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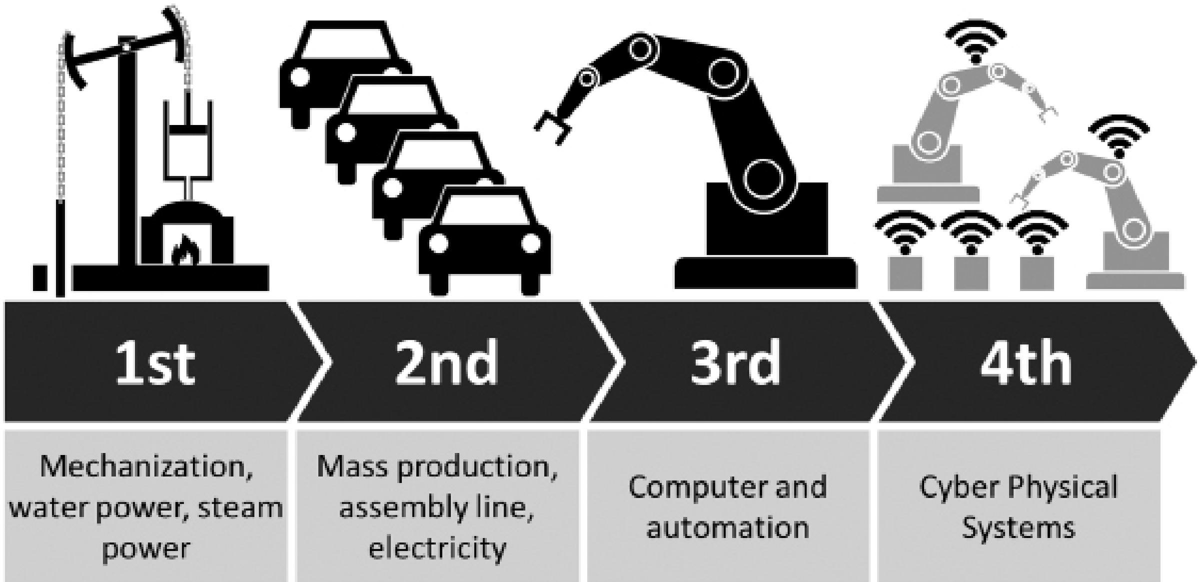
COMPUTER AIDED ENGINEERING – TOWARDS A DIGITAL TWIN TECHNOLOGY

We are living in a digital world, where rapid technology development gives rise to the fourth industrial revolution at an unprecedented scale. The Industry 4.0 era requires ever more sophisticated products which are not only able to operate at peak efficiency in wide range of conditions, but can also communicate with each other to create new, complex, and very often autonomous systems. Design, manufacturing, operation and maintenance of such products would not be possible without Computer Aided Engineering (CAE), which encompasses a range of advanced computer tools, programs and processes.

In the past few decades we observed an exponential growth in computing power. Modern smartphones are much more sophisticated than the most powerful computers, which were used during the Apollo programme to enable human landing on the moon[1]. Nowadays, powerful desktop machines allow engineers to create complex 3D drawings and perform real life analysis of various physical phenomena; whereas easy access to High Performance Computing means that even the most demanding simulations are within reach and can be incorporated in the design process.

[1] Website: Zmescience.com/research/technology/smartphone-power-compared-to-apollo-432, accessed on 25 V 2017.



