A Conversation On
Design Engineering 4.0
For Realizing Evolving Cyber-Physical Social Systems

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Jiao, Commuri, Panchal, Milisavljevic-Syed, Allen, Mistree, and Schaefer, "Design Engineering in the Age of Industry 4.0," *Journal of Mechanical Design*, 2021, 142(8), Paper MD-21-1199 https://doi.org/10.1115/1.4051041 (currently online only).

Recording
https://mymedia.ou.edu/media/Farrokh%20Mistree's%20Personal%20Meeting%20Room/1_hwt07k0a

Conversation on Evolving Cyber-Physical-Social Systems

The research theme, for the next three years, for the SRL@OU is evolving cyber-physical-social systems.

To get a better understanding of what evolving cyber-physical-social systems means and more importantly the questions worthy of investigating in Summer 2021 we have initiated a "A Conversations with X".

We will be inviting people to initiate a conversation anchored in their research interests. We expect all to be richer as a consequence of this conversation.

Our aim today is to foster dialog *with a purpose* between the SRL@OU community and friends and to offer a way forward for collaboration.

Industry 4.0 and Manufacturing

Industry 4.0: The comprehensive transformation of the whole sphere of industrial production through the merging of digital technology and the internet with conventional industry.

https://www.bundesregierung.de/Content/EN/Reden/2014/2014-02-19-oecd-merkel-paris_en

The combination of digital processes such as the Internet of Things, automation, robotics, and additive manufacturing—has a disruptive impact on mechanical engineering design. Not only do engineers need to redesign processes and operations to accommodate these new advances, Industry 4.0 impacts **how they design products** for increasingly smart manufacturing facilities.

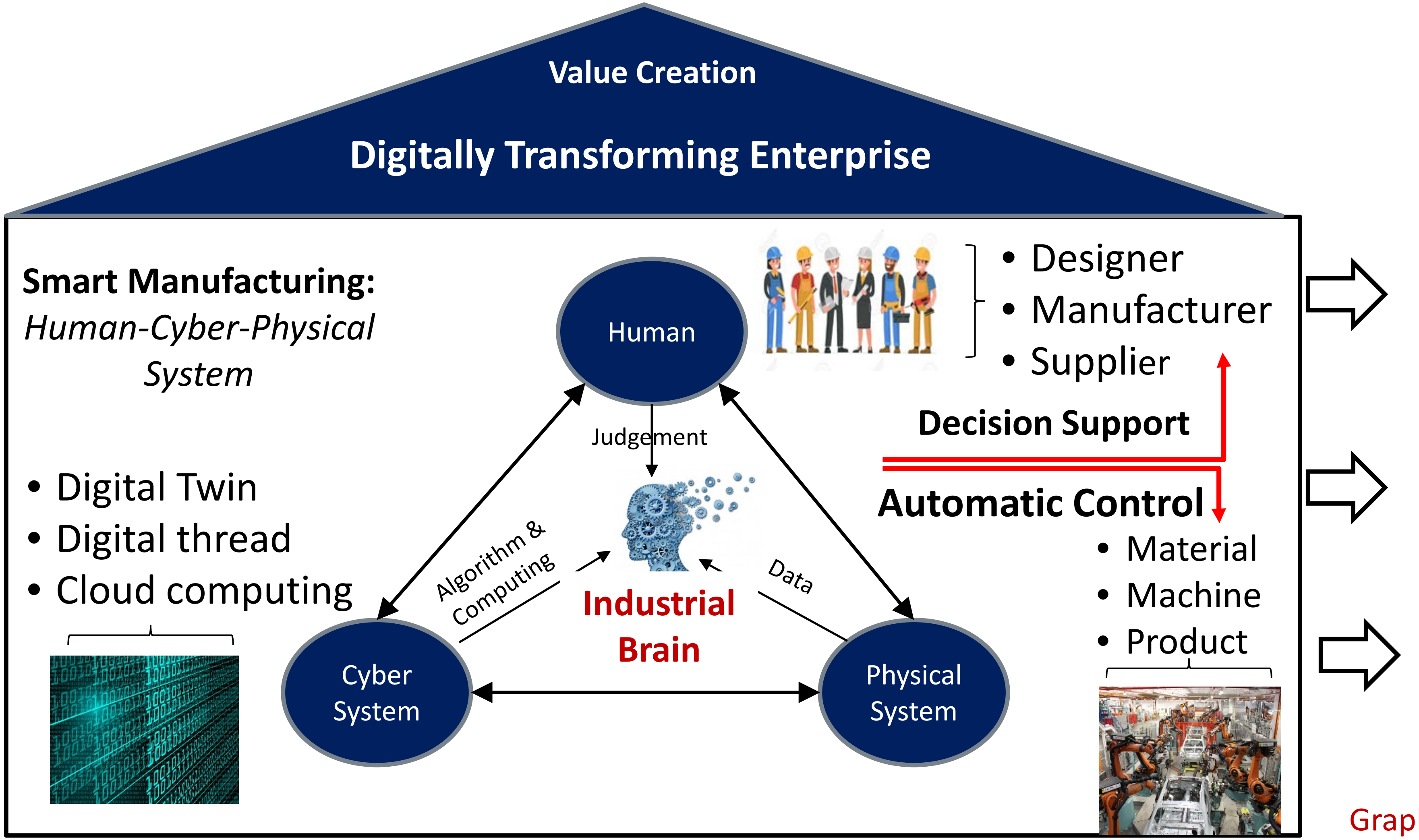
ASME https://www.asme.org/topics-resources/content/industry-40-impacts-engineering-design

