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Biologicalisation: Biological transformation in manufacturing

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ABSTRACT

A new emerging frontier in the evolution of the digitalisation and the 4th industrial revolution (Industry 4.0) is considered to be that of "Biologicalisation in Manufacturing". This has been defined by the authors to be *"The use and integration of biological and bio-inspired principles, materials, functions, structures and resources for intelligent and sustainable manufacturing technologies and systems with the aim of achieving their full potential."* In this White Paper, detailed consideration is given to the meaning and implications of "Biologicalisation" from the perspective of the design, function and operation of products, manufacturing processes, manufacturing systems, supply chains and organisations. The drivers and influencing factors are also reviewed in detail and in the context of significant developments in materials science and engineering. The paper attempts to test the hypothesis of this topic as a breaking new frontier and to provide a vision for the development of manufacturing science and technology from the perspective of incorporating inspiration from biological systems. Seven recommendations are delivered aimed at policy makers, at funding agencies, at the manufacturing research community and at those industries involved in the development of next generation manufacturing technology and systems. It is concluded that it is valid to argue that Biologicalisation in Manufacturing truly represents a new and breaking frontier of digitalisation and Industry 4.0 and that the market potential is very strong. It is evident that extensive research and development is required in order to maximise on the benefits of a biological transformation.

Introduction

In Germany in recent times a field entitled "*Biologicalisation*" involving the integration of processes, principles and resources of nature into technical systems has been gaining increasing focus. It is deemed to be of considerable significance in the mid to long-term scientific and technological developments and is considered to have the potential to transform manufacturing as we know it today and to open up new and extensive markets for industries involved in manufacturing technologies and systems development. The underlying hypothesis being tested/challenged in the work reported here is whether or not "Biologicalisation in Manufacturing" represents a breaking and highly transformational frontier of digitalisation and Industry 4.0.

The German Government High Level Committees/Working Groups include the Chancellor's Innovation Dialogue, the Federal Government High Level Strategy and the National Platforms. One of the last innovation dialogues on biotechnology started the discussion about this field entitled "Biologicalisation."

The three main pillars that have been identified are (Fig. 1):

1. Manufacturing and Materials,
2. Health, Food and Agriculture as well as,
3. Environmental Sustainability and Energy.

Biologicalisation has not yet been wholly defined for each of the 3 pillars referred to above. This development is not being viewed as an independent branch of science in its own right, but is expected to develop through progress, transformation and advances in various research and industrial areas (e.g. in Computer Science (CS), Information and Communication Technologies (ICT), Biotechnology, Manufacturing Science and Technology (MST), Biology, etc.).

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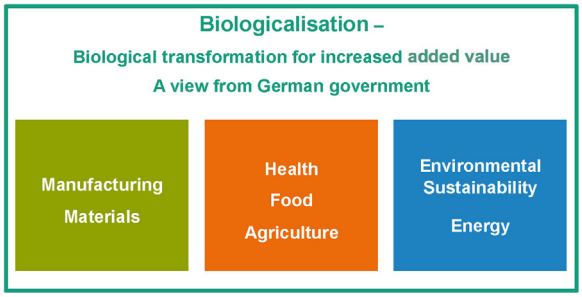

Fig. 1. The main pillars of biologicalisation [107].

It is anticipated by some that, although it is still at a very early stage, the field of "Biologicalisation" may represent the start of an entirely new revolution, which has the potential to impact the industrial and business environments significantly, indeed in a transformational manner. In a 2012 policy workshop organised by the European Science Foundation [1] in conjunction with other similar organisations (including the National Science Foundation of the USA) the theme "Nature Inspired Design and Engineering for a Sustainable Future" was addressed. In a summary report from this workshop it is noted that *"The big challenges of the 21st century, such as global warming, access to freshwater, sustainable production of food and materials, and improving quality of life in ageing societies, require a new approach to science and engineering more closely coupled with nature. Biologically inspired designs offer technologically novel and sustainable solutions to society's problems that may not be provided as quickly or economically by traditional approaches. A deeper understanding of how biological systems work can bring new insights and approaches to energy generation, conversion, storage, transport, and efficiency. It can also inspire advances in healthcare, and introduce a new age of materials with novel properties such as self-repair."*

This White Paper deals with "*Biologicalisation in Manufacturing*" and it is recognised that manufacturing in itself is a broad area with numerous specialisations. It is also important to note that there is evidence to show that the early stages of a biological transformation is taking place with some convergence occurring between biomimetics, biotechnology and the bioeconomy. While these areas are broader than the scope of this White Paper, it is important that the wider perspective beyond manufacturing be monitored and where appropriate be integrated.

