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Review article

Technical engineering as a stimulator of development and civilisational progress

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ABSTRACT

The article presents theoretical and practical aspects of the operation of a key engineering category, i.e. technical engineering, and its dominant influence on the level of technical and civilisational development in evolving societies. The introduction discusses the concept, role, and place of technical engineering, and the general methodological framework applied in it. It emphasises the strong links between the scientific theoretical foundations of technical engineering and engineering practice, which stem chiefly from societal needs and utilitarian passions of many researchers involved in the creative art of engineering. The following section presents technical and technological assumptions and practical achievements of selected categories of technical engineering, such as: civil, water, military, mechanical, electrical, process, materials, and extreme engineering. The article is a conceptual review and stresses the synergy between science, knowledge, and technology (mainly technical and applied), as well as competences and skills, against the background of utilitarian societal needs.

KEYWORDS

engineering, science, technology, concept, design, prototype, application

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1. The concept and subject of technical engineering

Engineering, which is generally understood as a universal, practical art of constructing useful material (technical) and non-material (systemic) products has its origin in the distant history of our civilisation, when its artefacts satisfied society's most urgent existential and subsistence needs. Engineering methods, technologies, and standards are currently applied with success in nearly all scientific disciplines and fields of economic and social life. In this sense, the approach based on the principles of pragmatic engineering stimulates scientific and technological development, and civilisational progress in modern societies. A practical engineering approach guarantees that the target designs and products have the required functionality and utility and that they meet the highest standards of safety and reliability.

Technical engineering is the practical art of creating things (visions, concepts, designs) that are new and original. At the same time, it is an innovative intellectual and experimental (research) activity that consists in modelling, designing, constructing, modifying, and maintaining useful and effective solutions to practical problems [1]. Modern engineering is an interdisciplinary category, based on a synergistic application of current scientific knowledge and achievements of modern technology. This activity requires finding solutions to practical problems of varying nature, complexity, and degree of difficulty [2]. More generally, engineering uses science and technology to drive the development of applied software (non-material) and hardware (material) technologies.

In the most general terms, engineering understood as the art of creating – designing, and constructing applied innovative works, can be divided into two basic strands: material (physical) technical engineering (technological, production-oriented, hardware), and non-material (intellectual) systems engineering (conceptual, service-oriented, software) (Fig. 1).

Advanced products of contemporary technical engineering (civilisation) are sometimes classified as works of applied art, which, apart from having pragmatic value, is also distinguished by some marks of aesthetic and creative originality. For example, grand designs and buildings created by world-class architects, which belong to the so-called civil engineering, are also works of art and symbolise the talent of their makers on the one hand, and the places, environments, and even epochs in which they were built on the other. The famous Sagrada Familia cathedral in Barcelona; a timeless masterpiece by the great architect Antonio Gaudi and an ongoing work in progress, is a highly controversial example of this. The same can be said of numerous objects classified as the so-called applied arts, which possess original aesthetic qualities and characteristics of works of art. The contemporary automotive industry is at the forefront here, especially the so-called studio designs, which sometimes are ahead of the era and technology in which they were made.

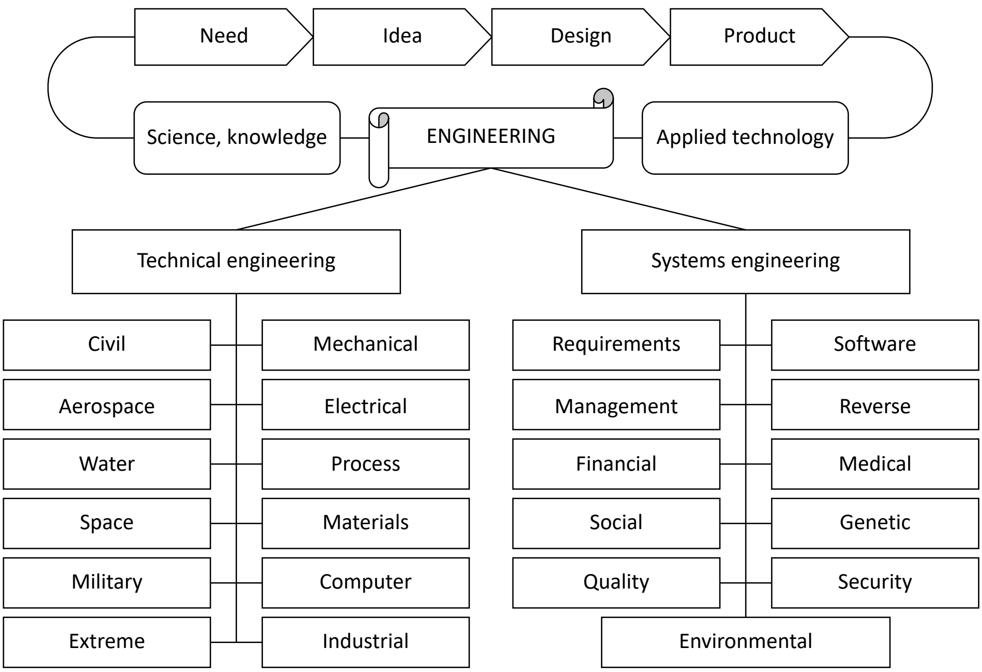

Fig. 1. Exemplary typology of selected types of engineering
Source: Own elaboration.

Throughout human history to-date, technical engineering has preceded the development of systems engineering (knowledge) and stimulated civilisational progress [1]. At the early stages, it was more of a craft or art than a rationally organised technology proceeding from a formal design, through systematic production, to utilitarian implementation [3]. Meanwhile, the global oversupply of all goods that we witness today, stimulated by the achievements of materials and production (process) engineering, has led to the need for the development of the so-called reverse engineering, which is known more widely as utilisation and recycling technology that deals with the processes of technological and environmental destruction of the enormous mass of used products and unnecessary waste.

