Acta Polytechnica **64**(3):194–204, 2024
https://doi.org/10.14311/AP.2024.64.0194

CZECHOSLOVAKIA/CZECH REPUBLIC AS A LEADER IN POLYMER TECHNOLOGIES IN CENTRAL EUROPE: FROM CONTACT LENSES TO 3D PRINTING

Marcela Efmertová

Czech Technical University in Prague, Faculty of Electrical Engineering, Historical Laboratory of (Electro)Technology, Technická 2, 166 27 Prague, Czech Republic

correspondence: efmertov@fel.cvut.cz

Abstract. The Czech Republic prides itself on a long-standing tradition in the scientific field of polymer studies and technologies. Seen in this light, the following article seeks to single out this particular tradition and to highlight some of the facts concerning practical applications that have been significantly enhanced by Czech experts such as Otto Wichterle in the latter half of the 20th century. Otto Wichterle, a prominent Czech chemist, revolutionised the field of ophthalmology with his invention of soft contact lenses. Despite the restrictive regime of Communist Czechoslovakia, Wichterle's innovative work in organic chemistry, plastics, and biomaterials led to the development of hydrophilic soft contact lenses. His home-based experimental setup, which included a children construction set, a bicycle light battery, a phonograph motor, and homemade glass tubing and moulds, resulted in the creation of a transparent and absorbent gel suitable for eye implants. Wichterle's pioneering work has had a profound global impact, with his invention now used by over 100 million people worldwide. His research has also paved the way for the development of "smart" biomaterials used in various medical devices.

Keywords: History of science, history of polymers, contact lenses, Otto Wichterle, Czechoslovakia, Institute of Macromolecular Chemistry, Czechoslovak Academy of Sciences, Czech Academy of Sciences, Josef Průša.

Motto The era of polymers – life is impossible without biological polymers; contemporary living standards would be impossible without synthetic polymers.[1]

1. Introduction

One of the Czech institutes engaged in the basic research of macromolecular substances – polymers[2] is the architecturally imposing *Institute of Macromolecular Chemistry* of the Czech Academy of Sciences (Czechoslovak Academy of Sciences between 1952–1992) (Figure 1). Its origins in 1959 are connected with its first Director Otto Wichterle (1913–1998) and architect Karel Prager (1923–2001). Otto Wichterle made the name of the institute thanks to two practical inventions – alkaline polymerisation of caprolactam and soft contacts lenses made of hydrogels (together with Drahoslav Lím (1925–2003)[3]). The institute boasted of its successful focus on the innovative thinking of its staff in the field of materials and material technologies (see [4]). That was also why Prague hosted, particularly during the 1960s, many major congresses and scholarly conferences. On the one hand, the institute reflected the worldwide development patterns prevailing in macromolecular science, on the other hand, it was under the sway of Czechoslovakia's postwar history, strongly affected by communist ideology and between 1968 and 1991, by the outright military occupation of the country by the USSR and some other countries, members of the former **Warsaw Pact (1955–1991)**. Optimism and political relaxation, bolstering up scientific activities and endeavors to re-establish links with Western Europe in the first half of the 1960s were replaced, **after the Prague Spring prodemocracy movements canceled by occupation in 1968, by a long period of decline and normalisation**[4] until the Velvet

[1]Motto has been taken from the discussion led by Prof. Piet J. Lemstra (*1946) of the Eindhoven University of Technology (Netherlands) at the 25th Prague discussion conference PMM in 2005. See also [1].

[2]The term polymer denotes a substance composed of a large amount of units, mers. It was Jöns Jacob Berzelius (1779–1848) who introduced it into chemical terminology.

[3]D. Lím graduated from the College of Chemistry and Technology within the CTU in Prague in the years 1945–1949, then he remained working at this school, where he met O. Wichterle. In the years 1959–1974, he became a researcher at the Institute of Macromolecular Chemistry of the Czechoslovak Academy of Sciences, he had to leave the institute during normalisation, he could not get a scientific job, and therefore worked for 5 years in a sugar factory in Kolín. In 1979 he emigrated to the USA. Lím has developed 150 patents, the last one was granted in July 2003. See [2], CV Lím and the correspondence with the scientist Paul J. Flory and the American Chemical Society (documents related to emigration) and Patents. And [3, p. 45–46].

[4]The period of normalisation in Czechoslovakia (1968–1989), was a tumultuous era characterised by the repressive policies enacted by the Communist regime in response to the liberalising reforms attempted during the Prague Spring of 1968. It aimed to implement a series of reforms known as "socialism

Figure 1. Monument to O. Wichterle in front of the institute in Prague – Petřiny, his patent numbers are inscribed in the crown of the statue's trees. The monument was ceremonially unveiled on 31 October 2005.

Revolution (1989), even though a well-thought-out series of research projects had never been stopped in Czechoslovakia either.

The fast development of industrialisation and industrial production in the latter half of the 20^{th} century brought about new requirements for developing technical products and machinery whose quantity was rising in keeping with social developments and growing living standards. Those new requirements concerned primarily low weight of products, long durability, and reliability, economically and environmentally acceptable manufacturing technologies, products' resistance to corrosion as well as their surface and aesthetic properties.

Developed from the mid-19^{th} century to the present day, synthetic materials have also had a significant impact on the face of our physical world. The materials based on macromolecules (polymer materials) are roughly divided into two large groups, *plastics* that are solid or rigid under ordinary circumstances, and *rubbers* that are soft and pliable. They are of natural or synthetic origin.[5] Plastic materials are, for example, Bakelite, celluloid, polyethylene, PVC (known in Czech as Novodur), nylon, silon (polycaprolactam), Plexiglass (Perspex) and others. Plastic materials have made production cheaper, not being directly dependable on natural resources; they caught people's eyes with their colorfulness, and primarily offered the hitherto unknown possibility of shaping. As a result, polymers constitute a continuous phase (matrix) in various types of composite materials. Genuine upsurge of synthetic polymers came in the 1920s.

