IDEAS

for better education & training for engineers

Shaping Our Sustainable Future Through Engineering

Committee on Education In Engineering
World Federation of Engineering Organisations
October 2025

WORLD FEDERATION OF ENGINEERING ORGANIZATIONS

FÉDÉRATION MONDIALE DES ORGANISATIONS D'INGÉNIEURS

COMMITTEE ON EDUCATION IN ENGINEERING

Journal IDEAS No. 23, October, 2025

IDEAS is a publication of the WFEO Committee on Education in Engineering, addressed to engineering educators, educational officers at Universities and leaders responsible for establishing educational policies for engineering in each country. The articles it contains reflect the concern of people and institutions linked to WFEO, to provide ideas and proposals with the object of improving formation of engineers. The issues of IDEAS were partially financed by World Federation of Engineering Organizations. This issue of IDEAS was financed by the Myanmar Engineering Council.

WFEO-CEIE & Myanmar Engineering Council held an International Conference on Engineering Education Accreditation (ICEEA) annually 2021 - 2025. This year ICEEA's deliberation was on the theme **"Shaping Our Sustainable Future Through Engineering"**. The conferences were intended to provide a scenario for the interactions among the professionals and experts from world reputed organizations to achieve the quality engineering education and accreditation. It had been launched and designated also for the purpose of deliberating on quality assurance systems, accreditation system, and the best practice in international and local engineering education.

Distinguished speakers of ICEEA 2025 contributed to the IDEAS Journal (issue number 23) that ***WFEO-CEIE & Myanmar Engineering Council*** published in October 2025. There are around 6 international papers on Engineering Education from honorable international experts in this issue.

This issue of IDEAS is financed by the Myanmar Engineering Council.

ISBN – 978-99986-0-477-3

Prepared for printing by:

Committee on Education in Engineering Office (CEIE)-Myanmar

Myanmar Engineering Council

No (5A), Khay Yay Pin Street, Lamadaw Township, Yangon, Myanmar

Table of Contents

Message from President of Myanmar Engineering Council, President of Federation of Engineering Organizations of Asia and the Pacific (FEIAP), Vice President of ASEAN Academy of Engineering and Technology

Prof. Dr. Aung Kyaw Myat

"The Myanmar Engineering Council (MEngC), ensures its role as a regulatory and statutory authority body for Myanmar Engineers by means of the engineering standards being relevant, and ASEAN and internationally recognized, is also currently hosting the Committee for Education in Engineering (CEIE) of WFEO. We do this in order to support the activities of WFEO-CEIE and to meet its valuable objectives. Among lots of activities of CEIE, the most prominent one is publishing annual IDEAS journals for several years.

In order to mitigate the impacts of climate change and disaster risks, to serve with better engineering systems and solutions for safe drinking water and sanitation and clean energy supply, etc, we need to train more engineers with the technical and soft skills. This can only happen if a thoughtful harmonization of engineering education systems is accomplished, through shared and up to date standards, mentorship processes and integrated governance systems. In order to do this, MEngC as well as CEIE fosters cooperation between global and regional professional engineering institutions. This IDEAS journal publication serves as a testament to our collective dedication and determination to enhance the quality and relevance of engineering education in our country.

It is a very important objective of CEIE for many years to help achieve the standards needed for engineers to deliver their services to meet the United Nations 2030 Agenda of Sustainable Development Goals (SDGs). MEngC maintains continuing engineering professional registration and licensing, as well as engineering education accreditation, in accordance with the Myanmar Engineering Council Law, Washington Accord guideline subscribed by IEA and we work with international organizations to promote the mobility of Myanmar professional practitioners in accordance with international rules and regulations. Therefore, IDEAS provides an excellent opportunity to highlight the importance of collaboration and knowledge sharing among educational institutions, industry partners, and other stakeholders. By fostering partnerships, we can bridge the gap between academia and industry, enabling a seamless integration of theoretical knowledge with practical application.