Production (manufacturing) engineering is undoubtedly the leading type of technical engineering. It uses nearly all other categories of technical engineering, such as material, process, mechanical, electric, computer, extreme, and other types of engineering for its purposes in a synergistic manner. According to the recommendations of the American Institute of Industrial Engineering, production engineering is a concept that covers the issues of planning, design, implementation and management, production systems, logistics systems, and securing their operation [4]. These systems are understood as socio-technical systems integrating workers, information, energy, materials, work tools, and processes in the entire product life cycle. In order to achieve the due efficiency of these systems, production engineering relies on technical, economic, and social sciences, as well as humanities, using ICT knowledge, knowledge of management [5], social communications, and stimulation of the creativity of employees. The fundamental element that differentiates production engineering from other technical disciplines is its orientation towards the human factor. The best systems operate through a continuous improvement of the work environment, in which human labour is the most important factor influencing efficiency, costs, and quality of work (Fig. 2).

It is not difficult to see that, apart from “industry-specific” types of technical engineering, production engineering also draws fully on the output of the related categories of systems engineering such as e.g. requirements, management, quality, reverse, software, financial, security, and other types of engineering. It can therefore be stated that production engineering, which is a leading engineering discipline, draws synergistically on the achievements of other types of general engineering, including technical engineering and systems engineering [6].

From the evolutionary and historical point of view, the civilisational career of mainly technical engineering began with traditional civil engineering, which has directly given rise to the so-called environmental types of engineering; civil, water, aerospace, and space engineering, as well as environmental engineering, which has been strongly emphasised in the modern era and stimulated by waves of environmentalism. The hard core of technical engineering, and especially production engineering, is currently very widely supported by softer computer technologies [7], while computer programmes and simulations [8], as well as modern technologies from the virtual world, give rise to numerous specific types of engineering, which have dominated the world of science and scientific research, as well as everyday social and economic life, not only as a fashion. Leaving fashion and media considerations aside, the current trend for different types and categories of engineering brings new values, achievements in science and research, and numerous implementation applications.

2. Methodological framework of technical engineering

Like any other scientific discipline and field of applied knowledge, engineering develops its own methodology, which ensures that it is sufficiently scientific and universal. As the area of

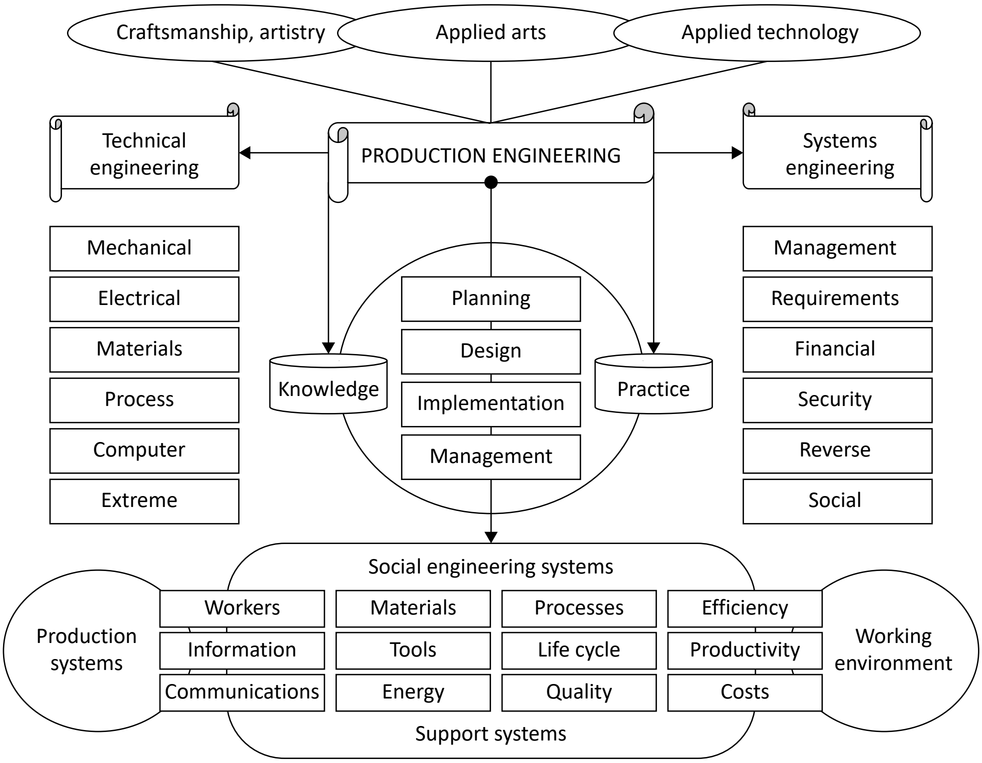

Fig. 2. Key position of production engineering
Source: Own elaboration.

pragmatic applications of engineering is very wide, its different types and categories develop their own particular methodologies built for the use of specific disciplines. As a result of this, two main methodological strands, relating to theoretical (fundamental, systemic) research and analysis and practical (applied, technological) applications have emerged in the field of engineering [2]. Nonetheless, the search for a universal engineering methodology, which would be independent of the specific character of the engineering disciplines under consideration and the research instruments applied in them, continues.