Digitally Transforming Enterprise and People

Digitally Transforming Enterprise (DTE) is characterized by the integration of digital technology into all areas of a business, fundamentally changing how it operates and delivers value to customers. This necessitates a cultural change that requires the DTE to continually challenge the status quo, experiment, and get comfortable with BOTH success and failure.

Internet of Digitally Transforming People (IDTP). Our graduates (UG and PG) who are digitally connected constitute the IDTP and must know how to adapt to change as per Charles Darwin.
"It is not the strongest of the species that survive, nor the most intelligent but ones most responsive to change."

Value Creation in a Digitally Transforming Enterprise



Take Away

Industry 4.0 is foundational to smart manufacturing.

Design Engineering 4.0 calls for

1. a cloud-based "HUB" to support distributed open innovation (product and process) in advanced manufacturing , and
2. a digitally transforming workforce

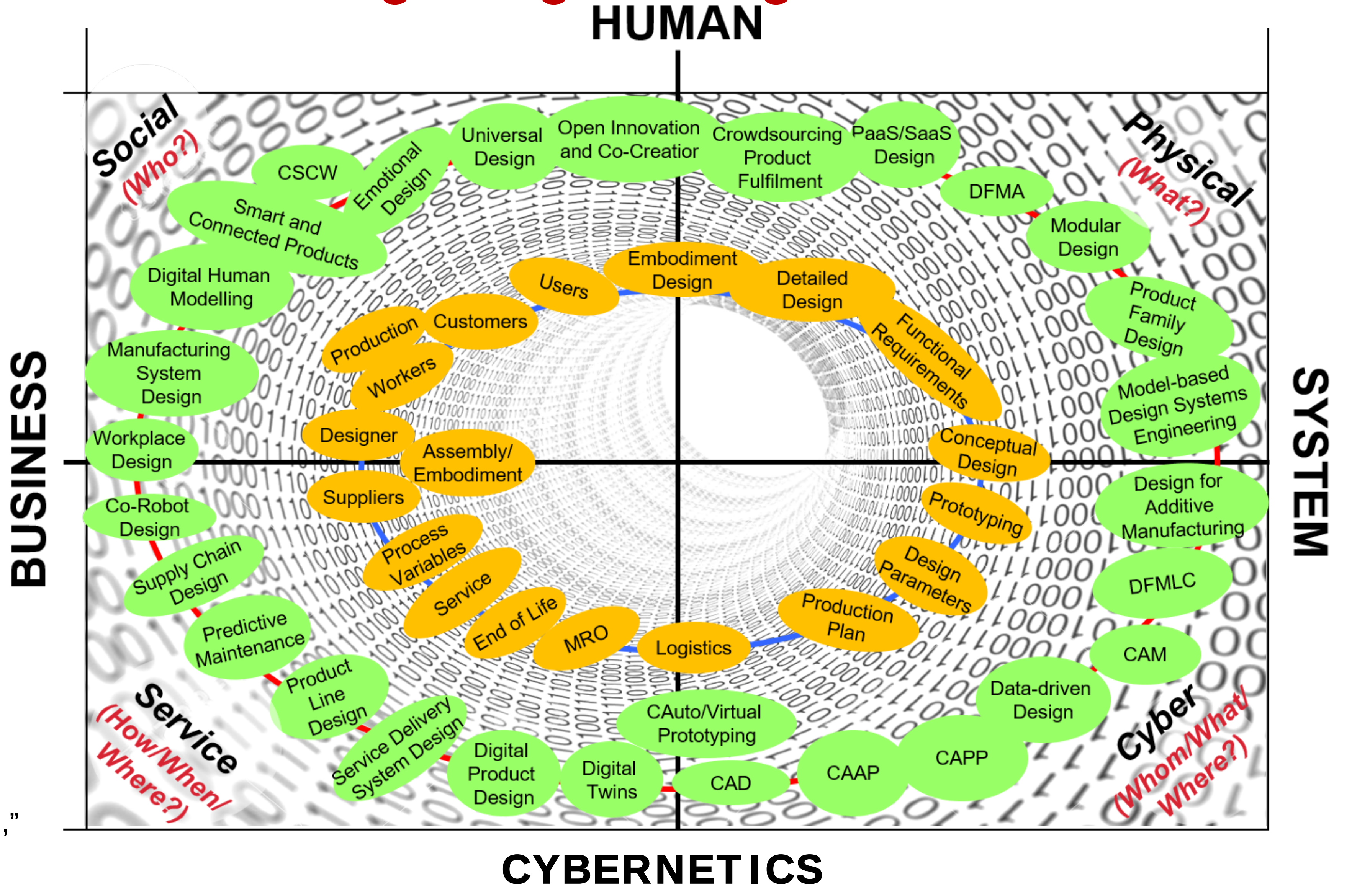
to sustain cyber-physical-social systems.

