Design for Manufacturing & Assembly Across Three Industrial Revolutions

Three Centuries
1760 – 2060

Bradford L. Goldense

June 18, 2024

Goldense Group, Inc.
26 Fuller Street
Dedham, MA 02026

Phone 781-444-5400
www.goldensegroupinc.com

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ISBN10 NA
ISBN13 978-1-937115-43-2

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Artisanship: Beginnings of Design – Standard Designs

Image Credit: Pinterest.

16th Century

The use of drawing to specify how something was to be constructed later was first developed by architects and shipwrights during the Italian Renaissance.

By the **early 16th century**, competitive pressures led to the emergence in Italy and Germany of **Pattern Books**: collections of engravings illustrating decorative forms and motifs which could be applied to a wide range of products, and whose creation took place in advance of their application.

Image Credit: Wikipedia.

17th Century

In the **17th century**, the growth of artistic patronage in centralized monarchical states led to large government-operated manufacturing epitomized by the **Gobelins Manufactory, opened in Paris in 1667 by Louis XIV**. Teams of hundreds of craftsmen, specialist artists, decorators, and engravers, produced products ranging from tapestries and furniture to metalwork and coaches. **This approach spread around the civilized world.**

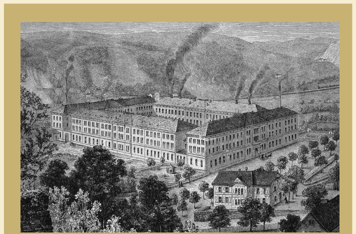

Image Credit: www.alamy.com

18th Century

One such operation remains today, the infamous Meissen porcelain workshop established in 1709. As long as reproduction remained craft-based, however, the form and artistic quality of the product remained in the hands of the individual craftsman, and tended to decline as the scale of production increased.

Source: "Industrial Design," Wikipedia, https://en.wikipedia.org/wiki/Industrial_design.

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Artisanship: Beginnings of Manufacturing – Steam Engine

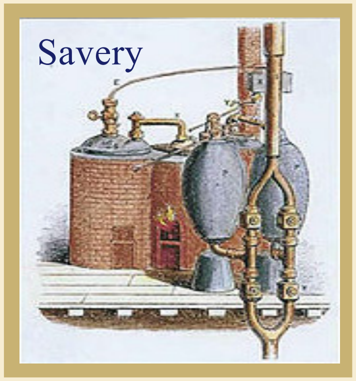

Image Credit: Wikipedia

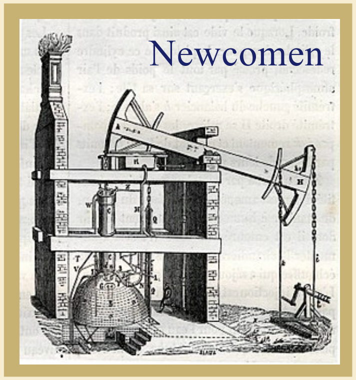

Image Credit: Wikipedia.

17th Century

In 1605, French mathematician David Rivault de Fleurance in his treatise on artillery wrote on his discovery that water, if confined in a bombshell and heated, would **explode the shells**. In 1606, the Spaniard Jerónimo de Ayanz y Beaumont demonstrated and was granted a patent for a steam-powered **water pump**. The pump was used to drain the inundated mines of Guadalcanal, Spain. In 1679, French Physicist Denis Papin, invented the Steam Digester (**pressure cooker**) which was used to extract fats from bones in a high pressure environment and create Bone Meal.

In 1698, Thomas Savery designed the **first steam engine to be applied industrially**. The "fire-engine" or "Miner's Friend" was a pistonless steam pump. Savery made two key contributions. First, in order to allow the water supply to be placed below the engine, he used condensed steam to produce a partial vacuum in the pumping reservoir using that to pull the water upward. Secondly, in order to rapidly cool the steam to produce the vacuum, he ran cold water over the reservoir.

18th Century

In 1712, Thomas Newcomen is said to have brought together the essential elements to develop the **first steam engine for which there could be commercial demand**.

- The concept of a vacuum (i.e. a reduction in pressure below ambient)
- The concept of pressure
- Techniques for creating a vacuum
- A means of generating steam
- The piston and cylinder

Source: “History of the Steam Engine,” Wikipedia, https://en.wikipedia.org/wiki/History_of_the_steam_engine.

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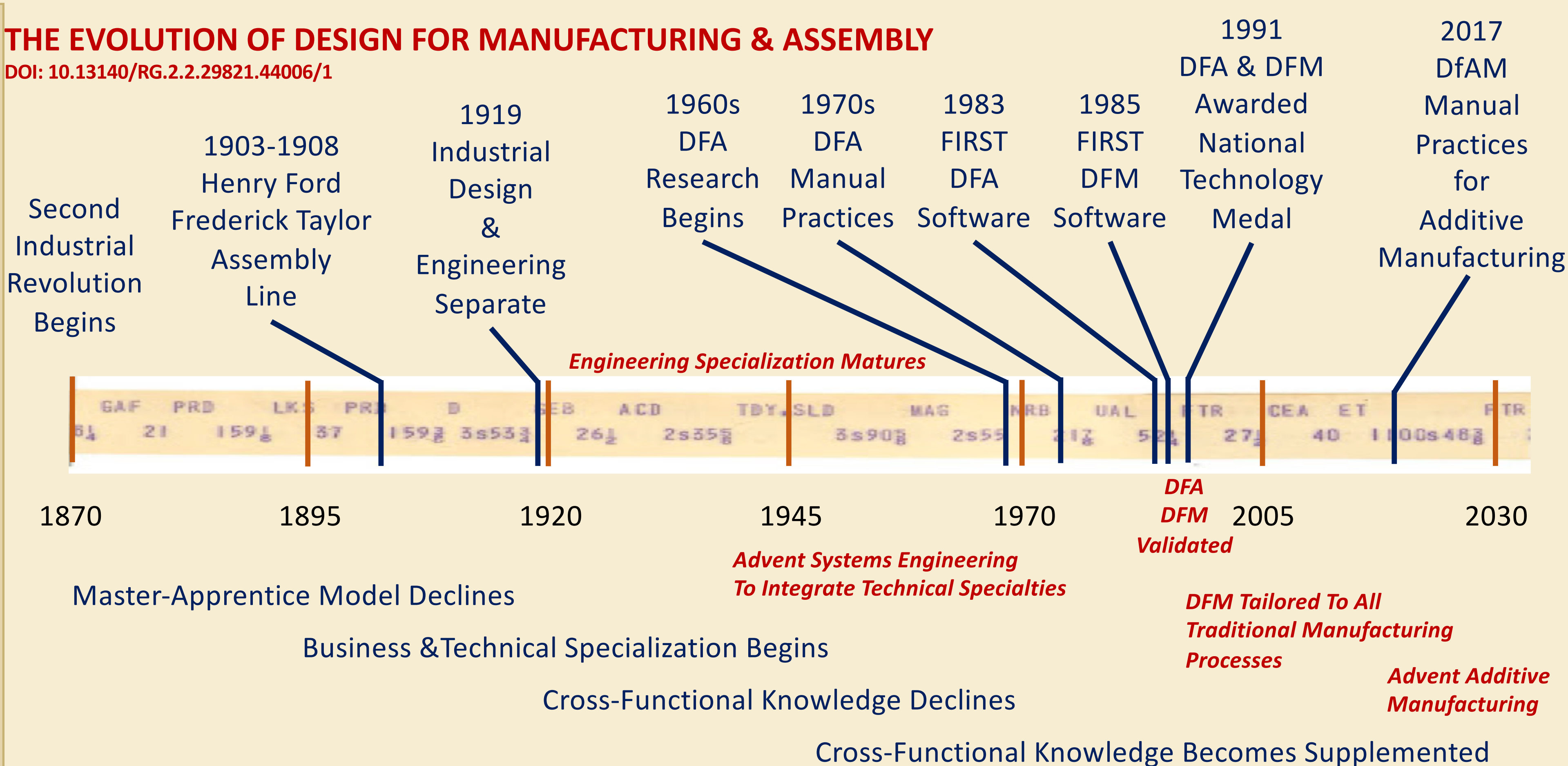
1st Industrial Revolution: Transition To Scattered Islands of Machine-Driven Production

THE EVOLUTION OF DESIGN FOR MANUFACTURING & ASSEMBLY

DOI: 10.13140/RG.2.2.29821.44006/1



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1st Industrial Revolution: Singular Machines Replace Many Artisans [Who Now Run Them]

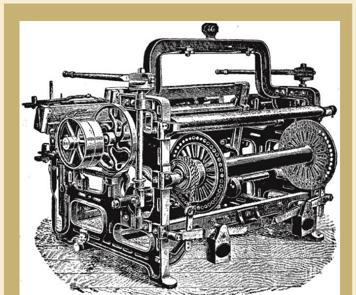

Image Credit: https://1785martaprovenza.blogspot.com/2015/04/applicazioni-della-macchina-vapore.html

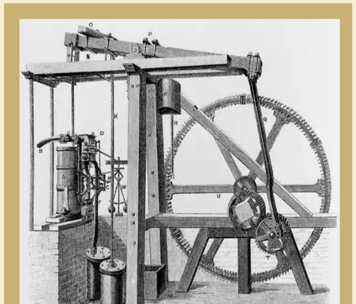

Image Credit: https://cncwmt.com/latest-news/the-history-of-machine-tools/

The Industrial Revolution, also known as the First Industrial Revolution, was a period of global transition of the human economy towards more widespread, efficient and stable manufacturing processes that succeeded the Agricultural Revolution. It started in Great Britain and spread to continental Europe and the United States, that occurred during the period from around 1760 to about 1820–1840.

The development of trade and the rise of business were among the major causes of the Industrial Revolution.

This transition included:

- Going from artisan production methods to machines
- New chemical manufacturing and iron production processes
- The increasing use of water power and steam power
- The development of machine tools
- The rise of the mechanized factory system.

Output greatly increased, and the result was an unprecedented rise in population and the rate of population growth.

The Industrial Revolution marked a major turning point in history. Comparable only to humanity's adoption of agriculture with respect to material advancement, the Industrial Revolution influenced in some way almost every aspect of daily life. In particular, average income and population began to exhibit unprecedented sustained growth.

The textile industry was the first to use modern production methods. Textiles became the dominant industry in terms of employment, value of output, and capital invested.

GDP per capita was broadly stable before the Industrial Revolution and the emergence of the modern capitalist economy. The Industrial Revolution began an era of per-capita economic growth in capitalist economies. Economic historians agree that the onset of the Industrial Revolution is the most important event in human history since the domestication of animals and plants.

Source: "Industrial Revolution," Wikipedia, https://en.wikipedia.org/wiki/Industrial_Revolution.

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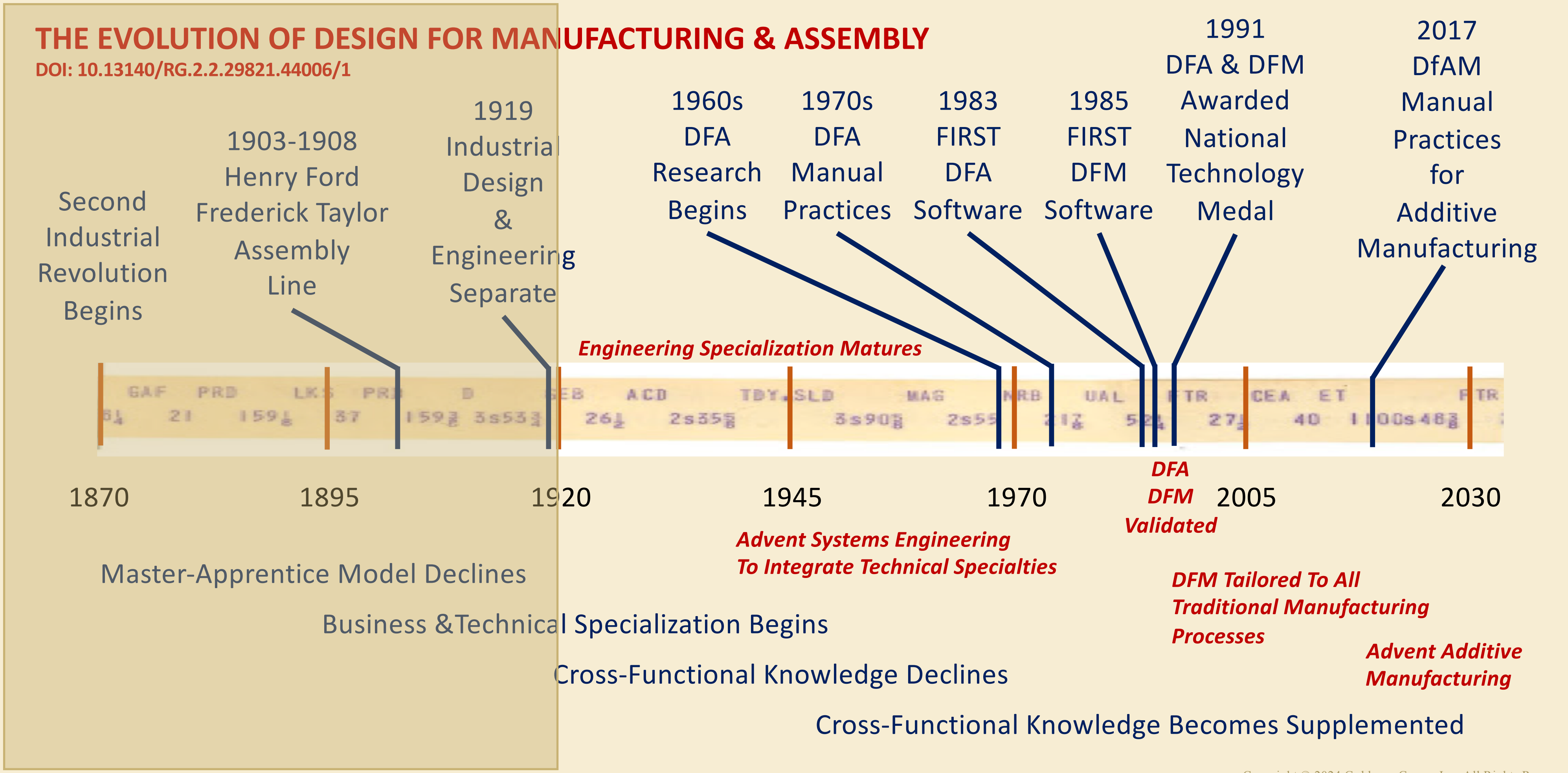
2nd Industrial Revolution: The Advent of Consumer Designs and Machine-Based Factories



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2^{nd} Industrial Revolution: Profession of Design Formalizes to Meet Consumer Wants

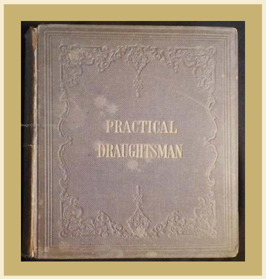

Image Credit: Abe Books.

