Future of Design and Manufacturing
Sustainable Strategy for 2035

Sachin Hebbale Lokesh
Plaksha Tech Leaders Fellowship, Purdue University

Abstract

Design and manufacturing consist of applying multiple processes and skills by understanding the needs of the customer and constraints of the available resources for the realization of physical products. Ever since the first industrial revolution, tools and methods used in these processes have been evolving rapidly with the advancement of computational methods, composite materials, and research. Looking at the historic advancement of digitalization, automation, additive manufacturing, and artificial intelligence tools (Figure. 1), Industry 4.0 has the potential to revolutionize the process for design generation, simulation, rapid prototyping, and automated manufacturing systems with intuitive tools. In the future, digital assistants will be able to automatically generate novel designs, simulate such designs considering materials and manufacturing constraints to give recommendations on composite materials and parameters which meet the desired quality. Big data generated from the sensors connected to products, manufacturing equipment, co-bots, and smart materials will enable us to integrate the physical and virtual worlds to form digital twinning. Digital twinning will aid everyone in the design and manufacturing ecosystem to instantaneously monitor, predict and control the performance of end-to-end equipment and processes involved in the realization of the product. We will also be able to seamlessly collaborate between various stakeholders involving designing, marketing, manufacturing, and supply chain departments. In 2035, the development of a circular supply chain focused on sustainable, environmentally friendly design and operational practices is going to be a key factor for organizations to be leaders and innovators.

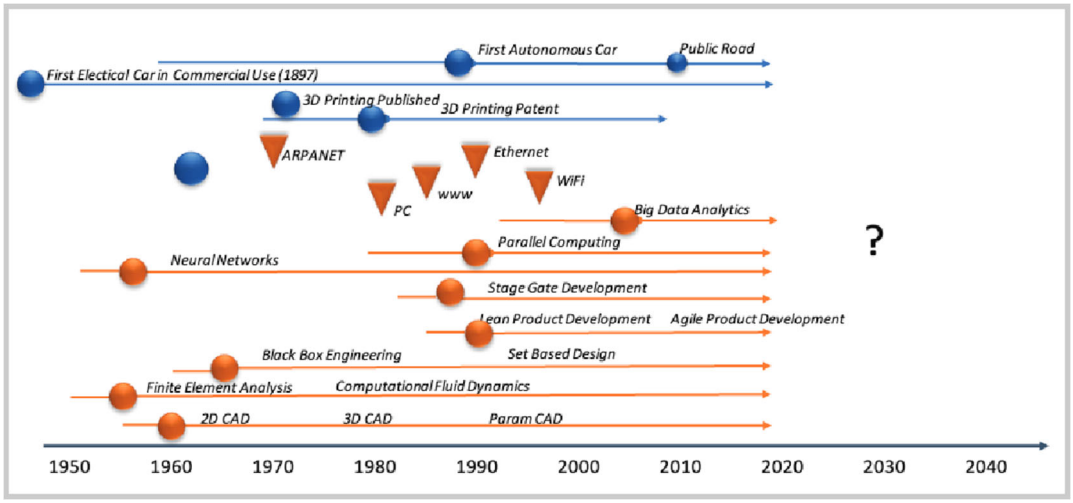

Figure 1. Timeline of new technologies (Source: Design Society)

Introduction

In the year 2035, the high-tech global design and manufacturing enterprise will be dynamic socio-technical systems where we can seamlessly design and develop products by collaborating with intelligent tools and people involving multiple engineering and management backgrounds. Cross-functional skills of horizontal and vertical departments are going to be necessary for employees to thrive in the design and product development environment due to the increasinguse of electronics and software for product realization. A large amount of data will be generated from sensors and IoT devices from end-to-end systems processes involving the design, engineering, manufacturing and supply chain, and product experience. Edge computing and efficient transmission and collection of data will be necessary as enormous amounts of data will be generated. Data generated from these processes will enable us to develop intelligent computational models which are capable of automating a variety of problem-solving and value-generating functions across user experience management, industrial design, engineering analysis, manufacturing, and supply chain management.

Characteristics of a global design and manufacturing company

1. Generative design

As generative design workflow (Figure. 2) evolves to create and discover new computer-aided designsconsidering the product specifications and manufacturing constraints, it will enable designers to be innovative and productive by generating designs that were earlier not possible in a short period. "The generative design takes system definitions and requirements as input and generates architectural proposals for the logic, software, hardware, and networks of the electrical and electronic systems using rules-based automation (Doug Burcicki, 2019)".

