Engineering 4 (2018) 748–753

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

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Engineering Fronts in 2018

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1. Introduction

Engineering science and technology is an important driving force in changing the world, and engineering frontiers (here referred to as "engineering fronts") are important guidelines for future directions in the development of engineering science and technology. Grasping trends in global engineering science and technology and quickly adapting to new directions in the current scientific and technological revolution have become strategic choices for countries all over the world. Since 2017, the Chinese Academy of Engineering has organized the Engineering Fronts research project, together with Clarivate Analytics and Higher Education Press, with the hope of bringing together the expert knowledge of global engineering and technology talents, assessing global frontiers in engineering research and development, and developing strategic opportunities to provide a reference for active responses to global challenges and sustainable development.

The studies in Engineering Fronts combine quantitative and qualitative analyses. On the quantitative side, published journal papers (e.g., from Science Citation Index Expanded), conference papers, and global patents are taken into consideration in order to identify possible fronts. On the qualitative side, experts are involved in the whole study process, as they propose candidate engineering fronts based on their perspectives and experience, research results from data mining, and interpret key results.

Each year, the study issues about 90 identified engineering research fronts and 90 engineering development fronts. Among these, 27 key engineering research fronts and 27 key engineering development fronts are selected for detailed interpretations. Here, we summarize the development of the 2018 edition.

2. Methodology

The term "fronts" in Engineering Fronts research refers to major forward-looking, leading, and exploratory directions in engineering that have a major influence on and leading role in the future development of engineering science and technology. These fronts form an important guide for cultivating innovation in engineering disciplines.

Engineering Fronts research incorporates the advantages of both literature data analysis and expert knowledge by adopting a combination of data analysis and multiple rounds of expert advice and interpretation. The research process is divided into three stages: data mapping, data analysis, and expert review. The research itself is organized through in-depth cooperation between bibliometric experts and field experts, and the research scope covers 53 subject groups in nine fields of engineering technology. Fig. 1 illustrates the specific implementation process of Engineering Fronts research, where the parts in green refer to data analysis content and the parts in purple refer to expert participation.

During the data mapping stage, we define the scope of the data mining through interaction between field experts and bibliometric experts. Most of the basic data on engineering fronts come from global high-level journals, important conferences, and Derwent Innovation patent classification numbers in nine fields; further supplementary data are obtained from key journals, papers, or keywords that are provided by experts.

The data analysis uses clustering methods to identify research hotspots and patent maps. When mining research hotspots, clustered topics are obtained by co-citation clustering of the top 10% Science Citation Index (SCI) journal papers and conference papers in the Core Collection of the Web of Science in the previous six years (2012–2017 in this case). Next, 50 candidate engineering research hotspots are selected from the topics in each field, based on the citation count, average publication year, and proportion of frequently cited papers. To reflect the emerging nature of research fronts, 20 clustered topics are separately identified from key papers with the average publication year no earlier than 2016. In the 2018 mining analysis of patent data for engineering development hotspots, 53 ThemeScape patent maps (which can quickly and intuitively display the distribution of engineering development technologies) were developed by clustering the first