Image Credit: Dorman Museum.

Image Credit: IDSA.

19^{th} Century

While the emergence of industrial design dates to to the growth of industrialization and mechanization that began with the **industrial revolution in Great Britain in the mid 18th century**. The earliest use of the **term "industrial design" occurred in 1839**, to retroactively describe the school of St. Peter which had been founded around 1750 regarding the instruction of draftsmen employed in preparing patterns for the silk manufacture.

The **Practical Draughtsman's Book of Industrial Design was printed in 1853**. The subtitle of the (translated) work explains, that it wants to offer a "complete course of mechanical, engineering, and architectural drawing." This work paved the way for a **big expansion in the field drawing education** in France, the UK, and the United States.

Christopher Dresser (1834-1904) is considered the first independent industrial designer. Born in Glasgow, Scotland, he was a pivotal figure in the Aesthetic Movement and a major contributor to the allied Anglo-Japanese or Modern Style (British Art Nouveau style). **In 1873 he was requested by the American Government to write a report on the design of household goods.** Consumers were demanding products with increased Aesthetic Designs.

20^{th} Century

The first use of the term "industrial design," in the context of a profession, is attributed to the industrial designer **Joseph Claude Sinel (1889-1975) in 1919 who proclaimed himself in writing to be an "industrial designer."**

While colleges like the **Rhode Island School of Design originated in 1877**, the country's **first industrial design degree program occurred in 1934 at Carnegie Institute of Technology**.

Source: Wikipedia: https://en.wikipedia.org/wiki/Industrial_design, https://en.wikipedia.org/wiki/Christopher_Dresser#Partial_bibliography.

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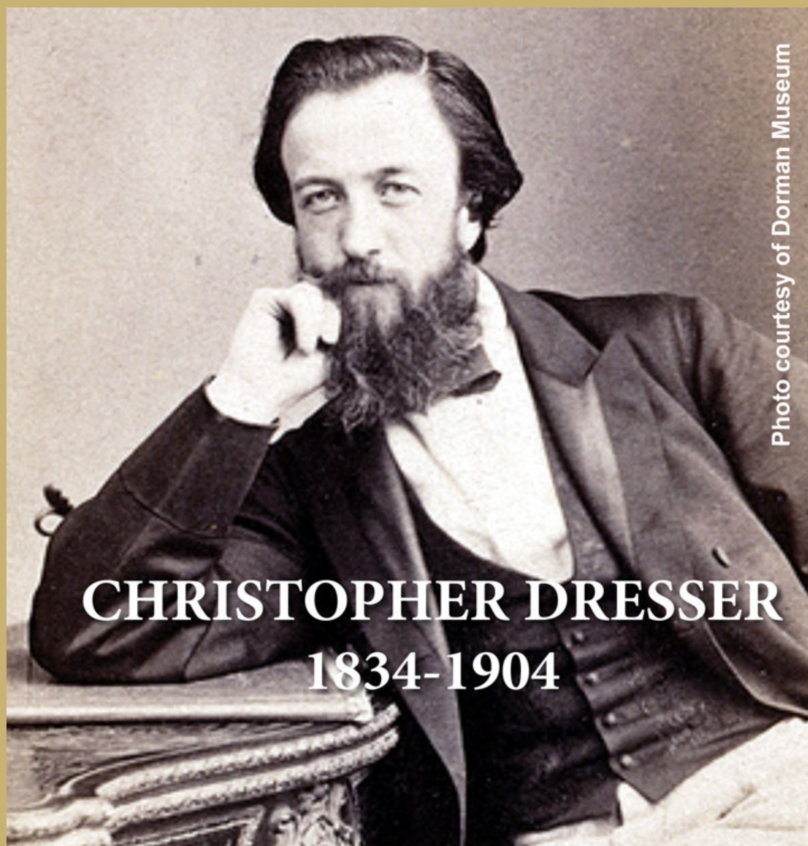
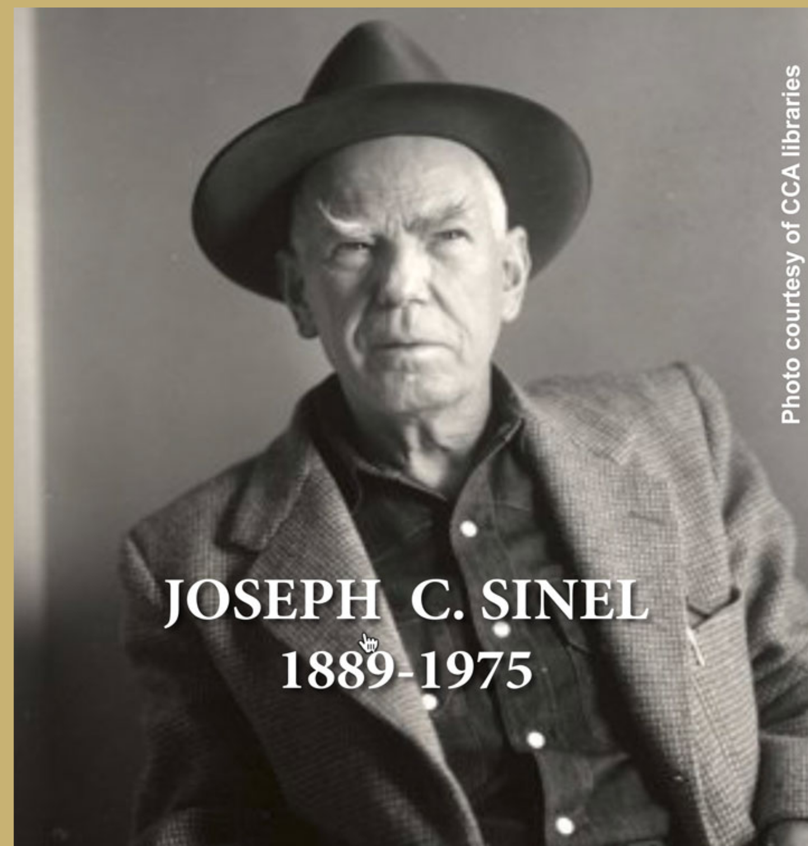
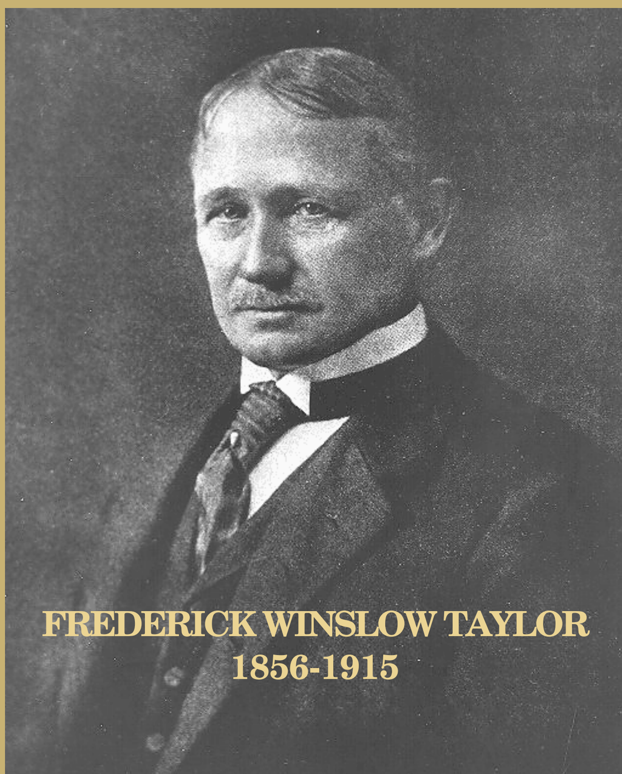
2nd Industrial Revolution: The Profession of Design Becomes Distinct From Engineering





2nd Industrial Revolution: The Standard Factory Formalizes



Father of Scientific Management

Advanced the two principal technical professions concerned with the management of a factory – engineering and accountancy.

Early factory workers differed with management on a fair days work for a fair days pay. Taylor reached a solution through the exact and detailed measurement – which yielded "standard" times, making it possible for each worker to always achieve "standard" or better.

Two principles had to be in place at all times. (1) Both sides must take their eyes off the division of the surplus as the all-important matter, and together turn their attention towards increasing the size of the surplus. (2) Both sides must recognize as essential the substitution of exact scientific investigation and knowledge for the old individual judgement in all matters relating to work done in the establishment.

Exposition Internationale Universelle Award, Paris, France, 1900
Cresson Medal, Franklin Institute of Pennsylvania, 1902
President, American Society of Mechanical Engineers, 1906
Honorary Doctor of Science, Sc.D., University of Pennsylvania, 1906
Doctor of Laws, LL.D., Hobart College, 1912

The rigidness of Taylor's standards were a solid beginning. His immediate followers, Henry L. Gantt and Frank B. Gilbreth Sr., made a larger contribution to the dynamics of management.

Source: Urwick, Lyndall F. & Wolf, William B., *The Golden Book Of Management,* American Management Associations, New York, NY, USA, Expanded Edition, Copyright © 1956, 1984, Pages 79-85.

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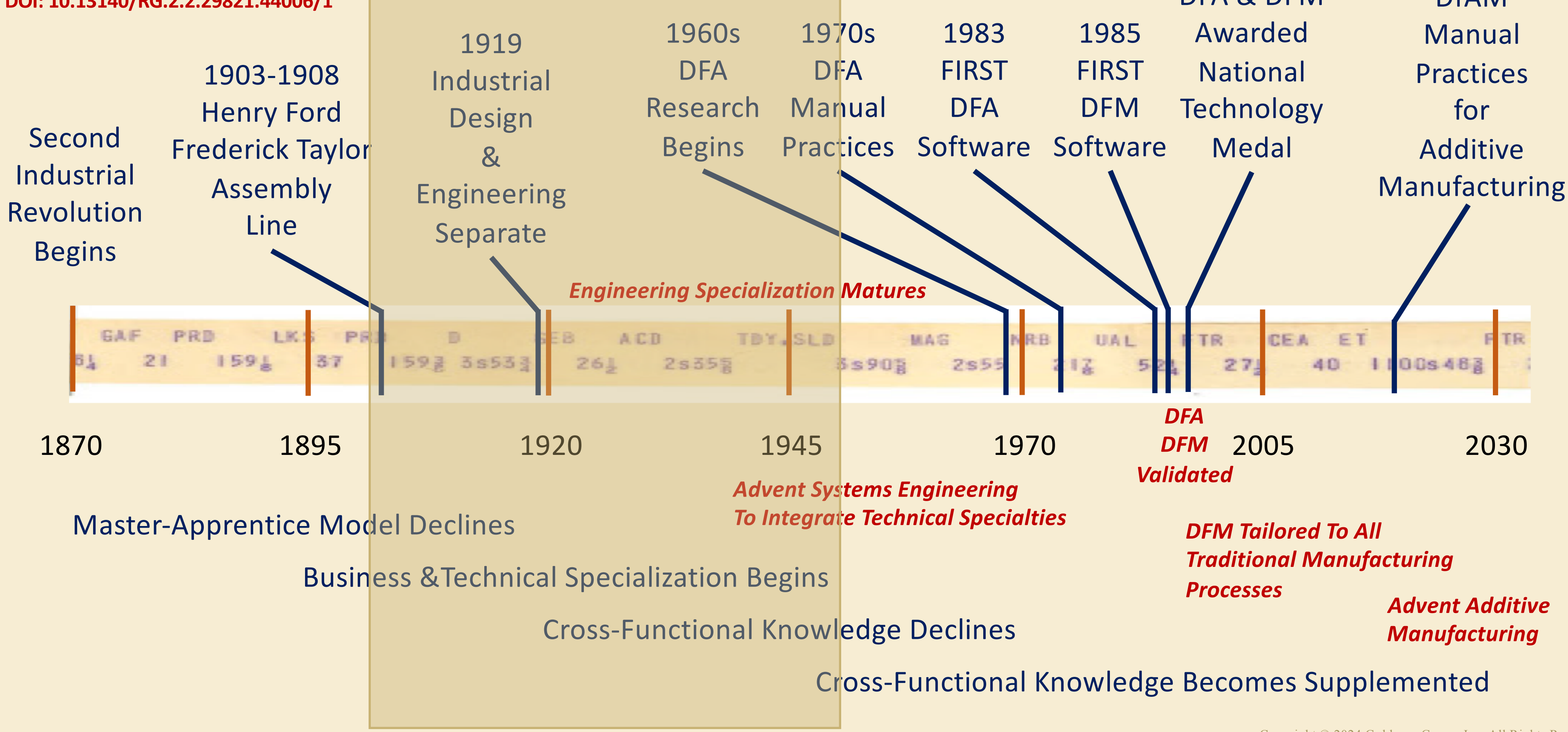
3rd Industrial Revolution - Part I: Technical, Functional, Process, & Job Specialization Matures [I Do This]