This was the first time in the history of materials that theoretical knowledge influenced technological progress. Many renowned chemical experts focused on discussing polymeric materials, especially Hermann Staudinger who addressed experimental chemical en-

with a human face", which sought to introduce elements of political pluralism, freedom of speech, and a decentralised economy within the framework of communist government. These reforms sparked hope and enthusiasm among the Czechoslovak population, but they also alarmed the Soviet Union and 6 countries of the Warsaw Pact (1955–1991, Albania, Bulgaria, Hungary, German Democratic Republic, Poland, Romania), fearing that the changes could weaken the influence of the USSR on its Eastern bloc. In August 1968, Soviet-led Warsaw Pact troops invaded Czechoslovakia to suppress the reforms and restore an orthodox communist regime. This marked the end of the Prague Spring and the beginning of the normalisation period. During the normalisation era, the regime cracked down harshly on political opponents, dissidents, intellectuals, and anyone perceived as a threat to the Communist Party's authority. Thousands of people were arrested, imprisoned, or forced into exile. Many citizens lost their jobs after checks in the Communist Party of Czechoslovakia and at workplaces, the children of the persecuted were not allowed to study, and the economic and living standards of these families dropped significantly for a long time. The media were tightly controlled and censorship was rigorously enforced to suppress any form of criticism or dissent. The regime emphasised centralised planning, prioritising state control over economic activity. However, the economy stagnated and living standards lagged behind those of Western European countries. Despite the regime's efforts to maintain control, dissent simmered beneath the surface, leading to occasional outbreaks of resistance such as the Charter 77 movement (1976/1977), which called for the government to adhere to its human rights obligations after the signed Helsinki negotiations in 1975. The normalisation period came to an end in 1989 with the Velvet Revolution, a series of peaceful protests and demonstrations that led to the fall of the Communist regime and the establishment of democracy in Czechoslovakia. The period of normalisation remains a significant chapter in the country's history, serving as a reminder of the importance of safeguarding freedom, democracy, and human rights. See [5–9].

[5]For the characteristic of plastics see [10].

gineers with the notion that molecules of polymers are linear chains. Later, in 1953, he won the Nobel Prize in macromolecular chemistry. This prompted an intense research into dual-functional monomers that seemed to be the most suitable for the synthesis of molecular chains. Proceeding from Staudinger's findings, Wallace Hume Carothers (1896–1942) prepared, during the 1930s, chloroprene rubber, polyesters, and polyamide 66, the famous nylon.

New materials based on linear polymers and 3D molecular networks quickly proliferated from the 1950s **to the 1960s**. Brand-new polymers kept appearing less frequently during the 1960s. As soon as the large companies had invested considerable funds into a specific manufacturing process, they were less willing to risk new, untried technologies. As a result, this gave rise to a specific hierarchy of polymeric materials, characterised not only by their properties but – to a large extent – by their price. As a result of these facts and the demands placed on production, polymers began to gain ground in practice. Polymers are described as one of the most salient materials of the present, i.e. *we are living in the era of polymers.* In actual fact, this was aptly illustrated in 1967 by a scene from the American movie *The Graduate* starring Dustin Hoffman as a university undergraduate Benjamin Braddock who is making up his mind about his chosen profession. At the beginning of the movie, his family friend McGuire gives him this advice: "*I want to tell you one word. Just one word: Plastics*" [11]. Over the past forty years, this scene seems to have acquired a definite cult status, and not just among chemical professionals.

2. General overview of polymer development

The development of synthetic polymers, markedly motivated by the need for better insulators, particularly for the electrical engineering industry, dates back to the early 20th century. This interdependence between the development of polymers and electrical engineering continues to this day. At that time, synthetic rubber was used, for instance, in accumulator boxes or as a replacement for natural rubber in tires. The early days of rubber technology in Czechoslovakia between the two world wars were connected with the Baťa company in Zlín, which manufactured the first bicycle tire casings back in 1931. At the end of the 1920s, synthesis of polymers made it possible to prepare cellulose acetate (CA) – material similar to celluloid, and shortly afterwards also polyvinylchloride (PVC) and polymethylmethacrylate (PMMA). Also introduced was the manufacture of urea-formaldehyde resins (UF). The 1930s saw the industrial production of polystyrene (PS), chloroprene rubber (CR) – so-called neoprene, polyesters, polyamides PA-66 (Nylon), PA-6 (manufactured in Czechoslovakia under the name Silon) and also branched low-density polyethylene (PE-LD). During World War II, polyamide and polyethylene grew to be truly strategic materials. Polyamide threads served for the manufacture of parachutes, polyethylene was used for the insulation of undersea cables and as an insulator in high-frequency coaxial cables. Together with polytetrafluorethylene (PTFE), this made it possible to construct radars. The first nylon threads were used, for instance, as brush bristles but also for the production of nylon stockings, a great hit for women from the 1950s onwards. The pace of development of polymer materials accelerated from the end of the 1940s. Epoxy resins (EP) could be utilised just as structural plastic material acrylonitril-butadiene-styrene (ABS). The 1950s saw the appearance of linear, high-density polyethylene (PE-HD), polypropylene (PP), polycarbonate (PC) and a multitude of various copolymers prepared from two or more types of monomers. Manufacturing facilities for commodity polymers were built across the world **in the 1960s and the 1970s** (see Table 1). Even though investments into production proved to be enormous, there emerged yet another new group of polymers with excellent thermal resistance, such as polysulphones (PSU) and polyimides (PI). In the early 1980s, the focus was on the preparation of polymer mixtures that allowed producing new materials through a simple combination of suitable components (e.g. PC/ABS, PE/PP, aromatic polymer Kevlar etc.). At the moment, the development in the field of polymers is focused on preparation of polymeric composites but also so-called smart polymers (materials that change their properties in response to external stimuli), polymeric nanomaterials, and biopolymers (polymers of natural origin). Plastic materials are generally known for very good electro insulation properties, being marked by the ability to cushion impacts and vibrations. Specific polymers have the advantage of transparency. However, there are also specific factors limiting the usability of polymers. These include, especially, low thermal resistance, significant change of mechanical properties with rising temperature, greater thermal expansivity, generation of electrostatic charge, dependence of polymers' mechanical properties on the time of loading, inflammability of the material, low resistance to UV radiation, time dependence of the properties used, etc.

At present, polymers are in great demand, for instance, as **building materials**. Since the 1950s, they have found their application in industrial branches – primarily in building construction, the automobile industry, electrical engineering, agriculture, packaging technology, household appliances, sporting equipment, and furniture, but also in medical disciplines etc. Global production of polymers has been constantly rising: 20 years ago (2012), this accounted for 288 million tons a year (57 million tons in Europe); for the sake of comparison, the worldwide production of polymers in 1950 amounted to a mere 1.7 million tons per year [12] (see Figure 2).

1496	Christopher Columbus brought balls of rubber from America
1791	Patent for impregnating textile with rubber
1843	Gutta-percha discovered
1844	Vulcanisation of rubber by sulfur discovered
1868	Celluloid discovered
1888	Tire invented
1907	PF discovered
1927	CA and PVC manufactured
1928	PMMA manufactured
1929	UF manufactured
1930	PS manufactured
1935	PA-66 prepared
1938	PA-6 discovered
1938	PE-LD prepared
1939	PTFE prepared
1941	PET discovered
1952	PE-HD discovered
1953	PP, PC discovered
1956	PPO discovered
1957	Fluorocarbon rubber prepared
1963	EPDM manufactured
1965	TPE manufactured
1965	PSU manufactured

Table 1. Chronological development of polymers until the 1970s [12].