https://doi.org/10.1016/j.eng.2018.11.004

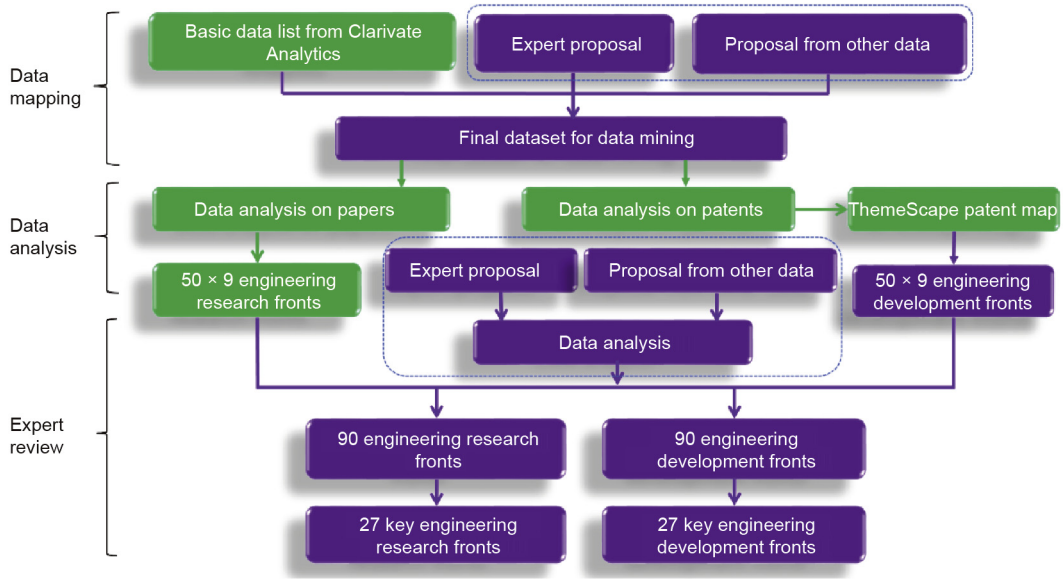

Fig. 1. Implementation flow chart for the Engineering Fronts research. The parts in green are based on data analysis and the parts in purple are carried out by experts from nine fields.

5000 most cited patent families published by Derwent Innovation of the 53 subject groups in nine fields in 2012–2017. This clustering is based on the semantic similarity between the patent texts.

During the expert review stage, the final fronts are determined through expert nomination, expert discussion, and questionnaire surveys. Field experts optimize and refine the results of the data analysis and interpret the patent maps. At the same time, to compensate for any missing engineering fronts that may have been caused by algorithm limitations or data delay in data mining, experts in each field are encouraged to check the results of the data analysis and nominate complementary fronts. After the data analysis and expert nomination, the total candidate research and development fronts are obtained. For the 2018 edition, a total of 482 candidate engineering research fronts and 415 candidate engineering development fronts were obtained. Next, the field experts conduct a number of rounds of seminars and questionnaire surveys; they finally select about 10 engineering research fronts and 10 engineering development fronts in each field, and then further select three key research fronts and three key development fronts to interpret in detail.

3. Overview of the *Engineering Fronts 2018*

The *Engineering Fronts 2018* report is based on 134 988 engineering research front hotspots obtained from co-citation clustering and 53 ThemeScape patent maps developed by Derwent Innovation of Clarivate Analytics. Through data selection, expert review, and expert revision, 94 engineering research fronts and 96 engineering development fronts were obtained. A total of 27 key engineering research fronts and 27 key engineering development fronts were selected and interpreted in detail in the nine fields (bold fonts in Tables 1–9).

3.1. Mechanical and vehicle engineering

Table 1 presents the top 10 engineering research fronts and the top 10 engineering development fronts in the field of mechanical and vehicle engineering. This field includes the following subjects: mechanical engineering, ship and ocean engineering, aerospace science and technology, weapon science and technology, power and electrical equipment engineering and technology, and transportation engineering.

Among these subjects are the following emerging engineering research fronts: the thermal management technology of lithium-ion batteries, cognitive wireless networks, target recognition based on tactility, and electric/magnetic field-enhanced nanofluid convective heat transfer. The emerging engineering development fronts are new types of ship propulsion system and unmanned aerial vehicles (UAVs).

Table 1
Engineering fronts in the field of mechanical and vehicle engineering.

Engineering research fronts	Engineering development fronts
• **Self-adaptive tracking of autonomous underwater vehicles**	• **Micro-electro-mechanical systems sensors**
• **Consistency control of multi-agent systems**	• **New types of ship propulsion system**
• **Self-adaptive neural network control of manipulators**	• **Unmanned aerial vehicles (UAVs)**
• Underwater autonomous navigation systems	• Gas turbines
• Thermal management technology of lithium-ion batteries	• Marine survey and positioning technology
• Global navigation satellite system optimization	• Autonomous control of unmanned ground vehicles
• Cognitive wireless networks	• Over-ocean communication, navigation, and positioning technology
• Target recognition based on tactility	• New generation of image display technology
• Assessment and utilization of inshore wave energy resources	• Takeoff, landing, and flying of aircraft
• Electric/magnetic field-enhanced nanofluid convective heat transfer	• New types of engine technology

3.2. Information and electronic engineering

Table 2 presents the engineering fronts in the field of information and electronic engineering this year. This field includes the following subjects: electronic science and technology, optical engineering and technology, instrument science and technology, information and communication engineering, computer science and technology, and control science and technology.

