Technology and Human Resource Investments for a Resilient Futuristic Design and Manufacturing Company

Rashmi Rama Sushil

Indian Institute of Technology, Madras

Advisor

Palaniappan Ramu

Technology and human resource investments for a resilient futuristic design and manufacturing company: some perspectives

Abstract

A futuristic high-tech global manufacturing enterprise, to stay resilient will need strategies for treating the uncertainties. This essay provides some perspectives for the same from the technology and human resource aspects.

Characteristics and research challenges

1. Reduced timeline for design cycle
    - Bypass expensive simulations by enabling learning techniques such as GAN
    - Inherently understandable visual analytics tool that can be used by decision makers in different verticals
2. Better efficiency: Digital Twins (DT) to monitor operations and predict failures
    - Hardware, software integration for a DT in Industry 5.0
    - Faster or reduced order computational models
    - Avoid planned obsolescence permitting better sustainability
3. Mode of operation and partnerships
    - Participatory and inclusive (visual analytics tool and DT enables the same)
    - Partnerships: Neoskilling, system integration, electronics and instrumentation, and advanced learning systems

1 Introduction

This essay discusses major upcoming global trends and critical challenges that the company will be facing in the next 15-20 years. For the company to position itself as a global high tech design and manufacturing enterprise in the year 2040, a detailed analysis of recent studies on emerging markets and on substantial new opportunities for manufacturing sectors around the world are presented. With the aforementioned overview, it is discussed how the company can reorient itself and the working of its employees to adapt to the changes happening both globally and domestically, with special attention on providing solutions with scientific foundations, i.e. state-of-the-art research ideas have been discussed with the intent that the company continue to be one of top leading global manufacturing and design enterprises.

In the past decade, the manufacturing and design environment has rapidly changed. Large developing economies leaped into the first tier of manufacturing nations and a new global consuming class emerged in developing nations [1]. Innovative manufacturing models, distributed small-scale local manufacturing, loosely coupled manufacturing ecosystems, and agile manufacturing [2] created means for new market entrants to take advantage of using technology to deliver better customized products at smaller scale.

Advances in materials, processes, and information technology opened the possibility of entirely new kinds of products and have radically altered how manufacturers operate [3]. Development of nanotechnologies has the potential to create a new era in microelectronics. Asian megacities will soon witness new lightweight vehicles because of the introduction of new materials such as lightweight steel and aluminum and carbon fiber into the auto manufacturing industry. All over the world, automakers are mastering new drivetrain technologies. Using advanced bioengineering techniques, pharmaceutical companies are trying to gain expertise in developing personalized medicines. Most of the interesting advances are in new production processes and in new information technologies. Additive manufacturing techniques such as 3D printing creates objects by combining small particles rather than by casting or stamping, opening up all sorts of possibilities to manufacture any shape. As the major manufacturing and supply chain management embraced industrial revolution 4.0, digital technology reached a whole new level with the help of interconnectivity through the Internet of Things (IoT), access to real-time data, and the introduction of cyber-physical systems [4].

Futuristic and high-value-added technologies are being developed using concepts such as artificial intelligence, smart technologies, smart factories, smart automation, or smart management such as the implementation of enterprise resource planning and automation of robotized processes to enhance efficiency of global design and manufacturing processes [5]. Such innovations do spark additional demand, but now the environment is much more uncertain. Thus fulfillment of these demands has become conspicuously challenging. And, in the last five years, the world has seen an unprecedented degree of uncertainty.