May I express my heartfelt gratitude to the Committee and all contributors for their strong and unwavering commitments and dedications to series of IDEASs for years as well as engineering education. I profoundly believe that IDEAS will have positive impacts on our engineering societies globally.

Prof. Dr. Aung Kyaw Myat

President, Myanmar Engineering Council

President, Federation of Engineering Institutions of Asia and the Pacific

Vice President, ASEAN Academy of Engineering and Technology

Message from Chair of WFEO Committee on Education in Engineering

Prof. Dr. Zaw Min Aung

"It is indeed my great pleasure to publish the prestigious IDEAS Journal, Issue No. 23. This milestone is a testament to the remarkable success of the annual ICEEA conferences, a collaborative endeavor between the Myanmar Engineering Council and the WFEO Standing Committee on Education in Engineering(CEIE).

During ICEEA 2021, 2022, 2023, 2024 &2025, we have had the privilege of hosting approximately 20 internationally-recognized speakers hailing from renowned organizations worldwide for each conference. Their insights, shared in insightful presentations, have illuminated our understanding of the future engineering education goals.

With the gracious contributions of the distinguished ICEEA speakers to publish their contributions in all editions of the IDEAS Journals, we have been publishing IDEAS Journals annually (IDEAS 20, 21, 22 and 23) also and they all are accessible on the WFEO Academy Website.

The IDEAS Journals have a strong purpose — to disseminate these profound ideas to a broader audience of engineering professionals globally. By doing so, we aim to elevate the standard of engineering education worldwide. Through these publications, we strive to amplify the impact of knowledge dissemination, transcending the constraints of time and place.

My deepest gratitude goes to all the contributors — the honorable international experts, the participating universities, and the supporting organizations. Your invaluable contributions have paved the way for this new initiative, expanding the horizons of learning and understanding. My heartfelt thanks also go to the dedicated members of the organizing committees of ICEEA from 2021 to 2025. Your unwavering dedication and hard work have been the driving force behind these successful endeavors.

My acknowledgement also goes to the pivotal role played by the president and members of the journal editorial board, the executive members of the Myanmar Engineering Council, the members of the Secretariat of CEIE, and the members of the Engineering Education Accreditation Committee. Your unparalleled moral, financial, and technical support have been indispensable, and we eagerly anticipate continuing this incredible journey together.

To put it in a nut shell, our team eagerly look toward the future, aspiring to organize more ICEEA conferences and publish IDEAS Journals. Together, we are shaping the future of engineering education.

Many thanks for your tremendous support and attention."

Warm regards,

Prof. Dr. Zaw Min Aung
Chair, Committee on Education in Engineering
Chair, Engineering Education Accreditation Committee

Professional Development and Lifelong Learning: The Role of the WFEO Academy

Dr Marlene Kanga AO FTSE FAA FREng Hon.FIEAust, Hon.FIChemE, FISC, DEng
WFEO President 2017-2019
Marlene.kanga@wfeo.org

1. Introduction

The World Federation of Engineering Organizations (WFEO) is the leading international body for professional engineering institutions, founded in 1968, under the auspices of UNESCO. WFEO members consist of more than 100 national professional engineering institutions and 12 international and continental/regional professional engineering institutions, representing more than 30 million engineers. WFEO is the Co-Chair of the Major Science and Technology Stakeholder Group at the United Nations and represents engineering at major the UN Organisations, including the UNFCCC and the COP meetings, UNEP, UNDP and other UN organisations.

2. Objectives of the WFEO Academy Training Portal

Education for engineers has been a core objective for the Federation since it was founded in 1968 and of the WFEO Engineering 2030 Plan. It was recognised that engineering capacity is key to advancing the UN Sustainable Development Goals. (Figure 1)

Figure 1: Engineering is needed to advance the UN Sustaoinable Debvelopment Goals.