Among these subjects, the fronts of interpretable deep learning, networked collaborative sensing and control theory, blockchain technology, and silicon-based optical interconnect chip technology were obtained through expert nomination and data-assisted analysis.

3.3. Chemical, metallurgy, and materials engineering

Table 3 presents the top 12 engineering research fronts and the top 12 engineering development fronts in the field of chemical, metallurgy, and materials engineering. This field includes the following subjects: new energy materials science and engineering, composite materials and engineering, metal materials engineering, catalytic engineering, metallurgical engineering, cell biology engineering, and other disciplines.

Among these subjects are the following emerging engineering research fronts: the functionalization and composites of nanocarbon materials, such as graphene and carbon nanotubes; lithium–oxygen ($Li–O_2$) and metal–air batteries; high-efficiency halide perovskite solar cells, luminescent materials, and sensitive detectors; new fluorescent molecular probes for bioimaging; and controllable synthesis, function-oriented modification, and the application of metal–organic framework (MOF) materials. The emerging engineering development fronts include the following: crystal engineering and large-scale applications of MOF materials; key methods for preparing graphene-based functional materials, and their application in energy storage; the development and application of additive manufacturing (3D printing); and cell therapy.

3.4. Energy and mining engineering

Table 4 presents the top 13 engineering research fronts and the top 14 engineering development fronts in the field of energy and mining engineering. Among the 13 research fronts, the following were obtained through data analysis: microgrids and smart distribution systems; 3D seismic data analysis and reconstruction technology; and new-generation solar cells, including perovskite, perovskite/Si heterojunction tandem, $Cu_2ZnSnSe_4$ thin-film, polymer, and quantum dot sensitized solar cells. Of these, the one about new-generation solar cells is a disruptive front. The interdisciplinary fronts are: advanced nuclear energy technology—fusion–fission hybrid reactor technology; key engineering technologies, equipment, and materials for the intelligentization of coal, oil, and gas exploitation; and spatial distribution prediction of residual oil and gas resources based on big data and cognitive theory.

Among the 14 development fronts, the following were identified through data analysis: advanced energy-storage technology in energy and power systems; the research and application of wireless power transmission and its related equipment; a renewable resources generation system and its operation and control; new tools and materials for petroleum engineering; and logging identification of unconventional reservoirs. Advanced nuclear fuel technology research and development is a disruptive front. The

Table 2
Engineering fronts in the field of information and electronic engineering.

Engineering research fronts	Engineering development fronts
• **Radar stealth technology**	• **UAVs and autonomous driving technology**
• **Interpretable deep learning**	• **Multi-dimensional image information acquisition, processing, and fusion technology**
• **New-generation mobile communication technology**	• **Display, interaction, and manipulation techniques for virtual reality and augmented reality systems**
• Networked collaborative sensing and control theory	• Optical fiber communication and all-optical networks
• Blockchain technology	• Identity authentication and access control in network security
• Quantum coherence measurement and decoherence control	• Cloud computing platforms
• Software robot-control methods	• Human–computer interaction sensing methods and applications
• High-resolution remote-sensing scene classification and image-processing technology	• Array sensor and array-sensing big data processing technology
• Silicon-based optical interconnect chip technology	• Broadband wireless communication systems
• Human body gesture-recognition methods based on deep neural networks	• New storage systems based on nonvolatile memory

Table 3
Engineering fronts in the field of chemical, metallurgy, and materials engineering.

Engineering research fronts	Engineering development fronts
• **Functionalization and composites of nanocarbon materials, such as graphene and carbon nanotubes**	• **Key materials and technology for large-scale energy storage**
• **Development of novel fuel cells**	• **Catalytic conversion of fossil resources and biomass**
• **Nanoscale and high-performance metal materials**	• **Green and intelligent metallurgical manufacturing processes**
• Carbon dioxide fixation	• Development and application of additive manufacturing (3D printing)
• Lithium–oxygen ($Li–O_2$) and metal–air batteries	• Preparation, structural connections, and applications of advanced composites
• Photocatalysis for solar energy conversion, pollutant degradation, and organic synthesis	• Key technologies and materials for supercapacitors
• Functionally graded nanomaterials	• New-generation high-energy lithium–sulfur (Li–S) batteries and solid-state Li batteries
• Design and preparation of supercapacitors	• Key methods for preparing graphene-based functional materials, and their application in energy storage
• Highly efficient electrocatalytic water splitting	• Preparation and application of light metal alloys
• High-efficiency halide perovskite solar cells, luminescent materials, and sensitive detectors	• Crystal engineering and large-scale applications of MOF materials
• New fluorescent molecular probes for bioimaging	• Advanced processing of rare and precious metals
• Controllable synthesis, function-oriented modification, and application of metal–organic framework (MOF) materials	• Cell therapy

Table 4
Engineering fronts in the field of energy and mining engineering.