2 Acknowledging the uncertainty in the context of design and manufacturing

Outrageous pressures on global supply chains created by the COVID pandemic and the subsequent series of lockdowns and restrictions which varied in their timing and severity from country to country, resulted in significant geographical shifts in supply and demand [6]. Economic and business environment became more challenging. Firms continue to struggle with a variety of international business challenges; for example, in the UK and the rest of Europe, due to Brexit there were increases in red tape and cross-border checks causing supply chain pressures. The global supplies of steel and commodities used in semiconductor production are threatened by the Russia - Ukraine conflict. Consequently, the increase in oil prices lead to increase in the production costs and disruption in shipping world-wide. Also, with climate change posing a major threat to our planet, business as usual is simply no longer an option if a sustainable future is to be achieved. Thus big corporations are compelled to revisit their globalization strategy and look to develop expertise locally, so that design and manufacturing disruptions do not happen in the future under conditions such as pandemic, natural or human induced calamities and its globalization does not have baneful impact on the environment.

Improvements to design and manufacturing processes will help companies meet their immediate-term operational and commercial challenges, but they also have an important longer-term role [7]. Company's manufacturing and designing capabilities honed during such crises will lead to development of robust techniques to tackle risks and understand better design methodologies [8]. It is evident and only logical that the companies that invest actively in the social capital, technology, and infrastructure of the future will dominate global manufacturing in the years ahead .

3 Addressing the big question

The big question is how all this complexity can be handled, particularly in terms of design, planning and execution. These challenges are new in many respects, hence past experience cannot be completely relied upon to generate solutions.

The first step is to understand major technological gaps and work on resilient designs and supply chain risk mitigation strategies capable of adapting to major disruptions. This section will discuss the challenges and its research solutions introduced from the design perspective followed by discussion on changes needed with respect to manufacturing aspects.

As highlighted in the previous section, in design, one of the key requirements is to develop expertise locally. Major challenges in doing that is to:

1. Build an ecosystem to reduce the design cycle time leading to product manufacturing and be able to accommodate customer's changing preferences in a shorter timescale
2. Ensure interaction between the various silos such as sales, design and manufacturing which is a paradigm shift from the over the wall design culture
3. Enable digital twins in the context of Industry 5.0 to better efficiency and productivity

1 requires knowledge management and ability to characterize problem complexities such as understanding variable correlations or interactions, identifying tradeoff solutions and physics extraction from data, among others. That is, a decision maker would prefer a design space exploration that permits understanding potential design options subject to requirements. The current time consuming elements of design include computational simulation (though these are attractive as an alternative to experiments), interpretation of simulation outputs, process plan for manufacturing, and certification. The challenge in 2 will be to arrive at a simplified and unified knowledge representation that decision makers in different silos are able to appreciate independently and together. 3 involves understanding and incorporating hardware interfaces that connect the physical model to the digital version.

4 Research strategy addressing the above challenges

It is expected that the future decision maker, owing to affordability and accessibility of sensors, will be armed with plenty of information and will be able to challenge the cross-discipline constraints [9]. Such a decision maker, in different stages of design, will be concerned more about the problem formulation, design space shape, and sweet spots to address 1. This will require advanced visualization techniques for enabling enhanced perception and seamless inspection in high dimensions. It is desired that such a visual analytic technique help in addressing 2 as well.

interpretable Self Organizing Maps (iSOM) is a visual analytics approach developed in the recent past and holds much promise to address several issues discussed above. iSOM is a modification of the conventional self organizing map (cSOM) which is a neural network technique to visualize higher dimensional data in lower dimension, usually in two dimensions. [10] introduced iSOM to visualize design space permitting targetted sampling to build accurate local metamodels as shown in fig (1). Recent work by [11] shows how iSOM can also be used to visualize pareto optimal solutions for a multi objective problem (fig (2)). [12] talks about inverse design method for integrated design space exploration of products, materials, and manufacturing processes for Additive Manufacturing domain. It uses ternary plots to visualize solution space but that limits working with only three goals at a time. [13] shows iSOM being able to provide visual form to compare greater than three conflicting goals simultaneously while accounting for design variables fig (3). Thus advanced visualization techniques such as iSOM show promise and the potential to work in high dimensional design space and deal with multiple constraint problems of different

