevic-Syed, Thames, & Schaefer, 2020). However, Wind and Rangaswamy (2000) anticipated is currently known as Industry 4.0 promises such as information sharing, automated manufacturing, real-time information, and mass customisation as a customer-centric strategy (NAE, 2004). Technological development, global problems, consumer expectations and market rivalry forced businesses to implement a new manufacturing paradigm. The expanding domains of smart manufacturing techniques promise to boost production and quality through waste elimination and efficiency enhancement. As a result, it ensures a high degree of resource optimisation, leading to long-term sustainability and profitability. For example, it is estimated that the economic value of Industry 4.0 would be $11 trillion by 2025, with a cost savings of up to 50% (Manyika & Chui, 2015). An industrial revolution happens when innovation increases production capacity, influencing the economy, society, and environment (Fonseca, 2018). In recent years, new technology evolution, Industry 4.0, or smart manufacturing, has been on the verge of ushering in the fourth industrial revolution. Therefore, Industry 4.0 has to be a great opportunity for engineers to resolve the dark side of previous industrial revolutions by ensuring the new industrial revolution considers TBL sustainability.

The major goals of Industry 4.0 are to expand manufacturing automation, processes optimisation, real-time data utilisation, agile supply chain, effective maintenance, better product and work quality, customisation, flexibility improvement, sustainability, and innovative products and business models (Milisavljevic-Syed, Thames, & Schaefer, 2020). Industry 4.0 facilitates real-time communication from the top floor to the shop and upstream to downstream and for the end-to-end life cycle (Abubakr et al., 2020). That will help to prioritise manufacturing order, job optimisation, and flexible production. Besides that, it helps manufacturing systems to make decisions without human intervention (from automatic to autonomous) to shift to individual mass production. Agility and flexibility are primary objectives of factory 4.0 (Abubakr et al., 2020). Therefore, investment decision-making is linked to Industry 4.0, a significant stage (Guzmán et al., 2020).

Many authors believe that effective transformation to Industry 4.0 depends entirely on leadership (Guzmán et al., 2020). Accordingly, leaders' capabilities are critical success factors in digital transformation (Klein, 2020). Industry 4.0 will affect the Organizations and business environment; therefore, leaders and employees need to be aware of its consequences for their Organizations (Larjovuori, Bordi, & Heikkilä-Tammi, 2018). According to Kohnke (2017), new skills and competencies, new leadership styles, and new Organizational capacities are required. One of the important UK government reports, the *Made Smarter Review*, identifies the three main areas for successful digitalization: adoption, innovation, and leadership (Department for Business, 2017). The report highlighted that boosting adoption and innovation would increase manufacturing growth by 3% per year and provide a net of 175,000 jobs, reducing CO_2 emissions by 6% and enhancing industrial productivity by over 25% by 2025. However, according to the report, lack of leadership is considered one of the main obstacles to capturing Industry 4.0 opportunities. In the following sections, leadership in the context of the new industrial revolution will be discussed in more detail.

V.1 Industry 4.0 Technologies:

Industry 4.0 is a set of different technologies. The main drivers are increased flexibility and efficiency, quality and productivity, customised/personalised mass production, and sustainability (Giannetti, 2021). There is no general consciousness about Industry 4.0 enabler technologies; some mention nine, and others mention five (Kipper et al., 2021). Industry 4.0 is based on various technologies, each of which is explained differently in different sources. However, here is an opinion on several forms of enabling technology with some personal modification. Industry 4.0 technologies combine four different technology approaches (World Economic Forum, 2017):

- Digital to physical converting (digital twins, advanced robots & 3D printing)
- Connectivity and power of data (IoT, big data analysis & cloud computing)
- Human-machine interface (immersive systems)
- Intelligence and analytics (artificial intelligence & machine learning)

Three dimensions define the industry 4.0 paradigm: vertical integration of manufacturing systems, horizontal integration across manufacturing value creation factors, and end-to-end engineering throughout the product life cycle (Giannetti, 2021). However, horizontal integration refers to the data and communication flow from downstream to upstream in the value chain and vice versa. Vertical integration refers to the data and communication flow from the factory floor to the top floor and vice versa. Finally, end-to-end engineering, which refers to the entire product life cycle from the cradle to the grave to the cradle again, focuses on value creation and sustainability. Another central concept is a smart factory, where a factory endeavours to minimise human interference by moving factories from automatic to autonomous operating mode, where the system can stand alone, understand, perceive, and solve problems (Tavallaey & Ganz, 2019). Moreover, Industry 5.0 as a new concept is proposed to support jobs, enhance the idea of technologies complementing people but not substituting them, and move from CPS to a human-cyber-physical system (HCPS).

In the light of Industry 4.0 implementation, Milisavljevic-Syed, Thames, and Schaefer (2020) determine two different stages. First, the early adoption stage includes the definition of the architectural model of CPS and cloud manufacturing (CM), focusing on vertical and horizontal sides, horizontal implementation, digital skills, and cyber security, which are the challenges. The second stage is the mature adoption that includes automation, vertical integration of CPS, exploring the new vertical potential to create new customer value, shift from CM to cloud-based design and manufacturing (CBDM), expanding CPS to cyber-physical production engineering (CPPE) to increase Servitisation and product-service systems (S+PSS), an innovative and sustainable business model, and digital skills. Cyber security becomes obvious in this stage.