Graphic courtesy Zhenjun Ming @ BIT. 2020

Research Opportunities - Design Engineering 4.0

Design Engineering 4.0 goes beyond conventional engineering design three-dimensional space to four-dimensional cyber-physical-social-service space comprising of four perspectives, namely, human, system, cybernetics and business.

Inner circle - Perspectives
Outer circle - Enablers



Jiao R and co-authors, 2021, "Design Engineering in the Age of Industry 4.0," ASME Journal of Mechanical Design, in print.

Engineering Design

Engineering Design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic science and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation.

Design Engineering 4.0 in Line with Industry 4.0

Industrial Revolution

Industry 1.0
- Mechanization
- Water/Steam power

Design of Customers (Dictatorial)

Design Engineering 1.0
- Functionality
- Volume
- Craftsmanship

Industry 2.0
- Electrification
- Assembly line
- Mass production

Design for Customers (Iterative)

Design Engineering 2.0
- Functionality
- Volume (high)
- Cost/Speed
- Standardization
- Interchangeability

Industry 3.0
- Automation
- Digitization
- Electronics/Computers
- IT/Internet (ICT)
- PLC/Robotics

Design with Customers (Collaborative)

Design Engineering 3.0
- Functional/Affective/ Cognitive needs
- Physical/Digital/Service
- Volume (low)/Agility
- Cost/Speed/Quality
- DFX/Design automation

Industry 4.0
- Smart connectivity
- Integrated intelligence
- Industrial IoT
- Human-cyber-physical systems
- Cloud Mfg. and Servitization
- Big data and AI
- New revenue streams

Design by Customers (Co-Creation)

Design Engineering 4.0
- User experience/Personalization
- Smart and connected product ecosystems
- Mass customization
- Business models/Value chains
- Open innovation/Co-creation
- Data-driven decision making

