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Net Positive Manufacturing: A Restoring, Self-healing and Regenerative Approach to Future Industrial Development

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Abstract

In today's consumer driven society, manufacturers can exert unparalleled environmental, economic and societal influence, either for good or bad. The recent uncontrolled industrial growth within both developed and developing countries has resulted in significant damage to the environment in an attempt to sustain economic growth at any cost. In response, global sustainability initiatives, due to inherent and inevitable economic barriers, have often adopted a *'Less Bad'* approach, which is based on meeting the demands of regional and national legislation and incremental efficiency measures. The benefits of such initiatives are now perceived as too small and too slow to tackle the needs of tomorrow. In this context, when *'Less Bad is Not Good Enough!'*, what should our aspirations and goals be beyond the scope of current sustainability strategies, methods, tools and technologies ? At the heart of the proposed paradigm shift through *'Net Positive Manufacturing'* is the ability of manufacturing businesses to adopt a restoring, self-healing, and regenerative approach and simply to put back more into society and the environment than what they take out. This radically novel vision for future industrial development presents a number of methodical, organisational, technological, as well as social and ethical research challenges which are explored in this paper.

Peer-review under responsibility of the scientific committee of the 15th Global Conference on Sustainable Manufacturing.

Keywords: Sustinable Manufacturing ; Sustainable Manufacturing; Resource Efficiency; Regenerative Self-healing Industrial Systems

1. Introduction

Our society and environment are changing at an unprecedented rate. There is a growing body of evidence which increasingly points to serious and irreversible ecological consequences if current unsustainable manufacturing

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practices and consumption patterns continue. Fortunately, the United Nations Environmental Programmed (UNEP) study entitled 'Global Environmental Outlook (GEO-6): Regional Assessments' indicates that it is not too late to reverse the worst impacts if consumers, industry and governments act now, citing the need for "enhancing sustainable consumption and production to reduce environmental pressures by addressing drivers associated with manufacturing processes and consumer demand"[1].

In this context, the escalating scale of the challenge ahead is becoming clear through a deeper understanding of the biophysical constraints of our planet. It has been estimated that by 2050 the global population will have risen to over 9 billion [2] and that greenhouse gas (GHG) emissions will have increased by over 50%, driven primarily by a projected 80% rise in global energy demand [3]. It has also been predicted that current reserves of copper, zinc, lead, nickel, tin, silver, and gold will almost be depleted by 2050 [4], and a study by Gardner-Outlaw and Engleman [5] states that by 2050 up to 4 billion people could live in areas facing water scarcity or stress. According to WWF and Global Footprint Network, by August 2 of this year (2017) humanity had used more from Nature than our planet can renew in the whole year. This means that the equivalent of 1.7 planets would be required to produce enough to meet humanity's needs at current consumption rates [6].

The impact of manufacturing activities has, therefore, become an area of great focus and concern at all levels, from public through to industry, government and NGOs. A range of initiatives, investments and regulations have been put in place to mitigate the effects of manufacturing activities, however, at present these are at best just managing to slow down the rapidly intensifying environmental impact, as opposed to eliminating or reversing the damages caused, as depicted in Fig. 1.

The author's previously reported research [7] proposed a scenario planning approach to understand the challenges and opportunities which lie ahead for future industrial development. In this research, by considering both quantitative and qualitative factors, a number of 'SMART Manufacturing Scenarios' have been defined to systematically identify the most influential factors affecting industry by 2050, and to mitigate against critical changes and disturbances through informed long term strategic planning activities [7].

The work reported in this paper aims to build upon this envisioning of the manufacturing challenges for 2050 through definition of a novel concept, entitled 'Net Positive Manufacturing (*Net+ Man*)', to better inform manufacturing companies about their wider impact and to provide greater insight into opportunities on how they can put more back into society and the environment than they take out. The *Net+ Man* concept is, therefore, not just about minimising the negative impacts, but also about redefining and re-structuring manufacturing so that all areas of society and the natural environment are demonstrably enhanced through industrial processes and systems. The initial part of this paper discusses the key learnings from the research on SMART Manufacturing Scenarios for 2050, and the latter parts present a number of methodological, organisational, technological, social and ethical research challenges to support the *Net+ Man* approach for future industrial development.