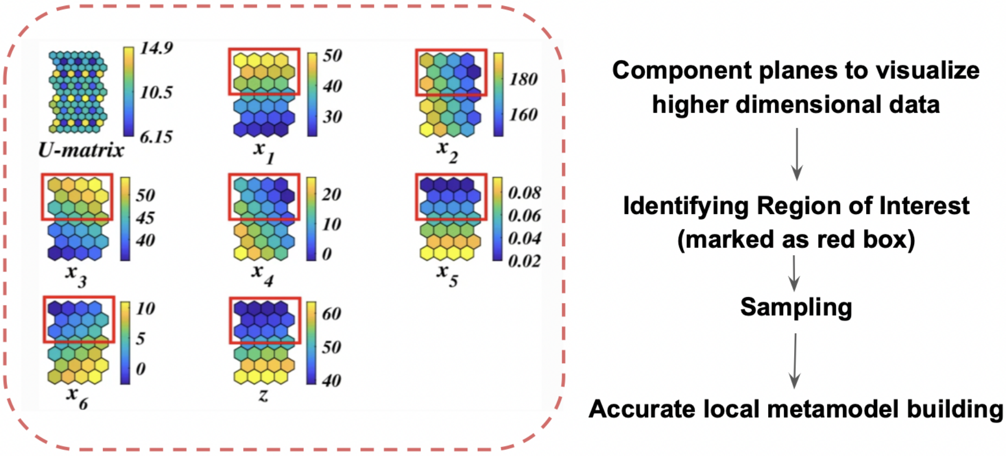

Figure 1: Design Space Exploration using iSOM for heat exchanger with six input dimensions and an output [10]

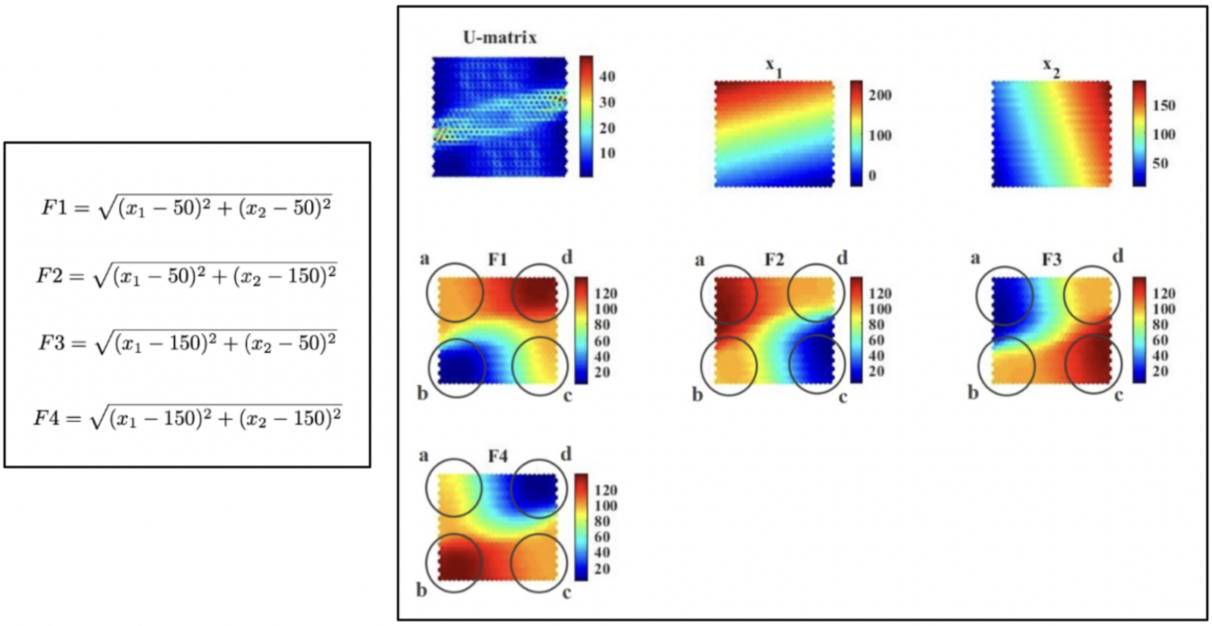

Figure 2: Understanding tradeoff, visualizing pareto fronts with iSOM for four objective problem; circles are for designer to make comparisons among various objectives [11]