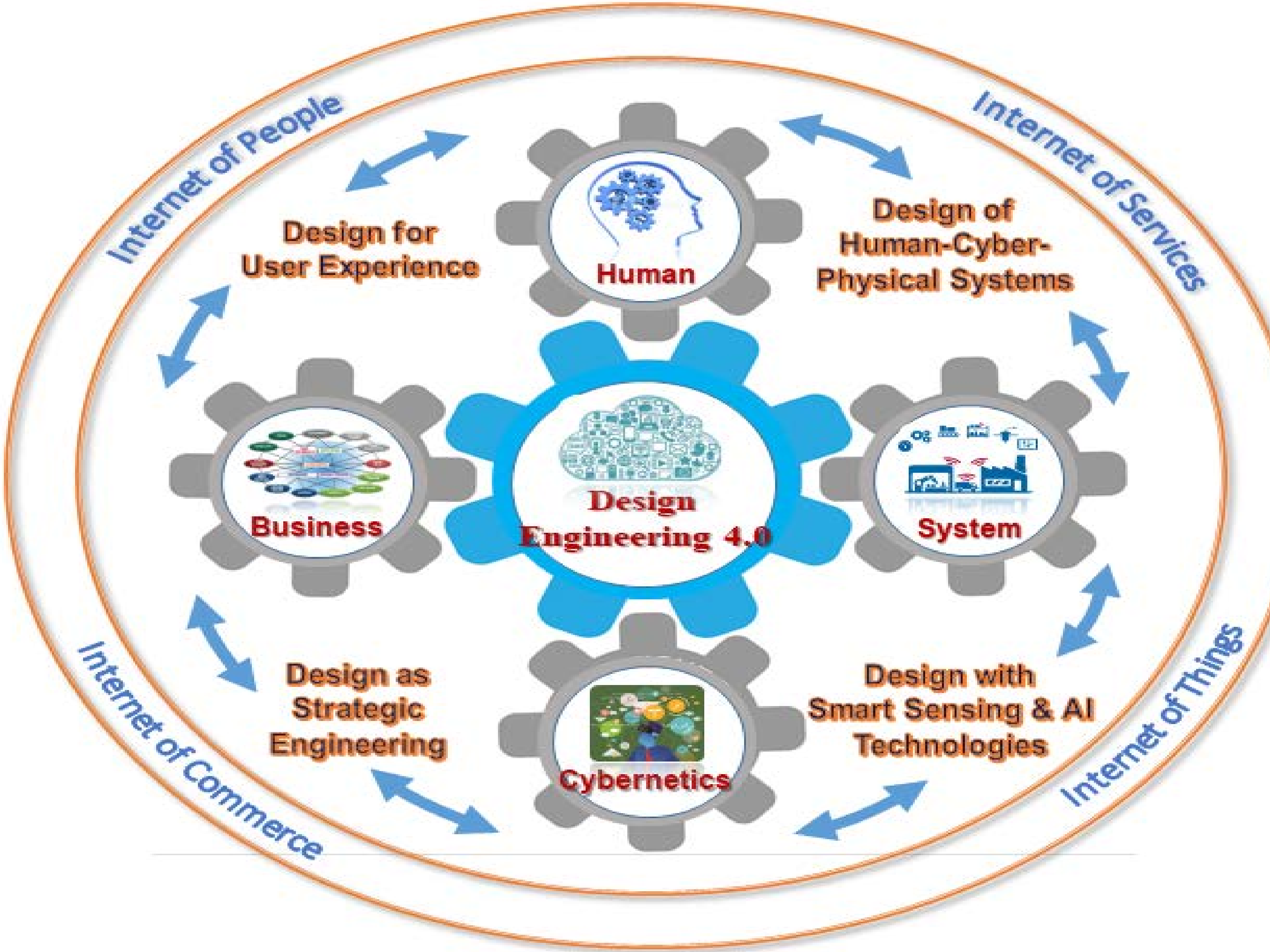
Evolution of Design

Design Engineering 4.0 and Smart Manufacturing

Design Engineering 4.0 represents the ‘human-cyber-physical view of the systems realization ecosystem’ that is necessary to accommodate the drivers of Industry 4.0 (IoX) and provide an open ecosystem for the realization of complex systems. Seamless integration of digital threads and digital twins throughout the product design, development and fulfillment lifecycle; ability to accommodate diverse and rapidly changing technologies; mechanisms to facilitate the creation of new opportunities for the design of products, processes, services, and systems are some of the desired characteristics of DE4.0.

Jiao R and co-authors, 2021, “Design Engineering in the Age of Industry 4.0,” ASME Journal of Mechanical Design, in print.

