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Forward to Sustainable Manufacturing Processes

KC Morris
Engineering Laboratory Systems Integration Division
Life Cycle Engineering Group Leader
National Institute of Standards and Technology
Gaithersburg, MD 20899 USA

Dear Reader,

When I was asked to write this forward, I was both delighted and humbled at the opportunity to be part of this important work. The focus of my own research at the National Institute of Standards and Technology (NIST) has been on propelling forward advances in sustainable manufacturing by creating repeatable practices using new technologies and standards for digital manufacturing. This book is a review of the results of efforts to create more Sustainable Manufacturing Processes over the last many years, and it encapsulates the foundations for the next evolutions to support this important area. My wish is that you find it an insightful reference as you venture on your own journey in the area of sustainable manufacturing.

The history of humankind is paved with ingenuity, cooperation, and competition. Some of the greatest technological leaps that have propelled us into the modern age were baited by competition and built on ingenuity and cooperation. Much of today's advanced manufacturing technologies started in the aftermath of World War II. During these times our abilities and ingenuities were focused on new leaps in transportation, equipment, security, and space exploration. Using our deepest imaginations, we created the technologies that enabled man to go to the moon, robotic explorers to go to mars, telescopes to peer even deeper into the vast unknown expanse of space, satellites to provide instant communication around the world, and the weapon systems to secure our nations. In those endeavors, we learned our strengths and our vulnerabilities as a human race.

The role of engineering and manufacturing in these undertakings cannot be overstated. The things we have achieved are the outcome of our collective and cooperative ingenuity applied to the pressing needs of the time and built on our imaginations to invent new products and solutions. The specification, precision, and certification of the capabilities needed to achieve such great feats are as vast as any scientific endeavor and yet, in the reverse, the object under study is not purely a natural phenomenon by rather a complex system of human agreements, defined as a “discipline”. These agreements enable us to construct and rely on a new kind of system—a system that incorporates natural phenomena together with a structured reality of our own making.

The engineers and manufacturers of today are being charged with forging ahead into a new world where our mission is one of global cooperation to ensure the survival of our species and ensure a continuously improving quality of life for the inhabitants of this world. As before, manufacturing is a pillar of this new society. While policy advocates may help to establish the will, it is the engineers and manufacturers who must define the way. From this challenge, sustainable manufacturing practices and principles emerge.

Sustainable manufacturing is one in which a carefully crafted balance of goals must not only be achievable but must also be manipulatable. The priorities of today will not be the same as those of tomorrow; the priorities in one locality may be different from those in others. Sustainable manufacturing will build on the digitalization of manufacturing in which the science behind the practice can be crafted and molded virtually before the actuality of production. Digitalization allows for focused experimentation to incrementally capture knowledge of the disciplines and add to our virtual understanding of the world. It enables exploration of yet unknown futures giving us the means to plan for desired outcomes and avoid crises.

This book is a story of sustainable manufacturing. It highlights the work developed in previous generations to enable the sophisticated manufacturing practices known today. It captures generations of learnings in how to manufacture more efficiently using a broad range of techniques by making the most of our resources—materials, energy, time, labor—while making the best achievable products. While the criteria that defines these parameters are subject to shift, the systems must be such that they can adapt.

The challenge of the modern-day is how to sustain life on earth while continuing to improve the standard of living for the inhabitants. The world’s population passed 2 Billion inhabitants in 1928; in 2021 (less than 100 years later) that number was 7.9 Billion and growing. Future projections by the UN indicate that growth rates will continue to rise and may pass 10 Billion by the end of the century. In the meantime standards of living around the world continue to increase. The result is growing demand for resources—food, energy, water, minerals, and other materials—pushing the bounds of the earth’s capacities and threatening havoc for the environment.

Manufacturing must be part of the solution to provide good quality of life in an increasingly crowded world, while managing available resources wisely. Currently, manufacturing and related supply chains account for a substantial portion of environmental impacts. Much of that is directly attributable to manufacturing production processes. Recent emphasis towards decarbonization identified industrial emissions as one of the hardest sectors to address in terms of carbon reduction due in part to the diversity of manufacturing processes, where each will need to be addressed individually. To move towards global decarbonization, reductions in these emissions will be necessary. Some manufacturing processes will need to be adapted to account for new energy sources. Similar challenges exist with changing demands on material availability, particularly for critical minerals. Likewise, automobile manufacturing is being disrupted with the introduction of electric vehicles, and agri-food manufacturing is being transformed to improve efficiency and reduce waste in food processing and distribution.