V.2 Challenges to Industry 4.0:

At the World Economic Forum (2019), global business executives discussed the corporate leadership challenges in Industry 4.0. however, building skills infrastructure and customers and a socially-oriented culture are the main challenges for leaders in the digital age. There are many reasons behind that; for instance, the first is related to the fact that technologies are moving faster than skills, which leads to a skills crisis. Second, social and staff resistance to new technologies; for example, two-thirds of people are worried about losing their jobs to robots. Third, dealing with millennial consumers and employees is another challenge that has to be considered. However, some recommendations were proposed to overcome these challenges. For example, being authentic and empathetic is important to build trust; and being open is important to embrace diversity. It significantly considered unique talents a competitive advantage; however, education should be a government issue to overcome the skills challenge. Businesses have to have a link with education institutions via business mentors.

Generally, the following are the most repeated challenges regarding the manufacturing industry in light of the transition to Industry 4.0. Resources availability is the major and most repeated challenge, particularly the lack of skills and the high capital investment, consistent with professionals' opinions. Then come the challenges of system integration, information management, trust in technology and cyber security, lack of infrastructure that affects the resilient supply chain, legal constraints, poor government support, lack of collaboration between academia and industry, short product life cycle due to constant innovation and rapid customer requirements, Organizational change, lack of standards of safety and ethics in human-machine collaboration, and lack of social acceptance and awareness (Thames, & Schaefer, 2020).

In digitalization, it is critical to talk particularly about the main social argument regarding Industry 4.0, which is the rising unemployment rate. According to the 2019 Annual Manufacturing Report, 89% of participants agreed that although more automation meant and could reduce staff because Industry 4.0 technologies facilitate improving productivity with a smaller workforce (Milisavljevic-Syed et al., 2020), others argue that that middle-skilled tasks will be substituted by technology, while non-routine cognitive tasks will be complemented by technology (Milisavljevic-Syed et al., 2020). For example, humans will continue to do cooperation, analysis, and creativity skills (Sartal et al., 2020). Industry 4.0 will eliminate jobs and revitalise the job market as well (Temelkova, 2018). Therefore, people need to sustain their competitive skills through education, lifelong learning and develop new competencies. However, in terms of the social level, there is currently no agreement in scholarly and insightful literature on the true effect of Industry 4.0 on the number of employees in the industrial sector in general and manufacturing in particular (Sartal et al., 2020). Abubakr et al. (2020) provide a four-dimensional career sustainability model in light of rapid industrial innovation. Authors believe that for individuals to sustain a job, and have to be resourceful, flexible, renew skills and integrate. Leaders as well should play a role in securing the right talents and developing them. Benešová and Tupa (2017) identify the most important hard and soft skills required in the manufacturing industry in light of digitisation. Such work would help business leaders and educators to collaborate to bridge the skills gap. Therefore, business leaders have to connect with universities to ensure the right effective talents are developed. Employees' fear of new technologies is due to their job loss, and business leaders' fear of new technologies is due to the lack of skills.

VI. Sustainability:

The concept of sustainability has led to considerable global change in the way of business thinking. However, sustainability adoption is one of the top priorities of businesses and leaders (Alison, 2020). The science of sustainability originates from two different economic schools. The first school argues that there is a limit to growth due to limited natural resources and the expected high consumption due to an increase in the future population. The other school argues that there is no limit to growth and that the market conditions will balance the supply and demand, which will motivate entrepreneurs to react to fill the market gap. Therefore, both schools, effective resource management or innovation technology are the main vehicles of sustainable development. However, it determines that natural resource has an end, humans consider the resource unlimited, as Julian Simon (1983) states, and they are the main contributors to a sustainable future.

In the 1970s, government, academia, businesses, and NGOs recognised the unsustainable development model. Population growth results in high resource consumption and high pollution as a result of the industrialisation boom. In 1987, The United Nations Brundtland Commission report was considered a major milestone for future sustainable development, where "sustainable development" was defined as development that meets current generations' needs without compromising the ability of future generations to meet their own needs". In 2015, the United Nations (UN) leaders approved 17 Sustainable Development Goals (SDGs) that address environmental, social and economic aspects (Sartal et al., 2020). The sustainable development concept has influenced political and economic decision making, especially after the UN SDGs were released. Sustainability development within an Organization has become key research because business is critical in making sustainability real. Particularly the manufacturing sector, since it has a significant contributing role in sustainable development, discussed later.

VI.1 Sustainability Theories:

Sustainable business development theories developed by Chang (2017) and his colleagues did excellent work summarising how sustainability theories have evolved (as shown in Figure 6). The research provides a clear background for the main theories:

1- Corporate social responsibility: According to Carroll (1999), the root of sustainable business goes back to the 1930s, and since that time, sustainability thinking has been expanding, aiming to understand the relationship between sustainability and companies. In 1953 the relation between society and business was first mentioned by Howard Bowen. In the research, the discussed Organizational strategy and action influence human lives from different aspects. Moreover, he defined the "social responsibility of businessmen" as the "obligations to pursue policies, make decisions, and follow lines of action which are desirable in terms of the objectives and values of our society". Afterwards, the term developed into "corporate social responsibility" (CSR). In the 1950s and the 1960s, the concept was not recognised broadly and attracted several critiques. For example, Milton Friedman argued that the social responsibility of firms relies on making money for its investors. Arguably, that might have many factors, such as lack of regulations and public awareness; therefore, the idea was considered a threat to business growth. In 1970 the concept started gaining attention when the Committee for Economic Development (CED) published A New Rationale for Corporate Social Policy.

