TECH FRONTIERS

Artificial intelligence and machine learning in engineering design

Engineering design is reaching new levels of competence and excellence using artificial intelligence (AI)

EEPC INDIA

THE engineering services market consists of the sale of engineering services. Engineering services' companies apply physical laws and principles of engineering in the design, development, and utilisation of machines, materials, instruments, structures, processes, and systems. Engineering services include the technical application of engineering in product designing, innovations, and others in industries such as building construction, mining, power and energy, transportation, manufacturing, and others.

ENGINEERING SERVICES GLOBAL MARKET

The global engineering services market is expected to grow from $830.48 billion in 2020 to $938 billion in 2021 at a compound annual growth rate (CAGR) of 12.9 percent. The growth is mainly due to the companies rearranging their operations and recovering from the Covid19 impact, which had earlier led to restrictive containment measures involving social distancing, remote working, and the closure of commercial activities that resulted in operational challenges. The market is expected to reach $1167.21 billion in 2025 at a CAGR of 5.6 percent.

The engineering services market is expected to benefit from steady economic growth in developed and developing countries. The International Monetary Fund (IMF) predicts that the global real GDP growth will be 3.7 percent over 2019 and 2020, and 3.6 percent from 2021 to 2023. This trend will be mainly driven by regions of Asia and Africa. According to the report, Asia will represent 66 percent of the global middle-class population by 2030. For instance, the Indian IT-BPM industry grew by 7.7 percent in FY 2017, with software products and engineering services reaching $25 billion. Going forward, the Asia-Pacific and West Asian regions are expected to be the fastest-growing markets in the engineering services, design, animation, and graphic designing industries. Developing countries such as India and China have started attracting foreign investments to improve their infrastructure. This was mainly due to an increase in internet penetration, growth in population, and increasing economic activity.

Lack of quality control and safety concerns of engineering firms may hinder the engineering services market growth. Defects or failures in construction activities result in high costs. These minor defects result in reconstruction to make the facility operations impaired. Increased costs and delays are the results of ineffective internal controls and safety measures which hamper the end-to-end quality. For instance, QuEST, an engineering services company, is facing difficulties caused by lack of understanding, problems in the execution process, and inconsistency across various business units. Companies in the industry are incurring high maintenance and budget costs to develop new and advanced methods to combat issues of safety and control.

The increasing popularity and adoption of the Internet of Things (IoT) across the globe is the latest trend in the engineering services market. Internet of things is a system of interrelated devices enabling transmission of data over a wide range of networks. IoT enables continuous innovations in real-time data analytics, design, and development products and helps businesses grow at a faster pace. Engineering service providers are increasingly using industrial IoT to improve and optimise their production process with better energy usage, resource allocation, and asset management. For instance, PureSoftware, an engineering services company, has successfully integrated IoT to engineering services and built a steady IoT platform to improve accuracy and speed to retrieve data. India has a 43 percent market share in the global IoT market followed by Western Europe and North America with 27 and 23 percent respectively.

The Construction Design and Management Regulation, also known as CDM Regulations/CDM 2015, came into force from 6 April 2015. These are the regulations governing engineering service providers with respect to construction projects of all sizes and types. This CDM regulation replaced Construction (Design and Management) Regulation 2007, aiming to improve the overall health, safety, and welfare of the workers and professionals involved in construction. This regulation specifies the general requirement, states safety norms, and minimum welfare facilities required at construction sites.

In 2020, Wipro, an Indian software services exporter acquired Eximius Design for $80 million. The acquisition is expected to strengthen Wipro's market presence in the semiconductor ecosystem. Eximius Design is a California-based engineering services company focused on ASIC design, systems, and software engineering. Eximius Design was founded in 2013 and has design centres in the US, India, and Malaysia.

Major players in the market are Tata Consulting Services (TCS), Infosys, WorleyParsons, Deaton Engineering Inc, and Aricent Group.

The countries covered in the global engineering services market are Brazil, China, France, Germany, India, Indonesia, Japan, South Korea, Russia, UK, USA, and Australia.

