Sustainable Production, Life Cycle Engineering and Management
Series Editors: Christoph Herrmann, Sami Kara

Rainer Stark
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Jérémy Bonvoisin *Editors*

Sustainable Manufacturing

Challenges, Solutions and Implementation Perspectives

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Sustainable Production, Life Cycle Engineering and Management

Modern production enables a high standard of living worldwide through products and services. Global responsibility requires a comprehensive integration of sustainable development fostered by new paradigms, innovative technologies, methods and tools as well as business models. Minimizing material and energy usage, adapting material and energy flows to better fit natural process capacities, and changing consumption behaviour are important aspects of future production. A life cycle perspective and an integrated economic, ecological and social evaluation are essential requirements in management and engineering. This series will focus on the issues and latest developments towards sustainability in production based on life cycle thinking.

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Foreword

Manufacturing is the main driver for welfare and prosperity of people. However, manufacturing also strongly contributes directly and indirectly to the depletion of natural resources, environmental burdens—affecting the health of animals, humans, and eco-systems—as well as to social conflicts. These negative effects expand along with the worldwide demand for industrial goods, which will further increase since the global population is still growing and less developed countries strive for the standard of living which richer countries already have achieved. And despite being aware of the prevalent limitations of natural resources and emission capacities of our planet, the demand for resources and the related pollution to the environment has continued to rise drastically. Thus, finding solutions towards a more sustainable development of global manufacturing—which simultaneously considers the triple bottom line with the three dimensions of sustainability—is of outmost importance and more urgent than ever.

Researchers of the CRC for Sustainable Manufacturing have taken up the resulting challenges and derived ambitious goals. These goals address the main tasks supporting the shift towards a more sustainable development in manufacturing, which are the identification of challenges and levers for change which matters most, the development of specific solutions to cope with these challenges, and the implementation of decision support methods for supporting deciders in the industry and policy to improve manufacturing activities based on the derived solutions. The identification of challenges requires a system thinking and a life cycle orientation in order to avoid problem shifting. Specific improvement measures may lead to local improvement but create negative effects on other manufacturing sectors, life cycle phases, or environmental impact categories. That means it is necessary to consider and evaluate different manufacturing scales from specific technologies and product concepts to value creation networks and up to global manufacturing activities regarding economic, environmental, and social criteria. Furthermore, innovative solutions must be found to improve technologies, products, and strategies for manufacturing activities which reduces resource demands, create products in the desired quality, and protect the health of workers, customers,

and all involved people. These solutions must be transformed into methods and tools—such as mathematical optimization approaches for specific planning problems or life cycle assessment models for products and processes—which supports engineers, planners, and designers in creating value-adding and sustainable products and services.

This publication provides research results which address the aforementioned challenges, solutions and implementation perspectives with regard to manufacturing and sustainable development. It contributes to this urgent topic by describing prevailing trends and findings in industry, economy, and society, by presenting concepts for manufacturing technologies, planning methods, and product designs, as well as by suggesting strategies for knowledge dissemination and employment of solutions within organizations. Overall, the present book gives insight into important fields of actions which are required to make the world worth living in now and for future generations.

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Preface

If the lifestyles of up-and-coming and also developed societies are shaped in the future by the existing, currently predominating technologies, then the resource consumption at play will exceed every accountable environmental, economic and social boundary known to man. The dynamics of global competition and cooperation can be utilized for lending wings to processes of innovation and mediation towards the ultimate goal and necessity of *sustainability* on our globe. A special focus lies in condensing engineering to *sustainable manufacturing*, thus specifically addressing artefact generation shaping human living.

Abstract, intangible concepts and goals, such as *sustainability,* overburden human beings, engineers and researchers in different ways. To date, it constitutes an overwhelming task to consistently apply a full, balanced view and critical cross-assessment of the full range of relevant dimensions, such as the environment (incl. climate, resources and all other natural systems), the economy and society—the classical three pillars of the modern understanding of sustainability. Furthermore, conducting such assessments on different levels of abstractions creates a personal feeling of powerlessness. Researchers, however, take on the challenge of investigating both laws of interdependence and the underlying core mechanisms in order to provide new systemic views of the challenging concepts and goals of *sustainability*. Engineers, in addition, attempt to derive methods, processes and technologies to help society and companies in finding holistic, specific and proactive solutions for *sustainability*. In that mission, *sustainability* gets broken down into controllable elements within an overall system network: products with their functions and behaviours, material selections, production systems, factories, enterprises, logistic elements, value creation networks, patterns of use behaviours, labour and payroll systems, welfare, health and so forth.