Any activity in the field of praxeological technical engineering originates from a real need, an original idea, and often from a kind of creative restlessness related to an unresolved problem. The first stage of creative engineering consists in a creative analysis and creative synthesis of the current state of research in a given field, which provides the basis for developing a conceptual solution to a given problem [9]. It is about creating a certain design vision e.g. based on a holistic systems theory, and using artificial intelligence tools, which are becoming increasingly popular [10]. Further steps involve building models which are more or less abstract or physical in nature, which is followed by the development of prototypes that are subjected to various testing procedures. The final stage is the practical implementation of the tested design, its instrumentation and supplementation with required tools, services, and theories (Fig. 3).

Each of the above stages, also known, respectively, as conceptual, technological, and application design, involves a series of specialised procedures that determine its character [11]. The

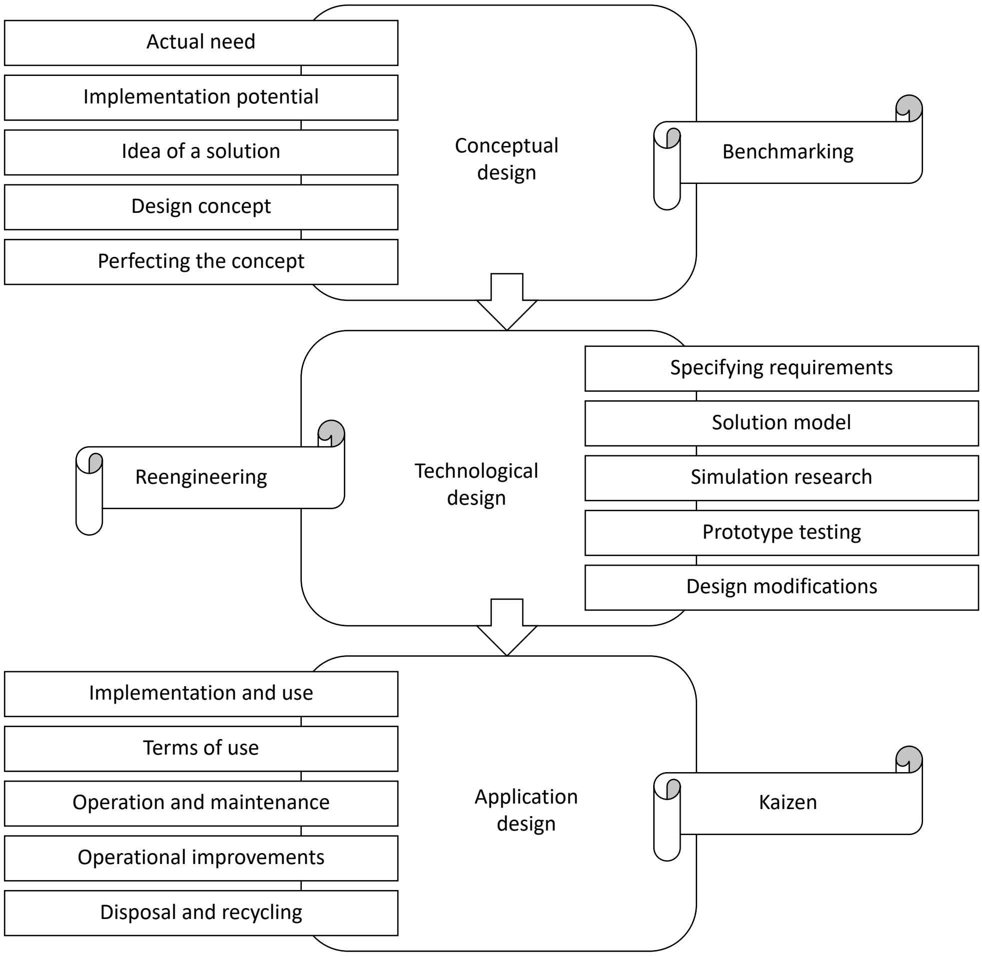

Fig. 3. Methodological scheme of technical engineering procedures
Source: Own elaboration.

stage of conceptual design involves: identifying an urgent social need for a specific product, confronting the identified need with the existing capacity for satisfying it, proposing an idea to solve the problem, developing a theoretical concept of a solution to the problem, continuous improvement of the proposed concept, for example, in terms of the Benchmarking approach, which involves comparing it to other models and similar considerations that exist in theory or in practice.

The stage of technological design is highly technical in nature and starts with specifying the organisational and functional requirements that the designed system (product) should satisfy. The model created on the basis of the specified requirements is then subjected to thorough testing, usually by simulation [8]. Positive results of modelling studies (simulations) pave the way for the development of a prototype that is very similar to the final solution. Positive results of prototype tests provide the basis for the decision about implementing the solution into social practice. The standards of continuous change and improvement, formulated as part of various Reengineering concepts, which argues for the necessity of making often radical changes and adjustments, both in the concept design and assumptions of the technological design, are very helpful at the stage of technological design.

The third stage is referred to as the stage of truth, as it determines the usefulness and practicality of the developed solution (product). It is initiated by the procedure of formal implementation and by the commencement of utilisation of the system (product). The terms of use of the system in question are determined and verified at this stage, which involves developing operating instructions and rules for systematic operational maintenance. In the course of the product (system) lifecycle, various improvements are made to enhance the quality and efficiency of the product. The Kaizen philosophy, which encourages continual improvements and leads to organisational and technical progress, is applied for this purpose. In line with the natural lifecycle of each product, this stage is completed by a standard disposal procedure and potential further recycling.