The regions covered in the global engineering services market are the Asia-Pacific, Western Europe, Eastern Europe, North America, South America, West Asia, and Africa.

The global engineering services market is segmented:

By type: Civil engineering services, environmental engineering services, construction engineering services, mechanical engineering services, others engineering services

By end user: Automotive, industrial manufacturing, healthcare sector, aerospace, telecommunications, information technology, energy and utilities, others

By engineering disciplines: Civil, mechanical, electrical, piping and structural engineering

By delivery model: Offshore, onsite

ENGINEERING DESIGN PROCESS AND ITS IMPORTANCE

Engineering design process is a common series of steps that engineers use in creating functional products and processes. The process is highly iterative – parts of the process often need to be repeated many times before another can be entered – though the part(s) that get iterated and the number of such cycles in any given project may vary.

It is a decision-making process (often iterative) in which the basic sciences, 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.

While the spoon is a very basic example, the complex artefacts that humans make today invariably involve engineering design. The Worli Sealink in Mumbai, the fastest car in the world, the supersonic jets, smart phones, the Burj Khalifa and the latest innovation in diagnostic medicine – all are examples of engineering design at work.

Engineering design is the use of scientific principles, technical information, and imagination in the definition of a mechanical structure, machine, or system to perform pre-specified functions with maximum economy and efficiency. The fundamental elements of the design process include the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation.

Thus, the prime purpose of engineering design is to apply scientific knowledge to the solution of technical problems. While engineers provide a technical solution, it is very important to understand that engineering design implies a solution that is aesthetic as well. In other words, designers too are involved to ensure that the end product is economical, eco friendly and appeals to users.

Engineering design tools

Many tools are available today that helps engineers/designers achieve their objective. Computer aided design (CAD) and computer aided engineering (CAE) are software that allow engineers to be creative while satisfying the technical requirements of a product. A few of the popular tools include PTC Windchill, CAE Suite of Solutions from Altair, 3D printers from Stratasys, MATLAB and SIMULINK from MathWorks.

Introduced in the 1960s to automate the task of design engineering, these tools have now grown phenomenally in terms of sophistication and functionality offered. Often time, special training is required to use these tools correctly.

Engineering design services

Because modern technology is so complex, it is now near about impossible for an individual to handle design and development of a new product singlehandedly. It takes a team of designers and engineers to successfully manufacture a new product. In order to achieve success, the design process must be planned carefully and executed systematically. Specifically, the engineering design process must integrate the many different aspects of designing in such a way that the whole process becomes logical and comprehensible. In addition, most of the CAD/CAE software available today is complex. It takes special training to understand, harness, and utilise the real power of these applications. Secondly, the cost of acquiring these tools is rather expensive. Many companies that need to develop products, therefore, outsource their engineering design requirements to agencies that provide such services. There are also times when the company has trained manpower and good CAD/CAE infrastructure, but the people working there are simply overloaded with work. In such cases too, companies' avail engineering design services to share their workload when they are hard-pressed for time.

A few of the engineering design services include:

• CAD design services
• CAE design services
• FEA services
• Moldflow services
• Thermal analysis services
• CFD services
• Structural analysis services
• Noise and vibration analysis services
• Kinematics and multibody dynamics services

In developing nations like India, engineering design services are the need of the hour. There are many small- and medium-scale industries that do not have the necessary infrastructure to thoroughly evaluate their product ideas and reach the manufacturing stage, and reputed design services companies are in good demand to assist them.

Figure1 shows the steps of the engineering design process

Engineers do not always follow the engineering design process steps in order, one after another. It is very common to design something, test it, find a problem, and then go back to an earlier step to make a modification or change to your design. This way of working is called iteration, and it is likely that your process will do the same!

