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European Union Conceptualisation of Industry 5.0: Opportunities and Challenges for Transdisciplinary Engineering

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Abstract. 'Industry 5.0' has been used as a term to describe alternative visions of the future of industry. Recently, a European Union Research and Innovation Policy Brief used the label Industry 5.0 to define a vision which is not driven by a new technology, but by a changed perception of value founded on human-centricity, sustainability and resilience. Transdisciplinary Engineering (TE) seeks to integrate knowledge and understanding to reduce the negative effect of engineering innovation on the environment and society, thus there likely exists a natural synergy between Industry 5.0 and TE. Consequently, in this paper we seek to understand what the opportunities and challenges of the emergence of Industry 5.0 might be for the field of TE now and in the future. A workshop involving multidisciplinary experts was convened to brainstorm and then explore perceptions. Opportunities include new research areas and potential access to funding. Challenges center on the extent that TE could, or should, align itself with Industry 5.0, and the lack of consensus around definitions of TE. Conclusions find that to attract funding, the community should clearly articulate how TE differs from complimentary and overlapping fields such as interdisciplinarity and systems engineering.

Keywords. Transdisciplinary Engineering, Industry 5.0, Future of engineering

Introduction

The term Industry 4.0 was coined in Germany in 2011. Since then, it has become widely used to depict a technological revolution in which connected devices and artificial intelligence bring about improved industrial efficiency [1]. Despite the transition to Industry 4.0 still being very much on-going, within the academic and non-academic literature, a new era is being heralded - Industry 5.0.

Within the academic literature the term Industry 5.0 first emerged in 2016. Since this point alternative technological visions of the future of industry have been proposed. More recently however, an EU concept for Industry 5.0 has focused, not towards any particular new technology, but towards a new perspective in which industry is asked to look beyond jobs and growth and appreciate a wider set of environmental and societal values [2].

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Like Industry 5.0, Transdisciplinary Engineering (TE) is considered to be an emerging field [3]. The practice of TE seeks to reduce the negative impact of engineering innovation on the environment and society by undertaking a holistic approach and the integration of knowledge and understanding from natural and social science disciplines and non-academic stakeholders [4]. At first sight, there appears to be an obvious synergy between TE and the EU concept for Industry 5.0, with both looking to go beyond a single disciplinary lens.

The aim of the work presented in this paper is two-fold. First to introduce the community to the EU conceptualisation of Industry 5.0, second to provide a preliminary exploration of the implications of the emergence of this paradigm for the field of TE. Within this study we present a workshop involving five participants with expertise across TE and key elements underpinning value-based Industry 5.0: economics, environment, and society. The research question addressed is: What are the opportunities and challenges of the emergence of EU concept of Industry 5.0 for the field of TE? Addressing this question is significant and may help to inform and shape the direction of the Society and the practice of Transdisciplinary Engineering.

The paper is structured as follows. First, a background including the different concepts of Industry 5.0 (Section 1). The method used in the workshop is described in detail (Section 2). The results are presented and discussed (Section 3). Finally, conclusions are formulated (Section 4), and future work identified (Section 5).

1. Background

The word 'revolution' is applied to a period of radical change to economic system and social structures, brought about by new technologies or ways in which the world is perceived [5]. Within industry several technological based revolutions have fundamentally changed the economic and social structures (Figure 1). The first revolution (1760-1840) saw steam power enabling mechanised production. The second (late 19th century) brought a transition from steam to electric and in doing so a move towards mass production. The third (1960s), often referred to as the computer or digital revolution, heralded the deployment of mainframe computing (1960s), personal computing (1970s and 80s) and the internet (1990s) [1, 5, 6].

The fourth revolution (21st century), often termed 'Industry 4.0', is characterised as a movement towards connected systems powered by data and machine learning [1, 5, 6]. Although there is no definitive list there are various technologies, of differing levels of maturity, which are considered to fall under the banner of Industry 4.0 including robotics, 3D printing, artificial intelligence (AI), the internet of things (IoT), autonomous vehicles, quantum computing, and materials science [7]. Where they are considered to differ from 3rd revolution technologies is that Industry 4.0 technologies blur the lines between the physical, digital and biological domains [5].