2- The book emphasises the important role of society as a support structure for keeping business. The Three-Dimensional Conceptual Model of Corporate Performance was a seminal work by Carroll (1979), a widely recognised effort putting CSR in a theoretical framework. Carroll divided CSR into four groups: "economic responsibility, legal responsibility, ethical responsibility and discretionary responsibility". Carroll's main topics are consumerism, the environment, discrimination, product safety, workplace safety, and shareholders. Reaction, defence, accommodation, and pro-action were four common methods outlined by Carroll. Orlitzky et al. (2003) revealed an obvious relationship between CSR and financial performance, improving a firm's reputation. It is considered as currently one of the primary trends in CSR that positively influences economic performance.

3- In his book "Strategic Management—A Stakeholder Approach", Freeman pioneered stakeholder theory, published in 1984. He argued that Organizations should extend relations beyond direct ones, such as academia, government, and environmentalists. He defined stakeholders as "any group or individual who can affect or is affected by achieving the organization's objectives". Friedman (1970) states that the main purpose of the shareholder approach is to maximise profits for investors and ensure long-term survival.
4- Corporate sustainability: The Brundtland report brought in the concept of corporate sustainability (CS). The concept does not have a common definition. The main trend of CS is to meet stakeholders' needs and balance economic, social, and environmental elements — TBL — of corporate performance, incorporating that into a sustainable business model (SBM). Many authors assert and provide evidence that TBL has a positive impact on firms' performance. Conversely, other writers argue for the ineffectiveness of TBL, and it is impossible to balance the three aspects while maintaining a profit. The research determines the difference between profit and growth potential with sustainability as a long-term objective. However, it is effectively well acknowledged that CSR and CS are indistinguishably linked, and Organizations use them interchangeably.
5- Green economics: the concept appeared for the first time in 2005 at the Fifth Ministerial Conference on Environment and Development. The UN defines a green economy as "activities that improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities". According to the UN (2013), green growth is a prerequisite for building a green economy. The main idea is that economic growth should be completely associated with better environmental practices. According to Jänicke (2012), the investment in updating the entire production system to environmentally friendly and resource-saving processes and products results in green growth. Green economics differs from the theories of CSR and CS since its focus is on how to promote sustainability in society. In other words, green economics focuses on the macro-policy environment rather than businesses, while CSR and CS focus on the micro-environment.
6- Co-evolution theory was driven from Darwin's evolution theory to business and management studies; the theory was born as a new approach. According to Porter (2006), Co-evolution is how Organizations and their environments evolve in tandem. The main factors for co-evolving business are strategy, ecosystem, technology, institutions, and practices. Firms can be influenced by economic and socio-political, and they can also impact the two environments by adjusting their strategic responses.

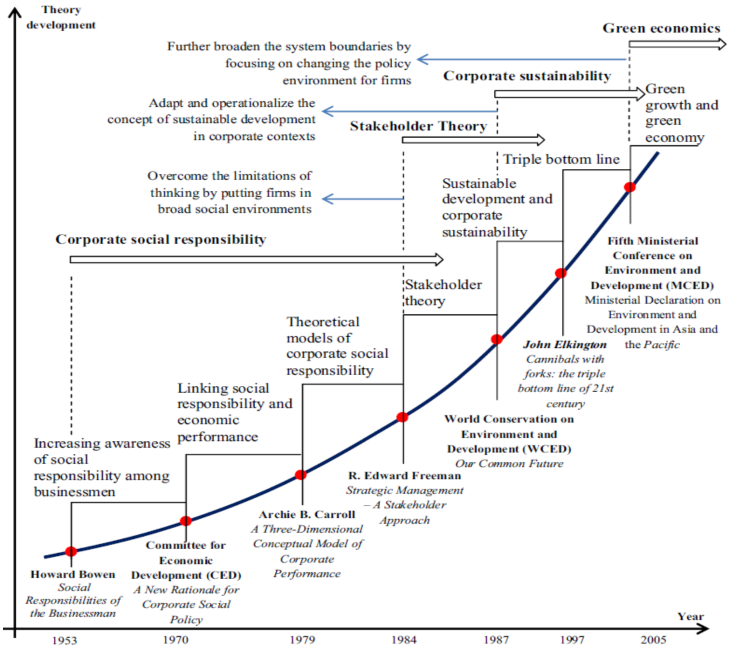

Figure (2) Evolving theories of business sustainability (Chang, 2017)