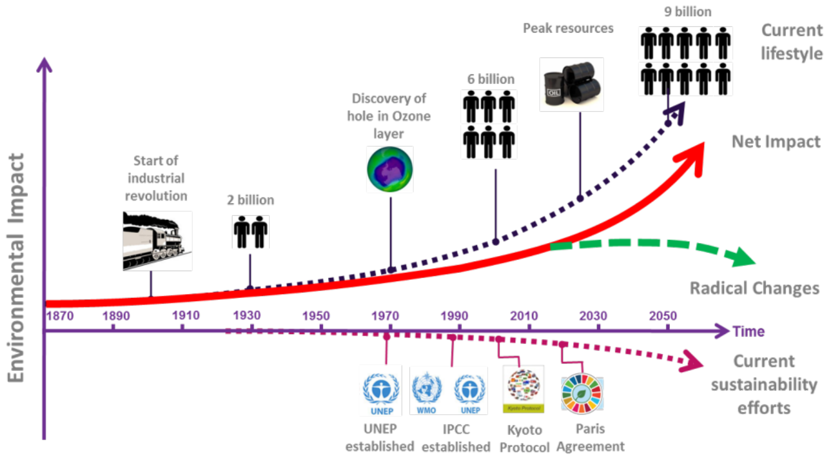

Fig. 1. The need for radical changes to eliminate or reverse the damages caused

2. Smart Manufacturing Scenarios

Scenario planning methodologies have been used for many years to improve the quality of strategic planning activities [8,9]. A two axes scenario planning methodology [10] was employed to generate SMART Manufacturing Scenarios. This required a systematic approach to identify the most critical factors affecting the development of the manufacturing industry over the next three decades with the aim of better understanding possible futures to support a range of strategic decisions related to design of future products, to develop the next generation of production technologies, and to adopt a responsible approach to business planning.

The initial stages of the study identified population growth (human impacts), climate change (ecological impacts) and resource depletion (manufacturing impacts) as the three key drivers affecting the environment and future of manufacturing. For each of these drivers, a range of interdependent and interlocking issues such as shifting global demographics, demographic distribution of populations (migration and urbanisation), availability and access to labour and skills, rapidly evolving environmental legislation, economy of climate change and their impact on resource depletion were investigated and analysed in order to identify how they might influence the future of society, environment, governance, and therefore, the manufacturing industry (for further detail readers are referred to [7]). The influences from these key drivers were consolidated into two critical axes, namely overall 'environmental impact' and 'resource depletion' to define four scenarios (see Fig. 2), which typify the various possible global conditions that a manufacturing company may face by the year 2050, as briefly described below.

i. *Sustainable Planet (SP)*: in this scenario, low consumerism and significant advances in sustainable technologies have created a planet where human life can thrive under sensible conditions. A circular approach to production and a fully closed loop economy have been realised by a societal shift towards responsible and equitable consumption behaviours. Manufacturing resources (materials, water, and energy) are obtained from renewable sources and the planet operates entirely on 'solar income'. Regular training of the workforce provides flexibility in operations and supports adoption of advanced eco-efficient technologies. Products are designed to meet real needs in the most efficient way, and are built to last or be upgraded as appropriate.

ii. *Unsustainable Planet (UP)*: in this scenario, high consumerism and lack of investment in environmental technologies has led to difficult and complex conditions in which manufacturing companies must operate. Access to all resources is severely limited and the cost of access to non-renewable resources and the implementation of severe environmental regulations have created very restrictive, high cost business operating parameters. Due to high demand for access to resources and skills, companies have developed more independent strategies for 'self-sufficiency'. Design of products is strongly influenced by a need to combat the ever increasing effects of climate change that have led to variations in localised weather conditions, food production and changes to infrastructure.