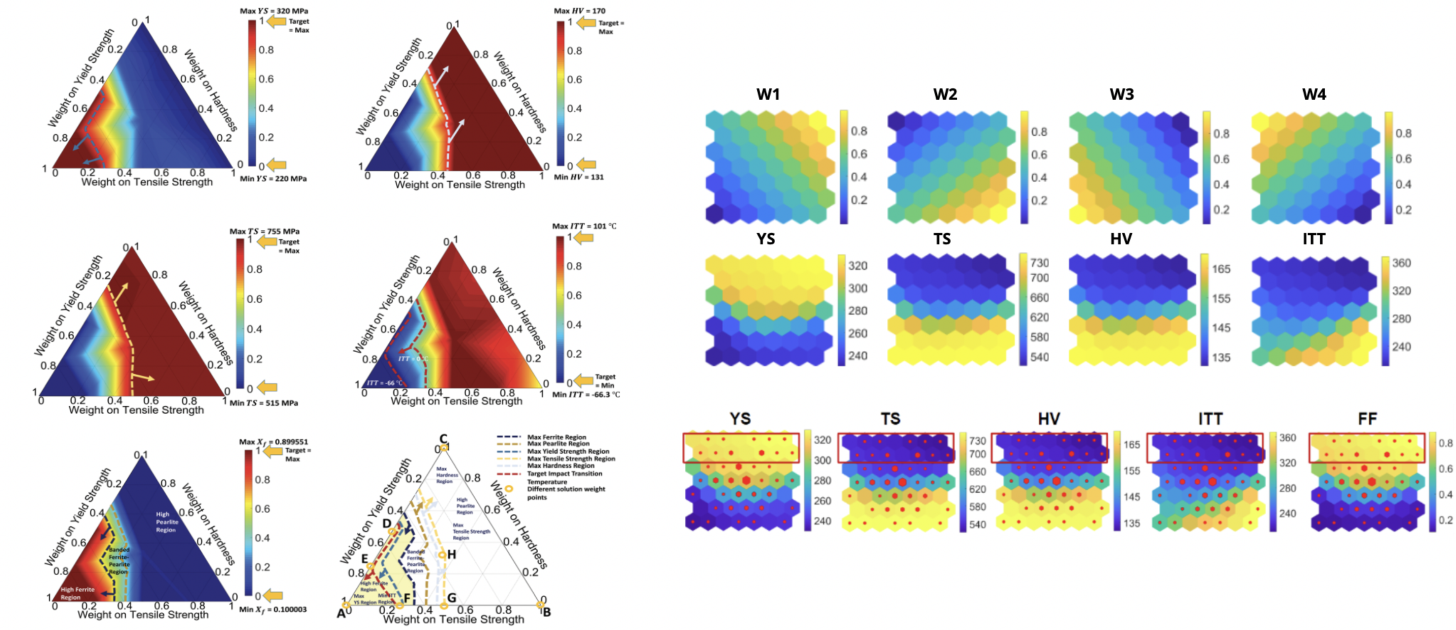

Figure 3: iSOM plots on the right show simpler visualization of solution space obtained by evaluating cDSP with four goals as compared to ternary plots on left [12]

fields. Visualizing the design space that includes the input and output space and enable intuitive decisions by DM contributes to reducing design cycle time. Moreover, they also have the potential to interfere an optimization algorithm and offer reference points or preferred solutions in an interactive manner directing the optimization algorithm to converge faster. Hence, such techniques makes them desirable for the company to review and invest in long term.