VII. Sustainable Manufacturing (SM)

Many authors argue that even the definition of the Brundtland report is widely used; however, it is still unclear and complex (Chang et al., 2017). Others argue that the definition does not apply to manufacturing (Sartal et al., 2020). SM, despite the lack of agreement on an SM definition, the definition of the US Department of Commerce is commonly used, which is "the creation of manufactured products that use processes that minimise negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound" (OECD, 2011; Moldavska & Welo, 2017). The National Council for Advanced Manufacturing (NCAM) defines SM similarly to the US Department of Commerce; however, it added "the use of technology" and overlooked the "social dimension". The American Society of Mechanical Engineering critiqued NCAM's definition since it neglected the design of products, processes, and systems and ignored the social factor (Carley et al., 2014). However, the design stage cannot be disregarded since it determines 80% of the future environmental impact (Stark et al., 2017, p. 112). First, Zhang and Haapala (2015) define SM as "The production of products in a way that minimises environmental impacts and assumes the social responsibility of employees, the community and consumers throughout the life cycle of a product, while at the same time they achieve economic benefits". Second, Giret et al. (2015) offer a more practical solution to SM as "The ideal SM scheduling system does everything (maximum efficiency) without using anything (minimum resources)". Indeed, resource optimisation and utilisation are fundamental engineering concepts where low cost and high-productivity ideas are a rule of thumb in the engineering environment. Engineers in the manufacturing industry are sustainability-oriented and aim to reduce resource use by improving manufacturing process productivity, eliminating excessive resource usage, and reducing waste and pollution generated by manufacturing activities. However, still, the social diminution is unclear. The most important social sustainability goals are to increase health, safety, quality of life, and ethics (Kishawy, Hegab, & Saad, 2018).

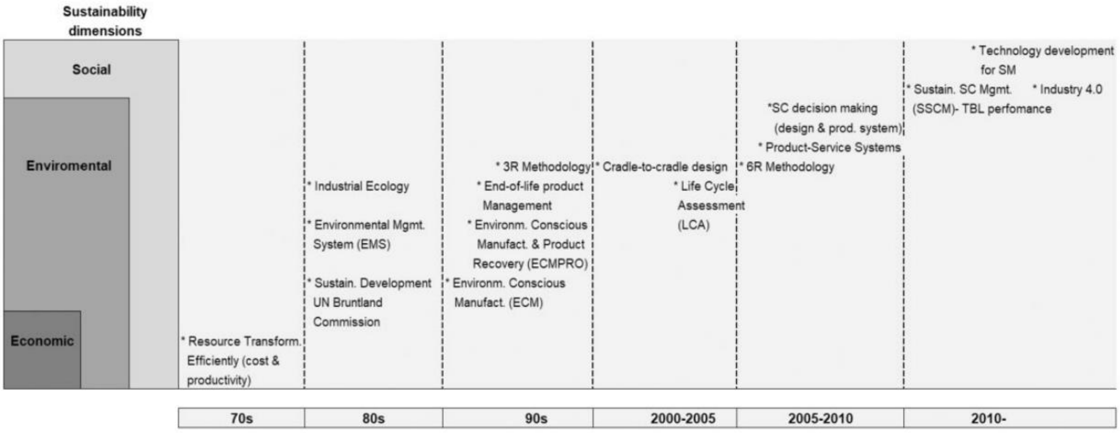

Figure (3) Sustainable manufacturing approaches over time (Sartal et al., 2020)

Sartal et al. (2020) traced different SM approaches over time, as shown in Figure 3. According to them, the first study on SM was done by Owen (1999) under Environmentally Conscious Manufacturing (ECM) by adding the concept of design from cradle to reincarnation. Then Sarkis identified the three main pillars for ECM strategy: product, process, and technology by proposing the well-recognised "R's" model, including reduction, remanufacturing, recycling, and reuse. Late, Gungor and Gupta (1999) add the "Product Recovery" concept to ECM, which becomes ECMPRO, focusing on the product development life cycle besides the manufacturing process. After that, O'Brien (1999) mentions the idea of "cost-saving" to improve the environmental performance process. Then the industrial ecology footprint concept and cradle-to-cradle design were developed. In 2003, Kaepernick, Kara and Sun addressed the idea of incorporating SM across the entire product life cycle, which led to the life cycle assessment approach (LCA). Indeed, LCA facilitates the assessment of the product life cycle (PLC) from cradle to gate to the grave. Later on, Jawahar and Bradley (2016) developed the "R's" to the "6R" model: reduce, reuse, recovery, redesign, remanufacture and recycle. Finally, technologically innovative approaches (Industry 4.0) at the system level were highlighted; for example, the idea of circular economy business models like Product-Service Systems. Moreover, Industrial Symbiosis as a concept seeks to structure industrial activity in the form of a living ecosystem in which by-products from one operation are employed as valuable raw material inputs for another (Stark et al., 2017, p. 167). Most recognisably, the new SM trend relies on the power of information that Industry 4.0 technologies such as sensors will make happen, as will be discussed later in the Industry 4.0 sections.