THE EVOLUTION OF DESIGN FOR MANUFACTURING & ASSEMBLY

DOI: 10.13140/RG.2.2.29821.44006/1



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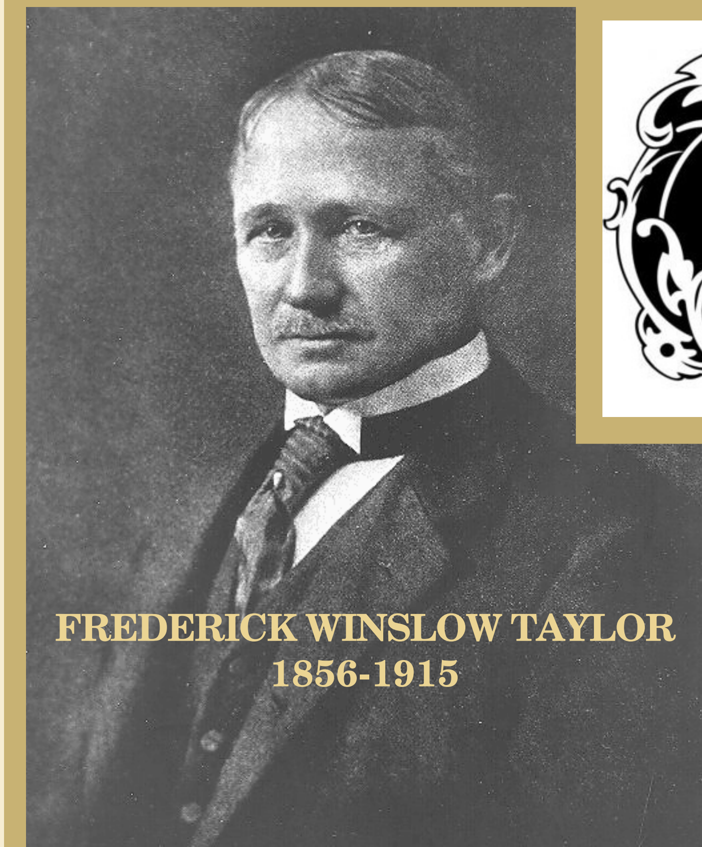
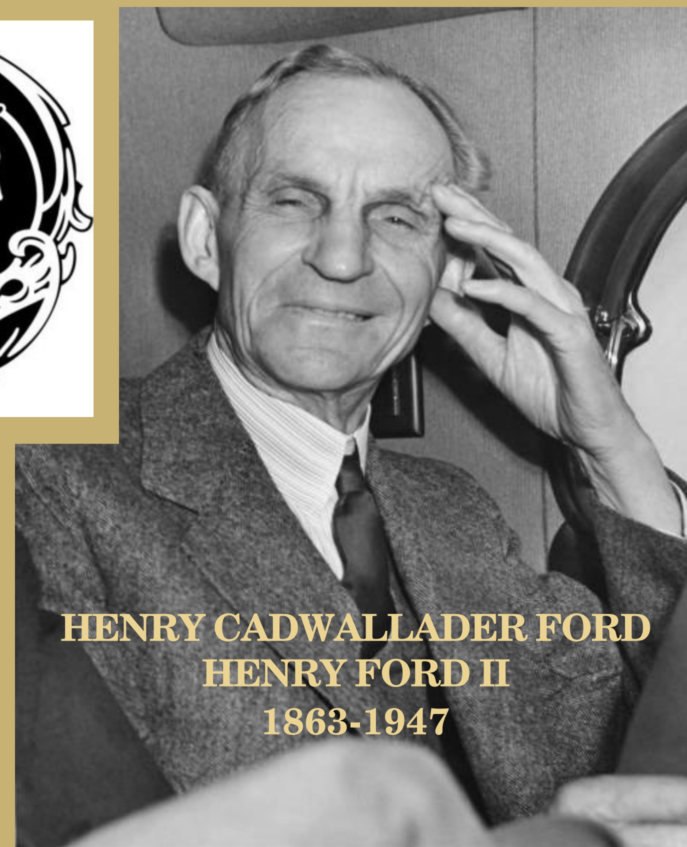
3rd Industrial Revolution - Part I: Two Visionaries Join Forces & All Heck Breaks Loose



FREDERICK WINSLOW TAYLOR
1856-1915

FORD MOTOR CO.
DETROIT,
MICH.



HENRY CADWALLADER FORD
HENRY FORD II
1863-1947

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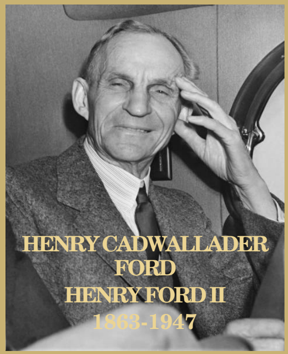
3rd Industrial Revolution - Part I: Ford Spawns an Explosion of Design and Manufacturing Capabilities



In his early 20s, he **built himself a small tractor** to help him on his father's farm. He then **built a steam engine** to power the tractor.

In December of **1893**, he built his first horseless carriage called the "**Quadricycle**."

Henry Ford saved his longtime friend and mentor Thomas Edison's last breath in a test tube. The test tube can be found in the Henry Ford Museum.

He developed a kind of mass production method that reduced the man hours on the factory floor tremendously. **In 1913, his company was the first to develop a moving assembly line for cars.** The technique was first deployed at a new plant in Highland Park, Michigan.

By 1914, Ford's mass production methods allowed the company to **93 man-minutes, down from 12.5 man-hours.** The moving assembly line allowed for Ford to implement a three-shift day. That in turn **increased the productivity tremendously**. By 1920, Ford was producing about one million cars a year, up from about 40,000 a decade prior.

Ford deployed moving assembly line technique of production that allows for items to move at a predetermined pace from one workstation to another until the final product is fully assembled. It's been said that Ford **divided the manufacturing process of the Model T into 45 steps.**

Ford made cars affordable.. It's been estimated that over **15 million Model T cars were produced**. At those figures, the Model T held a **50% market share of the American automobile industry by 1918**.

Source: World History Edu: https://worldhistoryedu.com/henry-fords-greatest-achievements-and-inventions/.

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3rd Industrial Revolution - Part I: Management Approaches & Worker Procedures Changed

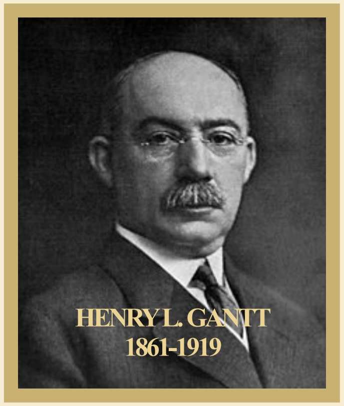


Image Credit: Wikipedia.

The Creator of the Gantt Chart - Circa 1910-1915

One of the earliest members of the Scientific Management community to direct his efforts toward the human being in industry. "In all the problems of management," he wrote, "the human element is the most important one."

His first original contribution was the "task and bonus" system of wages which he presented at ASME in 1901.

Gantt's next contribution was was to evolve graphic charts for production control. The "Daily Balance Sheet," forerunner of his better known Gantt Chart, was to give a picture of the prior day's work by noon the following day to facilitate continuous preplanning of production.

The final evolution, the Gantt Chart, was revolutionary at the time as it **changed production planning from being quantity-based to being time based**.

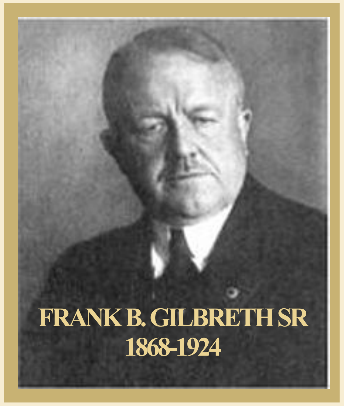


Image Credit: Wikipedia.

The Pioneer of Time & Motion Studies - Circa 1912-1924

Scientific Management, as Taylor and Gantt developed it, was a series of principles for analyzing the routines and procedures of workers on the job.

His first contribution was to develop lines of authority and responsibilities of each worker's job – Job Descriptions.

His unique contribution was on human efforts and the methods he devised for fleshing-out wasteful and unproductive movements. There was "one best way to do the work." If it could be discovered, it would add significantly to the gains Taylor was making in the overall system of management at a next levels of refinement.

He was the first to apply a motion-picture camera for analysis, and the **first to classify the elements of human motions. Gilbreth reduced all motions of the hand into some combination of 17 basic motions.**

Source: Urwick, Lyndall F. & Wolf, William B., *The Golden Book Of Management,* American Management Associations, New York, NY, USA, Expanded Edition, Copyright © 1956, 1984, Pages 95-98 [Gantt] and Pages 136-140 [Gilbreth].

Design for Manufacturing & Assembly Across Three Industrial Revolutions

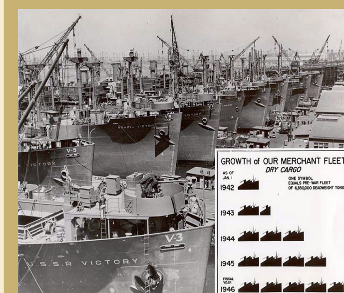
3rd Industrial Revolution - Part I: WWII Further Accelerates Everything Involving Products & Processes

During World War II, the United States created an intricate system for marshaling resources, designing and manufacturing weapons, and then getting them to the battlegrounds where they were needed. The system involved an extensive network of organizations and agencies, some of which had existed before the war and others that were created specifically for wartime. The network handled different aspects of the planning, research, financing, design, and production of weaponry. Concerns included converting existing factories to wartime production, constructing new ones, allocating and distributing raw materials, and devising techniques to improve design quality, such as operations research, ergonomics, and systems theory. Unskilled and semi-skilled workers had to be trained to produce war material, and then military personnel had to learn how to use it, thus fostering a vast training operation with new methods of instruction.

In addition, planning for the production of weaponry had to be integrated with military strategy. Thus, coordination was required between military planners, the organizations that did research on new weapons, and the factories or shipyards that produced them.[2] Research often led to innovative weapons that did not fit conventional strategic formulations but nonetheless had to be incorporated into new tactical plans. For the first time, scientists worked alongside engineers and designers, resulting in an enormous number of new devices, machines, and even systems for developing technology and managing production.

The key to U.S. mobilization was this coordinated effort. Major innovations in management strategy were required to keep track of a process whose complexity was unprecedented. No single system existed to ensure the effective management of the U.S. government's research, development, and manufacturing activities during the war. Nevertheless, success was achieved through a combination of related subsystems, as well as communication networks that involved government and military officials.

December 7,1941 – August 15, 1945
Pearl Harbor **V-J Day**



GAME-CHANGING INVENTIONS

1. Radar
2. Electronic Computers
3. Penicillin
4. Atomic Weapons
5. Jet Engines
6. Synthetic Rubber and Fuel
7. The Jeep
8. Duct Tape
9. Superglue
10. Microwave Ovens
11. Pressurized Cabins
12. Rocket Technology

Source: "12 Game-Changing Inventions and Innovations of World War II," History Tools, May 26, 2024,

https://www.historytools.org/stories/12-game-changing-inventions-and-innovations-of-world-war-ii.

Source: Margolin, Victor, "*The United States in World War II: Scientists, Engineers, Designers*," MIT Press, Vol. 29, No. 1 (Winter 2013), pp. 14-29,

Design for Manufacturing & Assembly Across Three Industrial Revolutions

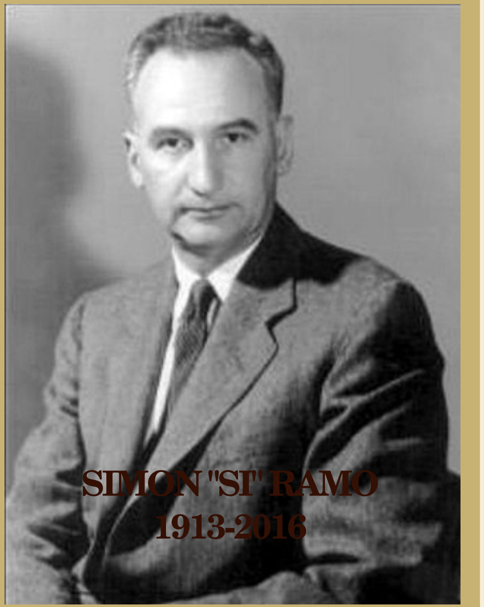
3rd Industrial Revolution - Part I: Systems Engineering – All Major Disciplines Achieve Specialization

The term systems engineering can be traced back to **Bell Telephone Laboratories in the 1940s**. The need to identify and manipulate the properties of a system as a whole, which in complex engineering projects may greatly differ from the sum of the parts' properties, motivated various industries, especially those developing systems for the U.S. military, to apply the discipline.

When it was no longer possible to rely on design evolution to improve upon a system and the existing tools were not sufficient to meet growing demands, new methods began to be developed that addressed the complexity directly. The continuing evolution of systems engineering comprises the development and identification of new methods and modeling techniques. These methods aid in a better comprehension of the design and developmental control of engineering systems as they grow more complex.

OPTIMIZATION TOOL SET

System architecture
System model, modeling,
Mathematical optimization
System dynamics
Systems analysis
Statistical analysis
Reliability engineering
Decision making



Simon "Si" Ramo was an American engineer, businessman, and author. He led development of microwave and missile technology and is sometimes known as the father of the intercontinental ballistic missile (ICBM). He also developed General Electric's electron microscope. He played prominent roles in the formation of two Fortune 500 companies, Ramo-Wooldridge (TRW after 1958, now part of Northrop Grumman) and Bunker Ramo Corporation (now part of Honeywell).

Source: Wikipedia: https://en.wikipedia.org/wiki/Systems_engineering, https://en.wikipedia.org/wiki/Simon_Ramo.

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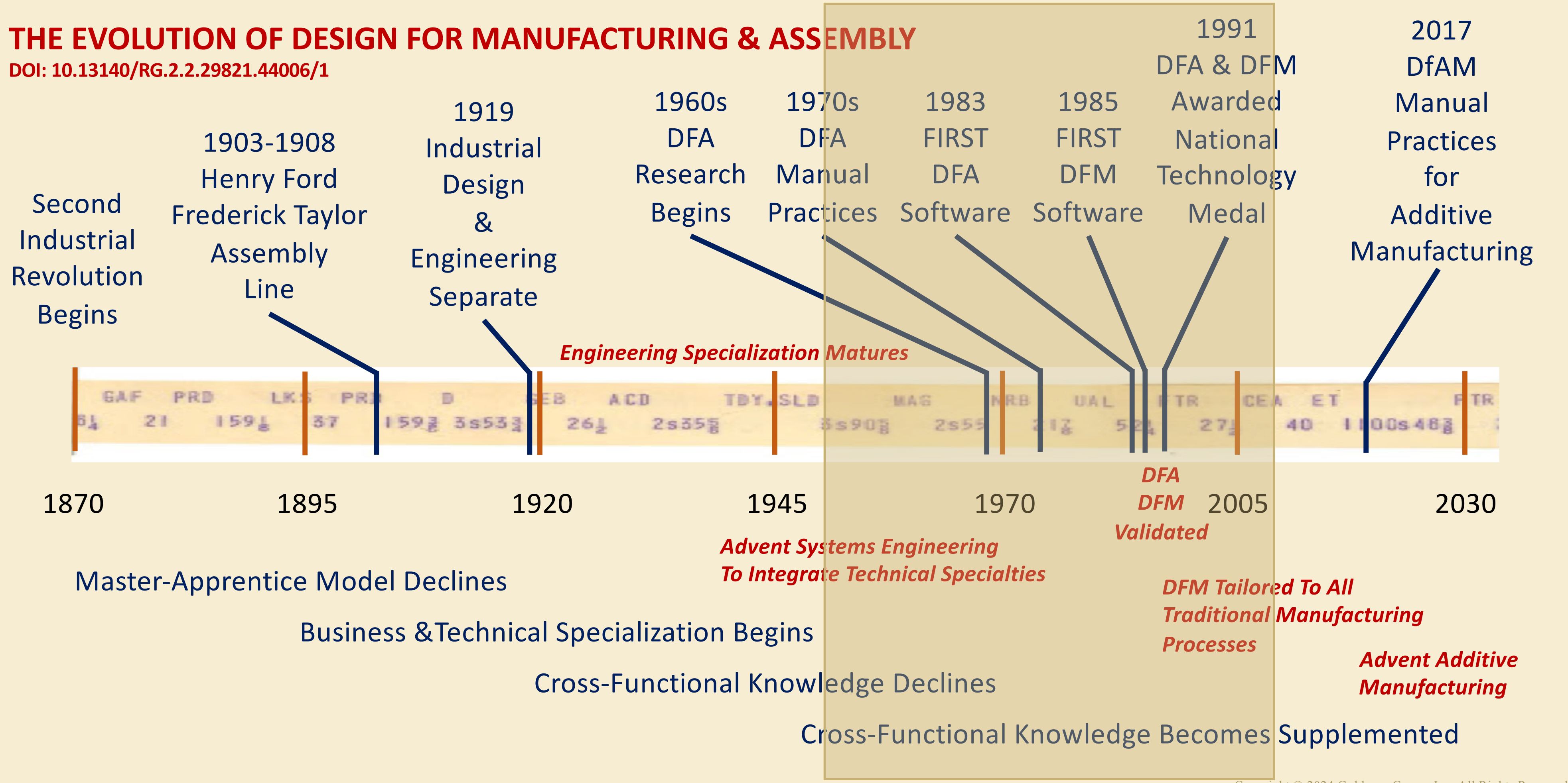