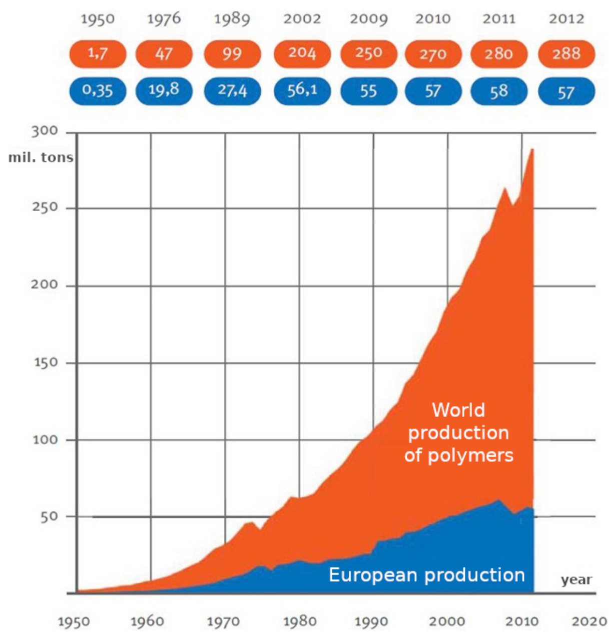

Figure 2. Worldwide production of polymers since the 1950s [12].

3. The Czech way in the development of polymers and Otto Wichterle

3.1. The family of Otto Wichterle

Czech polymer specialists have been devoted to the study of polymers since the 1950s. A leading expert among them was Otto Wichterle (1913–1998)[6] (Figure 3), a world-renowned Czech scientist and inventor, working primarily in the field of macromolecular organic chemistry, among whose founding fathers he definitely belonged. He was best-known for his discoveries and inventions that led the way to the essential improvement and worldwide distribution of soft contact lenses. These results stemmed from his original scientific work in the field of hydrogels. Wichterle also made his name with the discovery of artificial polyamide thread – silon and a gel used for removing graffiti [14]. In addition to his post of the Director of the Institute of Macromolecular Chemistry he was also a long-time professor at the University of Chemistry and Technology in Prague (abbreviation in Czech – VŠCHT).

Wichterle's own life story accurately reflected the historical events unveiling in Central Europe, while

[6]The documents on the life and work of Prof. Ing. RTDr. Otto Wichterle, DrSc., Dr. h. c. multipl. are kept in the Archives of the Academy of Sciences of the Czech Republic, coll. Otto Wichterle (1913–1998), NAD 471 and coll. of the Institute of Macromolecular Chemistry of the **Czechoslovak Academy of Science** (abbreviation in Czech – ČSAV), (NAD 205) and Academy of Sciencs of the Czech Republic (abbreviation in Czech – AV ČR), (NAD 635), cca 287 cartons, 29 boxes and 79 official books – inaccessible collections. The organisational structure of the institute within the Academy of Sciences: Department of Macromolecular Compounds of the Institute of Chemistry of the ČSAV (1953–1956); Laboratory of High-molecular Compounds of the ČSAV (1957–1958); Institute of Macromolecular Chemistry of the ČSAV (1959–1992); Institute of Macromolecular Chemistry of the AV ČR (since 1993). Archives of the Institute for the Study of Totalitarian Regimes (coll. Wichterle, KR_694353_MV_1-3). See also [13].

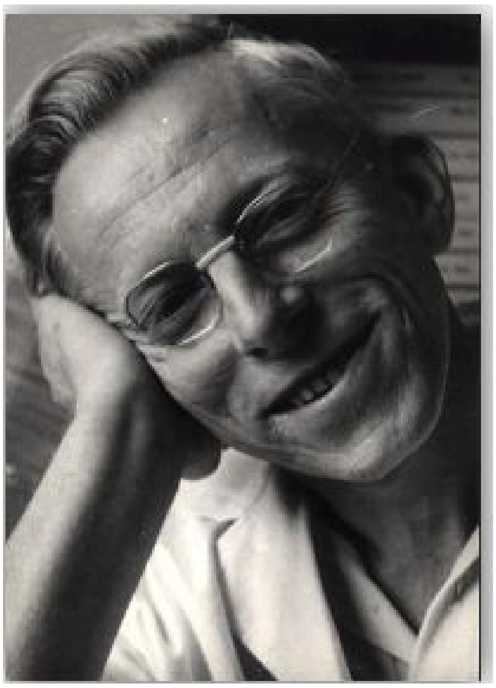

Figure 3. Otto Wichterle (1913–1998) was a Czech chemist and inventor, best known for his invention of modern contact lenses. [15]

he himself retained the building and pioneering ethos of Masaryk's first Czechoslovak Republic (1918–1938). This moral integrity made Wichterle's life in communist Czechoslovakia after the Second World War much more difficult, as he had been critical of the communist regime. Originally, he came from a family of businessmen in mechanical engineering from Prostějov. In December 1918, Otto's grandfather together with entrepreneur Kovářík established an engineering plant (the company's logo was composed of the first letters of the founders' names – Wichterle-Kovářík – WIKOV)[7]. In its key production program, the company manufactured farm machinery (hand tools, ploughs, threshing machines, potato harvesters, steam locomotives, stable diesel, petrol, and gas engines and generators for driving mills, workshops, and smaller plants, tractors, electromotors etc.) and starting in 1922, also automobiles, even models of aerodynamic shapes (car WIKOV 25-Kapka from 1931, Figure 4) [17]. After World War II, the extensive enterprise of the Wichterle family was confiscated, nationalised and renamed to Agrozet Prostějov [18].

O. Wichterle's family was enterprising, temperamental, inventive, resourceful, and affectionate, and supported all kinds of positive activities. Father Karel, a graduate from the Viennese Technic, had extensive knowledge of chemistry; mother Pravoslava (Slávka) was culturally minded. Otto's four older siblings spent their adult life studying foreign languages (Ema), mechanical engineering (Karel), sculpting (Hana) and business (Jan) [20, chap. 21]. In his childhood, Otto was frequently ill due to a shock sustained while drowning in a pond [20, pp. 15–19]. Despite that, he attained excellent education. He finished classical high school in Prostějov and then entered the University of Chemical and Technological Engineering of the Czech Technical University in Prague (CTU in Prague, abbreviation in Czech – ČVUT). During his studies between 1931 and 1935, Wichterle's chief subject was macromolecular chemistry. He enjoyed revealing connections between the structure of macromolecules and the properties of polymers. His field of knowledge covered even macromolecular biology, biochemistry, and biophysics. Thanks to his professors – Otakar Quadrat (1886–1963) [21] and Emil Votoček (1872–1950) [22, 23], under whose supervision he had written his dissertation thesis, defended in 1935, he achieved the doctorate of technical sciences in the following year. He was very liberal-minded and versatile in his branch, had a talent for innovations and inventive research. But he also had many outstanding personalities to follow since his predecessors included Jaroslav Heyrovský, Nobel Prize winner for chemistry in 1959 (1890–1967)[8], and distinguished professors at CTU in Prague: Rudolf Lukeš, František Šorm, Rudolf Brdička, Stanislav Heřmánek or Jaromír Pleška. Chemistry and polymer research projects have been studied at CTU in Prague and the Faculty of Natural Sciences of the Charles University since 1920, while the international journal *Collection of Czechoslovak Chemical Communications*, instituted by Emil Votoček and Jaroslav Heyrovský [26], was also published in the country. Before O. Wichterle could finish his habilitation with E. Votoček in 1939, the Nazis closed the Czech universities and Wichterle had to look for a job.