Given that the practical implementation of an innovative engineering solution is often associated with a high level of responsibility and a high risk of incomplete and not always fully determined functionality, implementation research and tests are used widely in technical engineering. Prototypes, scalable physical models, and simulation applications are built for this purpose and accompanied by experiments, destructive and non-destructive testing, fatigue testing, and other laboratory tests. The tests are expected to ensure the greatest functionality of the proposed solution, at the same time ensuring that a range of criteria related to safety, efficiency, and market competitiveness are met by a given facility or product. Engineers must design and implement solutions which are, above all, useful and safe, and which will not cause any unexpected or unintended damage [12]. For this reason, the final solution usually features a surplus "safety factor" (oversizing) to mitigate the risk of malfunction. However, the greater the "safety factor", the less effective the solution itself.

3. Civil engineering

Civil engineering was the earliest type of engineering to emerge in history; to put it simply, it has been changing the character and style of people's lives, from nomadic tribes to city dwellers settled in comfortable metropolises. It has altered the social aspect of our existence, contributing to the development of every human civilisation. In its practical applications, Civil Engineering is a branch of the engineering science and a discipline that combines skills such as design, construction, and maintenance of all types of built structures – bridges, roads, canals, dams, and, above all, buildings and structures in their natural, as well as social and economic, environments [13]. Civil engineering is one of the oldest engineering sciences and has been linked with the human existence since the beginning of history.

The beginnings of civil engineering can be traced back to the time between 4000 and 2000 B.C. in Ancient Egypt and Mesopotamia, which was when mankind abandoned its former nomadic lifestyle in favour of settling in one place. This necessitated the construction of permanent shelters that would remain intact in one place for several seasons. This was also the reason for the development of transport, which led to the invention of the wheel and navigation. The greatest contribution to the development of civil engineering was definitely made by the Romans during the heyday of the Roman Empire, as throughout the entire history of the empire they continued to build new structures such as: aqueducts, insulae, seaports, bridges, dams, and, above all, roads and communication routes [14].

In antiquity and the middle ages, the work of architects and builders was performed by craftsmen such as masons and carpenters, who could rise to the rank of "master builders".

The knowledge acquired by experience was retained and passed on within guilds and corporations which operated as closed associations, distrustful of innovation. Rather than creating original and modern things, they tended to copy structures, roads, and other built objects and then adjust them to the requirements of various magnates. The only exception was religious architecture, which was based on the canon of originality and uniqueness, integrated into local traditions and architectural styles.

In most cases, civil engineering is a tool for realising the visions of architects (designers), who are regarded as the first link in the construction process. The knowledge that is encompassed by the term "civil engineering" is traditionally associated with many engineering disciplines, such as environmental engineering, geotechnics, structural mechanics, transport engineering, hydrology, materials engineering, water engineering, geodesy, and production and management engineering [15]. The science called "civil engineering" is derived from the basic principles of physics and mathematics, while its study and development are closely linked to the development of mathematical and physical skills in successive civilisations. Since engineering expertise covers a vast area, its development depends on a number of specific disciplines, such as architecture, endurance strength of materials, structural mechanics, circuit theory, hydrology, and geodesy.

Modern civil engineering deals in particular with transport construction, including the building and dismantling of civil structures, especially fixed structures and transport hubs – roads and railroads with accompanying bridges, tunnels, collision-free multi-level junctions, large structures, and various industrial installations [14]. Civil engineering is closely linked with similar types of sector-specific engineering, arising from the division of transport into various branches, and relating to road engineering, rail engineering, water engineering, aerospace engineering, and pipeline engineering.

Civil engineering has a wide range of applications at all levels of life: in the public sector in the smallest villages and towns, as well as city centres of great metropolises, in municipalities, districts, and provinces, depending on the administrative structure of the country. It is also present in the private sector, at the level of individual owners of buildings and apartments, through small and large design and construction companies, to huge global corporations representing the useful art of construction. In the age of the market economy, architectural structures and buildings are the domain of commercial (development) companies at all stages of implementation of any project.

The domain of civil engineering consists, above all, of the design, construction, and maintenance (as well as disposal) of land-based facilities and utility structures, including residential, industrial, and service facilities, municipal, communications, and infrastructure facilities with varying social significance. A special place in this specification is held by the so-called communications engineering, i.e. transport and communications engineering, which includes road engineering, rail engineering, part of aerospace engineering (airport engineering), and pipeline engineering.

Road engineering is engaged in the construction of road networks and routes that serve various purposes and differ in terms of social prestige [14]. Motor roads, especially motorways and dual carriageways, must comply with the highest operational parameters and guarantee the highest standards of safety and environmental requirements. Similarly, railway engineering designs, builds, and maintains modern, highly automated and safe railway lines and routes, as well as railway stations, terminals, and accompanying civil engineering structures – bridges and viaducts. Meanwhile, transmission engineering has strong links with the chemical industry (pipelines, gas pipelines, pumping stations, tank farms) and the energy industry (transmission lines, transformer stations).

Water engineering, which is partly dependent on the terrestrial environment, deals mainly with issues related to the construction and maintenance of harbours, seaports, inland ports, as well as water dams, navigation channels, the regulation of rivers and waterways. Meanwhile, aerospace engineering, or, more specifically, airport engineering, covers the design and construction of airports (runways, parking stands), and all the facilities that accompany the safe operation of airports (hangars, fuel stations, service facilities). Airport passenger and cargo terminals, as well as various installations that guarantee the safe operation of airports, are currently subject to high performance requirements [16]. In the present day, all these categories of engineering must meet the stringent requirements of the so-called environmental engineering that uses advanced techniques and technologies in the processes of protecting and shaping the natural environment.

4. Water engineering

Water Engineering is a branch of science and technology involved in the study, design, construction and use of marine and inland hydrotechnical structures. It is divided into Inland Engineering and Sea Engineering. As it deals with engineering and construction problems, it is very closely linked to construction, however, due to the impact of hydrotechnical structures on the natural environment, it is regarded as a branch of environmental engineering.