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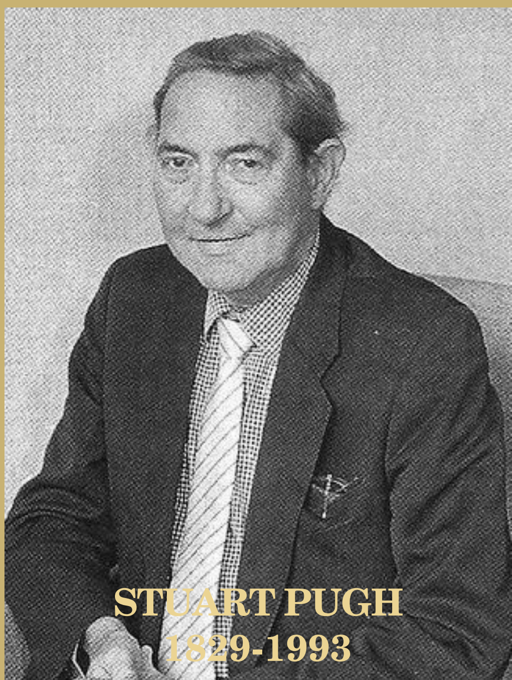
3rd Industrial Revolution - Part II: Robust Design Started In England & Bloomed In Scotland



Stuart Pugh **graduated from London University** with a degree in Mechanical Engineering and became a graduate apprentice for the British Aircraft Corporation. In **1956 he worked in the Warton Aerodrome** as a project engineer for the Mach 6 Wind Tunnel. In **1963** he became the **Chief Designer** of the Mechanical Product Division at the **Marconi Company**. In the later stages of his industrial career, Pugh worked within the **English Electric Company as Chief Designe**r in the Hydraulic Equipment Division, ultimately progressing to become Divisional Manager.

Pugh left industry in 1970 and began his academic career as a 'Smallpeice' Reader in **Design for Production at Loughborough University of Technology**. Later, he became the Director of the 'Engineering Design Centre'.

Pugh **moved to Scotland and in 1985** became the '**Babcock Professor** of Engineering Design' and the head of the 'Design Division' at the **University of Strathclyde in Glasgow**. The Design Division merged in **1989** with the Department of Production Management and Manufacturing Technology to create the Department of Design, Manufacture and Engineering Management **(DMEM)**, of which Pugh remained head until his **death in 1993**. It was here that Pugh produced his **seminal book, 'Total Design**: Integrated Methods for Successful Product Engineering', published in 1990. Pugh Introduced and taught Total Design across the faculty of engineering at Strathclyde University.

Soon after Pugh published his book 'Total Design', Professor Don Clausing (MIT) and Professor Ken Ragsdell (University of Missouri) encouraged Pugh to publish his collection of papers to make his work readily available to design engineers and managers. However, Pugh's untimely death from illness ultimately led **Don Clausing and Ronaldo Andrade (Universidade Federal de Rio de Janeiro, Brazil) to complete Pugh's book 'Creating Innovative Products Using Total Design: The Living Legacy of Stuart Pugh'**.

Source: Wikipedia: https://en.wikipedia.org/wiki/Stuart_Pugh.

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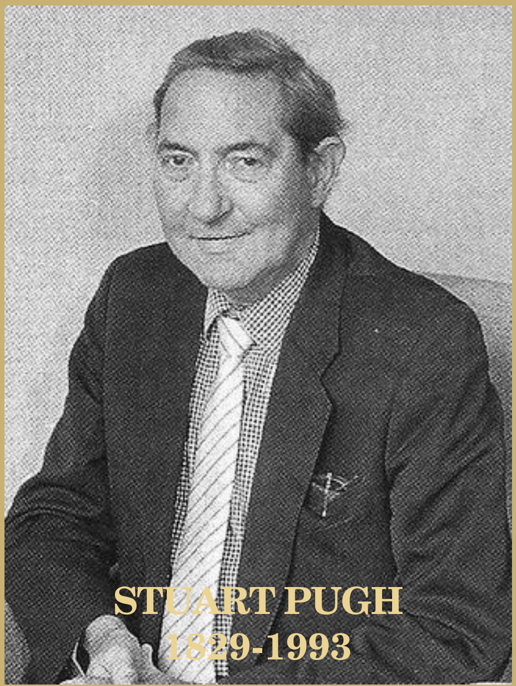
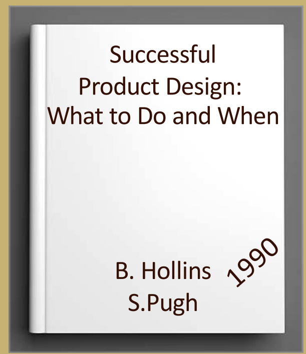
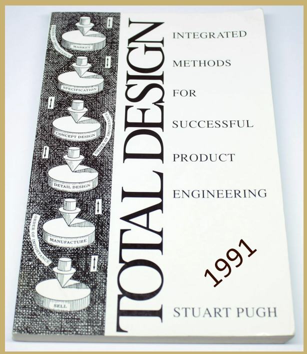
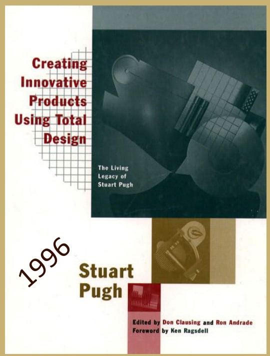
3rd Industrial Revolution - Part II: The Bloom Was Exceptional But Short Lived – Pugh Passed Suddenly









Stuart Pugh, Don Clausing, Ron Andrade, (24 April 1996). Creating Innovative Products Using Total Design. Addison Wesley Longman. ISBN 0-201-63485-6

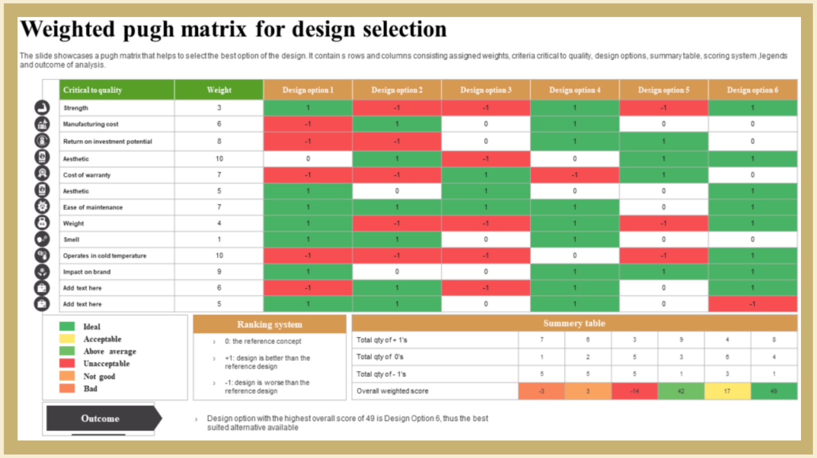
Pugh, S. (February 1991). Total Design: Integrated Methods for Successful Product Engineering. Addison-Wesley. ISBN 0-201-41639-5

S.Pugh, B.Hollins, (March 1990). Successful Product Design: What to Do and When. Butterworth-Heinemann. ISBN 0-408-03861-6

Concept Selection – Method of Controlled Convergence

Pugh's most famous work, "Concept Selection – A Method that Works",[4] describes Pugh's innovative 'controlled convergence' technique that was put to the test so successfully for **General Motors' Saturn** project.

Identification of Under-Served Market Segments Plotting Method



Weighted pugh matrix for design selection

The slide showcases a pugh matrix that helps to select the best option of the design. It contain s rows and columns consisting assigned weights, criteria critical to quality, design options, summary table, scoring system ,legends and outcome of analysis.

Critical to quality	Weight	Design option 1	Design option 2	Design option 3	Design option 4	Design option 5	Design option 6
Strength	3	1	-1	-1	1	-1	1
Manufacturing cost	6	-1	1	0	1	0	0
Return on investment potential	8	-1	-1	0	1	1	0
Aesthetic	10	0	1	-1	0	1	1
Cost of warranty	7	-1	-1	1	-1	1	0
Aesthetic	5	1	0	1	0	0	1
Ease of maintenance	7	1	1	1	1	0	1
Weight	4	1	-1	-1	1	-1	1
Smell	1	1	1	0	1	0	0
Operates in cold temperature	10	-1	-1	-1	0	-1	1
Impact on brand	9	1	0	0	1	1	1
Add text here	6	-1	1	-1	1	0	1
Add text here	5	1	1	0	1	0	-1

Ideal
Acceptable
Above average
Unacceptable
Not good
Bad

Ranking system

- 0: the reference concept
- +1: design is better than the reference design
- -1: design is worse than the reference design

Summery table

Total qty of + 1's	7	6	3	9	4	8
Total qty of 0's	1	2	5	3	6	4
Total qty of - 1's	5	5	5	1	3	1
Overall weighted score	-3	3	-14	42	17	49

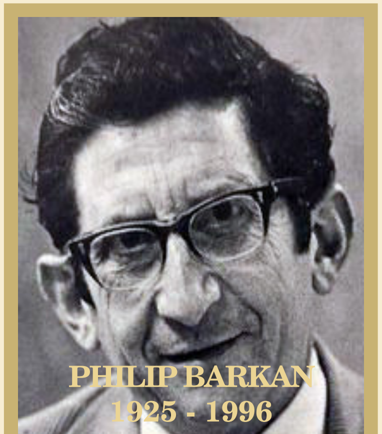
Outcome

- Design option with the highest overall score of 49 is Design Option 6, thus the best suited alternative available

Source: Wikipedia: https://en.wikipedia.org/wiki/Stuart_Pugh. SlideTeam: https://www.slideteam.net/blog/top-7-pugh-matrix-templates-with-samples-and-examples.

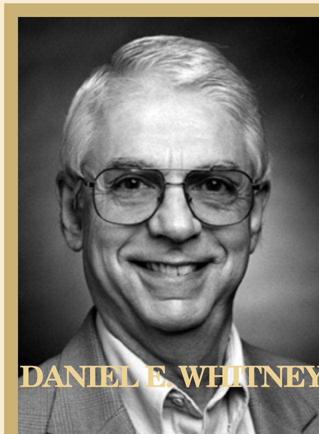
Design for Manufacturing & Assembly Across Three Industrial Revolutions

3rd Industrial Revolution - Part II: Design Producibility Was A Hot Topic – MIT & Stanford



DFMA Index
Design for Manufacturability Curriculum
The Importance of Product Planning
Integrated Use of Formal Design Methodologies
Early Six Sigma Champion

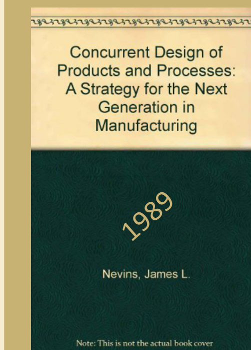
B.S., Tufts University, 1946
M.S., University of Michigan, 1948
Ph.D., Pennsylvania State University, 1953
US Navy
General Electric Engineering & Quality, 53 Patents
Israel Institute of Technology, 1971-1972
IEEE Fellow, 1972
Recruited-In Full Professor, Stanford, 1977
National Academy of Engineering, 1980
Confidential Consultant to Motorola

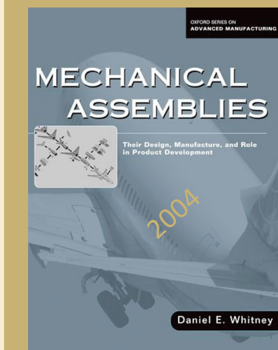


DFA & Automated Assembly
Computerized Assembly
Mechanical Assembly
Design for Automation
Computers in the Product Development Process
Complex Systems & Networks
Robotics

Research Gate
158 Publications

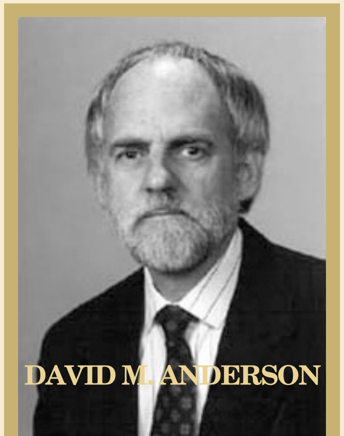
Ph.D., MIT, 1968
Professor, MIT, 1968-1974
Section Chief, Draper Laboratories, 1974-1993





Design for Manufacturing & Assembly Across Three Industrial Revolutions

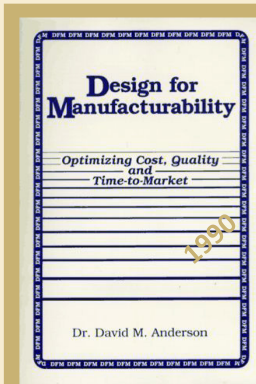
3rd Industrial Revolution - Part II: Design Producibility Was A Hot Topic – UC Berkeley, Swansea Univ.