The World Federation of Engineering Organizations (WFEO) is committed to advancing the UN Sustainable Development Goals through Engineering. On its 50th anniversary, in March 2018, it made the Paris Declaration on its commitment to engineering education, necessary to advance the UN Sustainable Development Goals through engineering. This was the first time that WFEO and UNESCO came together with a public statement – signed by Dr Marlene Kanga WFEO President and UNESCO Director Natural Science Sector. The declaration recognized the need for more engineers with the right skills, i.e. increase both the number and quality of engineering graduates. (Figure 2)

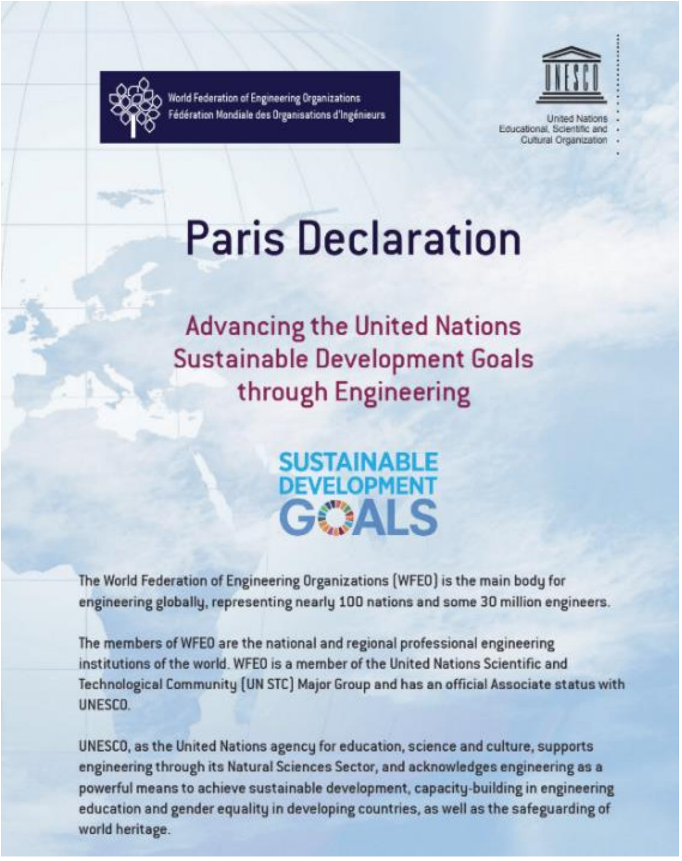
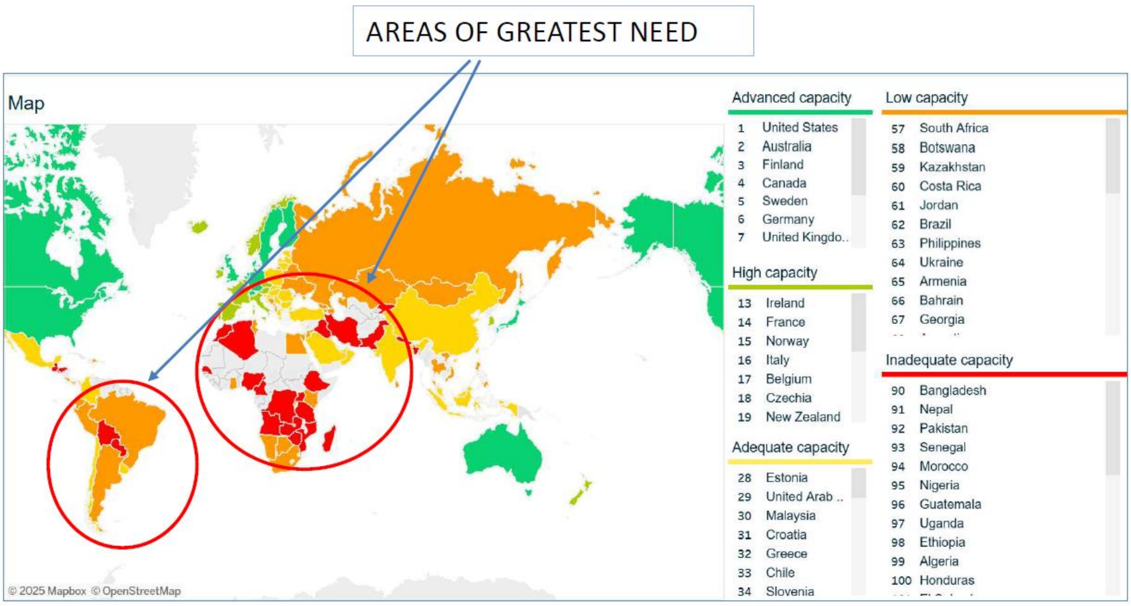