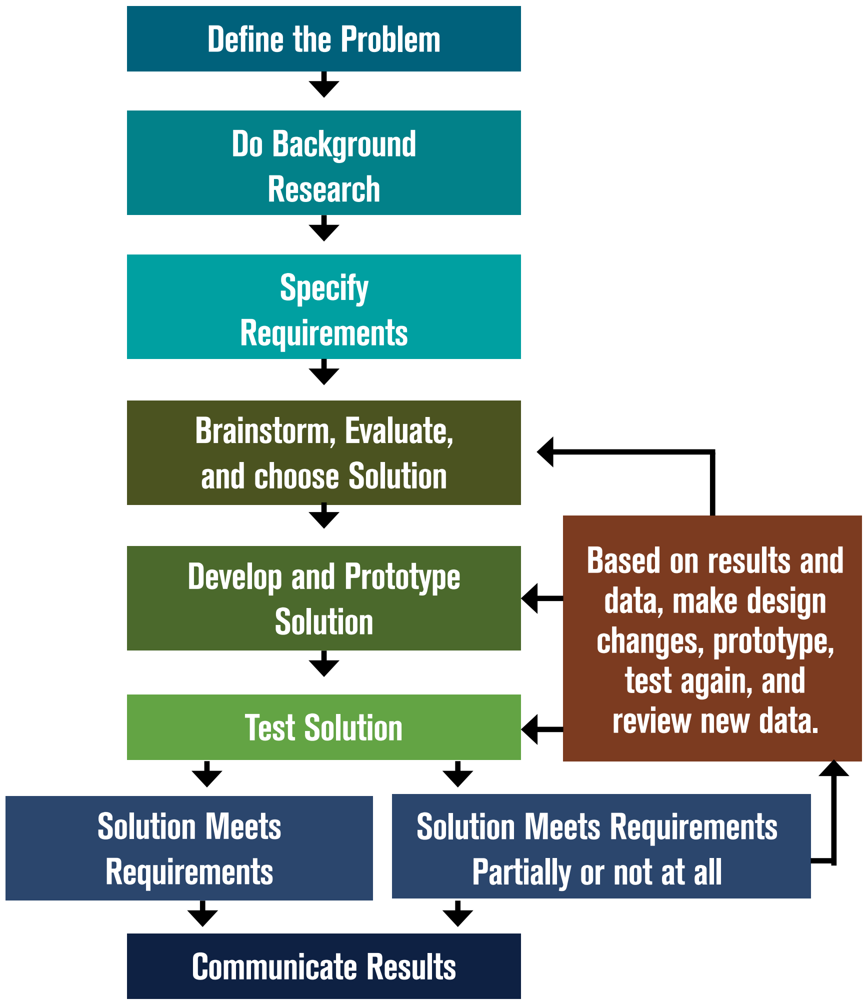
Generative design – driving force for engineering design

Generative design is a technology that uses artificial intelligence (AI) to transform the design process by identifying various design opportunities or design problems by giving a wide range of solutions or design options during design and testing. It will be one of the driving forces in the era of Industrial 4.0.

Introduction to generative design

Generative design is an iterative design

Figure1: Steps of engineering design process



process that involves AI and cloud compounding that will generate a certain number of outputs that meets certain constraints.

It is an evolution of human-AI collaboration where engineers or designers plug in the design objectives for AI and AI spits out endless iterations of design solutions.

This data-based approach can significantly accelerate companies to move designs forward into production, reduce the manufacturing cost, and take something to market at speeds that would be unimaginable. But finally, human intervention is required to make the final design decision, say for example, the aesthetic look, colour, and feel.

Although, generative design was introduced in product development few years ago, it was not successful or not effectively implemented. This is because it was difficult to get engineers and developers for developing 3D CAD software. And many previous users of the software have been tempted to describe it as a simulation tool or a topology optimisation system. But a lot has progressed from that time. Advancement in cloud computing, AI technologies, machine learning, simulation technology, 3D printing, and rapid prototyping enhanced the usage of generative design in the era Industry 4.0.

Early CAD versus generative design

In the past, all creative work existed in the engineer's brain and the CAD system simply recorded those ideas. In other words, starting a 'drawing' or CAD design was based on what you already know or ideas that were in your head, and you could tell a computer what you want to accomplish or what problem you are trying to solve.