Inland engineering covers areas such as the regulation of rivers and building barrages in them to create water reservoirs with fixed levels of damming (weirs) that enable inland navigation, the operation of water power stations, and water intakes. Dams are built on mountain rivers to create water retention reservoirs that are used in flood defence to store and release water and, at the same time, to enable the operation of peak and pumped storage hydroelectricity plants [17]. An important task of inland engineering is the construction and maintenance of navigation routes and canals for the purposes of various types of economic and tourist activities. These hydrotechnical structures bring economic and social benefits, however, they also cause various changes in river beds and their nearest polders, which results in raising the groundwater surface in the area, and sometimes in swamping and disruption of the movement of the river bed load [18].

Sea engineering is concerned with buildings, structures, and related engineering works both on the open sea and near the shore or directly on the shore, which are directly related to the sea (e.g. quays, jetties, harbour piers). Technologically advanced maritime structures built for the purposes of navigation and safety of shipping (lighthouses, buoys, and signal buoys) constitute a separate area of sea engineering. There has been growth in the number of surface structures built to exploit mineral resources deposited under the seabed (drilling platforms) and to harness the energy of waves, currents, tides, and winds on the open sea. In the age of huge intensification of world shipping and maritime transport, the universal problem of the safety of maritime traffic, which is an important branch of maritime engineering, comes to the forefront [19].

Traditionally, marine engineering is divided into three categories, including: marine construction, marine dredging, and underwater works. Marine construction is mainly concerned with harbour structures (breakwaters, quays, jetties, piers, dolphins), shipyard structures (ramps, lifts, hoists, dry docks), coastal protection structures (shore-connected breakwaters, aquatic sills, seawalls, and armours), offshore structures (e.g. offshore platforms, submarine pipelines), and special structures such as sea locks, canals, submarine tunnels [20]. The task of marine dredging is to carry out earth moving in the sea and in the coastal strip. The main role in underwater works is played by diving work related to the assessment of the surface prior to the construction of marine structures and to the assessment of the condition and safety of underwater elements of offshore structures that are subject to exploitation.

5. Military engineering

A particular type of civil engineering is military engineering. It meets the specific needs of the military sector and is developed to serve the purposes of perennial military struggles in different fields and theatres of war [21]. The extreme requirements of the battlefield have always inspired the enlightened minds of inventors, creators, commanders, craftsmen, and engineers to come up with new developments in technology and combat technology that would ensure military advantage and greater effectiveness of the military operations. Military engineering is concerned with the design and execution of optimum structural solutions, technology, and organisation of work in projects related to military road construction, fortifications, military geology, military hydrotechnics, technical camouflage, mechanisation of engineering work, explosive engineering, and military bridge building [22].

From the historical point of view, military engineering, which originally dealt with all material and technical aspects of combat operations, in the 20th century was initially restricted to the dimension of the so-called civil engineering, understood as the skill of erecting all kinds of buildings and structures other than functional buildings, intended mainly for military purposes. Modern military engineering is a field of military expertise that constitutes a part of the art of war and a section of the general engineering science. In the military domain, it covers fortification, explosive engineering, military bridge building, military road construction, technical camouflage, organisation and mechanisation of engineering work, military geology, military hydrotechnics, and other areas [23].

Technical military engineering is a highly specific field of engineering art, which combines two opposing areas of human activity: namely, destruction and creation. Ever since its inception, these two opposing tendencies have been constantly clashing, once dominating, then receding into the background, or occasionally occurring in parallel. Since they are inseparable, it is now impossible to determine which of them came earlier and which is more prominent [24].

Classic military engineering is perceived as an area of military expertise that constitutes part of the art of war and the subject of heavy engineering works conducted primarily in the theatre of war, as part of both offensive and defensive operations [25]. Generally speaking, it deals with the building of fortifications and engineering (combat) barriers, building of structures (bridges, crossings, viaducts), and keeping communication routes (roads, railroads, ports, airports) passable, especially in the zone of combat operations.

Tactical and operational camouflage and sapper operations, which involve planting mines and demining battlefields and areas situated in the immediate operational zone, are immensely important tasks of military engineering. Adequate engineering of the terrain is a very important element of operational advantage, which enhances the efficiency of command and the effectiveness of combat operations. Most modern armies in the world have specialised engineering troops that provide direct support to the activities of operational forces in combat. Engineering troops, also called sapper troops, operate heavy construction, road, floating, and crossing equipment, as well as explosive materials and weapons. Due to their specialised equipment and training, modern engineering troops play an essential role in the most critical combat situations, when the operations of all other troops and rescue services prove insufficient. The infallible units of engineering troops, their professional forces (personnel, knowledge, and experience), and the modern equipment and technical means at their disposal are the last chance in these circumstances.

6. Mechanical engineering

Mechanical engineering is a synergy of theoretical knowledge and engineering practice concerning the design, manufacturing, and exploitation of technical machinery and equipment [26], except for electrical equipment, which is the domain of the separate discipline of electrical engineering, power engineering, or electronic engineering. The primary areas of interest in mechanical engineering traditionally include: the fundamentals of machine construction [27], endurance strength of materials, material science, mechanism and machine theory, machine building technology, technical operation theory, precision mechanics, and other [28].

The most likely truth about the Industrial Revolution was that it was not so much an outcome of the activity of scientists, as the effect of hard and tireless work of craftsmen, masters, and engineers who never ceased trying and searching, often acted on intuition, and literally turned their observations into material results. Plainly speaking, the first engineers in the history of mankind were probably "mechanical engineers" engaged in the intuitive creation of the most indispensable and most practical physical objects. In this respect, common sense mechanical engineering was the original launching pad for many specific types of engineering, not only of technical character. Mechanical engineering led not only to the construction of great buildings and facilities, and to the development of efficient systems and processes, but, above all, to the creation of tools that separated human beings from the natural world.