	-20 YEARS	- 0 - TODAY	10+ YEARS
Main goal/objects	Product	PSS	Collaboration
Expected results	End-of-pipe → proactive	Proactive → Sustainable	Sustainable → Restoratory
Main aim	Tool building	Tool implementation	Consolidated integration
Basic Approach	Singular problem approach	System approach	Holistic approach
Envisaged cost-benefit	Sustainability = cost	Sustainability = no extra value	Sustainability = business
Sustainability ambition	Environment	Environment + (social)	Environment + social capital + economic
Business mindset	Linear economy	Closing the loops	Fully circular economy
What are we changing	Improve the product	Improve the process	Improve our competencies
Decision-making level	Operational	Tactical	Strategic

Figure (4) Sustainable manufacturing focus changing from 1990 to 2030 (Stark et al., 2017, p. 109)

Another study tracked SM evolution over time (Kishawy, Hegab, & Saad, 2018). The study found that traditional, lean, and green manufacturing trends before SM and 6R. The study also affirmed that to attain the advantages of SM, it is vital to continue improving present sustainable technology and process optimisation. Carley et al. (2014) claim that SM combines four concepts: green manufacturing, lean manufacturing, total quality management, and corporate social responsibility. However, green manufacturing is sometimes used as SM. Figure 4 shows SM changes from 1990 to 2030 (Stark et al., 2017, p. 109). Nowadays, SM is a strategic approach where collaboration, TBL, CE and new competencies development are considered the key success factors aligned with most of the research, particularly in need for developing new capabilities.

VII.1 Challenges to SM:

The major challenges to SM are lack of a clear strategy, direction, effective policies, leadership, technical and engineering knowledge, transparency, change resistance, ethics, privacy, safety, human-machine interaction, decentralised management chaos, new skills and talent, huge capital investment, data management and storage, reliable SM definitions, and standards and best practices, as well as an obvious gap between academia and industry in the SM field, lack of common SPIs, lack of integration tools and methods, lack of SM integration in day-to-day activities, problems changing staff's behaviour to sustainable behaviour and poor corporate culture, poor communication, lack of resources, and operation, legal and time constraints (Tennant et al., 2013; Abubakr et al. 2020; Carley et al., 2014; Jones, Michelfelder, & Nair, 2017).

Other authors identify the requirements that should be met to ensure an effective transition to SM, for a multidisciplinary approach, analytical skills, technical skills, culture change, measuring sustainability, setting targets and motivating people to take a clear direction and sustainability mindset in day-to-day decisions to assess value creation elements based on TBL sustainability (Stark et al., 2017, p. 8). However, the selection of sustainability metrics that vary depending on manufacturing and product type and their realistic use in decision-making is a concern for business leaders (Sartal et al., 2020). The main challenge is the trade-off between environmental improvement and economic growth. Socially, the industry attracts people to manufacturing by changing the traditional stereotype of the manufacturing environment from a dirty to a high-tech workplace (Milisavljevic-Syed et al., 2020). Further, to make the relation between TBL and Industry 4.0 clear as economically justified, effective integration of new technology and ensuring social acceptance are required (Abubakr et al. 2020). The task is to find a balance between the organization's needs and the needs of its stakeholders (Szczepańska-Woszczyna & Kurowska-Pysz, 2016). Moreover, in the manufacturing sector, technical and core business managers are usually engineers responsible for creating a sustainability culture and influencing their team to practise sustainability in day-to-day activities and understand the policies essential for SM and TBL factors (Ghaly, 2011; Jones et al., 2017). In manufacturing, engineers and engineering leaders have significant roles in ensuring TBL balance and effectively leading people and technologies.

VIII. Sustainable Leadership:

Sustainability leadership is critical for future sustainable development. There is an urgent need for a new way of leadership in business to priorities future sustainability that fundamentally has a different approach from the existing one (Haan, Jansen, & Ligthart, 2016). Sustainable leadership is a new leadership approach that considerably influences a business (Burawat, 2019). According to the European Commission (2011), sustainability leadership is practically defined as the ability of leaders to represent and direct actions in the Organization to "integrate social, environmental, ethical human right and consumer concern into their business operations and core strategy in close collaboration with their stakeholders" (Beth, 2018). A study found that the leadership role in sustainable business development is critical to achieving sustainability; however, sustainable business requires a change in the current structure. Therefore, leaders need to develop new business strategies and capabilities (Szczepańska-Woszczyna & Kurowska-Pysz, 2016). Another study found a direct relationship between the sustainable project and leadership competencies, where having the required leadership competencies is important to reach sustainability (Tabassi et al., 2016). Generally, a leader must build an intrapreneurship culture to boost employees' innovativeness, identify customers' values, be aware of the sustainability market, integrate TBL within Organizational activities, provide transparency, and manage sustainable performance indicators (Alison, 2020).

Many believe that sustainability is all about a social movement; thus, if an individual focuses on starting a movement, the person should have the courage to follow and show others how to follow (Sivers, 2010). A recent paper believes that attaining SDGs requires the kind of leader who can create and manage social movement (Rant, 2020). That paper studies Sadhguru' s behaviour, a well-known Indian author and social influencer who cares about sustainability and has inspired and transformed many. The study found that achieving a sustainable future requires the highest-level leaders concerned about the well-being of everyone and nature. The study recommends the following during sustainable transformation: the only skill required is the art of self and social management. It is experience-based and action-oriented, not concept-based, trust-based or authority-based, and requires leaders to develop self-awareness, not critical thinking.