Figure 2: WFEO and UNESCO signed the Paris Declaration on 4th March 2028 stating their commitment to advance the UN Sustainable Development Goals through engineering

The Global Engineering Capability Review (2025)[i] shows that the regions in greatest need of engineering capacity building for sustainable development are in Africa and South America (Figure (3)



Source: https://engineeringx.raeng.org.uk/programmes/skills-for-safety/global-engineering-capability-review/gecr-report-2025/

Figure 3: Areas if greatest need to develop engineering capability and capacity.

Recognising the need for capacity building in areas of most need, the World Federation of Engineering Organizations proudly launched the WFEO ACADEMY training portal on World Engineering Day, on 4 March 2022, with UNESCO and its partners, the International Engineering Alliance (IEA), the International Federation of Engineering Education Societies (IFEES) and the Global Engineering Deans Council (GEDC) and WFEO members and affiliates.

Initiated by Dr Marlene Kanga, Former President WFEO (2017-2019), the WFEO Academy was one of the first projects to support UNESCO Open Science Principles (Figure 4). It uses innovation and technology to transfer much needed skills to developing countries in Asia, Africa and Latin America.

Figure 4: The WFEO Academy Supports the UNESCO Open Science Principles

3. Structure of the WFEO Academy

The WFEO ACADEMY has three pillars:

Figure 5: Three Pillars for Capacity Building in the WFEO Academy

a. Training and build capacity for accreditation bodies and professional engineering institutions, enabling them to achieve international standards and the requirements of signatory status of the International Engineering Alliance.

b. Training for engineering educators to develop the curriculum and pedagogies for outcomes-based education that are also a key requirement to achieve these international benchmarks.

c. Training for qualified engineers, technologists and technicians for essential skills in areas such as safety, risk, project management, ethics and leadership that are required across all disciplines and are essential for competent and responsible practice.

4. Course Content

The course materials draw on recorded webinar resources of the members, affiliates and partners of WFEO. These webinars are obtained after specific events and conferences and gain a wider audience and greater utilization by being placed on the website. The presenter and organization providing the resource are acknowledged.

This is a sustainable approach, using the knowledge and good well of hundreds of experts that have given their time willingly for the webinars and will build knowledge and skills in the spirit of the UNESCO Open Science Recommendations.

Figure 6: The WFEO Academy advances the UN SDG #4, SDG #16 and SDG#17 by working in partnership with other engineering organizations to access content.

The training is available on demand, at any time and any place around the world. The website is available in more than 100 languages and in future the webinars will also be automatically translated. The content is available at no cost to individuals that are members of national members and affiliates of the Federation.

The training website also provides micro credentials for courses presented as modules such as the anti-corruption course that has been provided by the Global Infrastructure Santoi Corruption Centre. The professional development that is provided supports national registration and it is recognized as continuous professional development for engineers.

The training benefits are expected to have long term impact on the economies that are supported and thus support the mandate of both WFEO and UNESCO in building capacity for engineering education.