In addition, design cycle time reduction could include speeding up inferencing solution outputs, reducing simulation time by bypassing the same employing advanced algorithms such as Generative Adversarial Networks (GAN) that works on building a generator to breed synthetic data, arriving at design specifications by using algorithm such as transformers to extract relevant information from legacy documents and requirements information. The use of models such as the transformer, a sequence-to-sequence neural network model, can enable ease of information exchange from legacy to novice users. Fig (4) shows general flow of available data into useful information employing suggested techniques. This eliminates or at the least removes the dependencies on subject matter experts or expert opinions in the design cycle and leads to better knowledge management. Moreover, inferring simulation results can be automated because majority of the components are repeatedly manufactured in large corporations. That is, for example, in an automotive company, the structures team will design a chassis for all the models. Though the design parameters, materials might change between two chassis belonging to different models, the fundamental design of the chassis remains the same atleast within a particular segment (ex: Sedan or SUV). Therefore, if the simulation inference is documented properly, one can leverage deep learning techniques to develop a learning engine which can automatically infer a new simulation output. A general outline of working on a design starting with computer model to reaching smart manufacturing is shown in fig (5) ([14]-[16]). This can also be extended to include potential design changes to face better design conditions such as more strength or more stiffness. This permits the learning engine to act more intelligently. Moreover, simplified and inherently interpretable plots such as iSOM allow users with varied background (ex: design, manufacturing, sales) to understand the physics by just looking at the plots. Hence, this permits seamless communication between the different silos of design phase. Therefore, I will recommend the company to invest in advanced data driven learning techniques

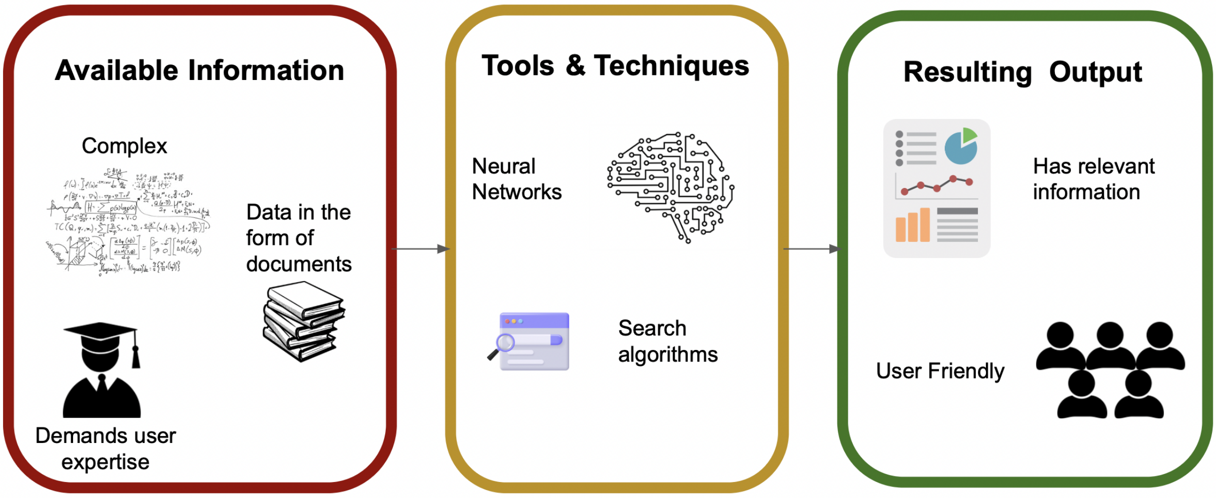

Figure 4: Speeding design cycle by using neural networks/transformer techniques

targeted at reducing design cycle time. From a human resource perspective, I will insist to train people in the intersection of learning techniques and design philosophy.