3.2. The Research by Otto Wichterle during World War II

At that time, while working on the subjects connected with his habilitation, namely during prepanation of *crotonaldehydacental*, he prepared rubber as a byproduct – the very first synthetic polymer Wichterle produced. His colleague, student Ivan Vavrečka, reported this discovery to Zlín and a representative of the *Research Chemical Workshops of the Baťa Company* came to Wichterle with an offer of a job in the local laboratories, which the latter accepted. There, he began to refine dichlorbutene and synthesise chlorcrotylated barbiturated acids, even though – due to

[7] The first business project came in 1878, when František Wichterle (1840–1891), originally the owner of municipal gasworks, with his brother-in-law Adolf Procházka established The First Prostějov Factory for Farming Machinery and Steam Engines, Metal and Iron Foundry in Prostějov. In addition to this enterprise, another company The Prostějov Joint-stock Factory for Machinery and Engines Ing. František & Ing. Josef (1868–1940) Kovářík, Prostějov was set up in Prostějov between 1894–1896. Both companies merged on December 22, 1918, which was the beginning of the enterprise Wichterle-Kovářík, whose share capital amounted to 12 million Czechoslovak crowns. See [16].

[8] Nobel Prize for chemistry (for polarography) in 1959. See [24, 25].

Figure 4. Car Wikov 35 Kapka (1931–1933): The first Czechoslovak car with an aerodynamic body. [19]

the war restrictions of supplies – he had to produce his own hydrochloric acid out of salt and sulfuric acid [27]. In mid-1940, he initiated research on polycondensation artificial substances, a study to which Wichterle devoted the entire time spent in Zlín. The principal purpose of this work was research into polyamides. They were studied both in terms of manufacturing possibilities and in terms of their chemical and mechanical processing and improvements. As a result, Wichterle was in a position to patent polyamide silk – Winop, i.e. essentially silon [27], while he managed to improve the textile properties of the thread, including its spinning. O. Wichterle had known the patent for Nylon 66 and Carothers's publications on polycondensation of 6-aminocaproic acid, obtained from caprolactam, and proceeding from such knowledge, he launched an experiment aimed at direct transformation of caprolactam into polymer. He succeeded in producing a polyamide substance suitable even for non-textile applications, e.g. surgical suturing, but the chief goal was to devise a method of jet spinning of the substance-polymer, producing a yarn suitable for making stockings and stocks. He had kept these findings from the Nazis. On the ground of suspicions of concealing this research, Wichterle was arrested by the Gestapo and interrogated for four months [13, pp. 35–48]. Following Wichterle's departure from Zlín, disputes arose around silon concerning the authorship of the invention of the thread, with some of Wichterle's colleagues trying to steal his invention [28].

3.3. Polymer Research by Otto Wichterle and his group

After World War II Otto Wichterle began cooperation with the Department of Chemical Engineering of the E. Beneš Technical University in Brno and with the CTU in Prague. In 1945, O. Wichterle returned to the University of Chemical Engineering at the Czech Technical University in Prague, whose activities were interrupted by the closure of Czech universities in 1939, where he completed his habilitation in organic chemistry, and began lecturing in general and inorganic chemistry. In 1949 he extended his habilitation to the field of plastic technology and devoted himself fully to the establishment of the Department of Plastics Technology. In 1949, he became its first professor and director. Otto Wichterle also pioneered novel forms of teaching: first of all, he presented to his students a theoretical physical-chemical explanation of the issue in hand, and only then he advanced to an experimental chemical presentation of the substance under scrutiny. He also applied himself to the studies of polyamides based on caprolactam and continued with the reversible polymerisation of caprolactam. Wichterle's idea involving narrowly networked hydrophilic gels capable of being swollen by water was applied here in 1952.

After the separation of the College of Chemical Engineering from the Czech Technical University in Prague, an independent University of Chemical Technology in Prague (VŠCHT) in 1952, was established and O. Wichterle became its professor. In parallel with the installation of Communist Party members in the school's leadership, Wichterle's conflicts and enemies increased. When Vladimír Maděra (1905–1997) was appointed as the new rector, a political purge began, leading to Otto Wichterle's dismissal on 31 August 1958. Research on intraocular lenses was liquidated at the VŠCHT. Wichterle was then granted scientific asylum at the Czechoslovak Academy of Sciences, where a more politically liberal environment prevailed than at the universities. On 4 December 1958, Wichterle was appointed head of the Laboratory of Macromolecular Substances at the Czechoslovak Academy of Sciences, which in the same year became the Institute of Macromolecular Chemistry in Prague 6, Petřiny. Wichterle became its director (until the so-called normalisation) and was responsible for most of its successes.

Indeed, the issue of correcting refraction defects, the key goal of Wichterle's research, was a problem occupying great minds long before the modern times; for instance, the idea of devising a system of water-filled glass tubes attached to the human eye was associated with the name of Leonardo da Vinci back in 1508. The branch of contactology has also been known for such notables as the French mathematician and philosopher René Descartes who wanted to place theoretical corneal lenses directly on the cornea of the human eye. In 1823 Englishman Sir John Herschel designed contact lenses made of gelatinous gel, a project that came closest to Wichterle's own concept of lenses made of soft material. Further developments came in 1880 thanks to Adolf E. Fick and August Müller who introduced scleral, glass contact lenses. In 1928, the Carl Zeiss-Jena company produced a test run of a set of lenses with various diameters of curvature and different scleral components. In 1936, William Feinbloom, who worked as an optician, presented lenses composed, in terms of materials used, both of glass and plastic. Hungarian doctor Joseph Dallos improved the scleral corneal contact lenses using the method of eyeprint scanning (or living eye impression technique) with the help of the substance Nagecol. During World War II, Dallos produced, together with the Czech technician Nissel, contact lenses for RAF pilots. Kevin Tuohy, an optician in California, came up with corneal contact lenses made of PMMA (plexiglass). During the 1950s, Wichterle and his colleague, assistant Drahoslav Lím (1925–2003) [2, 3, chap. Od kontaktních čoček k transplantátům (From Contact Lenses to Transplants). Příběh Drahoslava Líma, světového průkopníka chemie biomateriálů (The Story of Drahoslav Lím, a world-wide pioneer in the chemistry of biomaterisals), pp. 43–45], began preparing silicon – hydrogel HEMA (hydroxyl-ethyl-methacrylate $C_6H_{10}O_3$ was discovered as late as in 1960) suitable for the manufacture of soft contacts lenses. American chemical experts joined more than 15 years later with their rigid gas permeable material ROP (involving the manufacture of rigid contact lenses easily permeable by gases), but the practically usable lenses were first prepared by O. Wichterle.