Engineering research fronts	Engineering development fronts
• **Advanced nuclear energy technology—fusion–fission hybrid reactor technology**	• **Development and utilization system of fossil energy (coal, and unconventional oil and gas) and core technology and equipment**
• **Renewable energy power generation and energy storage: energy-saving and environment-friendly technologies**	• **High-voltage and high-power power electronic devices and equipment in power systems**
• **Key engineering technologies, equipment, and materials for the intelligentization of coal, oil, and gas exploitation**	• **Spent fuel reprocessing and nuclear facility instrumentation**
• Microgrids and smart distribution systems	• Advanced energy-storage technology in energy and power systems
• Critical technical issues in advanced high-performance fuel cells	• Research and application of wireless power transmission and its related equipment
• Efficient and clean processing and conversion of coal	• Renewable resources generation system and its operation and control
• *In situ* upgrading mechanism and key technologies for large-scale development of shale oil	• Advanced reactor technology and equipment development
• 3D seismic data analysis and reconstruction technology	• Use of wide spectral remote-sensing techniques to explore mineral deposits and geothermal resources
• Spatial distribution prediction of residual oil and gas resources based on big data and cognitive theory	• New tools and materials for petroleum engineering
• Seepage mechanism and efficient development of unconventional oil and gas	• Green mining technology (coal, oil, gas, ores)
• Fully intelligent integrated small modular reactor technology	• Logging identification of unconventional reservoirs
• Deep-space and deep-sea nuclear reactors and power-supply technology	• 3D geological modeling technology
• New-generation solar cells, including perovskite, perovskite/Si heterojunction tandem, $Cu_2ZnSnSe_4$ thin-film, polymer, and quantum dot sensitized solar cells	• Advanced nuclear fuel technology research and development
	• Safe, intelligent, and precise mining technology and equipment

interdisciplinary fronts are as follows: high-voltage and high-power power electronic devices and equipment in power systems; advanced energy-storage technology in energy and power systems; and the use of wide spectral remote-sensing techniques to explore mineral deposits and geothermal resources.

3.5. Civil, hydraulic, and architecture engineering

Table 5 presents the top 10 engineering research fronts and the top 10 engineering development fronts in the field of civil, hydraulic, and architecture engineering. This field includes the following subjects: structural engineering, civil engineering materials, geotechnical and underground engineering, bridge engineering, traffic engineering, architecture, HVAC (i.e., heating, ventilation, and air conditioning), municipal engineering, urban and rural planning and landscape gardening, surveying and mapping engineering, and water conservancy engineering.

Among these subjects are the following emerging research fronts: intelligent control systems for building environments, the migration and transformation mechanisms of microplastics in wastewater treatment, and the dynamic fusion of geographical spatiotemporal big data for smart cities. The emerging engineering development fronts are as follows: intelligent construction and 3D printing technology, green planning and building technology, and the collaborative development and utilization of urban underground space.

3.6. Environmental and light textile engineering

Table 6 presents the top 10 engineering research fronts and the top 10 engineering development fronts in the field of environmental and light textile engineering. This field includes the following subjects: environmental science and technology, environmental engineering, meteorological science, marine science engineering, food science engineering, and light industrial science engineering. Among these, environmental topics include pollutant pollution mechanisms, migration and transformation mechanisms of contaminants, automatic pollutant monitoring and warning, environmental restoration, resource recovery, and new energy and clean energy technologies. Marine-related topics include ocean acidification, digital simulation, and marine exploration technology. The topics related to light textile engineering are as follows: functional and intelligent wearable materials and equipment, and eco-leather technology.