Next we discuss about Digital Twin (DT) (fig (6)) Inventions and recent surge in sensors makes DT possible to address 3. A DT serves as an important tool that helps engineers and operators to understand the performance of the product, and also how it will perform in the future [17]. A DT allows users to investigate solutions for product lifecycle extension, manufacturing and process improvements, and product development and prototype testing. In such cases, a DT can virtually represent a problem so that a solution can be devised and tested in the program rather than in the real world (an example shown in fig (7)). The prediction of future performance is made based on the analysis of the data from connected sensors, which is further combined with other information sources for precision. This information aids organizations to learn better and faster about their product. The vital boundaries surrounding product innovation, value creation, and complex lifecycles can be also broken down with the information provided by DT [18]. DT help manufacturers and engineers accomplish a great deal, like:

- Visualizing products in use, by real users, in real-time
- Building a digital thread, connecting disparate systems, and promoting traceability
- Refining assumptions with predictive analytics
- Troubleshooting far away equipment Managing complexities and linkage within systems-of-systems

[20] talks about extending the DT to cover both design and manufacturing which will enable streamlining the transition from design to manufacturing. A digitally integrated platform helps create a strong connection between system design and production which further complements the systems within a system approach needed to create the products of tomorrow. In addition, finding solutions for challenge 3 allows arriving at the process plan for manufacturing while including the right to repair which can be considered as an aspect of Design for sustainability (DfX technique). It also helps to address planned obsolescence which otherwise generates more waste and hence affects sustainability. However, it is important to note that this will require interoperability between data streams, clarity on the interface required between the physical and digital models. DT in the industry 5.0 context refers to increased usage of robotics and more machine - machine interface. Therefore, I will plan to invest more on hardware knowledge that supports industry 5.0. In the human resource side, this means developing skills or reskilling existing social capital on robotics