But generative design turns the computer into the driving force for engineering design. In generative design engineers first define the design and functional parameters like maximum size depending on the installation or available space, weight, type of material, maximum load, type of manufacturing, and costs. Then the AI takes over, not only giving one improved design alternative, but rather dozens, hundreds, or thousands of potential design alternatives focusing in all possible directions.

Moreover, unlike traditional design engineering, it doesn't do this in blankness. The designs can be simulated and tested for performance in real world applications to help narrow down the right options for the design. In addition to the performance, the system generates designs suitable for CNC milling or 3D printing, additive manufacturing, and so on.

Topology optimisation versus generative design

Topology optimisation refers to the optimisation of available existing design by using simulation on 3D model. For example, the designer aims to reduce the weight without altering the outer shape. For this, he does not create complete new design but optimisation of known solutions. But generative design starts from scratch, where the designer defines few parameters and obtains optimised design solutions.

CASE STUDY – UPPER TORSION LINK IN LANDING GEAR

The objective of this case study is to give insight to what generative design is all about.

A torque link subassembly is selected to explore the feasibility of this generative design. **Figure2** shows 3D CAD model of complete landing gear and magnified view of upper torsion link. During CAD modelling a designer just tells the computer what s/he wants to accomplish, hence all dimensions are inputted to the software without giving any functional parameters and manufacturing methods. To optimise further, the designer wants to use other optimisation techniques subjected to various testing and simulation work.

But by using generative design we obtain the optimal solution. For this case study we used Autodesk Fusion 360 software (Generative Design).

The steps involved in generative design are:

1. ***Creating preserve geometry***: 'Preserve' selected geometry defines the loads and constraints associated to the case study. The green textured parts indicate preserve geometry as shown in **Figure3**.

2. ***Creating obstacle geometry***: This constrains the software to not put any material in between. Outside of that obstacle, generative design can work around it, as needed. Red textured part in the **Figure4** shows obstacle for the torsion link.

3. ***Setting up a design problem***: Use the constraints to define interfaces between design and the surrounding environment. Apply structural loads to simulate pushing, pulling, and twisting forces that the design should withstand. Alongside, one can specify the optimisation objectives such as factor of safety, stiffness, mass target, manufacturing process. A load of 4.48 KN is acting axially on the torsion link as shown in **Figure5**.

Figure2: 3D CAD model of landing gear assembly and magnified view of upper torsion link