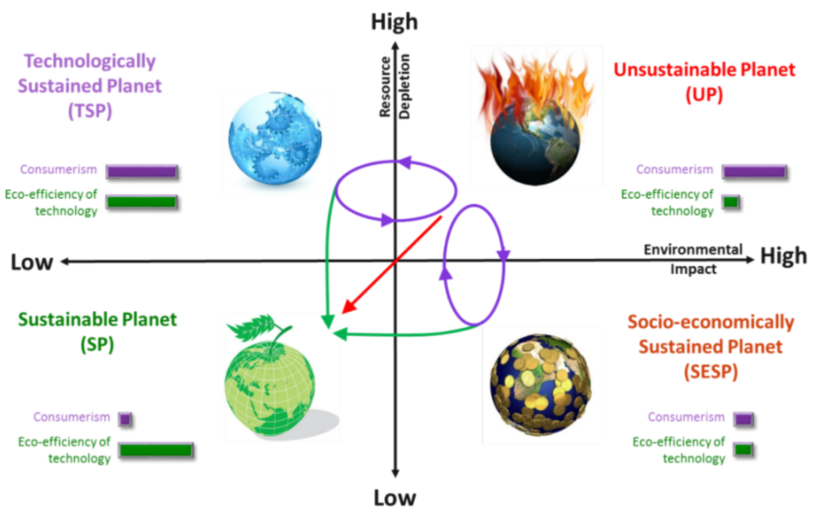

Fig. 2. The SMART Manufacturing Scenarios

iii. *Technologically Sustained Planet (TSP)*: This scenario describes a planet sustained by vast technological growth and advancements, with environmental impacts controlled by high tech, but resource intensive solutions. Consumerism remains high as this advancement in technology has provided capabilities to produce more products, and raised the requirement for highly trained and skilled labour. These advancements have favourably impacted the availability of resources, however, technological and product developments have centred on combating the effects of climate change, such as the impacts of flooding, droughts and high winds.

iv. *Socio-Economically Sustained Planet (SESP):* In this scenario, lack of investment in sustainable technologies has led to the creation of localised insular communities, formed to sustain a lifestyle in which continuous financial crisis has significantly driven down consumption patterns. Local and/or national coalition groups protect their own resources and production activities take place locally within these small communities, creating large demand for local flexible labour and cooperation. As consumers are more economically aware, companies require significantly more competitive products and must be strategic about product ranges and selected markets in which they operate. Products need to meet specific local needs and enable efficient, recoverable use of resources.

The most fundamental consideration with regards to these future manufacturing scenarios is the inherent reversals that may develop between TSP↔UP and SESP↔UP, as illustrated in Fig. 2. The loop between TSP↔UP represents a pattern often referred to as the *'rebound effect'* in which the eco-efficiency gained through technological advancements and improvements is offset due to significant growth in consumption of the product. The loop between SESP↔UP represents the cycle often referred to as *'boom and bust'*, in which during an economic crisis the frequently proposed solution is to 'excite the market' and encourage increased consumption through availability of 'disposable income' for consumers. In this context, the improvement in environmental impact during a specific period is wiped out by a period of rapid growth in consumption.

The most recent research on *Net+ Man* aims to mitigate against the technological rebound effect and socio-economic boom and bust approaches to provide a unique pathway to a sustainable planet, as depicted by the green arrows in Fig. 2 and discussed in more detail below.

3. Net Positive Manufacturing

3.1. Definition

Manufacturing has traditionally been defined as a process of 'converting raw materials into products, often in large volumes'. This unidirectional flow of materials (and other embedded resources) has resulted in the development of a set of methods, tools and technologies that aim to optimise production (often based on the cost reduction), maximise throughput, and more recently, aggressively promote increased consumption to increase profit. In this approach, the resource is '*consumed*' to provide the product functionality to satisfy consumer demands.

At the core of *Net+ Man* is the concept of *'borrowing resources'* to satisfy a specific need through a product and/or a service, and the ability to return these resources to a near original status for further use (see Fig. 3), a concept referred to as *'immortal use of resource'* [11]. The circularity in the use of resources, the ability to up-cycle or at least recycle (but not down-cycle) resources, the focus on only addressing *'real needs'* of users, and choice of providing required function through a product, a service or a combination of both (whichever option supports the achievement of aforementioned objectives), are the main cornerstones of *Net+ Man* upon which future industrial systems must be designed, planned and implemented.