Wichterle had also launched his research into the casting of gel lenses which, however, initially did not prove to be very successful and CTU in Prague stopped the whole project in 1958 [13, pp. 100–110]. Nevertheless, Wichterle continued his scientific efforts and performed polymerisation of monomers that he planned to use in surgery and also eventually in the preparation of contact lenses (compare [31]). Wichterle left the University of Chemistry and Technology, which had meanwhile split from CTU in Prague in 1952, after six years, at a time when political purges broke out in Czechoslovakia. These would have definitely affected Wichterle who then served as the Dean in the Organic Technology Department. He went to work in the Czechoslovak Academy of Sciences (abbreviation in Czech – ČSAV) in 1958 and took part in the establishment of the *Institute of Macromolecular Chemistry* and was elected as its first Director [32]. During his work in the institute, he solved the problem of the manufacturing technology of contact lenses when – during Christmas 1961 – he took advantage of the Czech construction kit Merkur (similar to Meccano; Figure 5), belonging to his two sons (Ivan – now a physical chemical expert and Kamil – a chemical specialist), which was driven by a bicycle dynamo (later on he used a more powerful engine from a gramophone) and thus tested rotational casting of contact lenses, and immediately afterwards, he filed a patent for it. The first lenses were made of a mixture of 80 % hydroxylethylmethacrylate and 20 % *di (ethylene glycol) methyl ether methacrylate* (DEGMA) to increase the balanced content of water in the swollen gel. The HEMA gel was used later. The new substance was light, soft, mouldable, and able to absorb water; other advantages included smoothness and transparency. Originally, until October 1961, lenses were prepared in a swollen state through the polymerisation of diluted HEMA; then a patent was submitted for xerogel, which made it possible to produce contact lenses without a solution, in a dry state. The foundation for these new gel lenses was a liquid substance that was poured into special vessels, connected to a rotational device. As the vessels rotated, the liquid level concaved. The

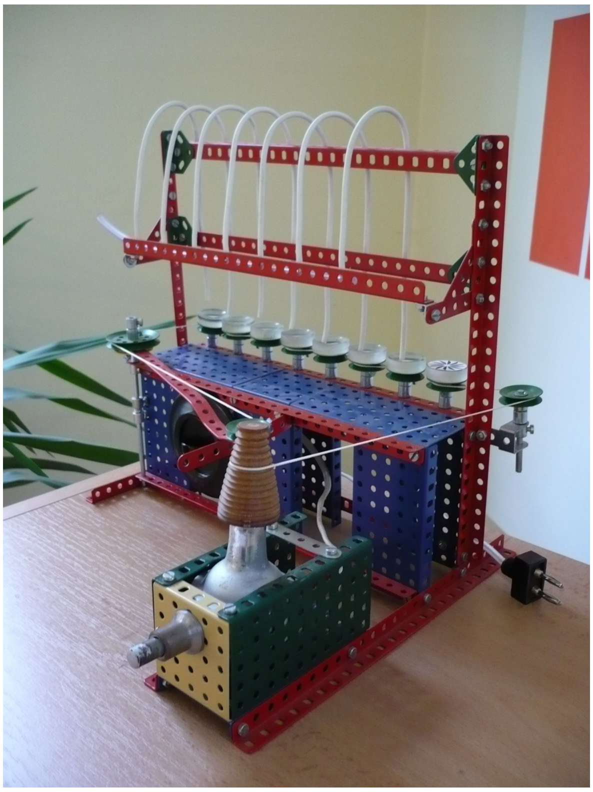

FIGURE 5. Merkur-based apparatus for centrifugal casting of contact lenses by Wichterle [29] (compare [30]).

actual degree of concavity could be adjusted – depending on the speed of rotation, the size of the vessel, and on the viscosity of the substance. After the substance hardened, the finished lens could be taken out of the vessel [33]. In 1966, O. Wichterle received the State Award in Czechoslovakia for hydrophilic gels. After the Velvet Revolution, when he had been absolved from all the false accusations from the time of the communist regime, during which he had to leave his scientific work on several occasions, he received the high state distinction – *Order of Tomáš Garrigue Masaryk, Third Class* in 1991.

It was particularly with this invention of soft contact lenses made from hydrophilic gels that made the institute internationally renowned. Wichterle focused on manufacturing at minimum cost, using the method of centrifugal casting in rotating open moulds. It was evident that the manufacture of lenses can bring Czechoslovakia considerable hard-currency profits. Mid-1962 saw the construction of elementary parts for the machine producing lenses (lens-machine) [34] and in 1963, the method of manufacturing contacts lenses had been brought to near perfection. At that moment, foreign businessmen began to be truly interested in the invention. A license contract was signed in Prague with Robert Morrison and the US National Patent Development Corporation [20, pp. 145–161] on March 12, 1965, and Wichterle's contact lenses had been nominated for Nobel Prize award; regrettably, the prize was not awarded.

During the political relaxation – at the time of the so-called Prague Spring in 1968 – Wichterle together with other academics, such as Jan Brod, Otakar Poupa, Miroslav Holub, and others, prompted the Czech writers Ludvík Vaculík and Pavel Kohout to write until then the severest criticism of the communist regime called *Two Thousand Words Belonging to Workers, Farmers, Clerks, Artists, and All*[9]. Throughout the period of normalisation (1970–1989) in the 1970s Otto Wichterle was persecuted for his part in the manifesto; he was removed from his office of the Director of the institute and was even banned from lecturing at universities. He was hindered to continue his research of contact lenses and the new management of the institute hampered him in conducting further negotiations with the US license partners.

During the normalisation, the lens machine and lens research were accompanied by court cases. In 1977, **Czechoslovak Academy of Sciences** gave up the license agreements in favour of the USA. **Czechoslovak Academy of Sciences** did not participate in further disputes and, without O. Wichterle's knowledge, sold his patents to the USA for an amount that did not even reach the revenues received from the license in the first year [20, p. 135], [36].