Design Engineering 4.0 Human-cyber-physical View of the Systems Realization Ecosystem



Design Engineering 4.0
Strategic Areas in Line with Industry 4.0

<table>
<tr><th rowspan="2">Key Principles of Digital Transformation for Industry 4.0</th><th colspan="3">Strategic Areas of Design 4.0</th></tr>
<tr><th>Artefact</th><th>Process</th><th>Human</th></tr>
<tr><td>Connectivity, Virtualization and Interoperability</td><td rowspan="2">(1) Smart and Connected Products</td><td>(2) End-to-end Digital Integration</td><td rowspan="2">(3) Customization and Personalization</td></tr>
<tr><td>Big Data and Information Transparency</td><td>(4) Data-driven Design</td></tr>
<tr><td>Decentralization, Modularity and Interactivity</td><td>(5) Digital Twins and Intelligent Design Automation</td><td>(6) Extended Supply Chains and Agile Collaboration Networks</td><td rowspan="2">(7) Open Innovation, Co-Creation and Crowdsourcing</td></tr>
<tr><td>Service Orientation and Networked Resources</td><td>(8) Product Servitization and XaaS</td><td>(9) Platformization for the Sharing Economy</td></tr>
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Opportunities and Challenges for Design Engineering

1. Smart and Connected Products
2. End-to-End Digital Integration
3. Customization and Personalization
4. Data Driven Design
5. Digital Twins and Intelligent Design Automation
6. Extended Supply Chains and Agile Collaboration Networks
7. Open Innovation, Co-Creation and Crowd Sourcing
8. Product Servitization and Anything as a Service (XaaS)
9. Platformization for the Sharing Economy

Drivers and Challenges of Design Engineering 4.0

Internet of Services

Rapidly changing technologies, customer requirements and preferences, and unpredictable and hard to manage disruptions will drive the future of the DE4.0 ecosystem. An important requirement in this area is the need to customize products to user requirements while producing products of ‘zero lot size’ and ‘mass production costs’. The challenges to be addressed are:

- ❑ How to design products and systems that are resilient, sustainable, and can adapt to changing conditions especially when the change cannot be anticipated at design time?
- ❑ How to develop standards for interfacing and using physical entities and their digital twins across the entire ecosystem from design to product realization?
- ❑ Can digital twins of design variants considered during the parameter selection and optimization phase of the design be used to rapidly respond to disruptions that affect production process?

Drivers and Challenges of Design Engineering 4.0
Internet of People

The distinction between the 'physical' and 'digital' selves of individuals will get blurred as Industry 4.0 technologies become prevalent. Individuals will play a dual role of co-creators as well as consumers of technology. Changing user preferences and the way users interact with the products and between themselves will be the main drivers of Design Engineering 4.0. The challenges to be addressed are

- ❑ How to foster an "Innovation Ecosystem" where consumers and design engineers play a creative role in shaping the systems of the future?

- ❑ How to develop and maintain a workforce that stays in tune with changing technological landscape?

Drivers and Challenges of Design Engineering 4.0

Internet of Things

Networked systems and prevalence of IoTs will make data easily accessible throughout the product lifecycle. The need to design systems that can collaborate and adapt to improve product quality, process reliability, system agility, and sustainability of the systems realization ecosystem will be the main drivers of Design Engineering 4.0. The challenges to be addressed are:

- ❑ Information extracted from diverse data streams in real-time will aid decision making. However, Data mining techniques applied to Big Data are based on the premise that information is encapsulated in the data in some form. Since initial design iterations are based on actual data, is it possible to design systems when partial or no data exists?
- ❑ Can one always build consensus when data streams do not indicate any reliable information or contain conflicting information?
- ❑ Can 'Synthetic Data' be created using the digital twins of the processes and used in the early design process?

Drivers and Challenges of Design Engineering 4.0
Internet of Commerce

System design and productization is driven to a large extent by the necessity to make profit. The challenges to be addressed are:

- How can design anticipate the many ways in which the product can be monetized?
- As a result of networked systems and ubiquitous design and data sharing, cyberthreats are no longer restricted to loss of privacy or the financial domain. One of the most urgent challenges is how can designers inoculate systems against threats when the nature of interaction between system components is unclear at design time?

On Evolving Cyber-Physical-Social Systems

1. What Do We Offer?

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Mentoring of the next generation professors who are eager to learn how to create knowledge, archive knowledge, mentor others and are recognized for their scholarship.

3. Key Notion

Perceive the evolving CPS system to be comprised of several services to be modeled as a multi-echelon network thereby ensuring the framework to be used to design it is agnostic to the services embodied therein.