The development of specialised machinery and tools during the Industrial Revolution provided the material basis for the age of steam and electricity, which was a watershed moment in the history of mankind, and for the domination of coal and steel. Nonetheless, although modern mechanical engineering originated in the 19th century, its origins date back to antiquity, which was the time of construction of numerous machines intended for civilian and military use. One of the best known examples is the Antikythera mechanism, a machine representing a level of complexity that would not be seen until the 14th century. Many inventions of that time, most of which were constructed or improved by Archimedes (for example, the famous Archimedes' screw) required skills and expertise which are still applied today for various everyday uses.

Breakthrough achievements of mechanical engineering, chiefly the invention of the vertical steam engine by T. Newcomen in 1712, and its technical refinement by J. Watt in 1769, followed by the development of the diesel combustion engine by R. Diesel in 1893. They gave rise to the era of industrial society and to the spectacular flourishing of mechanical engineering at the time. The breakthrough for the human civilisation was the invention of the mechanical engine, which made mankind completely independent of the unpredictable forces of nature, such as the wind, water, and sun, and from the physical work of animal and human muscles, enabling planned and organised economic activity. Subsequent generations of engines, beginning with the steam engine, through the internal combustion engine, then the electric motor, and finally the nuclear reactor, have been the basis not only of the rapid development of industry and manufacturing but, above all, of transport that connected various centres of social and economic life, which has trade exchange as its economic basis [4].

The spectacular growth of transport systems requires the use of the most advanced means of transport and devices, and equally advanced technologies and channels of communication, which stimulates the multi-directional development of mechanical engineering, civil engineering, water engineering, and aerospace engineering. The development of transport technologies has been accompanied by an equally turbulent development of communications systems, which is currently dominated by ICT and the phenomenal computer network called the Internet.

7. Electrical engineering

The incredibly useful electrical engineering is a branch of engineering that deals with the study and application of electricity and electromagnetism in various areas of life. It has its origin in the experiments performed in the early 19th century by A. Volta and then by M. Faraday, G. Ohm, A.M. Ampere, and others. The most important outcome of these experiments was the invention of the electric motor. The work of J. Maxwell and H. Hertz in the late 19th century marked the beginning of electronics. The subsequent inventions of the vacuum tube and the transistor (in 1947) led to the development of electrotechnology and electronics, which became an immensely attractive branch of engineering in the 20th century. The natural directions for the transformation of electrical engineering today is electronic engineering (semiconductors, integrated circuits) and modern quantum engineering (laser, fibre optics) [29].

The scope of interest of modern electrical engineering is very broad and includes sections such as electrotechnology, electrical apparatus (switches, contactors, fuses, transformers, chokes, capacitors), electrical machines (asynchronous motors, synchronous motors, DC motors, generators, transformers), electrical power engineering (generators, power plants, high voltage transformers, power switches, surge arresters, voltage transformers, current transformers), power electronics (voltage converters, power inverters), industrial automation (automation systems, contact automation, PLC systems), automation components (sensors, meters, relays, contactors, programmable controllers), electrical metrology, electrochemistry, electrothermy, electronics [30]. Electrical engineering focuses on large-scale power generation systems, large electrical installations, and power grids. The achievements and advances of electrical engineering to large extent provide the basis for the operation of modern robots [31] and industrial automation. Of course, they remain in a synergistic relationship with many other categories of technical engineering and systems engineering.

A very important branch of electrical engineering is energy engineering, which deals with the production, conversion, and transmission of electricity (high voltage) over long distances. Thanks to proper energy engineering systems, which include power plants and generators, as well as electric power equipment and transmission lines, all citizens, enterprises, and institutions in civilised countries have access to electric power, which is an essential marker of the standards of modern civilisation. In the face of the rapid rise in the environmental pollution in the recent years, a huge emphasis has been placed on the so-called green energy sources, especially zero-emission wind power plants [32] that rely on natural and unlimited wind energy and attract particular public interest. The future of a safe and efficient energy sector is increasingly identified with the eternal forces of nature, which are being harnessed by various branches of technical engineering, including water, mechanical, electrical, and extreme engineering [33].

8. Chemical (process) engineering

Chemical Engineering (Trial), more appropriately referred to as process engineering is an engineering science that deals with the design of operations and processes related to the flow of fluids, as well as thermal and chemical transformations conducted on an industrial scale [34]. The principles of process engineering tend to be practical "engineering laws" that enable the correct design of chemical installations. The rules developed for chemical engineering are often applied to the development of "non-chemical" equipment and installations, such as, for example, installations for the production and transmission of thermal energy in combined heat and power plants.

Hence, it is more common to talk broadly about process engineering, such as environmental, food [35], and agricultural process engineering, rather than just about chemical engineering. The basic concept in process engineering is unit process, referred to simply as process, which is a single act of transformation of physical or chemical energy or matter in an apparatus, and unit operation, which is a discrete set of physical transformations of matter (without a chemical reaction). Chemical processes include all phenomena accompanied by chemical reactions.

The development of process engineering has its origin in the Industrial Revolution too. It was necessitated by the rapid growth in demand for new materials and new manufacturing processes, which conditioned mass production on an industrial scale. Demand was so high that it led to the emergence of a new branch of industry for the development and mass production of industrial substances and chemical compounds. The role of chemical engineering was also to design and operate factories responsible for that production. The engineering of liquid fuels, which provide the basis of the fuel industry, recognised as the world's most powerful sector that directly guarantees the development of transport and communications, still plays a special role in this category today. The synergistic combination of process and chemical engineering has led to the development of the attractive branch of materials engineering, which is expected to protect mankind against the deficit of raw materials and various other materials that are necessary to ensure the smooth functioning of the civilisation of the future.