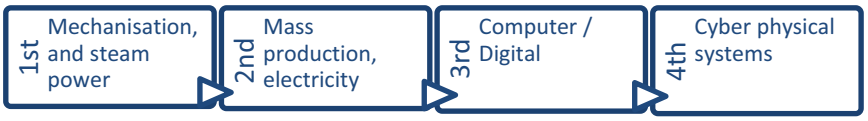

Figure 1. Historic Industrial Revolutions.

The value of a transition towards industrial digital technologies (IDT) is considered to be immense. The World Economic Forum in association with Accenture, estimated that globally, for the decade from 2016, there is an estimated $100 trillion of value for both industry and society to be realised through digital transformation [8]. Specific to UK manufacturing, the Made Smarter Review (2017), estimates that over the same period £455 billion of value would be realised through the early adoption of digital technologies within the sector [7]. Although governments around the world are actively implementing initiatives to support digital transformation there is growing discourse which suggests that Industry 4.0 will not be the final iteration and that another paradigm, Industry 5.0, is already on its way.

Within the literature concepts of Industry 5.0 can be broadly categorized into three visions. The first two take a more technological stance. That is, as in previous industrial revolutions the introduction of new technologies brings about disruptive change. The third vision for Industry 5.0 is not a technological revolution in the traditional sense, but a change in perception which encourages industry to look beyond the economic to become resilient providers of prosperity [2].

- Industry 5.0 (vision 1) – Bionics / Synthetic Biology. Bionics / synthetic biology is defined as the imitation and abstraction of inventions of nature [9, 10]. Proponents consider these technologies to be potentially transformational and amongst other things could change how we source materials, what we eat, and even how we grow food.
- Industry 5.0 (vision 2) – Human–Robot Working. The second and widely supported vision of the future asserts that whereas Industry 4.0 is about connected devices and automation, the next revolution will be about humans and machines working collaboratively. For example, 'cobots' learn how their human counterparts work and support them in their task predicting when the human worker needs a part and delivering that part to them at the right time [10, 11]. Whether this is a revolution, or an evolution of Industry 4.0 remains under debate [12].
- Industry 5.0 (vision 3) – Value Based. Industry 4.0 is primarily a techno-economic vision [2, 13, 14]. Although discussions within the literature are not completely devoid of societal and environmental considerations, generally these elements are approached from a consequential perspective [15]. That is, what are the environmental and societal benefits and challenges associated with the adoption of new technologies? Critiques consider that in the current context of climate change and social tensions the current model, with its focus on profit and growth, is not fit for purpose. The alternative vision of Industry 5.0 proposed does not represent a technological leap forward but instead sets Industry 4.0 in a broader context where technology is to be capitalised on, and

human-centricity, sustainability and resilience become the driving force. Rather than a revolution it is considered an evolution which complements and extends Industry 4.0 [16].

Although there was some prior discussion [13, 17], the profile of value-based Industry 5.0 has been raised through an EU Research and Innovation Policy Brief [2]. Supporting three of the Commission's priorities "An economy that works for people", "European Green Deal" and "Europe fit for the digital age", it has been the subject of a high-level expert group advising the Commission on research and innovation policy and is already being woven into policy initiatives. Despite its recent publication academic papers referencing this document are starting to be seen [15, 18-20].

When introducing value-based Industry 5.0 the EU identifies several challenges and respective enablers. Amongst these it is acknowledged that there is the need for transdisciplinarity (TD) and the integration of different research disciplines - life sciences, engineering, social sciences and humanities [13]. Despite this specific identification of the need for TD to enable Industry 5.0, to date there have been no attempts to capture the opportunities and challenges this might bring for the TE community and the practice of TE. This study aims to address this gap.