Each course currently consists of a webinar and a quiz. On completing a quiz successfully with 100% correct answers, a certificate is generated automatically on completion of each course and sent by email to the registered participant. 70+ courses have been established in October 2025 and more than 700- courses have been taken to date.

To encourage the uptake of courses, digital badges are generated automatically after 10, 20 or 30 courses are taken. In future specific digital badge will be sent on completion of a complete courses, such as the anti-corruption course. This badge can be sued on the registered participants' LinkedIn page or email sign off block.

Figure 7: Digital Badges awarded automatically after 10, 20 or 30 course are taken to encourage uptake.

5. WFEO Academy Outcomes

The WFEO Academy provides training at low cost to engineers and scientists around the world. It promotes Agenda 2030 and the Sustainable Development Goals, including Goal #4 – Education for all, Goal #17 Partnerships, using an innovative approach and advanced technology. It also activates the UNESCO Open Science Principles to transfer knowledge to countries that need engineering expertise.

The WFEO Academy is a valuable platform for the professional development of engineers and to achieve registration or professional credentials, for the members of WFEO. This promotes mutual recognition and mobility of engineers to locations where they are most needed.

The WFEO Academy will be developed further to deliver additional education and capacity building and promote international registration and mobility among WFEO members.

6. Conclusion

Recognized as a flagship WFEO Project. It is a WFEO Technology Start-up with proven success and ready to scale with expansion of courses in partnership with expert course providers in essential topics such as:

- Sustainability
- Systems Engineering
- Climate Change Resilience
- Leadership in engineering
- Anti-corruption and ethics in engineering

In future it is hoped that the WFEO Academy will develop structured programs, which on completion results in a micro-credential that is recognised for national registration and supports national registers with WFEO approved professional development for continuing professional development. In delivering on these objectives WFEO will be fulfilling its mandate that was established at its inception in 1968.

[i] Global Engineering Capability Review, Royal Academy of Engineering, 2025, https://engineeringx.raeng.org.uk/programmes/skills-for-safety/global-engineering-capability-review/gecr-report-2025

Work-Integrated Engineering Education – Applications and Lessons Learned

1.Prof. Dr. Jürgen Kretschmann, German Federation of Technical-Scientific Associations (DVT), Düsseldorf, Germany

2.Myo Thiri Kyaw, M. Sc., Technische Hochschule Georg Agricola, Bochum, Germany

Abstract

In his article in IDEAS, No. 22, October 2024, the first author has given an introduction on work-integrated engineering education (WIEE). He has highlighted the benefits of WIEE. It provides a suitable framework to improve the employability of students by learning in real-world situations. In continuation of this introduction, this article describes two specific case studies how WIEE can be realized based on existing engineering programs. These two examples are based on the personal experiences of the second author as a student in both programs. WIEE, when applied broadly and sustainably, can equip students to become not just skilled professionals but also active contributors to society's long-term resilience. It is shown how WIEE can work as both an educational strategy and a pathway toward building innovative and sustainable futures, in line with the goals of the United Nations 2030 Agenda for Sustainable Development.

Keywords: Work Integrated Engineering Education (WIEE), Applications, Sustainable Development

1.Introduction

"In theory there is no difference between theory and practice, while in practice there is."

(Benjamin Brewster, student 1882, Richard P. Feynman, Nobel Prize Winner, 1996) (Quote Investigator 2018)

Gaining theoretical knowledge in engineering is just a fundament to start to meet challenges in practice. These challenges can mostly not be overcome by technical skills learned in the classroom alone (Kretschmann 2024). To successfully act in diverse real-world contexts WIEE needs therefore a broad and sustainable approach that transcends disciplinary boundaries. Engineering education should provide flexible pathways that prepare students to apply their knowledge responsibly and sustainably.

The urgency of global challenges described in 17 Sustainable Development Goals (SDGs) demands adaptable educational models in engineering that cultivate transversal competencies such as problem-solving, creativity, and ethical responsibility. Universities, industries, and communities should collaborate to ensure that students are not only technically proficient but also resilient and innovative contributors to society.