The science that emerged to confront the challenges of the 20th century, is being adapted to confront these growing strains on our natural environment. Virtual design and manufacturing developed to meet the needs for high-precision, high-value products. Equipment for the space race was characterized by single-use products that were costly, one of a kind, and irreplaceable. Little room for mistakes existed. Early attempts at space orbit were undertaken through the engagement of human "computers" who worked laboriously to calculate the data needed to validate the models. As "digital computers" came online advances happened much more rapidly. As a society, we learned how to use computers for much more than simple calculations.
Human ingenuity was brought to bear in creating models of new aerospace products so that manufacturing could be reasoned out before material was manipulated. Computer Aided Design (CAD), Finite Element Methods (FEM), Computer Integrated Manufacturing (CIM), and other CAx technologies evolved along with the computer revolution. New software was developed to assist in forming the new models and to collect data necessary to validate capabilities against the real world in a systematic step-by-step fashion. Highly repeatable processes enabled new parts to be fully functional in the mind's eye before they were forged, cast, or created by a growing set of manufacturing processes. Systems also emerged to integrate business processes inside an organization and through the supply chains.

Today, these approaches are growing to represent an even broader range of capabilities. Manufacturing is integral to modern living touching on things as useful as household goods and appliances, as fundamental as food, as varied as materials, and as indispensable as vaccines. The digital approaches and the manufacturing science developed for high-tech precision parts are being expanded to address this broad range of needs. Advances in computing technology including Artificial Intelligence (AI) and Machine learning (ML) systems have evolved to manipulate the abundance of data, identify patterns, and inform analyses across a range of production processes. Integration of analyses of different viewpoints on a single physical object has brought forth the concept of Digital Twins. Digital Twins coordinate a collection of virtual interdisciplinary models fed by data from today and expanded to imagine future possibilities.

The problems of the future take on a different scope than those from which these approaches emerged. We need to use manufacturing to the best of our abilities to create the products that will be needed by future generations to thrive within the resource constraints of our global ecosystem. Waste must become a thing of the past. Environmental impacts must be closely monitored, studied, and managed. The digital manufacturing capabilities that were born of the demanding high-tech needs of the 20th century must be brought to bear on the problems posed by human growth in the 21st century. Approaches to sustainable manufacturing through digitalization will be essential to addressing the needs of our future world.

As with the demands on engineering technologies, the demands on sustainable growth are many facetted and will rely on our institutions to see that technology continues to grow in the directions needed to address new challenges. Four distinct types of institutions form the pillars of support and growth for engineering and manufacturing:

- Academia provides for education for future generations of scientists and engineers to understand, maintain, and propel our capabilities forward.
- Trade associations, standards, and certification bodies are vanguards of the established, proven, and controlled disciplines of engineering and manufacturing with commitments to address the needs of tomorrow.
- The business community provides jobs and embodies the corporate values needed for our collective future. Already multinational corporations are beginning to rise to the sustainability challenge with the vast majority of the largest corporations working towards and reporting on more sustainability in their practices. Corporations must exist beyond a profit motive as they are the responsible party for executing towards our future outcomes.
- Governments represent societal interests in imagining and creating this new world, negotiating global and regional interests, directing resources, and establishing foundational capabilities and policies to move society in a positive direction.

Concerted efforts to bring together the perspectives of these diverse parties will result in a future as we need it to be. In the words of the late Dr. Hal Gegel to whom this book is dedicated:

Sustainability is a value shared by individuals and organizations who demonstrate this value in their management policies, daily activities, and social behavior. Individuals and organizations have played a key role in creating our current environmental and social circumstances. The denizens of today and future generations must create solutions and adapt them. The role of education in sustainability as a shared value is clear, education is a forever role that universities along with governments must provide for everyone. (Dr. Gegel)