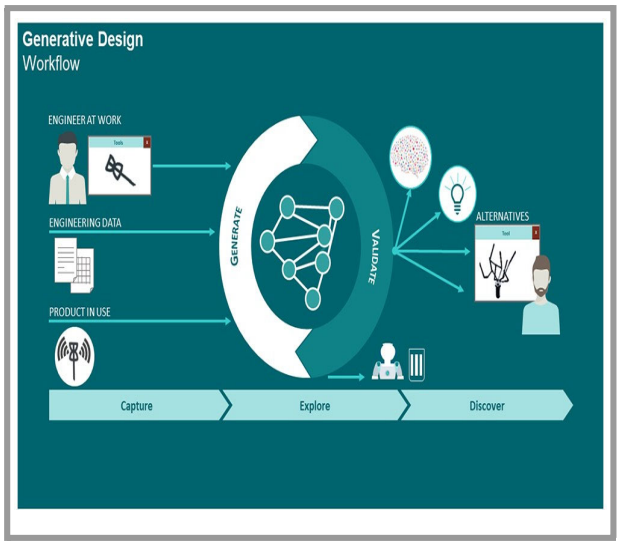

Figure 2. Generative design (Source: Siemens)

2. Computational modeling in research and development

In the paper "Learning to Design from Humans: Imitating Human Designers Through Deep Learning (Raina, A., McComb, C., and Cagan, J., September 16, 2019)", the authors talk about a two-step framework for design generation by extracting human design strategies and implicit rules from the historical designing data from humans. In "A self-learning finite element extraction system based on reinforcement learning (Pan, J., Huang, J., Wang, Y., Cheng, G., & Zeng, Y., 2021)" paper, Researchers used a reinforcement learning model which can

automatically acquire robust and high-quality element extraction rules for mesh generationaround the domain boundary. Results from the experiment demonstrated we can design agents that are capable of learning to create feasible and efficient designs without guidance. Machine learning models are also being used to create new composite materials, to develop reduced-order models, which simplifies the simulation of complex models by using datasets consisting of system characteristics derived from previous simulations and testing.

3. Augmented and virtual reality device will aid engineers in product development

Augmented reality and virtual reality software and products are being extensively researched and developed by commercial companies such as Dassault Systemes, Oculus, Magic Leap, Microsoft, and Apple. It is expected to become mainstream among the designing and engineering teams for collaborations and decision-making because of its ability to generate an intuitive presentation of complex and high dimensional data of design, engineering analysis, and materials structure.

4. Computational modeling to understand the users behavior

Researchers (Jack Beuth, Jonathan Cagan, Burak Kara, Kenji Shimada) [24] at Carnegie Mellon University are developing computational methods to understand how people design systems and products, and how users perceive and react to those products to build a tool considering the individual's aesthetic and product preferences. As connected products generate a stream of data about users product usage, such data will be collected and analysed to find patterns of behaviour and to incorporate those findings into new product development

5. Additive manufacturing for mass customization and responsive supply chain

Additive manufacturing is extensively used in aerospace engineering, manufacturing complex structures, and rapid prototyping. In the future companies need to adopt customer-centric manufacturing with short lead time and a responsive supply chain with an emphasis on customized products and services instead of production cost as the main criteria for competitive advantage in digital, reconfigurable additive manufacturing facilities for the aerospace project, researchers are testing and generating a knowledge base to create better tools and processes by creating the complete digitally twinned manufacturing process consisting of additive manufacturing equipment. Considering ongoing multiple research efforts, it can be used extensively for mass customization of various products with complex structures with composite materials.

6. Improved productivity due to digitalization and automation of the manufacturing process

In 2035, the majority of the repetitive and unsafe tasks on the manufacturing shop floor will be performed by robots and automated guided vehicles increasing the productivity and efficiency of the manufacturing activities. Computer vision, natural language process tools in combination with IoT devices will aid maintenance teams by alerting them of the deteriorating condition of

cutting tools and manufacturing equipment, to prevent system breakdown during the manufacturing process. These intelligent tools and software can also automate and improve the quality management process thus reducing the wastage of faulty products being manufactured. Also, they can aid in monitoring the violation of safety rules and guidelines by the workers, variations in the movement of robots, manufacturing equipment and automated guided vehicles thus improving the safety and quality of the overall workplace. Co-bots and wearable robots will improve human safety and capabilities to do difficult and intelligent tasks at ease.

7. Digital twin enabling predictive maintenance, optimization and development of A.I

In the future, continuous streams of data from IoT devices will enable the development of the robust digital twin which will be updated with a batch-wise and continuous stream of data from the design, engineering, machinery, manufacturing, and supply chain process. Also, smart components with embedded sensors that monitor their condition, stress, torque, and other parameters will become increasingly popular. This will pave the way for the development of the digital world replicating physical processes and equipment. This will aid in better operations management and development of A.I, predictive, and optimization models to improve the overall productivity and capability of the company.