Early professional experiences of the second author will illustrate the value of flexibility in career development and the transformative potential of work-Integrated education. Completion of foundational degrees in engineering and science often leads to initial roles in research and development. But career trajectories frequently extend into product management, sales, training, and leadership of environmentally sensible projects. Such pathways demonstrate that professional growth benefits from interdisciplinary skill development and adaptability to evolving organizational and technological contexts. WIEE can serve as a dynamic framework for enabling both students and professionals to continuously apply fostering outcomes that are beneficial at both individual and collective levels.

2. Broad and Sustainable Approach

A "broad" and "sustainable" approach to WIEE refers to an educational model that prepares students not only for the immediate application of their studies but also for long-term adaptability in their professional careers. The idea of "broad" reflects the expansion of opportunities available to students beyond theoretical science programs. Applied sciences programs establish strong connections between universities and external stakeholders by incorporating projects, research collaborations, and partnerships with industry. In this way, knowledge is not confined to the lecture hall but is linked to real-world practice. This broader orientation equips students with transferable competencies that allow them to move across disciplines and sectors, rather than being restricted to a single occupational path. For example, Applied Degree Education and the Future of Work: Education 4.0 discusses how applied programs are rethinking curricula to include partnerships with industry, innovative pedagogy, and real-world learning. WIEE is positioned as a central driver in Education 4.0, ensuring graduates can demonstrate real-world competencies rather than only acquiring knowledge. They conclude that WIEE should be fully embedded in applied degree curricula and industry partnerships to prepare learners for lifelong adaptability in the future of work (Hong 2020).

The "sustainable" dimension of WIEE, in turn, refers to the ability of graduates to maintain and develop their careers over time, even in the face of technological, economic, and environmental disruption. Sustainability in this sense is not limited to ecological considerations but extends to professional resilience. Graduates should be able to adapt their knowledge to new technologies, including artificial intelligence, automation, and digital platforms, so that they work alongside these tools rather than risk to be displaced by them. Research on career adaptability shows that flexible, self-directed professionals are better able to sustain employment and thrive in changing contexts, as adaptability has become a key driver of workforce development (Makwa et al. 2025). Similarly, studies indicate that cultivating a proactive orientation and the capacity to collaborate with AI systems can enhance career sustainability by turning technological change into an opportunity rather than a threat (Kong et al. 2023).

3.Case Study: Materials Science Program Mahidol University, Thailand

The second author´s initial academic formation occurred at the University of Technology (Yatanarpon Cyber City), Myanmar, within the Advanced Materials Engineering program, first offered in 2010 (University of Technology 2025). Completion of the bachelor’s program in 2015 provided a foundation in materials science, after which further study was undertaken at Mahidol University, Thailand, in the Materials Science Program, following a scholarship opportunity (School of Material Science and Innovation 2025).

The Mahidol program exemplifies the applied sciences model, emphasizing collaboration between academia, industry, and research institutions. During the master’s studies, a project conducted in collaboration with Peerapat Technology Public Company Limited (Peerapat Technology 2025) focused on improving the burning capacity of wick burners through sustainable solutions. This project demonstrated the benefits of integrating academic research with industrial application, leading to tangible performance improvements, such as presentation skill, intercommunication, problem solving skill and out of box thinking, moreover archived recognition at the PACCON 2019 conference through an Outstanding Student Poster Presentation Award.

Subsequent professional engagement of the author within Peerapat Technology’s Research and Development Department highlighted the adaptability of WIEE graduates in bridging laboratory research with operational and managerial functions. The author’s transition from laboratory-focused roles to front-office responsibilities, encompassing product management, customer engagement, and training, illustrates the capacity of work-integrated programs to produce graduates capable of operating across multiple organizational levels.