2. Method

The research question posed within this study was: What are the opportunities and challenges of the emergence of EU concept of Industry 5.0 for the field of TE? In addressing this question an on-line workshop was undertaken. A workshop is a commonly used research method in which a group of people come together to learn, acquire new knowledge, perform creative problem-solving, or innovate [21, 22].

2.1. Workshop Participants

Although workshops may be run for a variety of reasons common to all is that they bring together participants from different backgrounds [23]. Within this study participants were selected to bring together expertise in TE and across the key elements underpinning value-based Industry 5.0: economics, environment, and society (Table 1).

Table 1. Workshop participants expertise.

	TE	Economics	Environment	Society
Participant 1	X	X		X
Participant 2	X	X	X	X
Participant 3	X	X		X
Participant 4				X
Participant 5		X		

In terms of understanding of TE, two of the participants are Board members of the ISTE (Participants 1 & 2), whilst a third is a Reader in Transdisciplinary Digital Manufacturing (Participant 3). With regards to discipline and research focus the group included both engineering and social scientists, from the research fields of macroeconomics (Participant 5), human factors (Participants 3 & 4), and whole life value costing (Participants 1, 2 & 3).

2.2. Workshop Process

The workshop was undertaken during March 2022, via the Microsoft Teams application, and lasted 90 mins. Given the challenge in ensuring that participants fully engage with any pre-work the workshop was designed to be self-contained, that is, it did not require any study prior to or following the session [24]. The process used in the workshop is as follows:

- The background to the study was provided including: an introduction to Transdisciplinary Engineering, the research question, and the workshop process.
- Although all participants had each had prior exposure to the value driven based EU's Industry 5.0 concept, to ensure to refresh and focus their attention they were invited to reread the EU Research and Innovation Policy Brief [2].
- The participants were asked to individually brainstorm [25, 26] the opportunities and challenges that the emergence of value driving the EU concept of Industry 5.0 has for the field of TE.
- The participants were brought together to explore the insights generated by the brainstorming. The discussion was transcribed and recorded via the Microsoft Teams Application.

3. Results and Discussion

The brainstorming session, hosted on Slido (https://www.sli.do/), generated thirty-three insights (Table 2).

Table 2. What opportunities and challenges does the emergence of value-based Industry 5.0 have for the field of Transdisciplinary Engineering? Brainstorming results.

Number:	Detail
I1	Who should be driving this beyond the boundary of companies, countries.
I2	Challenge: potential counter effects when we analyse a topic. For instance, the view of a psychologist analysing the impact of digitalisation on workers could be contradictory/opposite to the view of an economist/engineer, etc... which always poses a challenge for agreements.
I3	Employees of the future - millennials - responsible companies and would take a pay cut - this speaks volumes regarding mindset and ways of working.
I4	Societal goals still focused on prosperity - could be misleading.
I5	What profiles of next generation workers do we need?
I6	60% of digital skills were on non-technical - e.g. openness - aligns well with TD.
I7	A more human-centric in the context of a transdisciplinary view, helps to have a multidimensional view of the problem. In a specific problem, for instance, the impact of digitalisation on the labour market, or in the anxiety of workers, wellbeing, etc...
I8	How to encourage more stakeholders' driven innovation from digital tech?
I9	Again looked at digital and focused on the 'process' 'technical' e.g.. safety - robots in hostile environments.
I10	Wider than manufacturing - which reflects a transformation on businesses as manufacturing is not just the traditional production.
I11	The six categories are technical so saying the right words BUT still not necessarily getting it.
I12	Challenge: find the incentives and benefits for the industrial partners/firms to join this view. While it is an interesting and desirable view for academics, may not necessarily be cost-effective yet for firms.
I13	Value is subjective and vary with context for different people, how do we define value for Industry 5.0? What is the unit of analysis?
I14	Clear alignment with societal benefit which maps with TE focus on societal benefit.