8. New database systems and data collection methods

As manufacturing companies will be digitized by 2035, it is clear that businesses will be dealing with massive amounts of data. So better data collection methods will have to be developed to collect data generated during the product development and manufacturing process, unlike today where data is often collected opportunistically without understanding its usefulness. From this data, new tools and techniques need to be designed to aid engineers in designing, simulating, and analyzing product quality. So designing big data systems in conjunction with the future design and manufacturing scenarios will be crucial for the success of the

Secured network infrastructure and strong data encryption technologies

As the number of connected devices in the system increases along with digitalization, thepotential cybersecurity threats will also increase the risk of system breakdown and compromisingof data confidentiality. In 2035, the importance of data being stored, processed, and transmitted will be of more importance to the company as it also comprises the manufacturer's intellectual property and data linked to privacy regulations along with design and manufacturing process data. To keep this sensitive data safe, the development of new technology and protocols will beof topmost priority to the companies. These efforts consist of developing technology and methods to securely transmit and store the data of all devices on local, and cloud storage. It also involves developing the capability to immediately detect and report any conditions or behaviors that could threaten the system's data's security. Failure to the prevention of attacks on critical infrastructure will be devastating for companies' existence in the competitive marketplace so companies will be having strong encryption solutions using cryptography, machine learning, and artificial intelligence. Responsibility of securing these networks and devices will be shared among the IoT

device manufacturers, cloud service providers, and owners of the data.

9. Eco-friendly materials and development of circular supply chain

Apple recently announced its plan to become carbon neutral by 2030, across its business, product development, and supply chain. A circular supply chain will be an important social and political factor in 2035, so companies need to be prepared to use renewable energy sources and eco-friendly materials in its product and across their supply chain process. Companies need to invest in research and development efforts to process and service the returned products of the companies.

Research challenges, partnerships and mode of operations

1. Research and development of future products requires interdisciplinary skills

Product realization involves people from multiple disciplines and relies on interdisciplinary scientific discoveries. Researchers, technologists from multiple scientific disciplines need to collaborate to perform applied research at the intersection of electronics, mathematics, computer sciences, and mechanical engineering. The discovery of such research will have a huge impact on innovation in the development of new product features, designing tools, manufacturing systems, and strong industrial cybersecurity.

2. Innovation and Entrepreneurship should be encouraged

The United States has been a leader in knowledge creation through research and development. However, countries like China, Israel, Canada, the United Kingdom, and India are catching up with the US in the development of innovative products and services through innovation and entrepreneurship. As quoted by Design society[5] “Innovation is the process of translating an idea, an invention or a technology into a new product or service that creates value for which customers will pay can be measured by the time-to-profit”. So for design and manufacturing companies to succeed in 2035, the development of entrepreneurial skills to develop innovative and industry-relevant products from decades of research findings is necessary. So, universities and companies should design programs to encourage entrepreneurship and intrapreneurship for the development of products and services by filling the gap between fundamental research, applied research, market and economical needs.

3. Development of automatic adaption and updating tools for computer software suites andinfrastructure

Most of the software in the present manufacturing setting is written using C, C++, Java, and FORTRAN for classical computing infrastructure.When a new accelerator or computational device comes along, a massive re-coding effort is required to keep the performance of systems

up to date as per the latest technology using languages like CUDA or OpenCL. In the end, such initiatives would require collaboration across national labs, various government agencies, universities, and software firms over a large collaborative network.

4. Human-centered design and engineering considering social aspects

Technologies in the future will be an integral part of human activities augmenting their capability to do effective and valuable work. It requires the development of new interfaces between humans and machines to maximize collaboration and mitigate harm to the economy. In a highly interlinked society and complex networks of global firms, relevant challenges should be addressed at the intersection of liberal arts and technology. Rather than approaching through single-discipline or technology alone. Such efforts should involve design thinking by understanding human behavior, perceptions, emotions, culture, environment, and preferences to meet the needs of social aspects and desired society structure.

5. Development of secured network, big data and machine learning systems

Around 2035, information should be shared across organizations and geographies without compromising proprietary information. So research centers and industry leaders should collaborate to establish standards and protocols for developing federated data infrastructure, data transfer protocols, and encryption technologies. Extensive research should be carried out to develop computational models, data mining, and analysis techniques to study the combinations of materials, design, and engineering analysis outcomes. Data mining and analysis techniques along with virtual and augmented visualization tools should be developed for handling structured, unstructured, and high-dimensional data.