[9]Printed on June 27, 1968 concurrently in the journal Literární listy (Literary papers) and the daily newspapers Mladá fronta (Young front), Práce (Work) and Zemědělské noviny (Agricultural newspaper). The text of the manifesto can be accessed from [35].

The regime tried to make his research work, which had to proceed outside the institute and on his own, yet more difficult by making his living conditions worse; his work contracts were concluded for short periods and he could not travel abroad. In spite of that, Wichterle kept intensely working on his projects.

Meanwhile, his colleagues appreciated him and his work, describing him as a dazzling chemical expert, well versed in selected sections of physics, an accomplished mathematician and also knowledgeable in parts of medicine, primarily those associated with eyesight. He enjoyed experimenting and theoretically commenting on the properties and reactivity of molecules [37]. In 1978, he finished a definitive version of an operationally tested prototype of a new continual machine for the manufacture of lenses. He also studied the possibilities of synthesising hydrogel carriers that could fix enzymes. He tested medical applications of hydrogels as implants into vocal chords, implants for artificial larynx, replacement of ocular vitreous, etc. Wichterle's position in the institute slightly improved in 1984 when, as an old-age pensioner, he could carry on his research.

After the *Velvet Revolution*, he was rehabilitated and in 1990, he was appointed President of the reformed Czechoslovak Academy of Sciences (Czech Academy of Sciences since 1992). He stayed at the head of the Academy until 1992. His scientific career is very well known – in addition to his extensive works: he was the author of at least 150 patents and more than 200 publications – he instituted the award of distinctions in his honor to young promising scientists under 35 years – *Otto Wichterle's Special Prize* [38]. From the 1950s onwards, Wichterle frequently participated in international scientific life, whenever allowed by the regime. In 1960, he was appointed Chairman of a symposium on lactam polymerisation in the United States, later lectured at the Harvard University and the **Massachusetts Institute of Technology in Cambridge (MA), at Stanford University in Stanford (CA), at the Wayne State University in Detroit (MI), and at the Notre Dame University in South Bend (IN). He also addressed centres of industrial research in Leominster (MA), Cleveland (OH), Richmond (CA), Pittsburg (PA), Richmond (VA), Elizabeth (NJ), and in other cities**[10].

4. Josef Průša and filaments for 3D printing

The second distinguished personality active in the sphere of Czech polymers, not in the sense of their scientific research but rather their practical applications, is the young Czech entrepreneur Josef Průša

[10]Elaborated according to a touring exhibition Otto Wichterle at the OPTA Trade Fair, 24.–26. 2. 2012 (lecture by Ing. Jiří Michálek, CSc.), Veletrhy Brno, a.s., pavilon B. See also [20, chap. Vyznamenání (Distinctions)].

(*1990)[11], who came to be known to the professional community as well as the public in 2012. At that time, he founded what is currently a skyrocketing company *Prusa Research, a.s.*[12], figuring among the world's biggest producers of 3D printers and their cartridges – filaments made of nylon, polycarbonate, carbon, etc., polymer print filaments for FDM print technology (Prusament PET-G, PLA, ASA etc.)[13]. Filament PLA is an excellent first material for learning 3D printing. It is easy to print with, being very cheap and producing components that can be employed for a broad scale of applications. Filament PET-G is resistant, virtually unbreakable, and suitable for contact with food, being commonly used for the production of containers for food and beverage bottles. Filament ASA 3D is a filament for 3D printers, being strong, rigid, and relatively easy to print. This material is also highly resistant to chemical influences and heat. In 2018, the Ministry of Industry and Trade, in conjunction with the *Institute of Polymers at VŠCHT*, supported the project called *Development of New Mixtures for the Manufacture of 3D Printer Strings*. Several manufacturing companies participated in the project and discussions were under way on the development of a high-quality consumer material for 3D printers operating with the FFF/FDM [45] technology. The Institute of Polymers at VŠCHT currently constitutes the principal scientific institute in the Czech Republic involved in long-term research into polymers, while also linking up to the era of O. Wichterle in this institution during the 1950s when its employees worked, among other projects, on the development of substances for the manufacture of Czechoslovak gramophone records, artificial running surfaces for skis, contact lenses, etc. The 1960s saw the introduction of the manufacture of Czechoslovak silicone rubber, the 1970s were the era of structural polyamide and domestic suspense polyvinylchloride, the 1980s were noted for the development of medical applications of polymers. At present, the institute avails itself of a special laboratory for medical applications of polymers. O. Wichterle's son Kamil [46, 47] currently stands at the head of the institute.

Průša is nicknamed *King of 3D Print* [48] and his principle is that all the specialised information should be publicly available and applicable to customers. An interesting stage in the company's development came during the COVID-19 pandemic when the company started producing-printing protective shields for medical personnel, components for lung ventilator CoroVent, adapters for face masks [49], and other protective aids against that fast-spreading infection. The company has been working on a project preparing print data to make it possible for ordinary users, who are not designers by profession, to design and print what they need by themselves. The modelling software has already been simplified; basic software tools are used in a similar way of putting Lego pieces together. As for the application of filaments, roughly four key areas are currently the centre of focus – weapons, building construction, food, and replacements of human organs[14]. These can be directly printed, or moulds are prepared by means of filaments which are then filled with required content-substance.

In conclusion, we can state that the production and consumption of commodity plastics has grown the fastest, and now accounts for more than 80 % of the volume of all manufactured plastic materials. The reason was, quite inevitably, their low price that facilitated high production but also a number of modifications that have paved the way for commodity plastics to new applications. This has once again proved that an important property of such substances, in addition to their physical and chemical parameters, is their price. Back in 1930, the global annual production of plastic materials (in fact, at that time it was only Bakelite and celluloid) reached hardly 23 000 tons. After the war, the figure exceeded 1.3 million tons, with the 2007 total reaching up to 260 million tons [1]. In the mid-1950s, the worldwide production of all polymers in volume units exceeded metals, and it may be interesting to note that this particular moment may have led to the description of the new era as the postindustrial society. That is marked by the fact that the number of people employed in services is higher than those in industry and farming. Why are polymers so successful? Numerous causes may be mentioned – easy forming properties by means of many plastic-processing technologies (injection moulding, blow-out, extrusion, or coating and lamination), of great importance is the low unit weight of polymers (standard glass beer bottle weighs approximately 330 grams, containing 0.75 liters of liquid, a polyethylene terephthalate (PET) bottle weighs a mere 38 grams and contains 1.5 liters); low weight and resistance to corrosion are also advantageous in automotive components or during construction of pipe distribution systems, in filters and membranes, building insulation, medical instruments, in elements of energy equipment, in various types of packaging; energetic usage of plastic waste is also highly acknowledged in environmental protection. On the contrary, the disposal of plastic and mixed waste poses a threat to modern society.