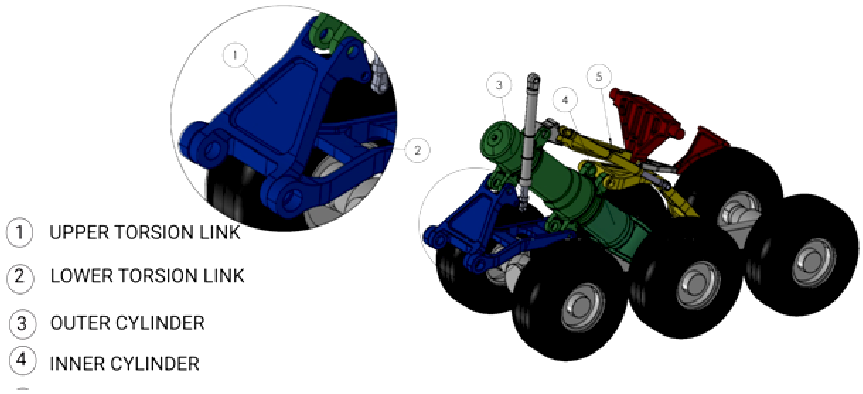


Figure3: Preserved geometry and starting shape

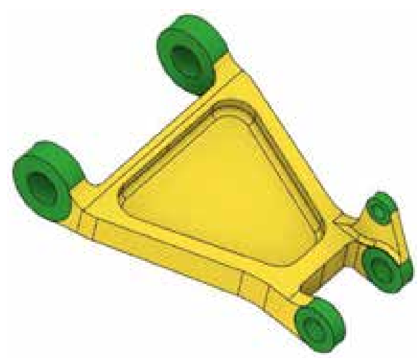


Figure4: Obstacle geometry

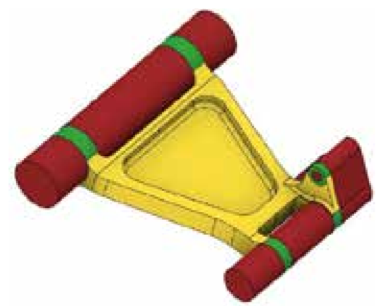
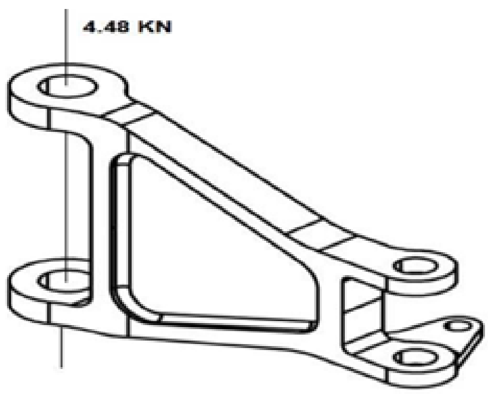


Figure5: Load acting on torque link

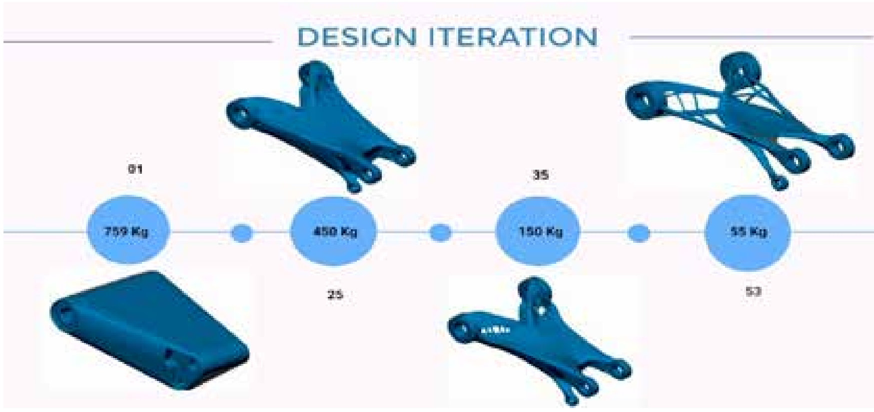


4. ***Explore outcomes***: Software generate outcomes that satisfy the design requirement specified in the generative study. Once the processing is done design alternatives called outcomes can be explored along with their properties. Generative design gives you the ability to select multiple manufacturing methods, from additive to 3 or 5 axes milling and more, to quickly explore numerous solutions for your design and engineering challenges. Presenting you with a range of solutions that meet your goals, the generative design software gives you the option to explore the various outcomes and even bring the solutions back into your CAD program to refine the design.

Figure6 shows a few design iterations by using generative design. This case study successfully demonstrates the potential of incorporating the generative design methodology for aircraft landing gear subassembly, i.e. upper torsion link. With the use of this process the overall weight, performance, product manufacturing time, and cost of the component will be reduced significantly.

With the use of the generative design method the torsion link achieves 48 percent light weight than original design with same performance characteristics.

Figure6: Design iterations from initial to optimal solution



Conclusion

Using AI software and the computing power of cloud, generative design enables engineers to create thousands of design options by simply defining their design problem – inputting basic parameters such as height, weight it must support, strength, and mate rial options.

With generative design, engineers are no longer limited by their own imaginations or past experience. Instead, they are collaborating with technology to co-create more, better, with less: more new ideas, products that better meet the needs of users, in less time and with less negative impact on the environment.

Another benefit of generative design is the ability to consolidate parts. Because generative design can handle a level of complexity that is impossible for human engineers to conceive – and because 3D printing can enable the fabrication of the complex geometries that generative algorithms often produce – single parts can be created that replace assemblies of many separate parts. Consolidating parts simplifies supply chains, maintenance and can reduce overall manufacturing costs.