With the emergence of Thailand’s Bio-Circular-Green (BCG) movement, the author had a chance to catalyze further institutional innovation. Within Peerapat Technology, the PP-Green department was established to facilitate the company’s transition from traditional chemical-based processes to environmentally sustainable solutions (PP-Green 2022). The author improved the leadership skill in the department involved collaboration with InnuScience Canada, overseeing the demonstration, training, and market development of biotechnology-based cleaning products. The company’s efforts in sustainability were formally recognized with the Sustainable Business Trophy 2022 from the Franco-Thai Chamber of Commerce, exemplifying the integration of sustainable principles within industrial practice.

This case study demonstrates that both soft skills and hard skills training provided by the Materials Science Program at Mahidol University offer graduates a lifelong education that supports professional adaptability.

4.Case Study: Technische Hochschule Georg Agricola (THGA)

The Georg Agricola University of Applied Sciences (THGA) in Bochum, Germany, offers a clear example of how Work-Integrated Engineering Education (WIEE) can be embedded at an institutional level. Established in 1816 as a public-private partnership, THGA has evolved into a state-accredited technological university of applied sciences with a wide range of bachelor’s and master’s programs (THGA 2025).

A distinguishing feature of THGA is its emphasis on flexible study formats. Approximately 41% of students are enrolled in part-time or practical part-time programs, which enable them to combine professional employment with academic studies. Classes are often scheduled during evenings or on Saturdays, making it possible for working professionals to engage in higher education without interrupting their professional careers. This structure ensures that learning remains directly connected to professional practice. Socially inclusive initiatives for students, such as the Competence Empowerment Centre (CEC), further highlight THGA’s commitment to linking education with broader societal development.

At the doctoral level, THGA combines advanced research with pedagogical training, reinforcing the reciprocal relationship between theory and practice. This institutional framework demonstrates how WIEE can be embedded not only through curricula but also through research priorities, organizational structures, and inclusive educational initiatives.

Within THGA, the Faculty of Mechanical Engineering and Materials Science illustrates how WIEE principles are implemented at the program level. The faculty offers bachelor’s and master’s degrees in Mechanical Engineering and Applied Materials Science, all structured to connect academic study with industrial application. Industry collaboration is central to the faculty’s approach. The Applied Materials Science bachelor’s program, for example, was developed in cooperation with companies such as ThyssenKrupp Steel and Deutsche Edelstahlwerke. Ongoing partnerships ensure that curricula remain aligned with current technological developments. Laboratory training, applied projects, and internships are integral components, giving students continuous opportunities to apply their knowledge in professional contexts.

Graduate career outcomes demonstrate the effectiveness of this model. Alumni from the faculty work in areas such as quality assurance in steel manufacturing, finite element method (FEM) analysis of heavy-duty components, turbo-engine design, and technical evaluation of damage cases and feasibility studies. These pathways highlight how WIEE equips students with specialized expertise as well as interdisciplinary competencies required by modern industry.

The faculty also integrates sustainability into research and teaching. Focus areas include resource efficiency, post-mining technologies, and the development of sustainable materials, ensuring that students are prepared to address pressing industrial and environmental challenges. At the doctoral level, the Prof@THGA initiative strengthens this orientation by combining advanced research with teaching preparation, fostering the next generation of academic and professional leaders.

Recent activity within the program further illustrates how WIEE is operationalized through international engagement and research collaboration. In August 2025, representatives from the Materials Engineering and Industrial Heritage Conservation (MEIHC) program participated in the 19th TICCIH Congress (International Committee for the Conservation of the Industrial Heritage), held under the theme “Heritage in Action: Legacies of Industry in Future Making” in Kiruna, Sweden (TICCIH 2025). Professors, researchers, and doctoral candidates from the program presented ongoing research projects and contributed to panel discussions throughout the congress. Significantly, the group organized and led a dedicated session on “Preserving Metal Objects: Sustainable Approaches in Monitoring and Materials Science.”