3.7. Agriculture

Table 7 presents the top 10 engineering research fronts and the top 10 engineering development fronts in the field of agriculture. This field includes the following subjects: agricultural resources, applied ecology, crop science, forestry engineering, agricultural bioengineering, animal medicine, agricultural machinery engineering, and agricultural informatization.

Among these subjects are the following emerging fronts: crop breeding by molecular design, intelligent agricultural equipment, the mechanisms of plant response to biotic and abiotic stress, the efficient use of solar energy in agricultural facilities, and the development and utilization of intelligent agricultural machinery. The disruptive fronts are as follows: CRISPR/Cas9 genome editing in agricultural biotechnology, utilization technology of animal stem cells, and animal models and animal genome editing.

Table 5
Engineering fronts in the field of civil, hydraulic, and architecture engineering.

Engineering research fronts	Engineering development fronts
• **Life-cycle reliability of civil engineering structures and systems**	• **Intelligent construction and 3D printing technology**
• **Ultra-high-performance and smart cement-based composite materials**	• **Green planning and building technology**
• **Highway pavement renewable materials and pavement materials rejuvenation**	• **Key technological systems in intelligent transportation**
• Green vernacular architecture	• Construction technology and intelligent equipment for ultra-long and ultra-deep tunnels
• Artificial intelligence (AI)-based architectural design methodology	• Collaborative development and utilization of urban underground space
• Intelligent control systems for building environments	• Novel deepwater foundations and wind resistance for cable-supported bridges
• Migration and transformation mechanisms of microplastics in wastewater treatment	• Ecofriendly building materials
• Fusion and processing of multilevel space–air–ground remote-sensing data	• Advanced treatment of urban water
• Dynamic fusion of geographical spatiotemporal big data for smart cities	• Regulation technology for urban storm-water
• Life-cycle safety of water-related engineering	• High-precision positioning navigation and spatiotemporal big data

Table 6
Engineering fronts in the field of environmental and light textile engineering.

Engineering research fronts	Engineering development fronts
• **Health effects of air pollution** • **High-resolution ocean circulation models** • **Intelligent wearable materials** • Transport and transformation mechanisms of contaminants under multimedia and multiple interfaces • Performance and mechanism of decontamination technologies based on environmental nanocomposites • The mechanisms of combined air pollution • Ocean acidification • Weather and climate predictability and model development • Mechanisms of food nutrition metabolism based on intestinal microbiomics • Deep treatment of dyeing and finishing effluents	• **Remediation technology for organic pollution in soils** • **Automatic monitoring technology for remote-sensing radar** • **E-innovation of monitoring techniques for pesticide residues** • Sewage and wastewater resources energy-recovery technology • Air pollution control technology • New energy and clean energy technologies • Automatic monitoring and early-warning system for disasters • Autonomous underwater vehicles • Ecological leather • Smart wearable textiles

Table 7
Engineering fronts in the field of agriculture.

Engineering research fronts	Engineering development fronts
• **Crop breeding by molecular design** • **CRISPR/Cas9 genome editing in agricultural biotechnology** • **Intelligent agricultural equipment** • Impact of climate change on crop production • Soil microbial diversity and biological nitrogen fixation • Plant diversity and global biosecurity • Heavy metal pollution in soil and stress on crops • Crop nutrition supply and agricultural sustainable development • Mechanisms of plant response to biotic and abiotic stress • Impact of forest structure on forest carbon cycle	• **Utilization technology of animal stem cells** • **Agricultural waste and biomass energy conversion** • **Crop transgenic technology** • Development of high-efficiency and low-toxicity pesticides • Animal models and animal genome editing • Introduction of disease resistance genes and their utilization • Efficient use of solar energy in agricultural facilities • Development and utilization of intelligent agricultural machinery • Forestry information database construction and ecosystem construction • Crop inbred lines' breeding and new hybrid varieties

3.8. Medicine and health

Table 8 presents the top 9 engineering research fronts and the top 10 engineering development fronts in the field of medicine and health. This field includes the following subjects: basic medicine, clinical medicine, medical informatics and biomedical engineering, pharmacy, public health, and preventive medicine.

Most of the research fronts are related to the following topics: the prevention, intervention, and drug safety evaluation of aging; the molecular mechanisms, targeted therapy, and stem cell therapy of disease; the discovery of new highly pathogenic viruses and their outbreaks, along with early warning and prevention; and precision medical research based on medical big data. The emerging engineering development fronts focus on the integration of big data artificial intelligence (AI) and medicine, and include AI and disease diagnosis, and AI health management.