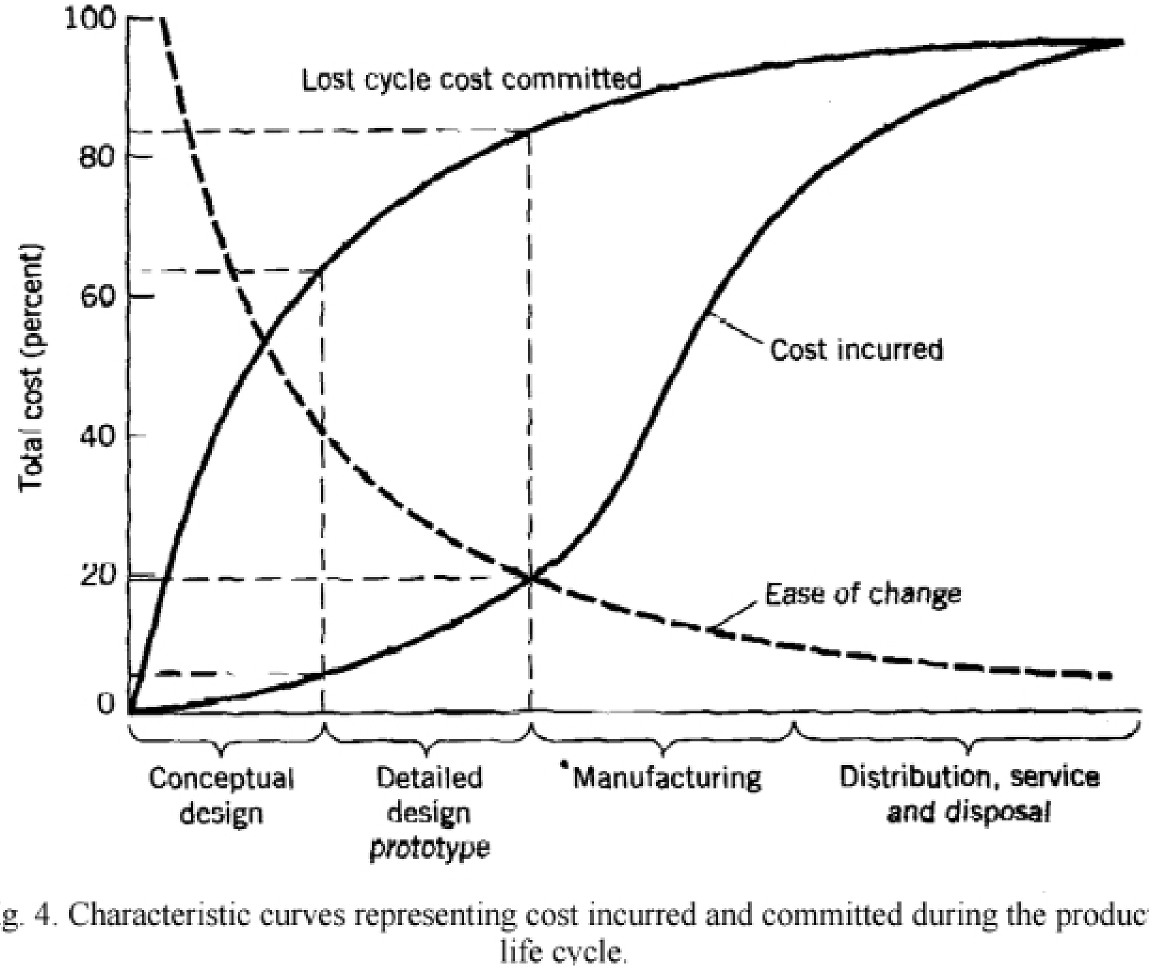
1. Four industrial revolutions; Christoph Roser at website: Allaboutlean.com AllAboutLean.com

Fast Internet connections and availability of small, cheap sensors introduced the „Internet of Things", a technology which allows wide range of data, related to the product operation and performance, to be gathered. Cloud and Big Data means that this information can be stored and processed to reduce operation costs and drive future design decisions. Traditionally engineers had a limited knowledge about the real-life performance of their products and had to rely on their intuition and experience in making those important decisions. This is no longer the case.

Thanks to these new, exciting technologies we are at the stage when the entire product's lifecycle, from the concept design, through the product lifetime, up to the decommissioning stage, can be modelled in a virtual world. Each individual product can have a digital twin, which stores not only all its parameters but also the history of modifications, maintenance and operations. This digital twin technology is introduced across industries: for aeroplanes, trains, cars and even for infrastructure projects.