9. Materials engineering

Materials Engineering is an interdisciplinary field of research and practical knowledge based primarily on natural sciences such as physics, chemistry, and biology, which uses advanced mathematical methods and IT tools, and is dedicated to analysing, designing, and constructing new engineering materials and improving the performance of materials that are commonly used in practice [36]. It is particularly concerned with analysing the influence of the chemical and physical structure of materials on their technical properties and performance, including their resistance, electrical, mechanical, optical, chemical, magnetic, and thermal properties, as well as their various combinations. The great hopes and expectations of the modern scientific and technical civilisation, unfortunately also in the area of military applications, result largely from the huge production and service potential of the dynamically developing materials engineering, especially from its reaching for molecular and atomic structures that guarantee the highest efficacy of the developed theories, and great efficiency of the applications being created.

Materials engineering investigates both traditional materials, such as ceramics, metals, polymers, as well as modern composites, semiconductors, glass fibres, biomaterials, and so-called smart materials with elements of memory. A promising direction in the research of material engineering is the use of natural materials from wood to silk, as well as ceramics, leather, and textiles, to design and produce new synthetic materials meeting, among others, the highest environmental standards. This line of research includes the development of methods based on nanothechnologies, biotechnologies, crystallography, liquid crystals, and superconductivity [37].

The utilitarian task of materials engineering is the study of the influence that the structure of the source material has on the physical and chemical properties of engineering materials, and on their performance-related features. An important objective of this study is to prevent (usually through the change in their structure) unwanted changes in the performance of the materials. This enables the development of new methods to obtain, use, and protect (for example, against corrosion) materials with specific performance characteristics. Not only does the research have a major impact on the intended performance characteristics of the end products but it also helps to investigate and develop effective methods of their production and processing. The performance characteristics of all objects and devices that we use depend on the features of materials they were made of, which, in turn, depend on the structure of the materials, shaped, for example, in the industrial manufacturing processes.

The discipline of industrial engineering involves scientific research aimed at solving practical material-related problems encountered in industry, as well as fundamental research e.g. at the level of quantum physics, aimed at understanding and describing phenomena that occur in crystal structures, as well as at designing and synthesising new materials. The achievements of technical sciences at the end of the 20th century proved that numerous new solutions and designs could only have been developed thanks to new materials. Owing to the development of materials engineering, we currently have materials that enable us to build objects and devices capable of working in extreme conditions, for example, in nuclear reactors, in space, or in deep sea.

The development of materials engineering, which draws on the achievements of quantum physics, and enables the recording and transmission of vast amounts of information, has stimulated radical advances in computer science. Meanwhile, biomaterials modelled on nature can already successfully replace “worn” parts of the human body, opening entirely new perspectives for transplant medicine. Materials engineering and its practical achievements have been the determing factors of various civilisational epochs in the human history, which were marked successively by: stone, ceramics, bronze (tin, copper, lead), iron and coal, steel, silicon (semiconductors), polymers, composites, functional (smart) materials.

10. Extreme engineering

Extreme Engineering is a new category of online media journalism, created mainly by the global channel Discovery Channel, which presents the most ambitious, often mysterious and shady projects, services, and visionary plans of our time, which are at the stages of exploitation, implementation, and planning, and which concern practically all forms and types of engineering solutions, in the area of technical engineering, as well as social and systems engineering [38]. Some of these are merely theoretical ideas taken from the world of Science Fiction and we may have to wait to see them realised, as contemporary engineering is not sufficiently advanced and does not have a sufficient material and technological potential.

The group of extreme engineering is dominated by gigantic products of technical engineering, such as huge civil engineering structures and buildings, masterpieces of the world’s architectural art, works of hydro-technical engineering, underground engineering, and various super-machines, ultra-modern devices, and technical installations. Examples of the art of civil engineering include: the underground in New York, the airport in Hong Kong, the bridge across the Bering Strait, the Panama Canal expansion project, flood dams in Venice, Gotthard Tunnel in Switzerland, El Cajon Dam in Mexico, Burj Dubai skyscraper, and many other. One of the most innovative projects, which was also geographically close to us, was the construction of the Eurotunnel under the British Channel.

Huge equipment and super machines are represented by offshore oil rigs, gigantic tankers and container ships, US aircraft carriers, huge loaders and excavators, and super trucks for the transport of minerals, ships, and spacecraft. A separate group consists of weapon systems, equipment, and combat equipment of modern armies, dominated by airplanes, missiles, tanks, cannons, combat vehicles, surface ships, and submarine vessels, as well as smart communication, command, and fire control systems.

A modern application of extreme engineering involves large-scale construction projects relying on trenchless methods in inaccessible and heavily exploited areas. Large cities have even issued guidelines for the renovation and construction of new networks using trenchless methods in areas with increased traffic and at historical and environmental sites [39]. Traditional, open trench laying of new and renovation of old power, gas, water, and communication installations in urban or industrial areas is a nuisance to investors and users. Drills and directional wells are the future of the installation industry in all its spectrums. The use of advanced localisation, laser, and drilling technologies means that there are practically no tasks that cannot be completed with the right engineering approach.