5. Conclusion

Time plays a crucial role in the lives of ordinary people and especially scientists. It enables them to shape their education and thus find an adequate place in

[11] He did not finish his university studies but is the laureate of the Starting EY Businessman in 2016 in the Czech Republic and the 2020 *EY Businesman in the Czech Republic* [39].

[12] In 2021 his company had 600 employees and a turnover of more than 2 billion CZK. See [40, 41]. The company's progress is described on the web pages see [42].

[13] Filament diameter is 1.75 as well as 2.85 mm. Weight of filament on the spool from 200 grams up to 8 kilograms with a wide-ranging scale of colors and materials, complete with dilutable filaments for supporting structures. See [43, 44].

[14] Interview with J. Průša [50].

society. The work of scientists ensures the economic and social (cultural) development of society, which is also reflected in the political level and influence of the state in which the scientist works. This position has historical roots and scientific work has a long tradition. Its manifestations can also be found in two socially significant recent phases in **Czechoslovakia** – after 1945 until the general upsurge of Czech society in the late 1960s, during the period of normalisation in 1970–1989, and after the Velvet Revolution of 1989.

The first stage shows the formation and development of an exceptional scientific personality, the Czech chemist and under-appreciated manager of Czechoslovak science (establishment of the Institute of Macromolecular Chemistry) Otto Wichterle, who received his education in the democratic First Czechoslovak Republic (1918–1938), but entered practice during the Nazi occupation (Protectorate of Bohemia and Moravia 1939–1945) and after 1945, when the power of the Communist Party was formed and consolidated in Czechoslovakia after February 1948. Wichterle sought his path, which was not always black and white, but always directed towards new inventive scientific results in the field of chemistry.

The results brought satisfaction not only to Wichterle, who came from an economically very successful Moravian business family (the Wikov agricultural machinery and automobile company) and who was able to make a name for himself with his research on Silon and soft contact lenses but also to the Czechoslovak Republic. Yet the communist leadership of the Academy of Sciences and the Czechoslovak Republic did not value the results of **Wichterle's** work, forbidding him to work abroad and to continue his research, and even economically undercutting him by selling his contact lens licenses to the USA without **Wichterle's** knowledge. The straightening of social relations came only with the Velvet Revolution and restored Wichterle's social and scientific respectability not only by allowing him to resume his research work but also by making him president of the Academy of Sciences and awarding him a state decoration.

The second of the expert practitioners – Josef Průša – started his business with scientific results after 1989. In 2012, he became the founder and owner of Průša Research, a company that started in a basement in Prague's Smichov district and which, after ten years, is now one of the largest manufacturers of 3D printers and their cartridges in the world (500 employees) [51]. Průša's motto for his company is simple: "My company will only be as good as my people" and it also means its full openness, where his products can be distributed to interested parties. Průša's company was also very active in solving the Covid-19 pandemic (development and production of protective shields). Průša's company is completely self-sufficient, which is a key aspect. O. Wichterle could only dream of such freedom. Průša's company develops itself. Everything is self-supporting, from software and hardware development to the production of most components, distribution and customer support in the context of economic and environmental sustainability.

References

[1] J. Kotek, M. Raab. Quo vaditis, polymery? *Vesmír* **88**(3):186–190, 2009.

[2] Archive of the National Technical Museum, Czech Republic. coll. Drahoslav Lím (NAD 834), 1953–2002, 2004.

[3] F. Houdek, J. Tuček, E. Fišerová. *České hlavy 2002 [In Czech; Czech Heads 2002].* Tváře, 2002. ISBN 80-86574-04-0.

[4] J. Masnerová. Ctnosti naše na tom visí jen, jak čas je vykládá [In Czech; Our virtues depend on it only as time interprets them]. In *Paměti a vzpomínky jako historický pramen*, pp. 367–387. Národní technické muzeum, Praha, 2006.

[5] R. Zejda. *1969–1988.* Akcent, 2001. ISBN 80-7268-200-8.

[6] J. Petráš, L. Svoboda (eds.). *Bezčasí: Československo v letech 1972–1977 [In Czech; Timeless: Czechoslovakia in the years 1972–1977].* Ústav pro studium totalitních režimů, 2018.

[7] M. Otáhal. *Opozice, moc, společnost 1969–1989. Příspěvek k dějinám "normalizace" [In Czech; Opposition, Power, Society 1969–1989. A contribution to the history of "normalization"].* Maxdorf, 1994. ISBN 80-85800-12-8.

[8] M. Heimann. *Czechoslovakia: The State That Failed.* Yale University Press, 2013. ISBN 978-0-300-17242-3.

[9] P. Kolář, M. Pullmann. *Co byla normalizace? Studie o pozdním socialismu [In Czech; What was normalization? Studies in Late Socialism].* Nakladatelství Lidové noviny, Ústav pro studium totalitních režimů, 2017. ISBN 978-80-7422-560-4.

[10] Historie plastů [In Czech]. [2023-12-21]. `https://is.muni.cz/th/jc6o7/5519230/pracestechnickym/plasty/historieplastu.html`

[11] The Graduate. Directed by Mike Nichols, based on Charles Webb's novel of the same name, Embassy Pictures 1967.

[12] L. Běhálek. Podstata, význam a historie polymerů. [2024-02-10]. `https://publi.cz/books/180/01.html`

[13] O. Wichterle. *Vzpomínky [In Czech; Memories].* Academia, 2007. ISBN 978-80-200-1495-5.

[14] Interview with editor Jiří Mrva, 1998. [2024-02-10]. `https://zlin.rozhlas.cz/otto-wichterle-vynalezl-nejen-kontaktni-cocky-nebo-silon-ale-po-navsteve-prahy-i-8474013`

[15] [2024-03-10]. `http://prague.czechcentres.cz/galerie/foto/otto-wichterle-vedec-a-vynalezce4`

[16] Wikov a jeho historie [In Czech; Wikow and its history], 2021. [2023-10-10]. `https://eshop.kovap.cz/magazin/wikov-a-jeho-historie`

[17] Wikov veteran club. [2024-02-10]. `https://wikovveteranclub.cz`

[18] Historie. Oslavili jsme 100 let od založení firmy Wikov! [In Czech; History. we have celebrated centenary since the foundation of Wikov company!]. [2024-02-10]. https://www.wikov.com/cs/o-nas/historie

[19] K. Haas. Wikov 35 kapka (1931–1933): První československý automobil s aerodynamickou karoserií. [2024-03-10]. https://www.auto.cz/galerie/veteran/167818

[20] O. Wichterle. *Vzpomínky [In Czech; Memories]*. Evropský kulturní klub, 1992. ISBN 80-85212-23-4.

[21] J. Boháček. Otakar Quadrat [In Czech]. *Akademický bulletin* (4), 2011.