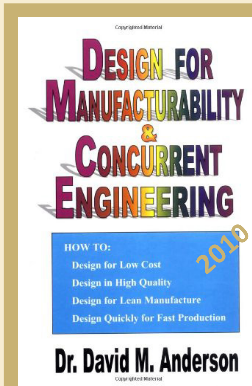


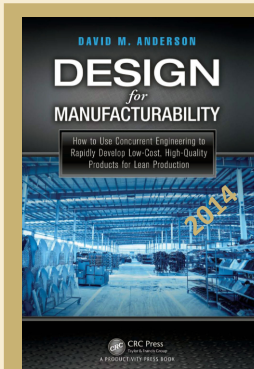
Design for Manufacturability
Concurrent Engineering

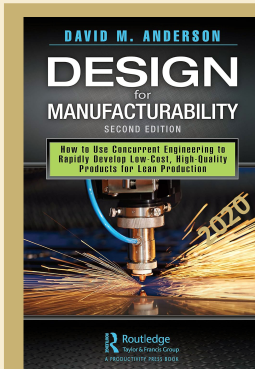
http://design4manufacturability.com

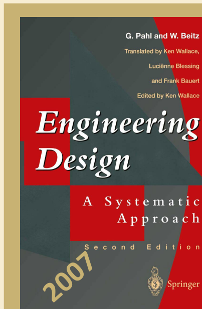
Ph.D., Mechanical Engineering, UC Berkeley
Professional Engineer, PE, Industrial Engineering
Professional Engineer, PE, Mechanical Engineering
Professional Engineer, PE, Manufacturing Engineering
Anderson Automation, Inc., 1977-1983
Certified Management Consultant, CMC, 1992-2023
Fellow of ASME, FASME
Life Member in SME, LSME











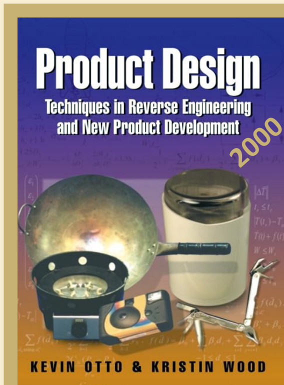
Translate & Edit
Seminal Work
By
Gerhard Pahl
Wolfgang Beitz

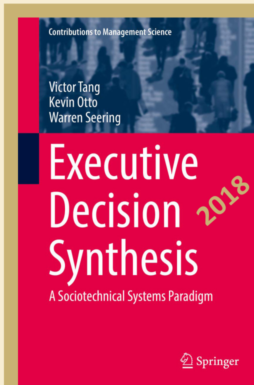
Enter, Brentwood School & RAF Cadets, 1958
Pilot's License, Age 17, 1961
Apprentice, Rolls-Royce Aero Engines, 1962-1963
Apprentice, Flugzeug-Union-Süd, 1964-1965
Sc.B., Swansea University, 1967
Aero Engines, Rolls Royce, 1967-1971
Fellow, Swansea University, 1978
Pilkington Teaching Prize, 1994
ASME Outstanding Design Educator Award, 2001;
Black Award, Innovation in Design Education, 2002
Fellow, Institution of Mechanical Engineers, 1991
Fellow, Smallpeice Trust, 1994
Fellow, Institution of Engineering Designers; 1994
Fellow, Royal Academy of Engineering, 1999
Honorary Fellow, Design Society, 2007
Honorary Doctorate, Brunel University, 2011

Design for Manufacturing & Assembly Across Three Industrial Revolutions

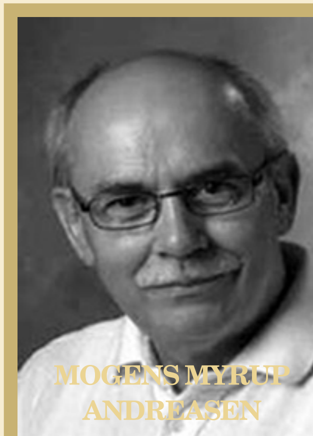
3rd Industrial Revolution - Part II: Design Producibility Was A Hot Topic – MIT, University of Denmark

Reverse Engineering
Designing In Uncertainty

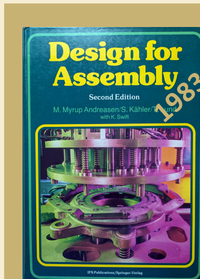




University of MN, 1983-1985
Ph.D., Caltech, 1988-1992
Professor, MIT, 1992-2001
VP, Product Genesis, 2001-2004
Associate Professor, Singapore University of Technology & Design, 2012-2015
Professor of Practice, Aalto University, 2015-2021
Professor, Mechanical Engineering, University of Melbourne, 2021-Present
President & CEO, Robust Systems & Strategy, 2004-Present



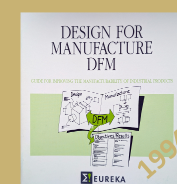
The Design Process
Design for Assembly



Seven Step DFM

Intro by Mogens

Thought Leader Pamphlet

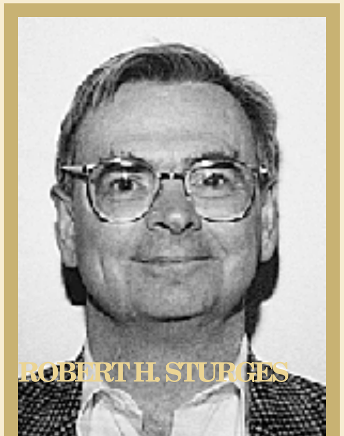


by FINN FABRICIUS

Professor, University of Denmark, 1998
Professor Emeritus, University of Denmark, 2007

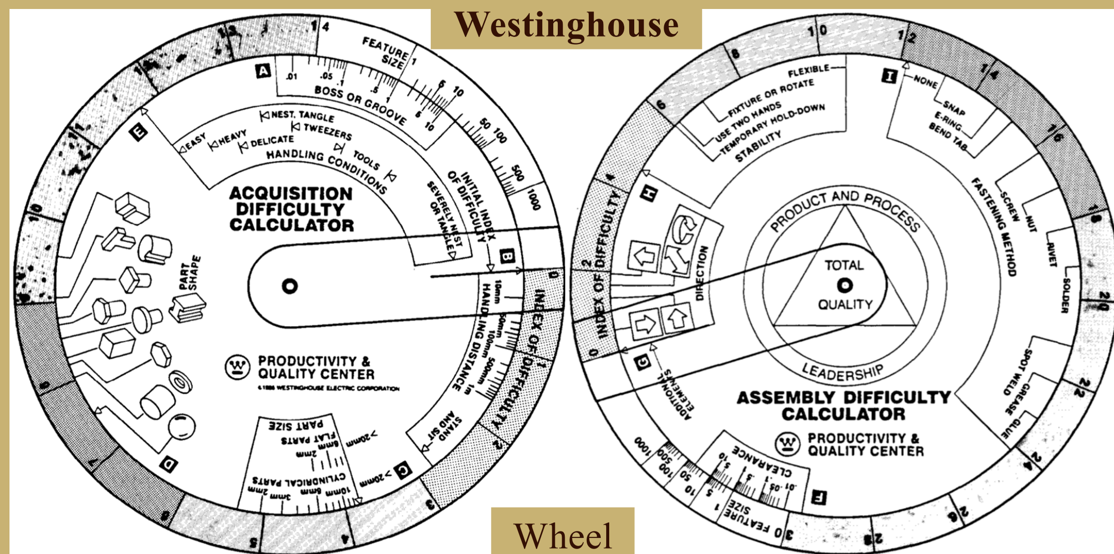
Design for Manufacturing & Assembly Across Three Industrial Revolutions

3rd Industrial Revolution - Part II: Design Producibility Was A Hot Topic – Carnegie Mellon



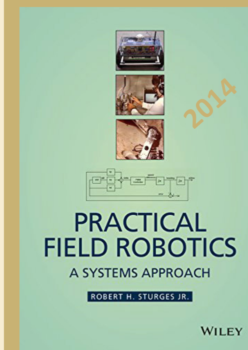
Design for Assembly
Fastenerless Assembly

Westinghouse



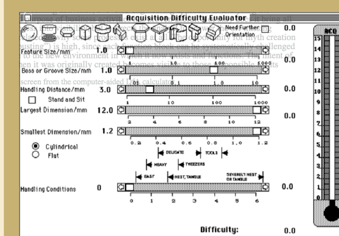
Wheel

Source: Sturges, Robert H. Jr., "*A Quantification of Manual Dexterity: The Design for an Assembly Calculator*," Robotics & Computer-Integrated Manufacturing, Pergamon Press plc, Vol. 6, No. 3, pp. 237 252, 1989.



B.S., MIT
M.S., MIT
Ph.D., Carnegie Mellon University
Professor, Carnegie Mellon
Professor, University of Virginia
Patents = 14

Computer-Aided DFA Calculator



Source: Sturges, Robert H. Jr., "*Practical Field Robotics*," Wiley Online Library, Appendix A, Page 154.

Design for Manufacturing & Assembly Across Three Industrial Revolutions

3rd Industrial Revolution - Part II: Industry Leaders Jump On Design Producibility – 1980s & 1990s

RCA
Price Systems

RCA Price Systems, 1973
GE Price Systems, 1986
Martin Marietta Price Systems, 1992
Lockheed Martin Price Systems, 1995
Price Systems LLC, 1998
Unison Acq. Price Systems LLC, 2021

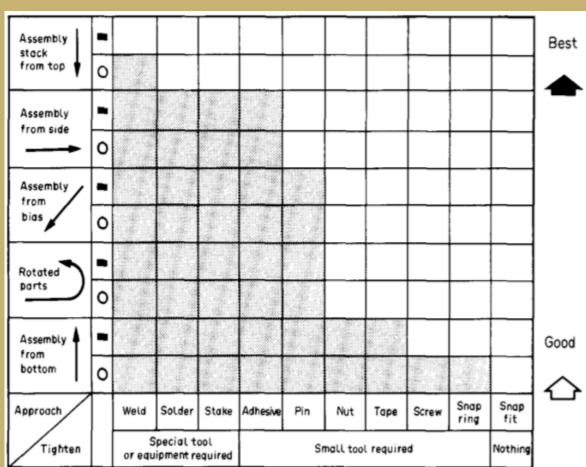
Sony
Design for Assembly/Disassembly Cost-effectiveness [DAC]

Hitachi
Assembly Evaluation Method [AEM]

IBM
ProPrinter 4201-001

Source: OpenMOV, "*IBM PCjr Proprinter XL dot matrix printer," openmov.museumofvancouver.ca,1986.*

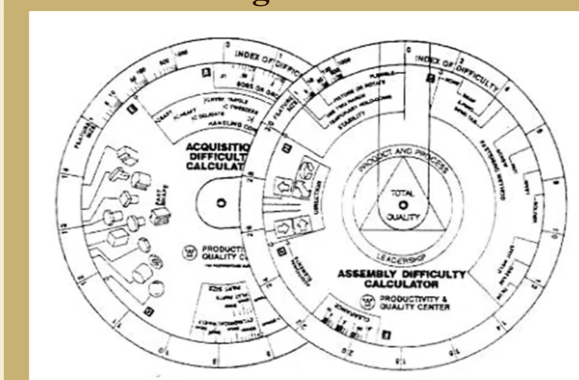
Xerox
Producibility Index Chart



Source: Sturges, Robert H. Jr., "*A Quantification of Manual Dexterity: The Design for an Assembly Calculator*," Robotics & Computer-Integrated Manufacturing, Pergamon Press plc, Vol. 6, No. 3, pp. 237 252, 1989.

Fujitsu
Productivity Evaluation Method [PEM]

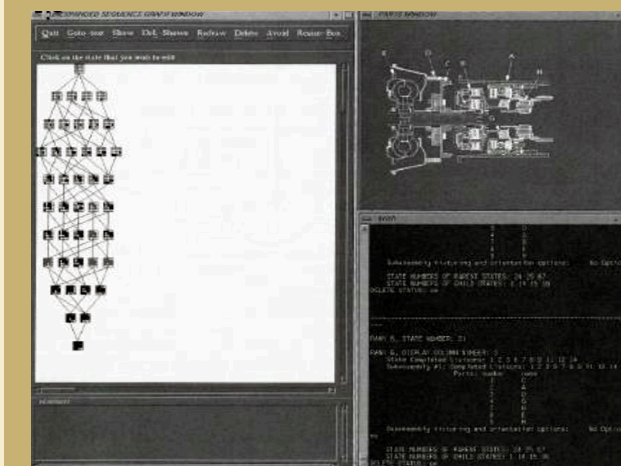
Westinghouse Wheel



The Westinghouse Wheel.

Source: Sturges, Robert H. Jr., "*A Quantification of Manual Dexterity: The Design for an Assembly Calculator*," Robotics & Computer-Integrated Manufacturing, Pergamon Press plc, Vol. 6, No. 3, pp. 237 252, 1989.

Draper Labs
Automated & Computerized Assembly

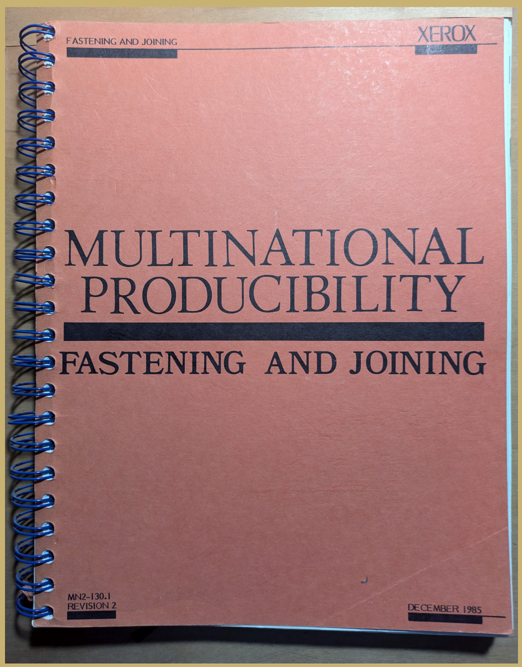


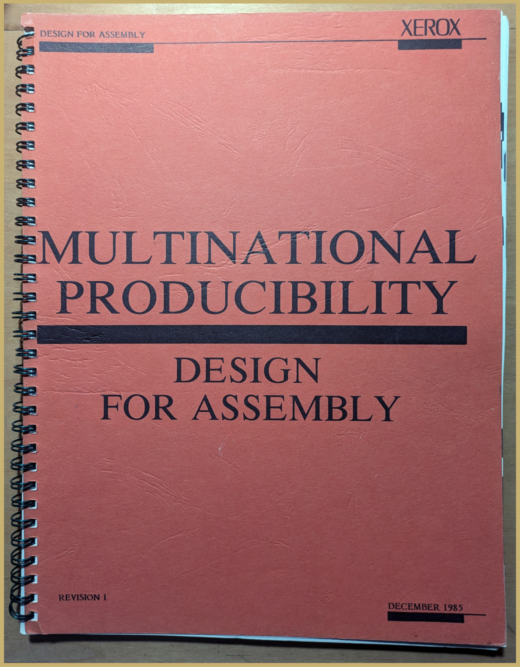
Source: Public domain.