The popularity of trenchless technologies is mainly due to the fact that their application makes it possible to avoid or minimise excavation works, which are especially troublesome in urban areas and in areas that are difficult to access. The high speed of trenchless works, often combined with lower costs and numerous environmental advantages, are only some of the many benefits of these technologies, which gave rise to the high level of interest in their application. The development of this branch of extreme engineering is inevitable, while the future of the trenchless technology is looking very optimistic.

Advanced products of social extreme engineering include the achievements of computerised telemedicine, complex surgical procedures conducted remotely over the Internet, astonishing genetic engineering experiments, as well as simulation images of major climatic, tectonic, epidemic, and communication disasters, failures of installation systems, and building structures. An attractive category of extreme social engineering, at least at the current level of scientific and technological development, are the so-called smart products, which operate according to pre-set programmes, controlled by advanced information and communication technologies. Examples of such products of the engineering art are unmanned aerial vehicles, computerised carriageways, smart apartments, houses, offices, and public utility buildings, as well as useful robots that support the work of medical, office, and sales personnel.

The worldwide computer network Internet, whose phenomenal universality, functionality, reliability, and massive scale has exceeded even the most optimistic visions and forecasts made at the end of the 20th century, is a particular product of extreme engineering. The direct, friendly, extremely communicative and useful Internet generates a host of completely new challenges, chiefly in the social, sociological, and psychological sphere, as all technical and technological barriers are overcome with relative efficiency and speed by highly advanced products of modern hardware and software technical engineering.

Practically all branches of technical engineering stimulate the development of Internet's technical and technological infrastructure and amplify its increasingly unlimited functionality and usefulness. Since the beginning of the 21st century, the Internet of Things has been developing very intensely alongside the classic "internet of people". It includes nearly all objects, products, and facilities that have been equipped with active or passive transponders (chips, tags) for automatic identification and continual communication with their entire environment by means of wireless communication [40].

Conclusions

Technical (technological) engineering as a rule deals with the creation of tangible structures and products derived from intellectual visions, expert concepts, and designs. It provides a physical, conceptual, and functional shape to specific projects, often based on artistic visions and ideas of their creators. Engineering technologies, structures, and material products serve as the basis for and interpretation of the civilisational development of modern societies. The art of engineering contributes in the highest degree to the dynamic development of the modern civilisation, which is commonly referred to as technical civilisation.

Technical engineering deals primarily with the development of applied technologies that stimulate scientific and technical development; therefore, it is sometimes directly compared to process engineering, which generates useful production, construction, and material technologies. Throughout human history to-date, technical engineering has preceded the development of knowledge engineering and stimulated civilisational progress. At the early stages, it was more of a craft or art than a rationally organised technology proceeding from a design, through production, to implementation.

The effects of these actions, based on the praxeological art of engineering, are material and non-material achievements of science and technology, scientific and technological development, and, above all, growing comfort and convenience of everyday life, and increasingly high standards of functioning of the modern civilisation. The pragmatic principles of the eternal art of engineering are applied in practically all spheres, fields, research disciplines, research areas, and, above all, in implementation applications. Its universalist principles, guarantee the creation of useful, effective, and safe solutions, projects, and applications that symbolise our civilisation, which proudly calls itself a technical civilisation, and that remains in a constant evolutionary spiral.

The comprehensive involvement of computer technology in engineering work has caused the borders between knowledge engineering (systemic) and technical (technological) engineering to erode; as a result, these two disciplines have become intertwined and complementary. The above-mentioned technical, technological, organisational, and market conditions have led to the emergence and then to a very rapid development of ultra-modern systems of computer-aided design, manufacturing, and production control in the form of a specialised hardware and software platform, commonly known as CIM, which stands for Computer Integrated Manufacturing.

The analysis demonstrates the importance of a pragmatic approach, based on universal canons of the art of engineering, in the modern social and economic life, as well as in the material and civilisational culture. A decisive role in shaping the material (physical, technical, practical), and non-material (systemic, symbolic, cultural) basis of the modern civilisation is played, above all, by tools and instruments facilitating all human work, means, and methods of effective solving of specific problems, and creative products of the human mind, hands, and all intellectual and physical effort.

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Conflict of interests

All authors declared no conflict of interests.

Author contributions

All authors contributed to the interpretation of results and writing of the paper. All authors read and approved the final manuscript.

Ethical statement

The research complies with all national and international ethical requirements.

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Biographical note

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Inżynieria techniczna stymulatorem rozwoju i postępu cywilizacyjnego

STRESZCZENIE W pracy przedstawiono teoretyczne i praktyczne aspekty funkcjonowania kluczowej kategorii inżynierii, tj. inżynierii technicznej i jej dominujący wpływ na poziom rozwoju techniczno-cywilizacyjnego ewolucyjnie kształtowanych społeczeństw. We wstępie omówiono pojęcie, rolę i miejsce oraz ogólny schemat metodologiczny stosowany w inżynierii technicznej. Podkreślono silne związki naukowych podstaw teoretycznych inżynierii technicznej ze sferą praktyki inżynierskiej, wynikające głównie z potrzeb społecznych, a także utylitarnych pasji wielu badaczy zajmujących się kreatywną sztuką inżynierską. W dalszej części zaprezentowano założenia techniczno-technologiczne i praktyczne osiągnięcia wybranych kategorii inżynierii technicznej, takie jak: inżynieria lądowa, wodna, wojskowa, mechaniczna, elektryczna, procesowa, materiałowa i inżynieria ekstremalna. Praca ma charakter konceptualno-przeglądowy i akcentuje synergię nauki, wiedzy i technologii (głównie technicznej i stosowanej) oraz kompetencji, umiejętności na tle utylitarnych potrzeb społecznych.

SŁOWA KLUCZOWE inżynieria, nauka, technika, technologia, koncepcja, projekt, prototyp, aplikacja

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