The editors of this book and all contributing authors are of the belief that it is now high time to provide tangible solution sets to address various levels of "system driven realization and delivery oriented" sustainability. Yet what does that actually entail? Unlike the rather general (but necessary) discussions surrounding a "complete enough set" of sustainability development goals, such as the 17 goals agreed by the United Nations in September 2015, a critical urgency is attached to work on

"how such goals need to be realized, and which solutions have to be made available for them." Manufacturing and its potential to deliver wealth and intelligent solutions to societies and human beings has been selected as a first prime route for investigating which changes are necessary for reaching a true state of *sustainability* in the future.

Sustainable manufacturing in this sense represents a manufacturing engineering's approach to coping with these challenges. Manufacturing technology is developed in the direction of economic competitiveness, of environmental compatibility with natural global frame conditions of resource availability and of social welfare with different societal frame conditions to suit the different human communities around the globe. This multidimensional goal system can be balanced by developing adequate economic, environmental and social criteria, with analysis of their interdependencies and application of that analysis for guiding technological innovation in respective economic, environmental and societal frameworks.

Before stepping up and striving for a position from which to set up a "circular economy"—an economy where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste is minimised—it is necessary to determine which elements need to be integrated into such a "system circle." Hence, the underlying new mind-set of this book assumes that the overall values of *sustainability* and those specific to *sustainable manufacturing* can no longer just be driven by assessment factors and goals of the three dimensions environment, economy and society. Instead, it has become necessary to fundamentally change core and specific mechanisms and elements of the following "interacting system of systems":

- The earth system with its natural resources and all associated ecological, biological and climatic sub-systems
- The societal system(s) and related behavioural patterns which are highly influenced by cultural, religious and ethnic values
- The economic system(s) originally driven by a profit theory based on the traditional production factors, such as land, work and capital, funds which was just recently however hugely impacted by new business model innovations, e.g. caused by the digital transformation

Research efforts in this book have investigated both specific technical approaches for ushering in changes to specific mechanisms ("the technical depth"), and on rather generic terms, overarching theories and methodologies on how value creation and its technical solutions can be variously influenced by specific earth and economic boundary conditions, i.e. the breadth of the overall approach.

The rather limited predictive capability of the timely progression of evolutionary or revolutionary changes to the solution set of *sustainable manufacturing* remains the first generic challenge of research in this field. This is the reason why system dynamic models are deemed to be appropriate candidates for overcoming such a research dilemma.

The second generic challenge in *sustainable manufacturing* deals with the contradiction between

- the desire to analyse the different aspects of the lifecycle behaviour of a product as narrowly as possible, and
- the obligation to provide a rather lean set of data, information and digital models for the design and determination of a product solution in the "Begin of Life" (BOL) phase of the lifecycle.

The right mix of both is decisive in the pursuit of enhancing the probability of influence on "smart and comprehensive decisions" as part of the engineering process of sufficiently sustainable products.

The ambition behind and need for driving changes from the different development levels of society and economy within both the highly developed and industrialized countries as well as from the perspectives and demands of the less developed and emerging countries represent the third overall challenge in *sustainable manufacturing*. Positive impact of the manufacturing sector on sustainability will thus only be possible if all participants actively involved think *locally and globally*.

This book is unique in its comprehensiveness in tackling research and engineering approaches in *sustainable manufacturing* and its global value creation mechanisms. It is the desire and intention of the editors that this book may serve to truly help researchers, industrial experts, politicians and interested members of society in the process of fully comprehending and further developing new solutions for driving and realizing *sustainability* with the help of manufacturing solutions. It is therefore an obligation for editors to stay in close contact with the growing community of sustainability oriented researchers, planners, engineering, managers, politicians and responsible individuals in all societies across the world.

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