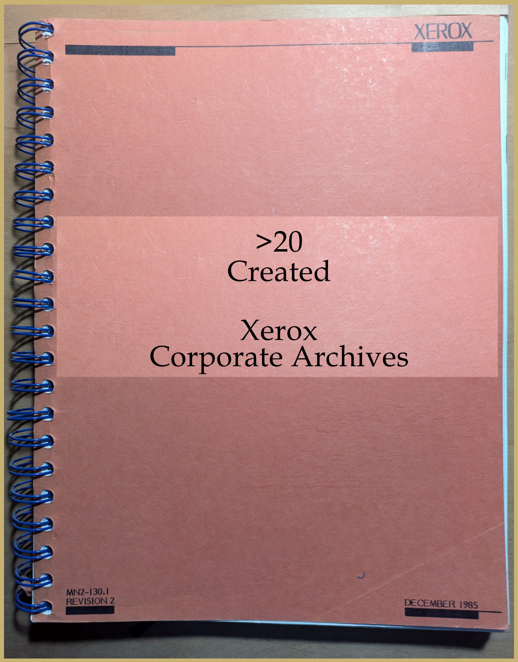
Design for Manufacturing & Assembly Across Three Industrial Revolutions

3rd Industrial Revolution - Part II: Industry Leaders Jump On Design Producibility – 1980s & 1990s

Xerox
Pumpkin Books





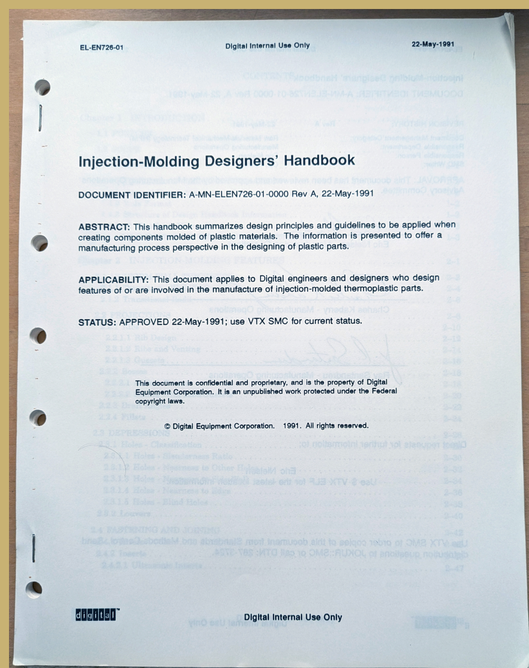


Source: The original works were accessed using Journalistic Reporter's Privilege. Images are of the original 1985 published works of Xerox Corporation.

Design for Manufacturing & Assembly Across Three Industrial Revolutions

3rd Industrial Revolution - Part II: Industry Leaders Jump On Design Producibility – 1980s & 1990s

Digital Equipment Corporation
"DEC Standard 101"


EL-EN726-01 Digital Internal Use Only 22-May-1991

Injection-Molding Designers' Handbook

DOCUMENT IDENTIFIER: A-MN-ELEN726-01-0000 Rev A, 22-May-1991

ABSTRACT: This handbook summarizes design principles and guidelines to be applied when creating components molded of plastic materials. The information is presented to offer a manufacturing process perspective in the designing of plastic parts.

APPLICABILITY: This document applies to Digital engineers and designers who design features of or are involved in the manufacture of injection-molded thermoplastic parts.

STATUS: APPROVED 22-May-1991; use VTX SMC for current status.

This document is confidential and proprietary, and is the property of Digital Equipment Corporation. It is an unpublished work protected under the Federal copyright laws.

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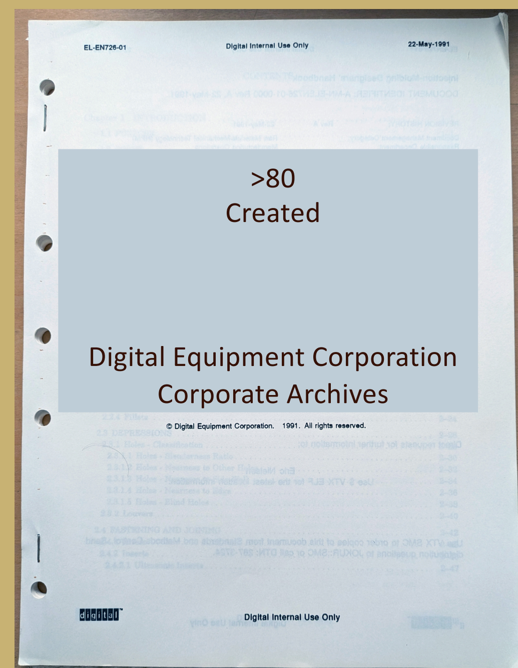
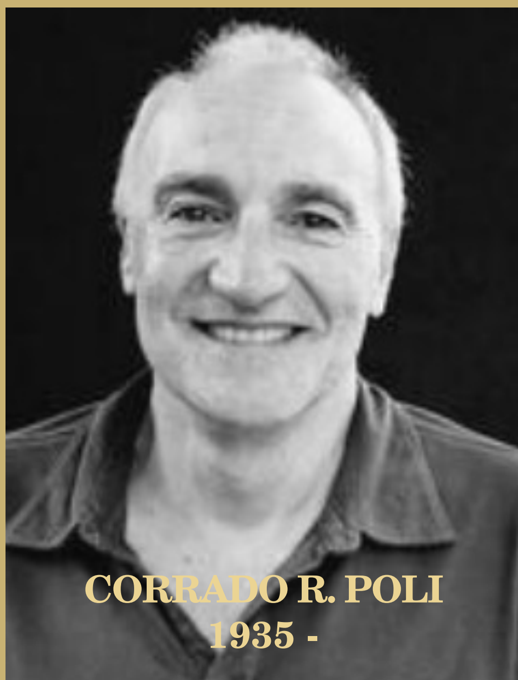
Digital Internal Use Only

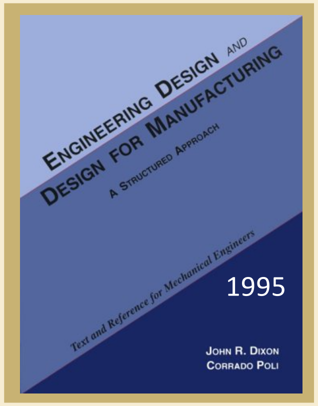


Source: The original works were accessed using Journalistic Reporter's Privilege. Images are of the original 1991 published works of Digital Equipment Corporation..

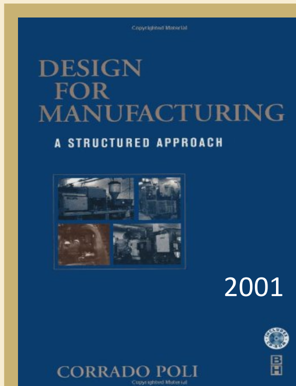
Design for Manufacturing & Assembly Across Three Industrial Revolutions

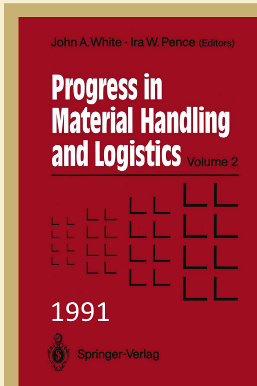
3rd Industrial Revolution - Part II: Design Producibility Was A Hot Topic – UMass Amherst





Research Gate
53 Publications





Research Gate
80 Publications

B.S., Renesselaer Polytechnic Institute, 1957
M.S., Renesselaer Polytechnic Institute, 1958
Ph.D., Ohio State, 1965
Dept. Head, Mechanical & Industrial Engineering, UMass Amherst

B.S., Syracuse University, 1967
M.S., SUNY Buffalo, 1969
Ph.D., SUNY Buffalo, 1974
Assoc. Professor, UMass Amherst, 1979-1980
Professor, RPI, 1991-2003
Professor, Dartmouth College, 2003-Present

Design for Manufacturing & Assembly Across Three Industrial Revolutions

3rd Industrial Revolution - Part II: Boothroyd Arrives With Disruptive Business & Technical Aspirations

Geoffrey Boothroyd was born in Radcliffe, Manchester, England on November 18, 1932. He obtained a Bachelor of Science in Engineering from the University of London in 1956, followed by a Doctor of Philosophy in 1962 and a Doctor of Science in 1974. Geoffrey Boothroyd, a renowned British educator and pioneer in the field of industrial and manufacturing engineering.

In **1967**, **Geoffrey moved to the United States** and became a member of the faculty at the **University of Massachusetts**, Amherst and later at the **University of Rhode Island**, residing for 28 years in Wakefield, RI.

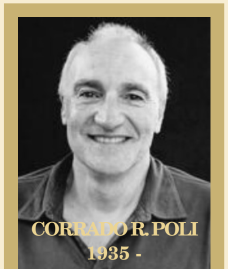
In addition to academia, Geoffrey **co-founded and served as the president of Boothroyd Dewhurst**, Inc. His work here was **instrumental in the development and popularization of Design for Manufacturing and Assembly** (DFMA®.)

The **DFMA** methodology helped achieve dramatic cost savings across a wide spectrum of global industries. His contributions to the field were recognized nationally when he was awarded the **National Medal of Science by President George H.W. Bush in 1991**, honoring his significant impact on manufacturing and engineering.

Source: https://www.dignitymemorial.com/obituaries/bradenton-fl/geoffrey-boothroyd-11611483

Design for Manufacturing & Assembly Across Three Industrial Revolutions

3rd Industrial Revolution - Part II: Design Producibility Was A Hot Topic – UMass Amherst



Research Gate
53 Publications

Design for Injection Molding: A Group-technology-based Approach, Dec 1991, Journal of Engineering Design

Design knowledge acquisition for DFM methodologies, Aug 1992, Research in Engineering Design

Design for Stamping—Analysis of Part Attributes that Impact Die Construction Costs for Metal Stamping, Nov 1993, Journal of Mechanical Design

Design for Stamping: A Group Technology-based Approach, Nov 1993, Concurrent Engineering Research and Applications

Research Gate
80 Publications

A

Handbook of Feeding & Orienting Techniques for Small Parts, 1970, Department of Mechanical Engineering, University of Massachusetts [**Seminal Work** – Boothroyd, Poli, and Laurence Murch Co-Authors]
[Handbook was also possibly republished in 1979? Unclear!]

Design for Economical Use of **Forging**: Indication of General Relative Forging Costs, Dec 1982, CIRP Annals [Boothroyd & Knight Co-Authors]

How **part design affects injection molding tool cost**s, Jan 1988, Machine Design

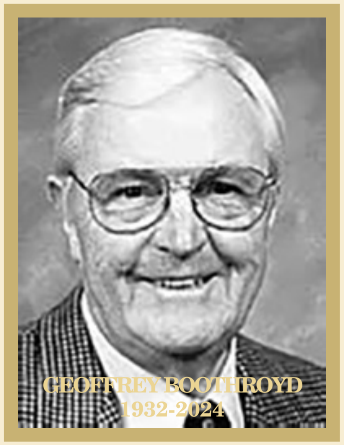
To Injection Mold, to Stamp, or to Assemble? A **DFM Cost Perspective**, Dec 1999, Journal of Mechanical Design

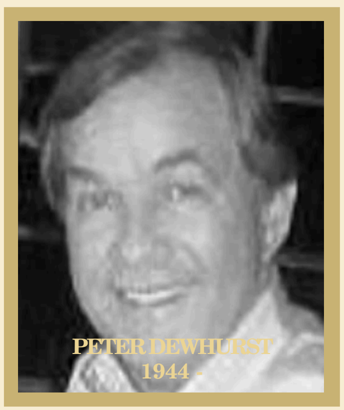
Designing New Products: **Compatibility** with Existing Production Facilities and Anticipated Product Mix, Nov 1994, Integrated Manufacturing Systems

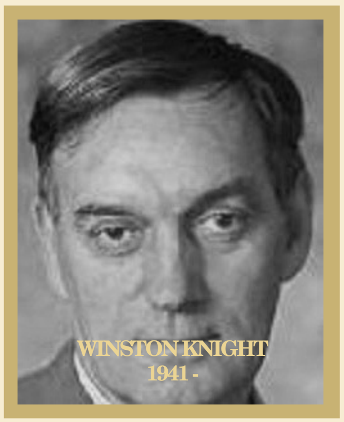
The **Compatibility** of Product Quality and Process Flexibility, Dec 1994, Quality Engineering

Design for Manufacturing & Assembly Across Three Industrial Revolutions

3rd Industrial Revolution - Part II: NSF Underpins BDI's Work - 10 NSF Grants 1974-1990 = $2,184,788.00







1. **Group Technology Applied to the Automatic Handling of Small Parts**
Award Number:7412611; Principal Investigator:Geoffrey **Boothroyd**; Co-Principal Investigator:; Organization:University of Massachusetts **Amherst**;NSF Organization:CMMI Start **Date: 07/01/1974**; Award Amount:**$372,300.00**;

2. **Fifth North American Metalworking Research Conference (Namrc-V)**
Award Number:7710189; Principal Investigator:Geoffrey **Boothroyd**; Co-Principal Investigator:; Organization:University of Massachusetts **Amherst**;NSF Organization:CMMI Start **Date: 05/15/1977**; Award Amount:**$3,000.00**;

3. **Design For Manufacturability**
Award Number:7710197; Principal Investigator:Geoffrey **Boothroyd**; Co-Principal Investigator:; Organization:University of Massachusetts **Amherst**;NSF Organization:CMMI Start **Date: 09/01/1977**; Award Amount:**$396,000.00**;

4. **Design For Manufacturability**
Award Number:7909761; Principal Investigator:Geoffrey **Boothroyd**; Co-Principal Investigator:; Organization:University of Massachusetts **Amherst**;NSF Organization:CMMI Start **Date: 09/01/1979**; Award Amount:**$150,000.00**;

5. **Workshop on Assembly and Inspection**
Award Number:8115036; Principal Investigator:Geoffrey **Boothroyd**; Co-Principal Investigator:; Organization:University of Massachusetts **Amherst**;NSF Organization:CMMI Start **Date: 05/15/1981**; Award Amount:**$5,525.00**;

6. **Economic Applications of Assembly Robots**
Award Number:8111917; Principal Investigator:Geoffrey **Boothroyd**; Co-Principal Investigator:; Organization:University of Massachusetts **Amherst**;NSF Organization:CMMI Start **Date: 09/01/1981**; Award Amount:**$361,425.00**;