I15	New avenues for collaboration across disciplines when we look at technology serving people.
I16	Claims innovation will come from digital tools - the wording is still quite technical.
I17	Talks about impact on society as key.
I18	TE may become consumed in I5.0.
I19	EU doc has a wider reach than academic papers.
I20	I5.0 integrates to other EU initiatives / priorities.
I21	Value driven I5.0 is only one future - what if a tech vision becomes dominant?
I22	May give access to more research funding.
I23	EU have already identified the link between Industry 5.0 and TE. Pushing an open door.
I24	TE courses or add as an element to existing courses.
I25	EU centric - ISTE are international.
I26	TE still emerging. Still debating the definition.
I27	More publicity might help to attract more member to the ISTE
I28	I5.0 talks about transdisciplinarity, but ISTE is TE. Is the community clear about the difference / is there a difference?
I29	Better/worse approaches to safety possible beyond those described in paper to the extent they empower workers rather than constrain them in maintaining their own safety. View in paper is a bit naïve and doesn't reflect modern accidents and their causes in an industrialised economy. (i.e., conjunction of safety science, Industry 5.0, engineering etc.).
I30	Skills issue may not so much be lack of 'digital skills' but rather ability to understand and work in a digitalised setting (view may be overly technical at present)
I31	Can have more resilient and efficient supply chains, think this is less about technology and more about business models that depend on keeping secrets from suppliers/customers. So needs wider paradigmatic shift perhaps.
I32	All this seems to ask a lot of the worker, what is being asked of the employer?
I33	In general, is too much being loaded onto I5.0?

Analysis of the output of the workshop brings together the insights on the opportunities and challenges from the brainstorm (Table 2) and the group discussion.

3.1. Opportunities

The participants considered there to be an alignment between the EU vision of Industry 5.0 and transdisciplinarity (I6, I7, I14, I17). Highlighted by Participant 1 within the discussion was the top-down value driven approach of Industry 5.0, and its alignment to the seminal work of Jantsch, who proposed that TD should start with understanding societal value [27].

Given the level of integration of Industry 5.0 with wider EU priorities and initiatives the participants considered there to be an opportunity both in terms of identifying new research areas and potential funding (I20 & I22). It was anticipated that there would be 'new avenues for collaboration across disciplines' (I15). With potentially greater reach than academic papers (I19), new members might be attracted to the community (I27). That the alignment had been acknowledged by the EU in their own documentation it was considered that the community would be 'pushing an open door' (I23) when it came to justifying a need for TE approaches.

The participants identified research gaps in several areas including value models, skills, and operationalising theoretical paradigms:

- **Value Models***:* Value is subjective and transcends the traditional boundaries of organisation and industry (I13). Research is required to develop universal models which enable the calculation of value in different contexts and with different bounds (I1, I2 & I12).

- **Skills:** In the face of these new digital technologies, the participants postulated that it may not be a lack of technical skills (e.g., computer programming) but rather the ability to function effectively within a digital environment. (I30). Research is required to understand the profile of the next generation of workers (I5) and how this could be delivered within an education setting (I24)
- **Operationalising Theoretical Concepts:** Participant 4 introduced the concept of Safety-2 [28], in which the focus is taken from looking at what the human did wrong which resulted in an issue, to what the human did right to prevent incidents occurring. It was proposed that the Industry 5.0 document promotes an attitude that replacing human beings with robots will address safety issues. However, modern views of safety are around empowering people to be proactive within a widespread safety culture rather than excluding or disempowering them. There are opportunities for modern and enlightened safety approaches to be woven into Industry 5.0 and might need TE to achieve.

3.2. Challenges

Although the participants saw opportunities, they also acknowledge there to be challenges. The core of these discussions focused on the extent that TE could, or should, align itself with Industry 5.0. and the lack of consensus around definitions of TE.