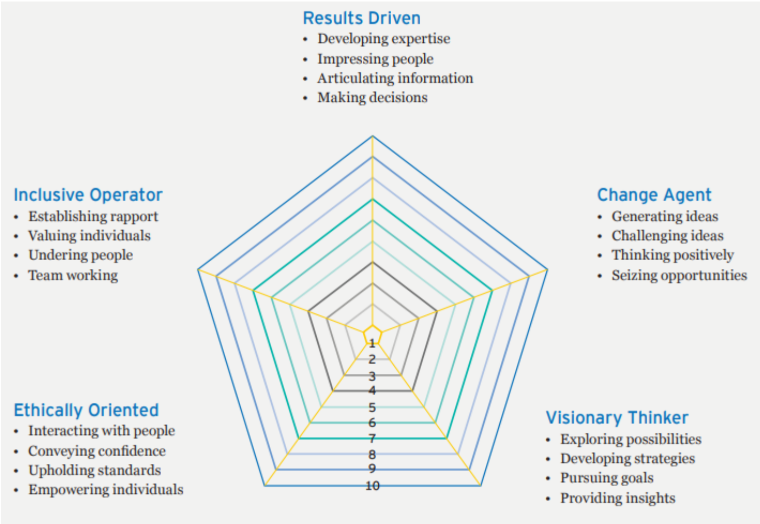

Figure (5) Behavioural competency model (Beth, 2018)

A behavioural competency model is shown in Figure 5. It is a model for sustainability leadership based on mixed-method research supported by Ernst & Young and others and published by the University of Cambridge identifies the leadership competencies for successful sustainability leaders (Beth, 2018). Generally, the study found in the literature that the most important sustainable leadership competencies are valuing individuals, impressing people, action-taking, embracing change, convincing people, directing people, developing expertise, building trust, innovative ability, challenging ideas, networking and interaction with people, self-confidence, interdisciplinary understanding and exploring possibilities. The result determines the five main characteristics of sustainability leaders: being results-driven, a change agent, visionary thinker, inclusive operator and ethically oriented. Moreover, the study shows that long working experience and high-level qualifications positively impact leaders' sustainability behaviours. However, that might differ depending on sectors or groups due to various factors such as development opportunities or Organizational culture. For instance, the study noted that geographical location shows different stages of sustainability development. Other writers, for example, confirm that factors such as education, cross-functional background, international assignment experience and position tenure influence sustainability levels (Haan, Jansen, & Ligthart, 2016). Most significant, in the previous model, the author acknowledges that the sustainability competencies change over time; therefore, they need to be reviewed regularly every five years. The author asked for the model to be studied in a larger sample size for quality analysis. The research potentially determines the low participation of the manufacturing sector

(7%) and that the majority of participants were postgraduates from the EU and the USA. In addition, Hind, Wilson, and Lenssen (2009) developed a leadership competency model for sustainable business utilising a mixed-method approach — questionnaires and semi-structured interviews — studying managers from European companies from different disciplines working in different sectors. The study found that the five significant reflexive competencies are system thinking, embracing diversity, managing risk, sense of balance, global and local interest, effective communication, and emotional awareness. It is worth mentioning that they built the study based on Wilson and Holton's (2003) six core competencies for responsible leaders: being open to new ideas, aware of everyone's role, and building partnerships in and out and engaging stakeholders, respecting stakeholders diversity and having a strategic view. Another study by Burawat (2019) conducted a mixed-method approach questionnaire survey and in-depth interviews with manufacturing SME managers. The study found that transformational and sustainability leadership are suitable for manufacturing. The difference is that transformational leadership relies more on a leader's charisma to impact the followers, whereas sustainability leadership focuses on motivating individual sustainable values. The study claims that one leadership style is more proper for the accomplishment of lean production.

IX. Industry 4.0 and Sustainability:

SSM is the ultimate goal of the new industrial revolution. Effective implementation of digital technologies helps improving efficiency, performance, resilience, flexibility, and sustainability. Many authors believe that Industry 4.0 will help leaders to balance TBL sustainability (Burawat, 2019). However, understanding SM and Industry 4.0 requires more in-depth analysis and empirical studies because it is now far from reality (Demartini, Evans, & Tonelli, 2019). "Industry 4.0 and sustainability are considered major trends in the current production system" (de Sousa Jabbour, Jabbour, Foropon, & Godinho Filho, 2018). Both concepts have a considerable influence on the manufacturing industry. In todays' society, manufacturing activities are highly connected to all aspects of human life. Many authors affirm the necessity for more endeavours to overcome TBL sustainability challenges and bridge the gap between academia and industry regarding SM (Abubakr et al., 2020). Further, many authors highlighted a considerable research gap in understanding SSM challenges and finding solutions (Antikainen, Uusitalo, & Kivikytö-Reponen, 2018).

Numerous authors believe that Industry 4.0 will enhance SM extremely. Many studies show a great opportunity for Industry 4.0 technologies to create comprehensive sustainable industrial value and enable a circular economy (Milisavljevic-Syed et al., 2020). Sartal et al. (2020) highlight the positive impact of Industry 4.0 technologies on SM. In the frequently cited paper "Opportunities of Sustainable Manufacturing in Industry 4.0 ", the authors present a state-of-art review showing the great opportunity of Industry 4.0 as an enabler of SM in two different contexts (Stock & Seliger, 2016). Macro sustainability, Industry 4.0 innovate sustainable business models, enhances value creation networks through a circular economy and industrial symbiosis. That will boost external coordination and collaboration to achieve 6R. Leaders have to lead beyond their Organizations' edges. Micro sustainability retrofitting equipment is a simple and cost-effective method of retrofitting current production facilities with sensor and actuator systems and the associated control logic to solve the heterogeneity of factory equipment. For humans, virtual reality training and simulation increase creativity, reduce risk and enhance learning. Industry 4.0 enables comprehensive resources efficiency and decentralised decisions making ensuring more agility. For processes, it enables more efficient processes, material selection and optimum design. Finally, in regard to the product life cycle, the product can be tracked via radio-frequency identification (RFID), which enables a closed-loop economy.