COMPUTER AIDED DESIGN

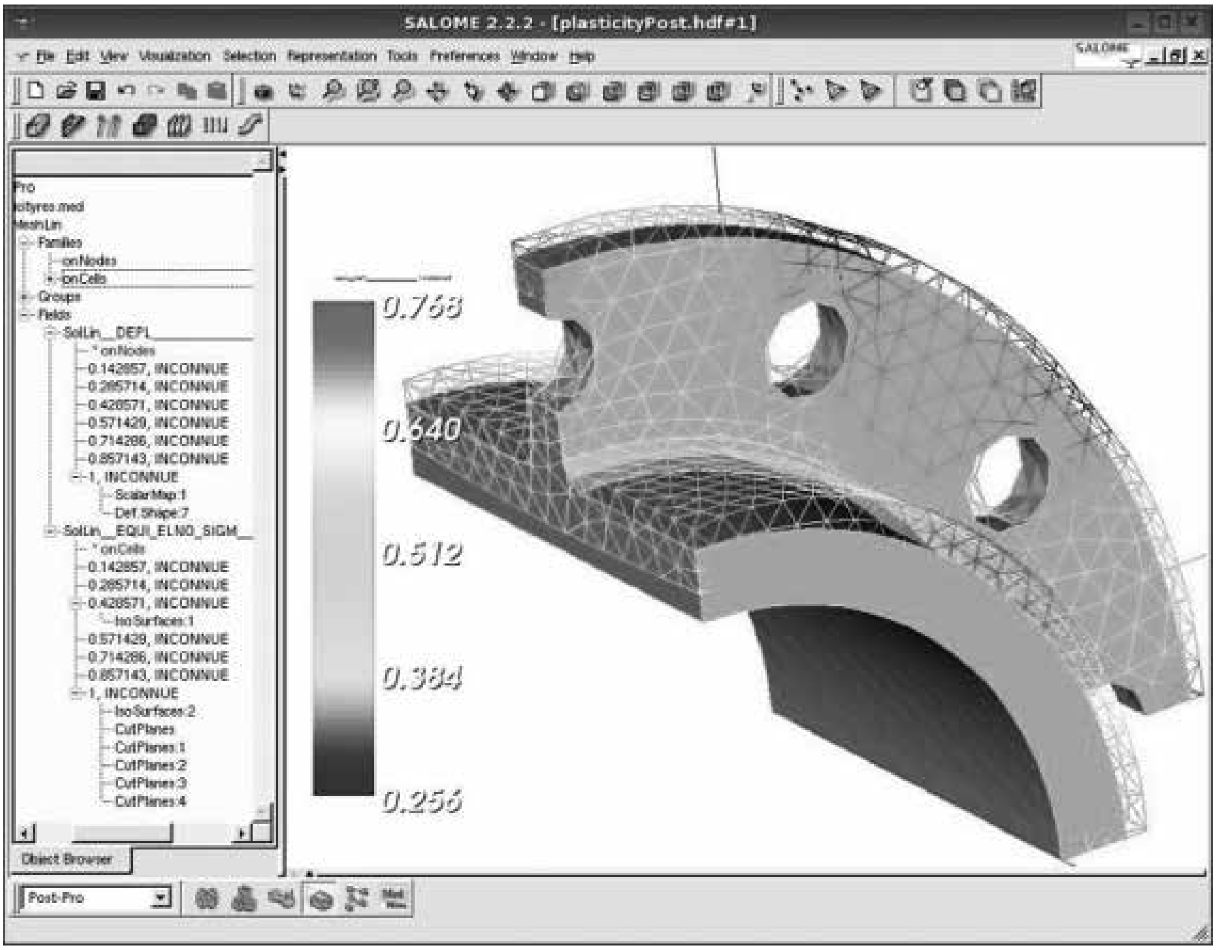
Design is the core of the engineering process. It is at this stage when the most important decisions are made, which, in turn, has an impact on the functionality and the cost of the final products. The same fundamental design principles apply regardless of whether we are considering it a small component of a larger system or a complex object such as a car, an aircraft or even a large infrastructure project.