[22] J. Dostál. Nekrolog [In Czech; Obituary]. *Hudební rozhledy* **3**(4), 1950/51.

[23] Profesor Emil Votoček (1872–1950) [In Czech]. [2024-01-10]. https://www.vscht.cz/skola/historie/votocek

[24] J. Koryta. *Jaroslav Heyrovský*. Melantrich, 1990. ISBN 80-7023-058-4.

[25] L. Pospíšil, M. Hromadová. Jaroslav Heyrovský – 50. výročí udělení Nobelovy ceny za chemii [In Czech; Jaroslav Heyrovský and the 50th Anniversary of the Award of the Nobel Prize for Chemistry]. *Chemické listy* **103**(11):900–901, 2009.

[26] R. Zahradník. *Za vládu rozumu [In Czech; For the reign of reason]*, pp. 22–26. Academia, 2002. ISBN 80-200-0942-6.

[27] Archives of the Academy of Sciences of the Czech Republic. coll. Otto Wichterle, carton 11, file 5–Průmysl, Baťa-Zlín. Certificate on the work of Dr. Ing. Otto Wichterle in the Research Institute Baťa a.s. in Zlín in the Years 1940–1945 (Institute Director Dr. Landa, 28. 5. 1945) [In Czech].

[28] Archives of the Academy of Sciences of the Czech Republic. coll. Otto Wichterle, carton 11, file 5–Průmysl, Baťa-Zlín. Article in Svobodné slovo daily, 15. 5. 1947. Special dispute over the authorship (author Dr. Vladimír Minařík) [In Czech].

[29] Vernissage of Hana and Otto Wichterl's exhibitions at the Muzeum Prostějovska, 2013.

[30] H. Masaříková. Obrazem: Výstava Wichterlových láká na čočkostroj i třistakilové plastiky [In Czech; By image: The Wichterle exhibition attracts the lens machine and the three-story sculptures]. *Prostějovský deník* 2013-04-05. [2024-01-13]. https://prostejovsky.denik.cz/volny-cas/obrazem-vystava-wichterlovych-laka-na-cockostroj-i-tristakilove-plastiky-2013040.html

[31] N. Efron. *Contact lens practice*. Elsevier Butterworth Heinemann, 2017. ISBN 978-07-0206-660-3.

[32] O chemii, životě a náhodách [In Czech; On chemistry, life and chance]. *Vesmír* **68**(3):152–156, 1989.

[33] D. Štádlerová. *Otto Wichterle a jeho přínos světu [In Czech; Otto Wichterle and his contribution to the world]*. Master's thesis, West Bohemian University in Pilsen, Faculty of Arts, 2015.

[34] J. Boháček. Vzpomínka na velikána české vědy Otto Wichterleho [In Czech]. *Akademický bulletin* (6), 2013. [2024-01-10]. http://abicko.avcr.cz/2013/06/03/index-2.html

[35] Text manifestu 2000 slov [In Czech]. [2024-02-10]. https://www.totalita.cz/txt/txt_2000slovt.php

[36] T. Obrusníková. *Otto Wichterle-osobnost a jeho patenty [In Czech; Otto Wichterle-personality and his patents]*. Bachelor's thesis, Masaryk University, Faculty of Medicine, 2012.

[37] J. Šebenda, M. Hudlický. Otto Wichterle (1913–1998): The father of soft contact lenses. *Journal of Polymer Science Part A: Polymer Chemistry* **37**(9):1221–1223, 1999. https://doi.org/10.1002/(SICI)1099-0518(19990501)37:9<1221::AID-POLA1>3.0.CO;2-C

[38] M. Franc, V. Mádlová. *Dějiny Akademie věd ČR v obrazech [In Czech; History of the Academy of Science of the Czech Republic in Pictures]*, p. 256. Academia, 2013. ISBN 978-80-200-2172-4.

[39] EY podnikatelem roku 2020 České republiky se stal Josef Průša [In Czech]. [2023-02-10]. https://www.ey.com/cs_cz/news/2021/04/ey-podnikatel-roku-2020-ceske-republiky-je-josef-prusa-zakladatel-a-majitel-spolecnosti-prusa-research

[40] Josef Průša: Digitalizaci máme v genech [In Czech], 2021. [2023-02-10]. https://www.abra.eu/josef-prusa-digitalizaci-mame-v-genech/

[41] J. Žižka. Průša tiskne jiný svět [In Czech; Průša Prints a Different World]. *MED* (12):6–9, 2019.

[42] Náš příběh [In Czech]. [2023-02-10]. https://www.prusa3d.com/cs/stranka/nas-pribeh_875/

[43] 3D tiskárny Original Prusa přímo od Josefa Průši. [In Czech; 2024-02-10]. https://www.prusa3d.com/

[44] České filamenty. [In Czech; 2024-02-10]. https://www.ceskefilamenty.cz

[45] Print with smile [In Czech]. [2023-02-08]. https://www.materialpro3d.cz/znacka/print-with-smile/

[46] Ústav polymerů: Výuka a výzkum [In Czech]. [2023-02-10]. https://pol.vscht.cz/files/uzel/0009474/0001~~Cy0uSSwLyM-pzE0tKvVJLTm8MFvBONBIwcjAyBgA.pdf?redirected

[47] O ústavu [In Czech]. [2023-02-10]. https://pol.vscht.cz/o-ustavu

[48] Král 3D tiskáren Průša je v Guinessově knize. Rozehrál orchestr tiskáren [In Czech; Průša, King of 3D Printers, is in the Guiness Book of Records. He Conducts an Orchestra of Printers]. *iDNEScz* 2019. [2024-02-10]. https://www.idnes.cz/ekonomika/domaci/3d-tiskarny-rekord-guinessova-kniha-rekordu-prusa-research.A190815_113322_ekonomika_fih

[49] Je hořkosladké vidět u lékařů štíty z našich tiskáren, říká Josef Průša [In Czech]. *iDNEScz* 2020. [2024-02-10]. https://www.idnes.cz/ekonomika/domaci/3d-tisk-josef-prusa-koronavirus-stity-ministerstvo-zdravotnictvi.A200411_134707_ekonomika_kou

[50] Jsme garážová fabrika. Nejradši děláme vše sami, říká podnikatel roku Průša [In Czech]. *iDNEScz* 2021. [2024-02-10]. https://www.idnes.cz/ekonomika/domaci/ey-podnikatel-roku-prusa-rozhovor.A210407_192752_ekonomika_mato

[51] J. Mašek. Podnikatelskou olympiádu vyhrál Josef Průša a jeho celosvětově úspěšné 3D tiskárny [In Czech; Josef Průša and his globally successful 3D printers won the Business Olympiad]. *Hospodářské noviny* 8. 4. 2021.