3.2. Background

The term *'Net Positive Manufacturing'* was initially coined by Forum of the Future, WWF-UK and the Climate Group [12] to refer to a set of twelve principles for business as a guide for implementing organisational changes that would lead to ecological, environmental and social benefits from industry across value chains, sectors and systems as opposed to the drive for growth and profit with limited consideration of the larger picture. These principles mainly addressed the key organisational challenges involved in implementing a net-positive approach.

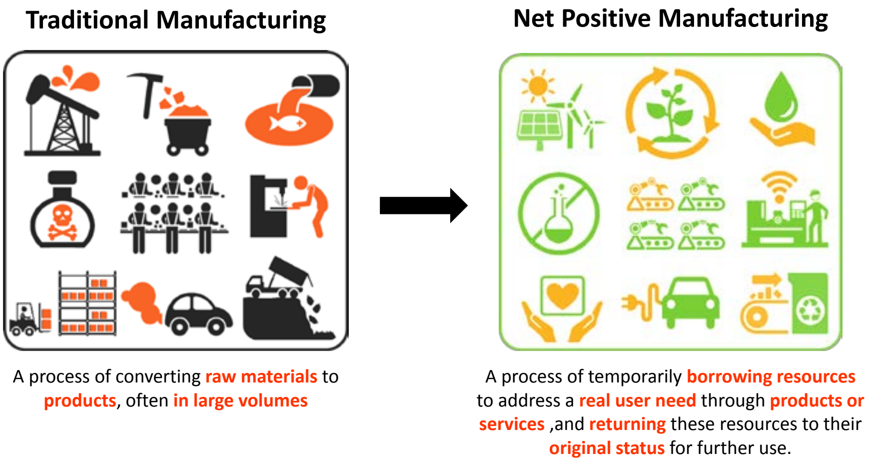

Fig. 3. The Underpinning Principles of Net Positive Manufacturing

As stated previously, for a large-scale, comprehensive and rapid adoption of a *Net+ Man* approach by manufacturers around the globe, the authors assert that further research is required to address a number of methodological, technological, social and ethical as well as organisational challenges, to aid with transformational strategic directions in future industrial development. These challenges are wide-ranging, a subset of which are discussed under each aforementioned heading in the remaining sections of this paper.

3.3. Methodological, Organisational, Technological, Social and Ethical Research Challenges in Net+Man

3.3.1. Methodological Challenges

A net positive impact often requires a big shift in approach and outcomes, and cannot be achieved by business-as-usual [12]. In this respect, some of the methodological challenges for manufacturers are:

Adaptive Behaviour: Future manufacturing industry must have the ability to react to many changes, such as type and amount of available and accessible resources, ever-changing structure of supply chains, shifting pattern of consumer need and demand, and dynamic operating conditions due to the impact of climate change. This necessitates flexible, intelligent and adaptive capabilities which can only be achieved through long-term strategic planning as well as careful considerations of many tactical and operational issues. An example of such behaviour could be based on the concept of foraging factories that are aware of opportunities to forage waste from other manufacturers, retail collection points, their customers and consumers, and at times even landfills to replenish their resources.

Restorative Behaviour: Future production facilities should adopt a system level approach together with appropriate tools and technologies to become aware of and to restore what has been damaged, changed and consumed as part of their day-to-day activities within both their local surroundings and the wider environment. This novel approach would encourage the concept of ‘factories as one of the building blocks of future urban areas’ for their refining, decontaminating and cleansing capabilities. An example of such behaviour could be practices of using polluted river water rather than public water supply in manufacturing processes that conclude by releasing effluent that is cleaner water than what was extracted from the environment.

Regenerative Behaviour: This involves adopting a regenerative process for inventory management in which manufacturers identify resource depletion not only in their internal processes but also throughout the entire supply chain and continuously attempt to replenish the resource stock as any suitable opportunity arises. Such regenerating system will possess the added benefit of being more resilient. Examples of such regenerative behaviour could involve manufacturers as active agents for sustainable forestry, main stream developers and innovators of next generation recycling technologies for their products, and investors and main stakeholders for the growth of renewable energy.