2. Characteristic curves representing the cost of the product during its lifecycle; N. Bilalis, „Computer Aided Engineering – CAD", Technical University of Crete report, 2000

The traditional design process involves the inception of an idea based on the requirements defining the desired functionality of the final product. Then, during the concept design stage, various assumptions are made, which, in turn, define the parameters, the objectives, as well as the constraints of the design. Next, throughout the detailed design stage, teams of engineers from different disciplines propose and evaluate various concepts to achieve an optimum product, which satisfies the defined requirements at minimum cost. This involves numerous studies, analyses and experiments which finally lead to the creation of a prototype, which can be manufactured. Development of a new product can be relatively quick and take place in a matter of weeks, but for more challenging projects it can take years and require substantial investment at an unknown rate of return.

The design process, is by nature an iterative procedure, during which the original design evolves, as more information becomes available. This results in one of the main challenges of the product development (fig. 2). Although, the



3. Example of a cad model used for structural analysis; Website: C*aelinux.com*

cost incurred at the concept design stage is relatively low, the committed cost rises dramatically as the time progresses. The figure also shows that decisions made at the early stage have a great impact on the final product and that the scope for change in the detailed phase is very limited. This can lead to expensive problems, if a major design flaw is uncovered during the prototype testing, and a fundamental redesign is required.

Various concepts have been investigated to aid this issue, e.g. Set-Based Paradigm[2], however, in practice, any design methodology depends on the capability to generate as much information about the product as possible in early stages of the design process, when changes are relatively easy and inexpensive. Therefore, Computer Aided Design (CAD), which involves the generation of digital models, a range of simulation tools and easy prototyping is very important, as it enables extensive studies at a low costs to be conducted.

[2] D. K. Sobek II, A. C. Ward, J. K. Liker, *Toyota's principles of set-based concurrent engineering*, „MIT Sloan Management Review", Winter 1999, 40, 2, p. 67–82.

In modern CAD, the entire product is modelled in a designated CAD package which stores its shape, dimensions, material properties and interaction with different components of the system. This model forms a basis for subsequent performance studies and is used in manufacturing. One of the main advantages of the CAD model is that it can be parameterised, which, in turn, allows various variants of the design to be easily studied and the resulting data to be fed back to the original model. Sophisticated CAD models also contain large databases of materials properties and standard parts, such as nuts and bolts, which can be used to speed up the design process.