Key technology to support its employees in being globally competitive

In 2035, the flow of information and physical activities will happen across the world where engineers from remote locations will be able to collaborate with robots on the manufacturing shop floor. Designers from different locations can instantly collaborate to work and modify the component through multi-user access tools. Employees need to share analysis information or tools with people internal and external to the organization. All this activity requires collaboration frameworks and technology to facilitate conversation without compromising intellectual property and security.

Due to increased collaboration and cross-functional work, companies need to have employees who are good at critical thinking and communication to understand the different perspectives and complexity of the system. The workforce should be encouraged to learn continuously to stay relevant to the changing market needs.

Conclusion

The first industrial revolution was driven by the discovery of the idea that we could drive machines using steam energy and subsequent revolutions were followed by the discovery of electricity, mass production systems, computers, and automation technologies built around previous revolutions. The future revolution will be built upon the integration of cyber-physical systems with socio-technical systems i.e it is about integrating digital, physical, and biological systems. It took centuries for scientists and engineers to discover and formulate the fundamentals of nature in the fields of maths, physics, chemistry, and biology. From those findings, humans have continued to create new engineering streams and technologies generating information and knowledge at a much faster rate than in previous centuries. Ongoing research on genome editing, stem cells, reverse aging, neuro implantations and brain interface devices, autonomous machines and robotics, composite materials, and artificial intelligence are all potential enough to change how we live and work in society. The future looks promising with increased productivity and better living standards; however, it also requires people to stay relevant to technologies and find meaningful work in the digital society.

KPMG research "Beyond the Hype [26]" report highlights that the impacts of digital transformation are huge with the growing market for advanced cybersecurity, augmented reality, and IoT devices with an overall market amounting to more than US$4 trillion as of 2020 and it is expected to rise in the upcoming years. The digital transformation provides multiple challenges and opportunities to research communities which should be addressed by all of us to create a better and sustainable society.

References

1. https://asmedigitalcollection.asme.org/mechanicaldesign/article/141/11/111102/955339/Learning-to-Design-From-Humans-Imitating-Human
2. https://www.cambridge.org/core/journals/ai-edam/article/abs/selflearning-finite-element-extracti on-system-based-on-reinforcement-learning/75000DF8A16544C462457A78E1C12853
3. https://ntrs.nasa.gov/api/citations/20180002010/downloads/20180002010.pdf
4. http://www.manufuture.org/wp-content/uploads/Manufuture-Vision-2030_DIGITAL.pdf
5. https://www.designsociety.org/publication/43268/Product+Development+2040
6. https://asmedigitalcollection.asme.org/memagazineselect/article/139/10/38/380304/AI-and-the-F uture-of-the-Machine
7. https://www.cambridge.org/core/journals/mrs-communications/article/machine-learning-for-

com posite-materials/F54F60AC0048291BA47E0B671733ED15
8. https://www.cambridge.org/core/journals/ai-edam/article/abs/selflearning-finite-element-extracti on-system-based-on-reinforcement-learning/75000DF8A16544C462457A78E1C12853
9. https://www.sciencedirect.com/science/article/abs/pii/S0169814121000469
10. https://www.springer.com/gp/book/9783319578699
11. https://www.tctmagazine.com/additive-manufacturing-3d-printing-news/mtc-metal-additive-man ufacturing-hub-aerospace/
12. https://weareatlas.com/resources/case-studies/drama-project-case-study/
13. https://medium.com/@starstorms
14. https://www.sciencedirect.com/science/article/abs/pii/S0360835217302188
15. https://engineering.cmu.edu/news-events/news/2019/11/13-cagan-ai-learns-to-design.html
16. https://www.meche.engineering.cmu.edu/news/2018/10/zhang-and-yao-earn-mfi-award-4d-printi ng.html
17. https://www.autodesk.com/campaigns/generative-design/transforming-business
18. https://medium.com/autodesk-university/ai-digital-twins-and-the-future-of-product-design-processes-1d70e5c3013d
19. https://tulip.co/resources/industry-4-0/
20. https://www2.deloitte.com/content/dam/insights/us/articles/3749_Industry4-0_cybersecurity/DUP_Industry4-0_cybersecurity.pdf
21. https://www.additiveflow.com/
22. https://redshift.autodesk.com/ai-in-manufacturing/
23. https://damassets.autodesk.net/content/dam/autodesk/docs/pdfs/futureofmakingthings/FutureOfMaking_ADSK_v3.pdf
24. https://www.meche.engineering.cmu.edu/directory/bios/cagan-jonathan.html
25. https://www.accenture.com/us-en/blogs/industry-digitization/how-ai-driven-generative-design-di srupts-traditional-value-chains
26. https://assets.kpmg/content/dam/kpmg/xx/pdf/2017/05/beyond-the-hype-separating-ambition-from-reality-in-i4.0.pdf