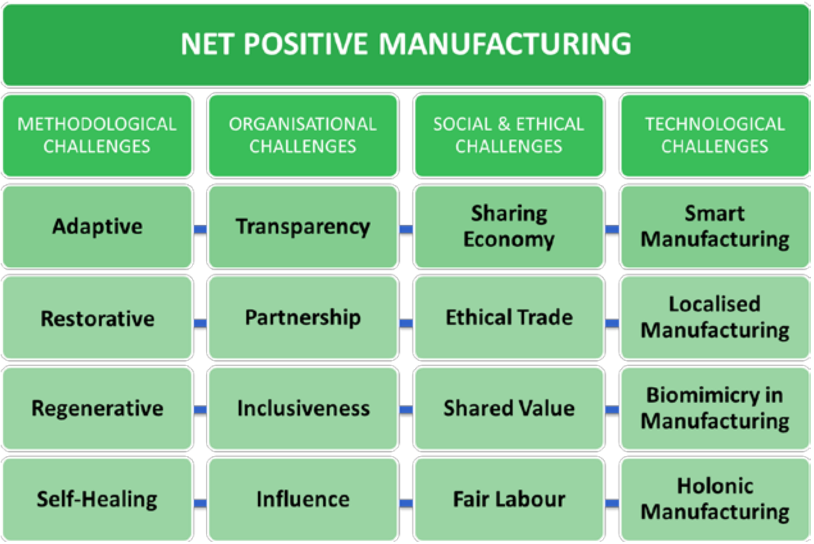

Fig. 4. Methodological, Organisational, Social and Ethical, and Technological Challenges in Net Positive Manufacturing

Self-Healing Behaviour: this refers to the ability to recognise operational glitches, difficulties and complications and to take corrective actions to respond and/or to stop wasteful and contaminating activities. The key aspects of self-healing systems are digitalisation, decentralisation, amalgamation, and progressive intelligence to support an autonomous cooperative operation among production processes. Big data analytics will be crucial for implementation of such self-healing control mechanisms. An example of self-healing behaviour could be continuous real-time energy monitoring, both at the micro and macro levels, to support predictive maintenance and malfunction recognition due to a critical fault that would result in wasted energy and rejected products.

3.3.2. Organisational Challenges

Future manufacturing organisations should have the ability to demonstrate evidence of net positive through best practice in corporate responsibility and sustainability across the spectrum of social, environmental and economic impact areas, in line with globally accepted standards. In this respect, some of the organisational challenges [12] are:

Transparency: Reporting on progress through consistent, authentic and independently verified sources will enable organisations to compare and contrast their progress towards *Net+ Man*. This will lead to better understanding of standards and replicability, and will facilitate both a proactive approach to community building and a reactive approach to respond to wrongdoing, conflicts and complications.

Partnership: Entering into partnerships and networks will help create greater impacts and increase momentum towards *Net+ Man* both locally and globally. Precompetitive cross-sectorial joint research and development initiatives based on sharing data and knowledge are essential for the development of many of the tools and technologies required to support *Net+ Man*.

Inclusiveness: An inclusive approach will ensure that all stakeholders will be able to provide input and be involved in the process of creating positive social and/or environmental impacts. The procedural, process and system solutions needed to support *Net+ Man* often require contributions by many if not all staff within a manufacturing enterprise, and at times across one or more production supply chains.

Influence: The active and public engagement with policymakers for positive change that does not only serve the personal interests of the corporate leadership or is in the narrow interest of the company. Out-of-date regulations and legislation which have been developed by governments based on a ‘command and control’ approach lack focus on innovation and improvement. Policies defined based on ‘Economic Instruments’ have the potential to be a game changer, but require direct and detailed involvement by industry to make sure they are addressing the real issues and are applicable.

3.3.3. Social & Ethical Challenges

In spite of the seemingly negative image of the sector, the authors claim that manufacturing is crucial to solving complex environmental and social problems. The underlying social and ethical challenge for manufacturers is to take on the responsibilities of good corporate citizenship which are fundamental to *Net+ Man*. In this respect, some of the social and ethical challenges are:

Sharing Economy is the futuristic goal of a more democratised marketplace to optimise the use of resources through mutualisation of excess capacity in goods and services. The 'sharing' in sharing economy refers to the use and access of shared physical or human resources or assets, rather than the fact that there is no monetary exchange which underpins different forms of value exchange based on a hybrid economy.