7. **Economic Applications of Assembly Robots**
Award Number:8514024; Principal Investigator:Geoffrey **Boothroyd**; Co-Principal Investigator:Peter **Dewhurst**; Organization:University of **Rhode Island;**NSF Organization:CMMI Start **Date: 09/15/1985**; Award Amount:**$114,300.00**;

8. **Programmable Automation and Design for Manufacturing Economic Analysis**
Award Number:8513930; Principal Investigator:Franklin **Snyder**; Co-Principal Investigator:Peter **Dewhurst**, Geoffrey **Boothroyd**, Phillip **Ostwald**, Jeffrey **Funk**; Organization:**Westinghouse R&D Center;**NSF Organization:CMMI Start **Date: 09/15/1986**; Award Amount:**$488,543.00**;

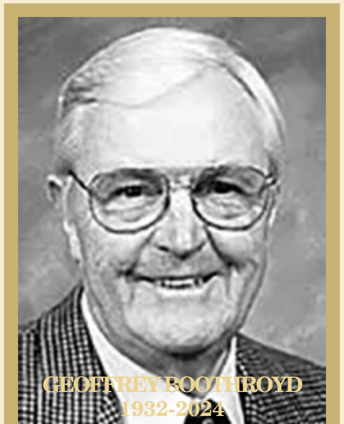
9. **Selection of Manufacturing Processes and Materials for Component Parts**
Award Number:8908214; Principal Investigator:Geoffrey Boothroyd; Co-Principal Investigator:Winston **Knight**, Peter **Dewhurst**; Organization:University of **Rhode Island**;NSF Organization:CMMI Start **Date: 12/15/1989**; Award Amount:**$279,995.00**;

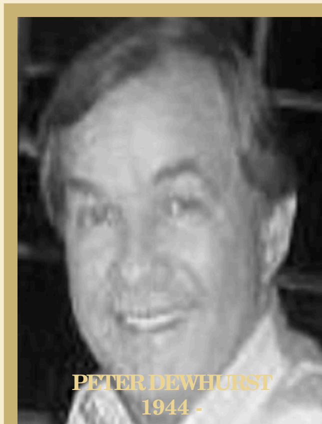
10. **Design for Manufacturability and Assemblability Instructional Studio**
Award Number:9051268; Principal Investigator:B. Lee **Tuttle**; Co-Principal Investigator:; Organization:**Kettering University**;NSF Organization:DUE Start **Date: 05/01/1990**; Award Amount:**$43,740.00**;

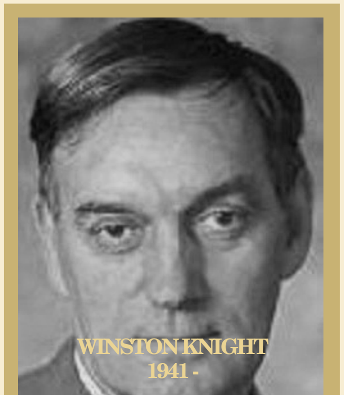
Source: National Science Foundation, https://www.nsf.gov/, Award Search.

Design for Manufacturing & Assembly Across Three Industrial Revolutions

3rd Industrial Revolution - Part II: BDI Disrupts With New-To-The-World Offerings & Industry-Firsts



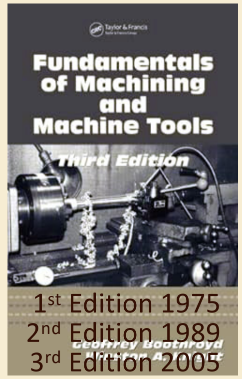


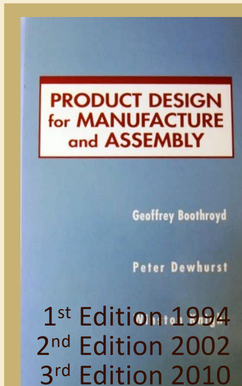


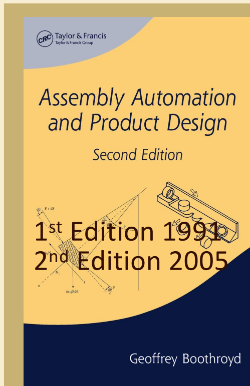
Seminal Works 1970-1981
- *Handbook w/ Poli, 1970*
- *Coding Scheme w/ Ho, 1976*

Company Forms, 1980
- *NSF Final Report, 1981*

First DFA Software, 1983
First DFM Software, 1985
National Medal of Honor, 1991
DFMA® Trademark, 1993
850 Corporate Users, 2020







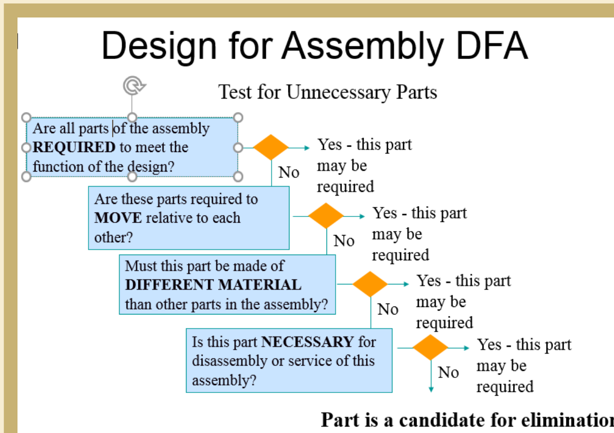
Industry Firsts

Created Theoretical Minimum Part Count Now Industry Standard

Formula for "Design Efficiency"

First DFA Software
First DFM Software

Expanded DFMs Across Part Types & Processes



Early Corporate Sponsors

Initial	Additional
AMP Digital Equipment Navistar Xerox Motorola Loctite Dupont Chrysler Ford	Ford General Motors John Deere

Source: Meeker, David G., BDI 30th Anniversary Conference, June 1-2, 2015.

Design for Manufacturing & Assembly Across Three Industrial Revolutions

3rd Industrial Revolution - Part II: BDI Evolves Original Data Sets To Defensible Proprietary Assets

SEMINAL WORKS

1970 - 1981

Boothroyd, G., Poli, C.R., and Murch, L.E., ***Handbook of Feeding and Orienting Techniques for Small Parts***, University of Massachusetts, Amherst, MA, **1970**.

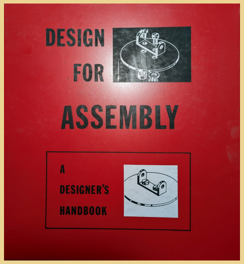
A

Boothroyd, G. and Ho, C., ***Coding System for Small Parts for Automatic Handling***, SME Paper ADR76-13, Assemblex 111. Chicago, October **1976**.

Boothroyd, G and Wilson, W.R.D., **Design for Manufacturability**, NSF Final Report. University of Massachusetts, Amherst, MA, **1981**.

RED BOOK

Copyright
1983



The development of portions of this handbook was carried out in collaboration with the **University of Salford Industrial Center**, England (General Manager, B.D. Richardson, Project Managers K.C. Swift and A. H Redford).

The work was mainly funded by NSF Grant APR77-10197. Additional financial support for this work has been provided by **AMP**, Inc. and **Xerox** Corp.

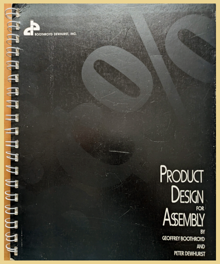
Finally, the authors would like to thank **Alan Redford** for his helpful comments and the following individuals and companies (in alphabetical order) for their suggestions, financial support and continued encouragement: **AMP**, Inc. (Joe Sweeney and Ed Paukovitz); **Digital Equipment** Corp. (DoM Sambuto and Fred Kuenzig); **Emhart** Corp. (Gene Chartrand); **GE** Co. (Gerry Hock); **IBM** Corp. (Morris Krakinowski and Tim Karlberg); **Philips** (Jaap Boorsma); **Siemens** (J. Hauesler); **University of Salford Industrial Center** (Barry Richardson); Westinghouse Corp. (Tibor Csakvary); **Xerox** Corp. (SidneyLiebson).

WHITE BOOK

Copyright
1987

BLACK BOOK

Copyright
1983, 1987, 1989



Work leading to this product design for assembly handbook, including development of databases and research in **automatic and robot assembly**, was undertaken with the aid of grants from the National Science Foundation and from industry.

Original studies of the design for high-speed automatic assembly classification systems were carried out with the close collaboration of Dr. **Alan Redford** of the **University of Salford, England**.

We wish to thank all of those graduate students who have participated in our design for assembly research programs. We would also like to express our gratitude to the **NSF** and the following companies who provided grants to support the research. **AMP**, Inc., **Digital Equipment** Corp., **Ford** Motor Company, **General Electric** Company, **Gillette** Company, **IBM** Corporation, **Westinghouse** Electric Corporation, and **Xerox** Corporation. Finally, our appreciation is due to the numerous companies and individuals who have provided encouragement during the past 10 years. - G. Boothroyd and P. Dewhurst, Wakefield, RI, November 1989

Source: The original works were accessed using Journalistic Reporter's Privilege. Images are of the original published works of Boothroyd-Dewhurst, Inc. Selected text is accurately excerpted as written from the inside front pages of the original published works.

A

Boothroyd Dewhurst, Inc. v. Poli, 783 F. Supp. 670 (D. Mass. 1991)

BOOTHROYD DEWHURST, INC., Plaintiff,
v.
Corrado POLI, Defendant.
Civ. A. No. 89-1650-F.

United States District Court, D. Massachusetts.
June 12, 1991.

***671** John L. Welch, Wolf, Greenfield & Sacks, P.C., Boston, Mass., for plaintiff.

John J. Dempsey, Chapin, Neal & Dempsey, P.C., Springfield, Mass., John C. Linderman, McCormick, Paulding & Huber, Hartford, Conn., for defendant.

MEMORANDUM AND ORDER

FREEDMAN, Chief Judge.

Plaintiff Boothroyd Dewhurst, Inc. ("BDI"), a Rhode Island corporation which is the successor to a Massachusetts corporation, Boothroyd & Dewhurst, Inc. ("B & D, Inc."), brings suit against Professor Corrado Poli ("Poli"), charging in a four-count complaint that Poli's activities have violated the Copyright Act, 17 U.S.C. §§ 101 *et seq.* (count one), section 43(a) of the Lanham Act, 15 U.S.C. § 1125 (count two), the Massachusetts Consumer Protection Act, Mass.Gen.Laws ch. 93A ("chapter 93A") (count three) and constitute unfair competition under the common law of Massachusetts (count four). Defendant has filed counterclaims, alleging that plaintiff through the actions of its principals, Professor Geoffrey Boothroyd ("Boothroyd") and Professor Peter Dewhurst ("Dewhurst") has unfairly competed in trade in violation of chapter 93A, §§ 2 and 11 (count one) and Massachusetts common law (count two).

Source: Justia: https://law.justia.com/cases/federal/district-courts/FSupp/783/670/1362309/

Design for Manufacturing & Assembly Across Three Industrial Revolutions

3rd Industrial Revolution - Part II: BDI Successfully Fends-Off Competitors Emerging In Their Space

A

Corrado Poli
"Electronic Spreadsheet" & "Assembly Analysis and Linebalancing Spreadsheet"

Boothroyd Dewhurst, Inc. v. Poli, 783 F. Supp. 670 (D. Mass. 1991)

BOOTHROYD DEWHURST, INC., Plaintiff,
v.
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MEMORANDUM AND ORDER
FREEDMAN, Chief Judge.

B. Poli's Spreadsheet and Plaintiff's Allegations of Infringement

By **1983 Poli had become a consultant for Digital Equipment Corporation** ("DEC"). Boothroyd avers that he and Dewhurst "allowed" Poli to use their copyrighted DFA Software, which was apparently being used by DEC with Boothroyd and Dewhurst's permission. Boothroyd [Declaration (Aug. 16, 1990) ("Boothroyd Decl.")] at ¶ 11. He asserts that, without their knowledge or approval, Poli then created and distributed a so-called spreadsheet derived *directly* from Boothroyd and Dewhurst's DFA Software, thereby infringing on BDI's copyright.

In **1984** B & D, Inc. learned that Poli had also prepared a **software package for DEC entitled "Electronic Spreadsheet,"** believed by plaintiff to be based upon both the derivative 1983 Poli spreadsheet as well as plaintiff's copyrighted DFA Software and Handbook. The title page of the electronic spreadsheet actually lists Poli as one of three co-authors and indicates that DEC owns the 1984 copyright.

According to plaintiff, Boothroyd and Dewhurst relied on Dempsey's assurances until they learned that Poli had produced a **new, revised spreadsheet late in 1984, "Assembly Analysis and Linebalancing Spreadsheet" ... and an associated software version,** both of which Poli considered to be non-infringing.

Sapphire Design Systems
1st Commercial Software Competitor

Boothroyd Dewhurst, Inc. v. Poli, 783 F. Supp. 670 (D. Mass. 1991)

BOOTHROYD DEWHURST, INC., Plaintiff,
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MEMORANDUM AND ORDER
FREEDMAN, Chief Judge.

Magistrate Judge's Report at 9-14 (most footnotes omitted).

Plaintiff's tolerance ended when its principals perceived defendant's activities as a possible commercial threat. In **1989, Richard Adler** ("Adler"), a Stanford University graduate student, contacted BDI seeking a license to use BDI's copyrighted material. Plaintiff refused Adler's request, concerned about possible misuse of its product, which had been supplied to Stanford solely for teaching purposes. Plaintiff's Opposition to Defendant's Motion for Summary Judgment, Exhibit 39 (4/12/89 letter from Dewhurst to Adler). **Shortly thereafter, plaintiff's principals read in a trade magazine that Adler's company Sapphire Design Systems, Inc. ("Sapphire"), had obtained a license to use Poli's DFA methodology**. Convinced that the material Poli was licensing to Sapphire was BDI's copyrighted material, **BDI filed this suit on July 28, 1989**.

Design for Manufacturing & Assembly Across Three Industrial Revolutions

3rd Industrial Revolution - Part II: Boothroyd-Dewhurst, Inc. DFMA® – Recognized As A National Asset!

1991 National Medal of Technology and Innovation Management

Geoffrey Boothroyd, left, with President George Bush Sr. and Peter Dewhurst

Source: Image - https://www.dfma.com/backgrd.asp. Award for Boothroyd - https://nationalmedals.org/laureate/geoffrey-boothroyd/. Award for Dewhurst - https://nationalmedals.org/laureate/peter-dewhurst/.