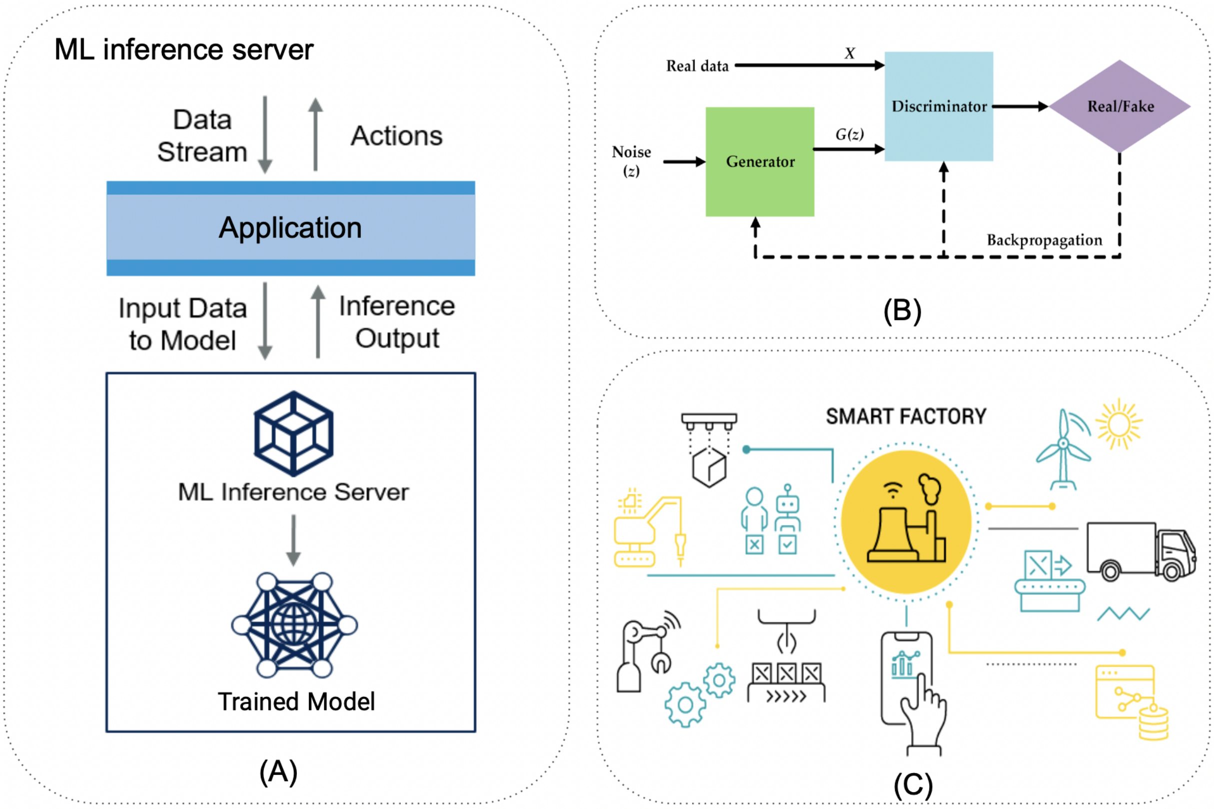

Figure 5: (A) Computer models ; (B) GAN for simulation ; (C) Smart manufacturing

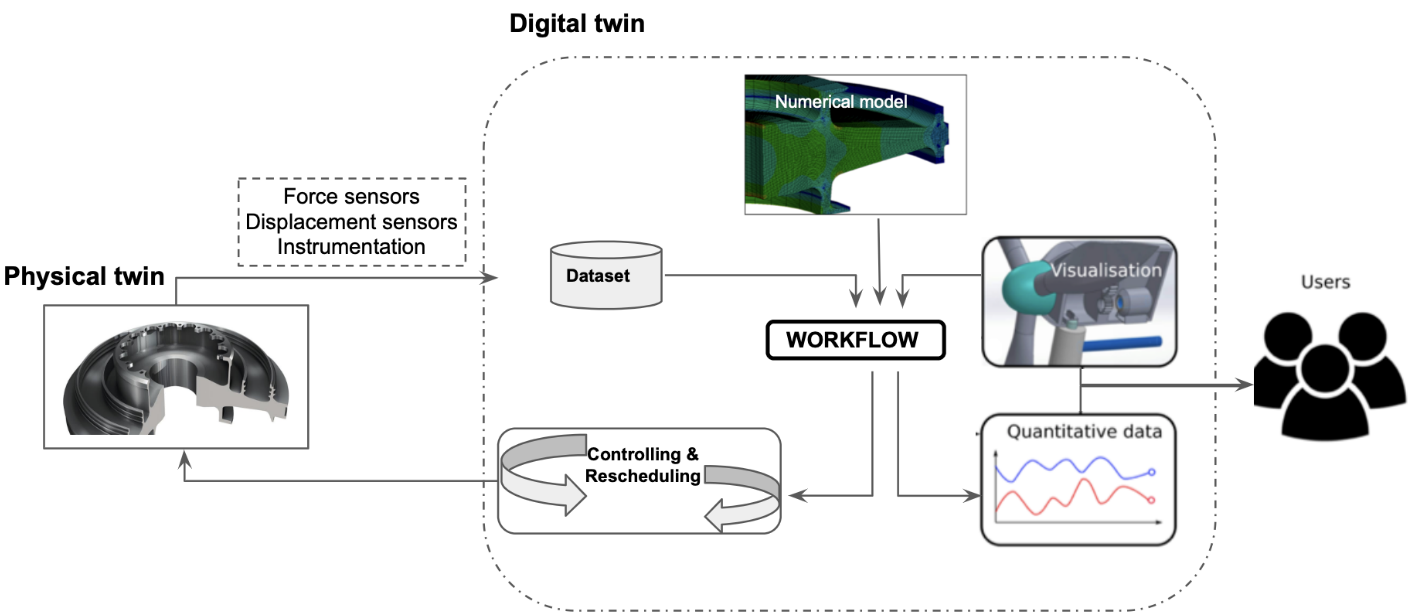

Figure 6: Basic outline of Digital Twin technique

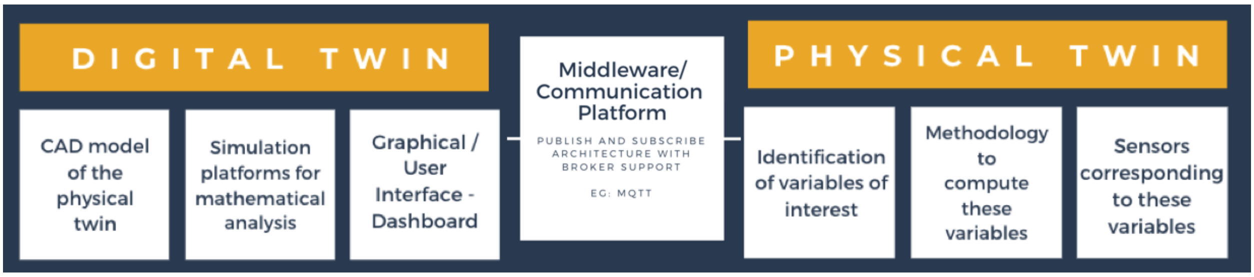

Figure 7: Illustrates the concept of Digital Twins through a bending beam test bench [19]

and instrumentation that connects software and hardware. In addition, classically DT requires high fidelity computer models which are expensive to build and run. Hence, it is important to focus on decreasing the computational expense. This requires interventions in simulation techniques such as FEM or CFD, among others, where advances in numerical methods need to be leveraged. For instance, techniques such as Scaled Boundary Finite Element hold promise to reduce the computational cost by orders of magnitude while bettering the accuracy compared to FEM. Sensor outputs are predominantly in the time domain and they are the inputs to the computer model to simulate the output. However, not all parts of the time signal need to be processed. From past experience or legacy information, DMs know the motifs or patterns where failures are likely to happen. Therefore, one needs to be able to process the large time signals to identify specific motifs that is of interest from a failure perspective. Techniques such as iSOM permit visualizing time signals efficiently and are useful to identify motifs that are likely to lead to failure. Hence, only that part of the signal need to be processed and the simulation run for the corresponding time strand. Such an approach will lead to exponential reduction in computational cost. Of course, techniques such as GAN which was discussed earlier can also be used to bypass the computational simulation resulting in additional computational expense savings.

The discussion about the challenges and its solutions brings us to one of the significant points - who is expected to implement the mentioned solutions. There is a major shift evidently needed in the skill set required by company's workforce. Over the past 20 years, manufacturing companies saw on average 25 percent improvement in productivity, mainly due to automation and standardization in production processes [21]. Thus the manufacturers are in need to rethink their workforce