Ethical Trade forces manufacturing industry to assume responsibility to improve the working conditions and environmental impacts of their supply chain both locally and globally and to help producers in developing countries achieve better trading conditions by advocating the payment of higher prices to exporters, as well as improved social and environmental standards.

Shared Value aims to create economic value in a way that also creates value for society by addressing its needs and challenges, and is a novel vision for manufacturers to find business opportunities in social problems with a focus on maximising the competitive value of solving social problems. This can be accomplished by reconceiving products and markets, redefining productivity in the value chain, and building supportive industry clusters at the company’s locations.

Fair Labour ensures that workers will be fairly compensated for their work, have a safe and secure working environment and be subject to reasonable working regulation which at its core aims to eliminate child labour, slave labour, and forced labour.

3.3.4. Technological Challenges

Recent years have seen a rising awareness among manufacturing companies of all sizes that current incremental changes are not making the necessary progress towards eliminating or even reversing the environmental impacts of global industry. There is, therefore, an urgent need to adopt strategic stepwise actions that provide readiness for upcoming challenges and resilience to future changes. In this respect, some of the technological challenges are:

SMART Manufacturing is based on flexible, reconfigurable and predictive systems that are underpinned through implementation of intelligent self-aware processes [13] which have access to the entire manufacturing data across factories and throughout enterprises [14] to facilitate significant improvements in productivity and costs, while supporting a proactive strategy to managing the environmental impact based on the *Net+ Man* concept. This has led to development of novel product strategies based on an ‘eco-intelligent manufacturing’ [15].

Localised Manufacturing is the ability to produce customised and/or personalised products at geographically dispersed locations via decentralisation of manufacturing activities [16]. Such a localised approach to production not only minimises the significant inherent impact associated with transportation of both raw materials and products, but also enables manufacturers to reduce their waste through operating closer to their consumers and intended markets [17]. One of the major benefits of localised manufacturing is the ability to better support provision of customised and/or personalised products which is seen as a key enabler for focusing on customer specific needs.

Biomimicry in Manufacturing is the adaptation of models and systems inspired by nature in manufacturing applications to solve complex problems through the creation of products and processes that respect the constraints of our eco-system on earth [18]. The underlying principle is that the design and production of materials, products and manufacturing systems that are modelled on biological entities will enable the attainment of the long-term goal of ‘living within the means of our natural environment’[19].

Holonic Manufacturing originates in the work of Koestler (1967), entitled “The Ghost in the Machine” [20]. The term “holon” describes nodes on a hierarchical tree, referred to as a “holarchy”, which is a system consisting of holons as building blocks that could operate in an automatous cooperative manner with other parts of a complex system. The key attributes of Holonic Manufacturing are the ability for self-regulation, adaptability to changes and recovery from disturbances [21].

4. Concluding remarks

The rapid proliferation and widening range of impacts associated with climate change, ever-increasing concerns regarding depleting resources, together with national and global pressures and expectations by consumers and governments alike have forced manufacturers to question the viability and effectiveness of their sustainability initiatives to meet their long-term requirements. In this context, the SMART Manufacturing Scenarios presented in this paper provide insights into a number of alternative global conditions that a typical manufacturing company may face in the future. It should be noted that these scenarios do not represent four mutually independent possibilities, but instead it is envisaged that the planet could easily shift between these different states as economic crises force lower consumption, or new green technologies improve capabilities to lower the ecological footprint.

The research on *Net+ Man* aims to mitigate against the technological rebound effect and socio-economic boom and bust approaches, and to provide a unique pathway to a sustainable planet. At the heart of this proposed paradigm shift is the recognition that meeting the stringent requirements of future global conditions cannot be met by incremental improvements and requires a fundamental step-change involving a number of methodological, organisational, social and ethical, and technological challenges highlighted in this paper.

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