OTHER STEPS INVOLVED

Powder injection moulding for flexibility of design

Powder injection moulding (PIM) is one of the near net manufacturing technologies for the manufacturing of complex, precise components from either metal or ceramic powder.

The PIM method combines the design flexibility of the plastic injection moulding process and material selection choices from powder metallurgy to combine into a single process.

Net shape manufacturing

The name implies that the technology produces components that are closer to the finished size and shape with minimal final processing or machining and further reducing energy consumption in secondary processes, ensuring less material wastage, and usage of cooling fluids.

Figure7 shows part samples produced by the PIM method – we can find applications in all areas of life, from automotive, power tools and aero engines to medical devices, orthodontics, consumer electronics, and so on.

Figure7: Part samples produced by PIM method

POWDER MATERIALS AND CHARACTERISTICS

Stainless steels, nickel alloys, low-alloy steels, cobalt alloys, and binary alloys have been used extensively in powder metal injection.

The ideal characteristics of these materials would be to hold spherical morphology for excellent flow, low oxygen levels with high packing density allowing faster sintering process, and sufficient inter-particle friction to avoid distortion after binder removal process, free of internal voids.

Powder metals are available in wide range of particle size distributions with an ideal characteristic of 4-8 microns as mean particle size, tap density >50 percent rth and contacted angle of repose >55.

ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING

Just like with many other industries, artificial intelligence and machine learning are changing engineering. Even though these technologies are now seemingly 'everywhere,' we shouldn't overlook how truly incredible they are and the remarkable things they enable us to do today and will allow us to do tomorrow. For engineers, artificial intelligence and machine learning might cause the tasks they do to evolve, but it can also help them do things they weren't capable of before. Since the earliest days of computing, scientists and other thinkers have been fascinated by the notion of creating a machine capable of replicating the human brain. It used to be thought that the analogy of the human brain is like a computer ran deep. However, we now know that the picture is much more complicated, the way that the brain works goes beyond a simple computer. We still do not fully understand how consciousness arises in the human brain, and there is still much debate surrounding whether consciousness can be separated from advanced intelligence. But artificial intelligence need not be this complex; we see far simpler examples of what we might describe as artificial intelligence on a regular basis. The voice assistants pre-installed on every modern smartphone are just one example and now these same AIs are being integrated into alarm clocks and speakers so that they can be used to control a variety of smart devices around the home.

What is artificial intelligence and machine learning?

First, let's get clear about our definitions of artificial intelligence and machine learning.

The field of AI was begun in 1956, but it has been only in the last decade that significant progress has been made to allow the technology to be widely used and experienced by many outside technology circles. Today, artificial intelligence is one of the fastest-growing emerging technologies and describes machines that can perform tasks that previously required human intelligence.

Machine learning takes it a step further. It's one of the latest artificial intelligence technologies where machines can learn by taking in data, analyzing it, taking action, and then learning from the results of that action.

Artificial intelligence and machine learning in engineering

Artificial intelligence that is used in the engineering sector uses software and hardware components. As machines become more sophisticated, they will be able to support not only smart production lines and complex manufacturing tasks, but will also be able to design and improve tasks over time – with little or no human intervention – through machine learning. Robots have been used by automobile manufacturers on the production line for quite some time and have gone from completing simple engineering tasks to now handling many precision moves required for some of the most intricate parts of the process.

Many of the tasks engineers are responsible for, such as design and simulation, can be enhanced with the support of artificial intelligence tools. Consider how computer aided design (CAD) was once just a supplemental tool to engineering, and today it is a fundamental part of the daily workflow. These tools will help improve the capabilities of engineers and make it possible to explore design and weight-saving options that weren't ever possible before.

Another way artificial intelligence can support engineering tasks is to break down silos between departments and help to effectively manage data to glean insights from it. AI programs can provide automation for low-value tasks freeing up engineers to perform higher-value tasks. By using machine learning to discover patterns in the data, machines will be incredibly important to help with engineering judgment.

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