Integrating Industry 4.0 with the current manufacturing paradigm to reshape production and consumption to ensure SM is promising, as de Sousa Jabbour, Jabbour, Foropon, and Godinho Filho (2018) identify 11 critical success factors in SSM: leadership, Organizational change readiness, top management commitment, strategic alignment, training and capacity building, empowerment, effective team working, Organizational culture, effective communication, project management and national culture and regional differences. However, the potential research is based on a theoretical approach and focuses only on green manufacturing (environment dimension), not TBL. Another study provides empirical evidence on how two different UK companies hugely benefit from digital technology to enhance sustainability (Demartini, Evans, & Tonelli, 2019). The authors identify three competitive dismissions for Industry 4.0 technologies: productivity, sustainability, and resilience. In detail, Industry 4.0 technologies help lower disruption, enhance efficiency, reduce carbon emissions, cut cost, improve machine lifetime and customer satisfaction. Authors find that the transition to SSM requires Organizations to embrace change, plan for sustainability, innovate new sustainable business models, raise awareness, adapt to a circular economy, reduce emissions, enhance energy efficiency, use new technologies, enhance performance through effective resources management. However, the previous study demonstrates that sustainability is defined as an environmental component, ignoring social and economic aspects. There is a shortcoming in understanding SM in terms of the TBL dimensions. However, one of the main social sustainability advantages of Industry 4.0 in manufacturing is the reduction of musculoskeletal disorders through human-centred automation solutions. Therefore improve employees' health and safety, which are the key social and economic sustainability factors, and reduce an economic loss (Stark et al., 2017). More advantages will be uncovered in the future, since the technology is early, particularly regarding social aspects, the most controversial side.

SSM studies have explored three challenges of Industry 4.0 and SM together. Technical complexity and lack of collaboration between different parties such as academia, government, and industry, continuous learning and support for entrepreneurial culture are the main obstacles to SSM

(Demartini, Evans, & Tonelli, 2019). The other study identified five main barriers to SSM financial: measure investment risk, profitability; structural: unclear responsibility and lack of information transparency; operational: supply chain and infrastructure; attitudinal: risk avoidance and perceptiveness of sustainability; and technological: design and integration (Antikainen, Uusitalo, & Kivikytö-Reponen, 2018). The third study revealed that new competencies requirements and stakeholders' collaboration are the main challenges to SSM (Antikainen, Uusitalo, & Kivikytö-Reponen, 2018). Leaders' decision making and risk-taking are considered key to adopting SSM. For example, the trade-off between cost and time presents challenges for leaders' decision making. In other words, fast-adoption costs are higher than late adoption costs; however, fast-adoption advantages are incredible. Bavestrelli identified 30 different business dilemmas in digital transformation, comparing short-term and long-term gains (Milisavljevic-Syed et al., 2020). Leaders' decision-making would be a turning point and considerably impact Organizational survival in the digital age.

X. Conclusion and Implications.

X.1 Conclusions:

Engineers show different perspectives of leadership due to their distinctive identities. Farr and Brazil (2009) argued that most traditional leadership models lack consideration of technical quality; therefore, more research is essential to understand how engineers lead in technology-based companies. It is unfair to measure engineering leadership against traditional leadership theories where principles have been set by researchers not familiar with the engineering profession's patterns (Rottmann et al., 2014). According to Gurdjiian and Lane (2014), determining the reasons behind the failure of leadership development studies is overlooking the context and leaders' mindset (Almalki et al., 2016). However, most engineering leadership research focused on entry-level engineers to equip them with essential non-technical skills. Moreover, there is a clear lack of empirical studies in the field, resulting in a lack of understanding of "engineering leadership" and its definition and roles. Despite that, professional experience is pivotal to developing engineering leadership and identity (Choe et al., 2019).

Further, in the majority of the engineering leadership studies related to population size, no general agreement of what engineering leadership is, use of different leadership models, and investigation of different leadership levels, sectors, and geographical areas because most of the studies have been conducted in Canada and the USA. Most of them focus on education programmes. Most engineering leadership models were based on universities' engineering leadership programmes in countries that developed these programmes and were built theoretically without practical validation by engineers' experiences (Schell, 2017). Although education starts addressing non-technical competencies in engineering education, there is a lack of evidence on whether these programmes meet the industry needs

(Handley et al., 2016). Hence, many scholars and professionals demand that the collaboration between academia and industry be enhanced to bridge the engineers' leadership competencies (Veile et al., 2019).