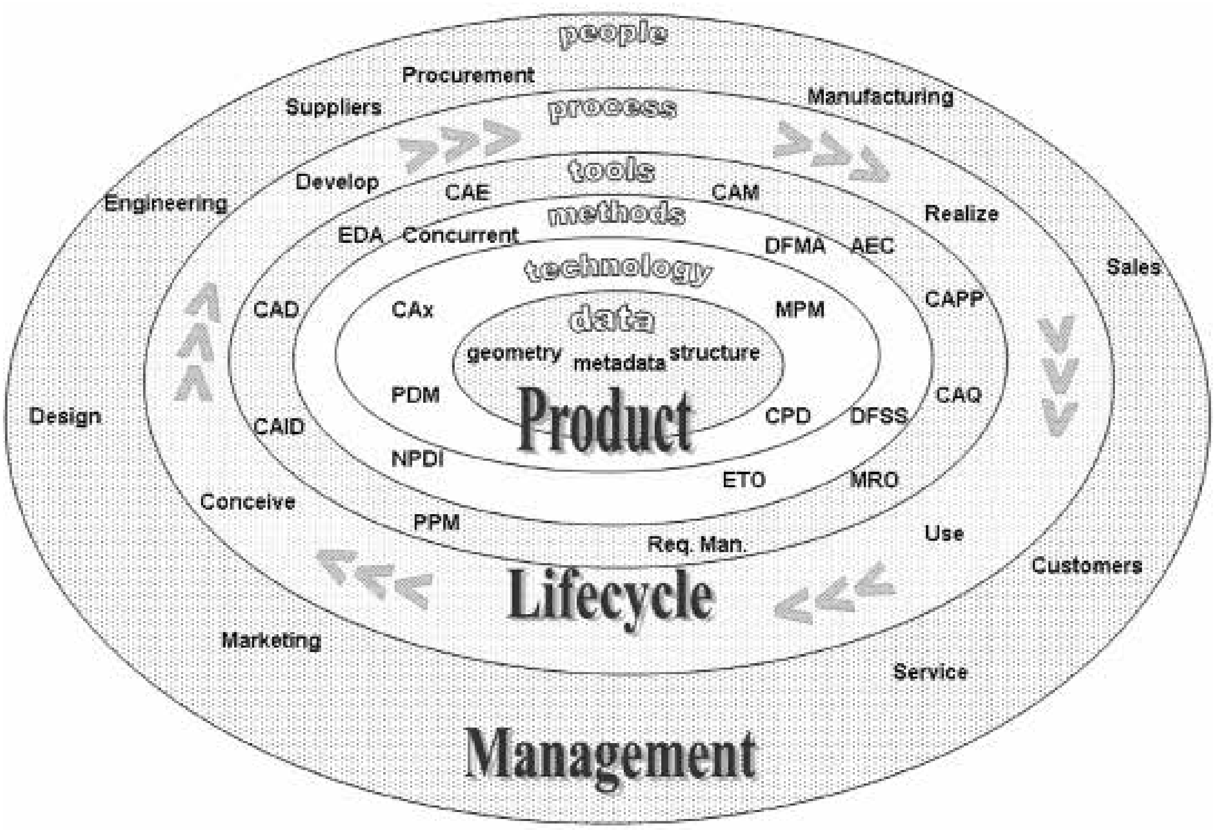
Once the concept for the product is determined, the model undergoes a thorough investigation, which, depending from the scale of the project, can utilise simple mathematical models or a complex Multiphysics simulation involving fluid mechanics, structural analysis, heat transfer, electromagnetics etc. Sophisticated computer packages are used to investigate the physical properties of the product and to predict its performance. The simulation coupled with optimisation packages are used to efficiently explore the design space and to determine the best parameters of the models. Some modern packages can produce designs, which are highly innovative, and show features which normally wouldn't be proposed by even the most experienced engineers.

Eventually, every product needs to be manufactured at some point and here CAD also plays a major role. The Virtual Prototyping means that the manufacturing process is defined long before the product enters the factory and various aspects of the assembly line are optimised to achieve the best possible performance both in terms of quality as well as the cost of the final product. The advent of 3D printing means that the virtual models can be quickly and cheaply turned into physical products which can undergo extensive testing.

Design packages, widespread simulation and virtual prototyping are the main CAD features. This brief overview shows how the modern technologies are used for better risk management and allow for the right decisions to be made at the early stages of the design process, giving the engineers tools and freedom to innovate.

BEYOND DESIGN – PRODUCT LIFECYCLE MANAGEMENT

One of the aims of the fourth industrial revolution is to extend the application of CAE beyond the design phase and introduce it into the entire product lifecycle management, which includes operations, maintenance and eventual decommissioning. These days, high-speed Internet along with minia-



4. Various aspects of PLM; Website: En.wikipedia.org/wiki/File:Product_lifecycle_management.png

turised sensors allow for nearly any type of measurement to be collected in real time. This ability, combined with large data centres and cloud computing, opens an entire new world of possibilities, both for engineers and entrepreneurs.

For instance, the aircraft engine manufacturer, Rolls-Royce, is using its engine health monitoring data to collect information about the performance, fuel consumption and health of each individual engine that is currently in use[3]. This enables the company to anticipate any upcoming problems and to ensure that adequate measures are in place if a failure occurs. The new technology has impact not only on the engineering aspect but on the business model as well. Rolls-Royce has recently introduced new maintenance programmes which use the data to cater for the needs of individual customers.