3.9. Engineering management

In the field of engineering management, the engineering fronts focus on demand-driven technology. Table 9 presents the identified fronts. The top 10 engineering research fronts include engineering management in the mechanical, electrical, energy, environmental, medical, construction, and agricultural disciplines. Among these subjects are the following emerging engineering research fronts: service-oriented strategies of manufacturing enterprises, charging strategies for electric vehicles, and the utilization of land resources under the Shared Socioeconomic Pathway.

The top 10 development fronts concentrate on mechanical, transportation, energy, medicine, construction, electronics, and other disciplines. Among these, the key fronts for detailed interpretation are as follows: electric vehicle charging management methods and systems, intelligent health management methods and systems, and intelligent connected vehicle technology.

4. Discussion of methodology

As President XI Jinping stated: "Engineering benefits humankind, and science and technology create the future." The Engineering Fronts research is based on existing engineering

Table 8
Engineering fronts in the field of medicine and health.

Engineering research fronts	Engineering development fronts
• **New taxonomy based on aberrant molecules and targeted therapy** • **Stem cell and cell therapies** • **Precision medicine research based on biomedical big data** • Prevention and intervention of aging • Safety evaluation, risk control, and quality standards of traditional Chinese medicine • Regenerative medicine and regeneration microenvironments • Discovery of emerging highly pathogenic viruses and their epidemic warning and control • Neurodegenerative disorders • Gut microbiota and tumor development	• **Stem cell technologies** • **AI and disease diagnosis** • **Biomedical materials** • Tumor immunotherapy • AI health management • Genome editing • Robotic surgery systems • Telemedicine • Personalized therapeutic cancer vaccine • Medical 3D printing technology

Table 9
Engineering fronts in the field of engineering management.

Engineering research fronts	Engineering development fronts
• **Service-oriented strategies of manufacturing enterprises**	• **Electric vehicle charging management methods and systems**
• **Charging strategies for electric vehicles**	• **Intelligent health management methods and systems**
• **Utilization of land resources under the Shared Socioeconomic Pathway**	• **Intelligent connected vehicle technology**
• Impact of climate change on water resources in arid regions	• Risk management methods and systems
• Diagnosis of mental diseases using mobile-device sensors	• Building information modeling (BIM)-based construction management systems
• Strategic plans for regional environmental management	• Monitoring-system development based on positioning technology
• Energy management based on distributed microgrid technology	• Energy management control methods and systems
• Water–energy–food nexus	• Logistics management methods and systems
• Application of ecosystem services in ecological risk assessment	• Medical service management methods and systems
• Impact of built environment on commuting	• Intelligent medical management methods and systems

scientific papers and patents, and on the institutional situation of engineering. This research identifies key technologies in engineering science and technology from the engineering technology supply capability, and has great significance in assessing engineering technology trends and optimizing technology layouts.

However, Engineering Fronts research is complex system engineering that involves a large amount of data analysis, as well as interaction between experts and data. The 2018 edition of Engineering Fronts has achieved significant results in terms of innovation in data-mining methods, interaction between experts and data, and project research processes. However, the original data range, technology granularity, interactive feedback mechanism, and data support for key front interpretations have yet to be improved. For example, in regard to the national publication advantage, the use of an extremely small number of highly cited papers or patents for identifying clusters does not represent an overall picture of the fronts. In addition, data used from current published engineering scientific papers and patents have a certain degree of delay.

Subsequent Engineering Fronts research will introduce different types of data and different analytical methods; it will also improve the ways in which the involved experts interact with the data. From the perspective of demand, we will analyze and assess breakthroughs in a new round of scientific and technological revolution and industrial transformation. Proceeding from a close focus on engineering science and technology development, we will find new growth points in the deep integration of industry, academia, and research. We will consolidate the major theoretical problems and technologies in the field of engineering science and technology in order to provide scientific decision-making supports for the deployment of engineering science and technology innovation and to promote the progress of human civilization.

Acknowledgements

We are grateful to the academicians of the Chinese Academy of Engineering (CAE), Engineering Sciences Press, the China Knowledge Center for Engineering Science and Technology, and related field experts and bibliometric experts for their guidance and assistance during the Engineering Fronts research.