Sustainability is one of the fundamental goals of Industry 4.0. Although smart SM and Industry 4.0 have drawn the interest of the science community and industry in recent years, attempts to analyse the state of the art of these two emerging paradigms still lack in the literature (Sartal et al., 2020). There is a consensus demanding new leadership competencies for the digital era because of a substantial shift in politics, economy, society and technology (PEST) elements and pressure for business TBL sustainability. However, lack of leadership is considered one of the main issues in driving Industry 4.0 towards sustainability. Many authors assert a lack of empirical studies on sustainability and digital leadership, which need more profound research since they are early (Rossini et al., 2019). In the context of manufacturing, Larjovuori et al. (2018) state that "The role of leadership in digitalization in the manufacturing industries is an issue that would need its study". Indeed, the impact of engineering leadership on the adoption of SSM is still unknown (Rossini, et al., 2019). Engineering and technology are central to innovation and sustainable transformation. However, the diversification of sustainability and its technical problem-solving demand that engineers concentrate on soft skills and leadership development to avoid huge losses in the future (Almalki et al., 2016). However, during 13 years of practical experience in the engineering environment, researchers have observed that innovation, collaboration, and process optimisation are intrinsic to the engineers' mindset. It has been noted that most of the sustainability and Industry 4.0 leadership competencies are close to the engineers' identity. Engineers are problem solvers, innovators, change agents, and lifelong learners; they have an advantage for guiding the coming industrial revolution towards sustainability. However, collaboration, sharing knowledge, and seeking help are naturally part of engineers. As no one knows everything, that is not necessarily associated with effective communication because their focus is on solving technical problems, not people problems (Schell, 2017).

Avoiding many different leadership models majority shares the same ideas with slight differences. However, these models focus on different aspects of leadership, ranging from style to competencies to roles to results. There is an agreement about the roles of leadership 4.0; however, there is no clear idea about how to apply it in the real world and the roles of different leadership positions. All the previous studies have not investigated the leadership 4.0 characteristics of engineering leaders or sustainability. Moreover, none of these studies has been conducted in Saudi Arabia.

Further, numerous leadership competencies have been found. A leader cannot have all competencies for success. Studies idealise the leadership role. However, study something real, practical, and applicable. Notably, situational, transformational, transactional, and authentic leadership styles appeared more than others. However, studies were recommending one style, while other studies recommended a mix of different styles. Others believed that the future needs a new leadership approach beyond existing ones. All studies have different points of view and make the difference based on time, culture. However, consider significant factors in studying leadership competencies. However, innovation and change are the most frequently repeated requirements in leadership literature for sustainability and the digital age, diversity, inclusivity, capability, strategic thinking, and Organizational culture.

X.2 Implications:

Engineering leadership is a new research field in academia. This study will contribute to other studies concerned with leadership in the context of engineering, sustainability, and Industry 4.0. It might be a starting point for many researchers who want to investigate the role of the engineer as a leader in the industrial 4.0 revolution and sustainable manufacturing (SM). Also, it contributes to bridge the gap between academia and the industry by understanding engineering leaders' roles and responsibilities in SSM. Moreover, to investigate leaders challenges in manufacturing industry in the transition to SSM. The results of the study will help industry to recruit effective leaders and improve leadership programme development. It will boost the engineering curriculum to prepare future engineers with the required leadership competencies required by the industry to overcome obstacles during the new industrial revolution. Future engineers have to study and exercise leadership and business skills before graduating, owing to the significance of these skills (Almalki et al., 2016). Further, the study will focus on the manufacturing sector owing to its high value in modern society, and transition to SM will potentially contribute to mitigating global challenges and ensure a sustainable future. Significantly, the manufacturing industry is the main sector associated with the industrial revolution and dominated by engineering and technical professions. By having a clear understanding of effective engineering leaders' competencies associated with the successful transition to SSM, the current slow pace of Industry 4.0 technologies' adoption would improve, since the lack of effective leadership is the main challenge to doing so.

The study is based on a multidisciplinary approach that combines three different disciplines, namely engineering leadership, sustainability leadership and leadership 4.0. The study's novelty lays in merging all these different leadership approaches together in one study. It is the first time according to the researcher's knowledge that such research has been dedicated to investigating the role of engineering leaders in SSM. Furthermore, the current study follows a socio-technical approach to bridge the gap between social science and engineering concerns. It is possible that TBL sustainability will play an important role to bridge the gap between the social science and engineering knowledge, since it is presumably a common interest for both. At the same time, sustainable development relies on technological innovation as innovation is the heart of world growth. According to many publications, innovation is the main key to tackling and ensuring decent life on our planet. Consequently, engineers as problem solvers and innovative thinkers have an important role in leading innovation towards sustainability. However, solving these problems requires more than technical ability and analytical skills

(Paul et al., 2018). In simple terms, technical innovation is associated with needs and opportunity (National Academy of Engineering, 2004); SM is a need and Industry 4.0 is an opportunity. Moreover, global challenges require technological innovation and visionary leadership (Schell, 2017). Despite strategic thinking being an important competency for Industry 4.0 (Guzmán, Muschard, Gerolamo, Kohl, & Rozenfeld, 2020), engineers have lack of vision associated with the lack of training engineers have for visionary leadership (Almalki et al., 2016). Some authors believe that leadership is about envisioning and shaping the future (Haan, Jansen, & Ligthart, 2016). Therefore, the current research will enhance engineering leaders' foresight, since Industry 4.0 and sustainability are future trends that require foresight. Finally, the majority of manufacturing companies currently are in transition, giving this research historical significance. Conducting research at a time when the world is on the verge of a new industrial revolution is rarely able to be repeated.

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