Automotive is another example of the industry which is welcoming the opportunities offered by the introduction of digital twins and extensive digitisation[4]. Each day several new solutions are incorporated into manufacturing pro-

[3] B. Read, *Aftermarket Revolution*, „Aerospace Magazine", March 2016, p. 18.

[4] KPMG report, Website: Smmt.co.uk/wp-content/uploads/sites/2/smmt_the-digitalisation-of-the-uk-auto-industry_kpmg-apr-2017.pdf, accessed on 25 V 2017.

cess to enable more efficient management of the plants and supply chains. As modern cars are equipped with more sensors, a direct connection can be forged between the car manufacturer and the end customer giving the latter more information about the performance and health of their vehicle. Finally, the implementation of an autonomous driving technology can be accelerated by increasing the fidelity of the control software by the data collected from all models in use – a technology that allows unprecedented data collection, which no car manufacturer would be able to gather on their own.

Civil industry also embraces the digital twins by widespread incorporation of the Building Information Modelling (BIM) paradigm[5]. Application of BIM, means that each infrastructure model has its own digital copy which stores all technical drawings, 3D models, information about services and much more. Availability of this information means that the construction process can be modelled a priori, significantly decreasing the cost of the project by predicting and eliminating potential problems. The digital twin can be also used throughout the lifetime of the building to decrease the operations overhead by highlighting when necessary maintenance works need to take place. It is worth mentioning here that the Association of Polish Engineers in Great Britain is a great advocate for BIM and is currently creating such a model for the Polish Social and Cultural Centre – POSK.

As shown in the cases mentioned above, the application of PLM, CAE and digital twin technology can lead to significant savings and increase performance in various industries. The data collected throughout the lifespan of a given product can also be fed back to the engineers working on next generation designs and drive future design decision.

CHALLENGES

Although the technological change moves at an enormous pace, there are still challenges that need to be addressed. One of the main difficulties associated with adoption of the aforementioned technologies is the integration of various software packages. Most of the tools available on the market use their own data format and although standardisation attempts are made[6], interaction between different software products remains challenging and vital data can be lost at the interfaces.

[5] NBS, *National BIM Report*, 2017.

[6] Website: En.wikipedia.org/wiki/CAD_standards, accessed on 25 V 2017.

Using the same model for different applications creates challenges on its own. While a 3D CAD model designed for manufacturing might contain every detail of the product down to the smallest bolt, the model used for analysis has to be stripped form all necessary details to enable efficient simulation. This creates extra overheads and may break connectivity between the various digital versions of the product.

Large amount of data generated by CAE tools and gathered by the sensors throughout the lifespan of the product needs to be properly managed and stored. Extensive databases can lead to data overflow, where the information stops being useful. These databases are also attractive targets for hackers, industrial espionage and terrorism. High levels of security are therefore necessary. Cybersecurity becomes a necessary requirement rather than anoption[7].

Finally, sophisticated tools and models require sophisticated users, who are able to understand how they work. Colourful pictures generated by the data analysis software may be appealing to the eye but, if not interpreted properly, they can lead to wrong decisions which might have serious ramifications in the future. Therefore, university education needs to cater for those needs and focus on physical understanding of the physical phenomena rather than just teach students how to use a specific software.

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KOMPUTEROWE WSPIERANIE PRAC INŻYNIERSKICH – TECHNOLOGIA TWORZENIA KOPII CYFROWYCH

Streszczenie

W epoce Przemysłu 4.0 inżynieria podlega postępującej digitalizacji, obejmującej praktycznie wszystkie jej aspekty: od procesu projektowania poprzez wytwarzanie aż po eksploatację produktów. Artykuł opisuje technologie i procesy, które umożliwiają tworzenie tzw. cyfrowego bliźniaka – cyfrowej kopii danego produktu, która zawiera jego wszystkie parametry. Zaprezentowano tu wpływ informatyzacji na proces projektowania i *product lifecycle management* oraz przedstawiono wyzwania stojące na drodze rozwoju tej technologii.