Design for Manufacturing & Assembly Across Three Industrial Revolutions

3rd Industrial Revolution - Part II: Other Notable DFA & DFM Contributors – DFA & DFM Honor Roll*

Honor Roll Actively Practicing		Honor Roll Deceased & Retired
Alan Redford University of Salford	**David G. Meeker** DEC, Compaq, HP, Bose, MIT, BU, Neoteric Product Design	**Alfonse Adler** University of California Deceased
Kenneth G. Swift University of Hull	**Christopher Tsai** Kodak, RIT, Global Productivity, BDI	**Gordon P. Lewis** Xerox, DEC, Datum 3D Deceased
Julian D. Booker University of Bristol	**William Devenish** Motorola, NEC, Nokia, Harris, FMC, Kohler, L3Harris, The Devenish Group	**F. James McWilliams** DEC, Compaq, HP, Sun Deceased
Steen Kahler & Thomas Lund University of Denmark	**Matthew Miles** Ingersoll Rand, Amphenol, Raymond, Dynisco, Markem, Ambri, Mission Technologies, VAVE Consulting Services	**A.J. Overton & David Nevela** DEC, Compaq, HP Deceased
Finn Fabricius Institute for Product Development (IPU) ListenWhy Engineering	**Robert A. Williams** HP, Agilent, Keysight, Nilfisk, Dry Development, Creative Design Solutions Consultants	**James L. Nevins** Draper Laboratories Deceased
Nicholas Dewhurst BDI	**Jonathan E. Freckleton** RIT	**Miles Parker** Parker Group Retired
John Breckenridge BDI	**Gerhard Pahl & Wolfgang Beitz** Technical University of Darmstadt	**William Branan** Motorola Retired
Brian Raposa BDI	**Jay P. Mortensen** Deloitte, Bethlehem Steel, Toyota, Raytheon, Mercury Marine, Maytag, Rexnord, KPMG, LG	**Vincent P. Render** Ford Retired
	Michael E. Corbett Deere, IBM, Galileo, Zymark, Invacare, PinDot, Jaior, Corbett Engineering	**Michael F. Carter** General Motors Retired

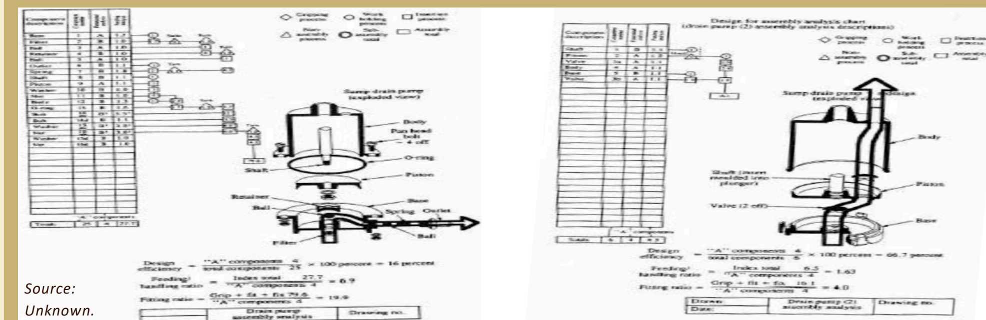
** Not Mentioned Earlier In This Presentation*

Design for Manufacturing & Assembly Across Three Industrial Revolutions

3rd Industrial Revolution - Part II: A Budding Industry – The Cat Eventually Gets Out of The Bag - 1990s

Lucas Engineering
UK

Natural Addition To
Established Engineering Firm



Source:
Unknown.

Galorath Incorporated SEER-SEM
USA

Established Defense
SW Costing Software, Adds Hardware

SEER for Software (SEER-SEM) is composed of a group of models working together to provide estimates of effort, duration, staffing, and defects. These models can be briefly described by the questions they answer:

- Sizing. How large is the software project being estimated (Lines of Code, Function Points, Use Cases, etc.)
- Technology. What is the possible productivity of the developers (capabilities, tools, practices, etc.)
- Effort and Schedule Calculation. What amount of effort and time are required to complete the project?
- Constrained Effort/Schedule Calculation. How does the expected project outcome change when schedule and staffing constraints are applied?
- Activity and Labor Allocation. How should activities and labor be allocated into the estimate?
- Cost Calculation. Given expected effort, duration, and the labor allocation, how much will the project cost?
- Defect Calculation. Given product type, project duration, and other information, what is the expected, objective quality of the delivered software?
- Maintenance Effort Calculation. How much effort will be required to adequately maintain and upgrade a fielded software system?
- Progress. How is the project progressing and where will it end up. Also how to replan.
- Validity. Is this development achievable based on the technology involved?

Source: Wikipedia, https://en.wikipedia.org/wiki/PRICE_Systems.

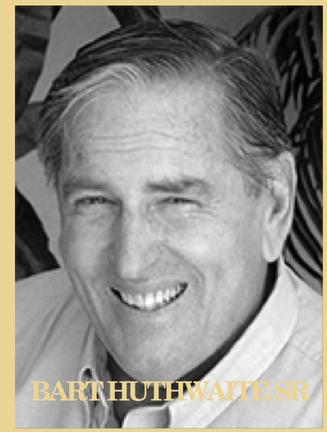
Munro & Associates
USA

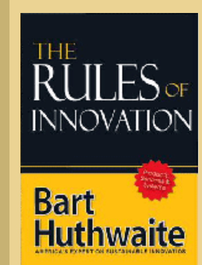
MOTORTREND

AUTO BEAT

INSIDEEVs

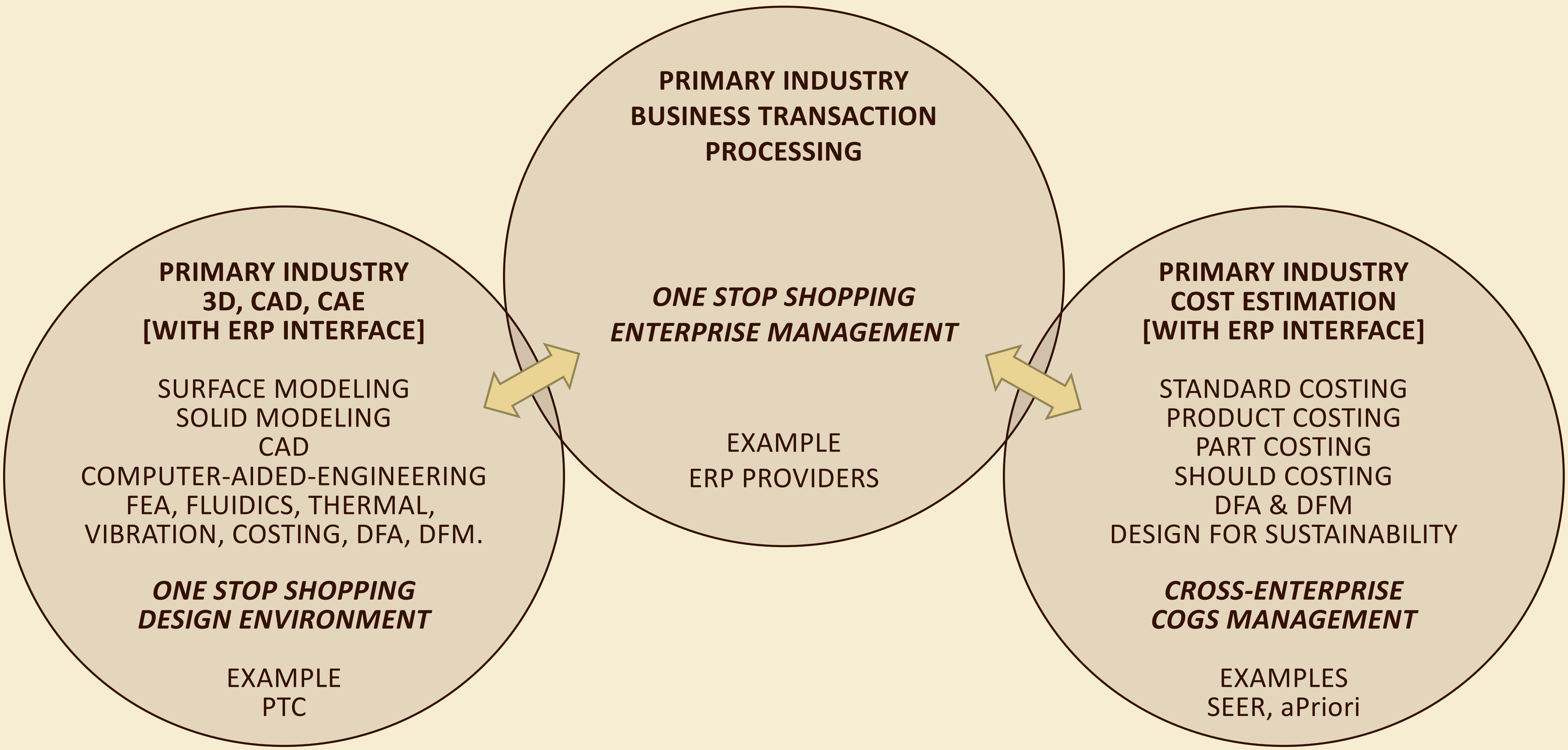
Huthwaite Innovation Institute
USA





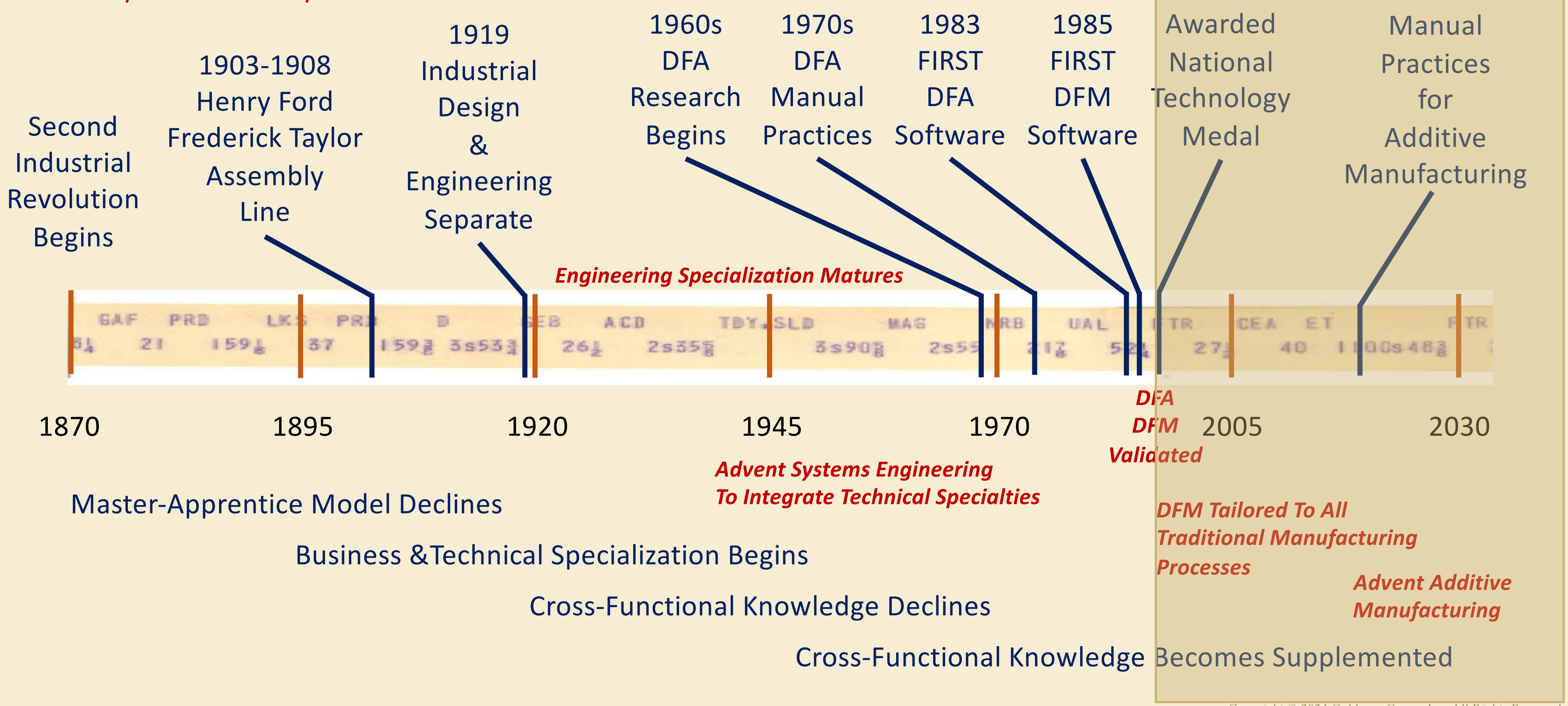
Design for Manufacturing & Assembly Across Three Industrial Revolutions

3rd Industrial Revolution - Part II: Other Industries Extend SW Platforms Into DFA & DFM - 2000s



THE EVOLUTION OF DESIGN FOR MANUFACTURING & ASSEMBLY

DOI: 10.13140/RG.2.2.29821.44006/1



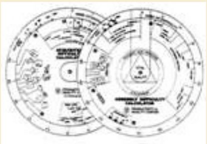
Design for Manufacturing & Assembly Across Three Industrial Revolutions

4th Industrial Revolution: DFA & DFM Expand To DFX – Expected Body Of Knowledge Lifecycle Growth

Design for Producibility

1880
Term
Coined

Westinghouse



WESTINGHOUSE
"THE WHEEL"

Pugh
RCA
Boothroyd
Dewhurst
Knight
Xerox
Fujitsu
Draper
Sony
Lucas
Meeker
Munroe
Datum3D
Sapphire

1960s-1980s

Product Costing
DFA 1980s
DFM 1990s
Test

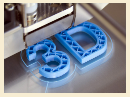
Manual Assembly
Semi-Automated Assembly
Fully Automated Assembly
Robotic Assembly
AI Assembly

Disassembly
Recyclability
Environment
Sustainability

2020s

German Green Dot Recycling

Source: Chris Carroll, Photographs By Peter Essick, "High Tech Trash," National Geographic Magazine, National Geographic Society, Washington, DC, USA, January 2008.

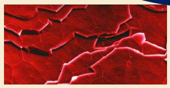


Source: Ingerestingfacts.org

Source: Chris Carroll, Photographs By Peter Essick, "High Tech Trash," National Geographic Magazine, National Geographic Society, Washington, DC, USA, January 2008.

2010s

Sheet Metal
Structural Foam
Tooling
PCB
3D Printing (M1, M2, M3, P1, P2, P3) +10
Thermoforming
Extruding
Molding (B, I, P, M)
Composite Materials
Structural BioMaterials (M1, M2, M3, P1, P2, P3) +10
Stamping
Casting (I, S, D)
Cost



Source: Julian Vincent..

Bodies of Knowledge Take 60-100 years to mature........

Zero Gravity
Reliability
Micro-Nano

2060

1980s-2000s

END

THANK YOU