planning and hiring processes and also plan on building transition hubs to empower their workforce, enabling them to be able to execute company's vision. The proposed research set up and methodologies provide an opportunity of re-skilling the existing workforce in manufacturing. Since the techniques suggested are intuitive and easily interpretable, we can teach and involve employees with good experience in manufacturing sector to actively participate in the designing process using tools we have suggested. Thus we can leverage their knowledge and re-calibrate their task to improve upon existing designs. Working towards creating flexible working environment, accelerated by digital transformation which involves training in algorithm development, data science, machine learning and instrumentation, among others is the key to sustain in today's dynamically changing scenarios [7].

5 Closing remarks

Even though it is difficult to figure out how the complexities of working as a designing and manufacturing enterprise will interact with the uncertainty of present and future, the advancements in technology and innovations are the strongest drivers of growth that are to be smartly incorporated into company's functioning. After analysing the major global challenges the company will have to face in the coming future, following is the identified strategy proposed for the company:

- Understanding, development and implementation of learning and deep learning techniques that are domain agnostic and can scale easily
- Advance visualization approaches to be inherently interpretable and to scale across higher dimensions (ex: iSOM)
- Hardware interfacing protocols for implementing Digital twins
- Working towards building a system that enables local expertise and delivers better customised products

The competition in the global market will only increase. Keeping this in mind, above strategies have been discussed such that company can constructively handle the compound pressures and associated uncertainties of fast advancing economies and technologies. Most of the solutions discussed above incorporate the use of the most cutting edge technology of that time, thus ensuring that company makes best use of the developments of the world and is able to build upon them.

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