2. Research Thrust

We hypothesize that

- ALL grand challenges can be modeled as Cyber-Physical-Social systems.
- Public policy is foundational for addressing any grand challenge.

Hence, evolving CPS to support policy making.

4. Potential Applications of CPS

Sustainable solutions at the nexus of People, Planet and Profit for

– Rural development
– Connected communities
– Monitoring green house gases (GHG)
– Education

5. Collaborators

Cloud-Based Decision Support

Zhenjun Ming. BIT. China.

Rural Development

Ashok Das. SunMoksha. India.

John Hall. U at Buffalo.

Connected Communities

Li Song. AME OU.

Sustainability – Monitor GHG

Pejman Kazempoor. AME OU.

Binbin Weng. ECE OU.

Evolving CPS Systems

Jelena Milisavljevic-Syed. U of Liverpool. UK.

Anand Balu Nellippallil. Florida Institute of Technology. USA.

Education

Shan Peng. BIT. China.

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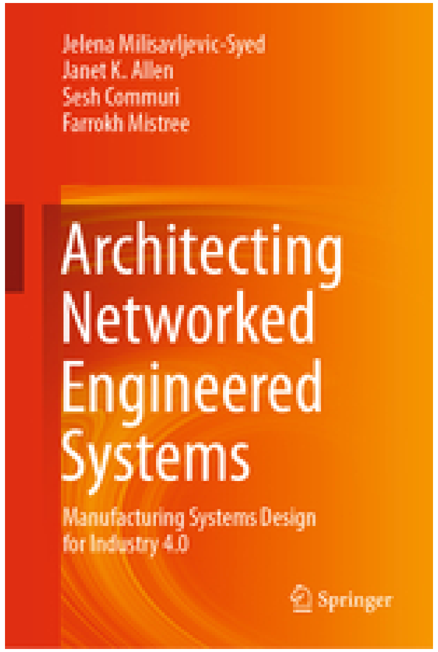

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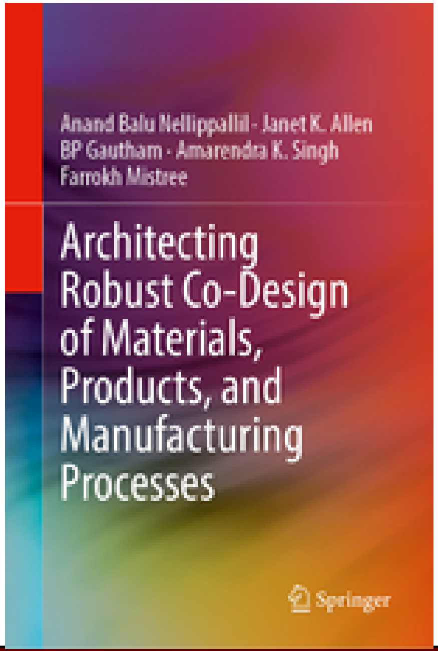

4. Architecting Knowledge-Based Platform for Decision Support in the Design of Engineered Systems Springer Nature. July 2021

Policy Making for Disruptive Innovation in the Pre-competitive Space

Monographs 4

Cloud-Based Platform for Decision Support (CBDS)

Monographs 1 and 3. Previous Slide

Monograph 2

Fail-safe Supply Network (FSSN)

- manage variations and disruptions in the healthcare network
- identify and preserve local reliabilities of healthcare facilities against variations
- maintain flexibility levels and responses of non-disrupted facilities to replace disrupted ones
- remain robust and resilient to disturbances
- mass customization of the healthcare network

Design for Dynamic Management (DFDM)

- dynamic management of variations
- adaptable and concurrent design of entities in the system-based model as digital twins managed by digital threads
- reconfigurations in breakdown of interconnectivity between elements of the healthcare system

Formulation-exploration (FO-EX)

- dynamic positioning of the customer order decoupling point (CODP)
- bottleneck(s) detection with the corresponding improvements implementation
- decision support to clinicians and patients on the input-output association
- delivers mass personalization in the healthcare

Data Curation: Synthetic Data

- manage data privacy issues
- providing efficient and effective strategies
- support decision making by the clinicians and patients in an environment of distributed learning
- use of synthetic data including text mining

Monograph 5 – Lin Guo's dissertation. 2022.

Questions for clarification?

Interested in collaborating?

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