In this paper, the scope of manufacturing is restricted to the areas of work of the International Academy for Production Engineering (CIRP), which has a strong orientation towards discrete parts design and manufacturing. Five of the scientific technical committees (STC's) deal with the processes of Cutting (C), Electro- Physical and Chemical Processes (E), Forming (F), Abrasive Processes (G) and Machines/Machine Tools, while the other five STC's encompass Life Cycle Engineering and Assembly (A), Design (Dn), Production Systems and Organisation (O), Precision Engineering and Metrology (P) and Surfaces (S).

In addition to the STCs, collaborative working groups (CWGs) with an average life of 3 years are formed to address particularly important topics of the day. The CWGs frequently conclude their work with the publication of a CIRP Keynote Paper on the topic.

After considerable deliberation, the authors of the White Paper defined the term "Biologicalisation in Manufacturing" as being:

> *"The use and integration of biological and bio-inspired principles, materials, functions, structures and resources for intelligent and sustainable manufacturing technologies and systems with the aim of achieving their full potential."*

The underlying objective of this White Paper is to review the topic of "Biologicalisation in Manufacturing" in light of recent and current developments in advanced manufacturing and to provide an independent, international perspective and a vision on potential future developments. The authors seek to provide insight into the potential for intelligent and sustainable advanced manufacturing technologies and systems in the context of the use and integration of biological and bio-inspired principles, functions and resources. The scope of the work presented relates to biological transformation in manufacturing, recognising that manufacturing is inextricably linked to each of the other fields in all the pillars as shown in Fig. 1: Materials, Health, Food, Agriculture, Environmental, Sustainability and Energy.

Biologicalisation in Manufacturing – a new emerging frontier of digitalisation and Industry 4.0

The underlying concept of "Biologicalisation in Manufacturing" is not new. What is new, however, is the acceleration of the realisation of the concept, which builds on the capabilities available today and into the future through digitalisation and Industry 4.0 developments. Although not called by this name, the principles of biologically inspired manufacturing systems have a long history. Our late colleague and CIRP Past-President Professor Kanji Ueda (Japan) published in the journal CIRP Annals – Manufacturing Technology in the 1990s in this area, which he called "Biological Manufacturing Systems (BMS)". At that stage he wrote that "Today's manufacturing faces significant trends of cultural diversification, lifestyle individuality, activity globalisation and environmental consideration". In his paper [2] he reported that Biological Manufacturing Systems (BMS) was proposed as a next generation manufacturing system concept aiming at dealing with non-pre-deterministic changes in manufacturing environments based on biologically inspired ideas such as self-growth, self- organisation, adaption, and evolution. BMS cover the whole product life-cycle from planning to disposal. At that point in time, however, the digitalisation was at a very early stage of development and the technology of the 1990s was inadequate to facilitate the realisation of many of the concepts of the day.

Concerning the work reported in this White Paper and in line with the definition developed for Biologicalisation in Manufacturing, the approach adopted has been to analyse the factors and drivers relating to and influencing the key elements of the manufacturing value chain from an overall manufacturing technology and systems perspective. This is summarised in Fig. 2. For this purpose, the manufacturing field has been subdivided to include: Section "Materials and Surfaces";

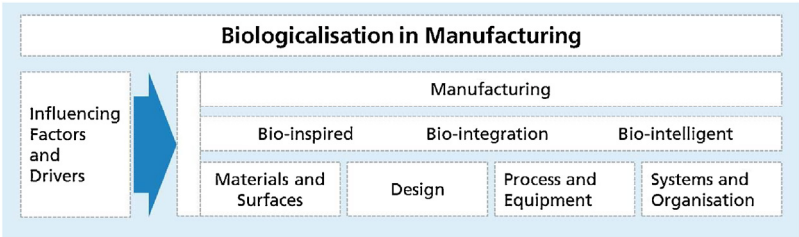

Fig. 2. Scope of work addressed in this White Paper.

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