The EU document places value-based Industry 5.0 firmly on the current EU research agenda. The participants recognised the potential opportunities it brings for TE researchers. However, it was also acknowledged that whereas value-based Industry 5.0 is an EU concept, the TE community is international (I25). As such although Industry 5.0 might bring research opportunities for some, these opportunities may not be open to all.

The EU documentation was considered to have a wider reach than academic papers (I19), although beneficial, there is also the risk that in aligning too closely with this vision as TE may become consumed, being seen merely as a method used in Industry 5.0 (I18). Conversely, what would the implications be if value-based Industry 5.0 fails to gain traction and another more technology-based paradigm becomes dominant (I21). As stated by Participant 5 during the discussions 'in economics we talk about diversifying our portfolio'.

Although the participants acknowledged an alignment between Industry 5.0 and societal benefit which is espoused in the seminal work of Jantsch [27], the participants questioned whether the messaging within the EU document was clear. For example, the aim is for societal value, but this can also include 'prosperity' (I4). There were also concerns that the document was still technically focused (I16) and that perhaps wider paradigmatic shift was required (I31).

In terms of definitions the EU acknowledges the need for 'transdisciplinarity'. It does not specifically request TE (I28). Two points were raised during discussions: Do the EU and the TE community have the same definition of transdisciplinarity? (Participant 3), and is there a difference between transdisciplinarity and the practice of the TE? (Participant 2).

4. Conclusion

The EU concept of Industry 5.0 was published in 2021. Rather than a revolution, it is considered an evolution which complements and extends Industry 4.0. Within this work we start to explore the opportunities and challenges the emergence of this concept has for the field of Transdisciplinary Engineering.

The results of a multidisciplinary workshop identified several opportunities and challenges. There was a perception amongst the participants that because the concept integrates within EU policy this would potentially result in research opportunities for those practicing TE. A recent podcast by the acting head of Industry 5.0 at the European Commission's Directorate-General for Research and Innovation supports the view that there will be increased funding of Industry 5.0 stating that they are moving on from developing the concept of Industry 5.0 and will begin the implementation and roll out. With this comes a host of initiatives (awards, conferences, training) aimed at developing the framework and raising awareness [16]. What his comments do not support is that this funding will be directed towards supporting TE research.

Within the EU's own documentation, it acknowledges a need for transdisciplinarity. However, as identified by the participants, their definition of transdisciplinarity may be different from that held within the TE community. Indeed, as highlighted in the work of Lattanzio et, al., even within the community there is not a single definition, but rather a landscape containing weak and strong conceptualisations [29]. To respond to funding calls having a common understanding, or at least of a way of articulating similarities and differences will be key.

Building on this, the Industry 5.0 concept has a broad remit which cannot be completely contained within the context of engineering. Comments by the acting head of the EU initiative highlight the need to broaden the focus of Industry 5.0 even more if it is to be embedded. For example, there needs to be research on employment policy and taxation systems. The questions for the TE community are: why is a Transdisciplinary Engineering proposal a better fit for funding than a more generic Transdisciplinary proposal? What is it that differentiates what is done within TE to what is done within other transdisciplinary communities such as the Swiss Academies of Arts and Sciences Network for Transdisciplinary Researchers [30]? Being able to articulate the added value of TE will be a significant factor for success.

Currently the future of industry is unknown. The EU concept of Industry 5.0 may win out. Alternatively, another paradigm may be more successful. Engaging with the EU's Industry 5.0 initiative may, or may not, lead to opportunities for TE research. However, not being part of the conversation is a risk. As pointed out by one of the participants there are a number of overlapping fields to TE, if we do not engage, we might find that 'someone else has eaten our breakfast'.

5. Future Work

This work offers an initial exploration. The opportunities and challenges which are identified will be influenced by the expertise and context of the participants. For deeper analysis, further studies with different participants are required.

Notwithstanding, the results of this study expect there to be potential research funding opportunities associated with the emerging EU Industry 5.0 paradigm. To

prepare for future success immediate efforts are required to define TE and capture the differences between TE and other overlapping fields.

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