Contributions addressed topics such as the preservation of metal objects, degradation of polymer coatings under artificial versus natural weathering conditions, and the application of active thermography, machine learning, and artificial intelligence to monitoring and detection processes. In addition, the program itself and its collaborative research initiatives were highlighted, demonstrating how education, research, and practice intersect.

The congress also included a technical visit to the Aitik copper mine, owned by Boliden AB, one of Europe’s largest open-pit copper mining operations. This provided participants with first-hand insights into large-scale mining processes and machinery, contextualizing their academic work within an industrial setting (Boliden Aitik Company 2025).

These activities strongly reinforce the WIEE approach of the faculty. By engaging in international conferences, doctoral candidates and faculty not only disseminate research but also gain professional experience in presenting, networking, and exchanging knowledge with global experts. The integration of practical field visits—such as the exposure to ongoing mining operations—further bridges academic inquiry with industrial realities. This combination of scholarly presentation, applied research, and on-site industry observation exemplifies how the program cultivates adaptable professionals capable of operating across academic, industrial, and heritage conservation contexts.

5.Techniques of WIEE in Practice: Lessons Learned

The case studies show that Work-Integrated ‘Engineering Education (WIEE) is not a one-size-fits-all model. Instead, it works through a combination of techniques that bring academic study and real-world practice closer together. Looking across the examples, a few common strategies stand out that make WIEE both effective and sustainable.

- Flexible Study Formats

At THGA, flexibility is built into the structure of its programs. Students can choose full-time, part-time, or practical part-time pathways, which allow them to keep working while studying. This means they don’t have to step away from their professional lives to advance academically. Flexibility here is not just about timetables—it also extends to how the curriculum is designed, leaving space for professional responsibilities, international experiences, and even lifelong learning.

- Industry Collaboration and Co-Creation

Both Mahidol University and THGA show how powerful it is when universities and industry work hand in hand. Collaborations with companies such as Peerapat Technology, ThyssenKrupp Steel, and Deutsche Edelstahlwerke shape the curriculum, so it reflects real industry needs. These partnerships also open the door to internships, applied research, and even product development. In this way, knowledge is co-created rather than simply taught, ensuring students graduate with skills that employers genuinely value.

- Applied Research and Project-Based Learning

Both programs place a strong emphasis on learning through doing. At Mahidol, the wick burner project linked academic research with an industrial challenge and led to real performance improvements. At THGA, research on sustainable materials provides similar opportunities to apply theory to urgent industrial needs. At the doctoral level, the Materials Engineering and Industrial Heritage Conservation (MEIHC) program even takes WIEE into cultural and heritage contexts, showing how adaptable the model can be beyond traditional engineering.

- International and Interdisciplinary Engagement

WIEE also extends beyond national borders and disciplinary silos. Participation in the TICCIH Congress is a good example: students and staff not only presented their research but also engaged with international experts, exchanged perspectives, and even visited an operational copper mine. These experiences help students connect their academic work with global industrial realities while also broadening their cultural and societal awareness.

- Integration of Sustainability and Responsibility

Sustainability is a thread running through all the case studies. The student project at the Mahidol University adopted a sustainable strategy for the development of wick burners. At THGA, research in post-mining, resource efficiency, and sustainable materials reflects an equally strong commitment to tackling ecological and societal challenges. This shows how WIEE isn't just about producing skilled graduates—it's also about nurturing professionals who are ready to act responsibly and contribute to long-term resilience.

- Transversal Competence Development

Finally, WIEE consistently develops skills that go beyond technical knowledge. Graduates learn how to manage projects, communicate effectively, think creatively, build networks, and make ethical decisions. These so-called transversal skills are what enable them to adapt to nonlinear career paths, respond to technological change, and contribute to innovation in a wide range of professional contexts.

Taken together, these techniques show that WIEE is best understood as a set of interconnected practices rather than a single formula. By combining flexible learning, close collaboration with industry, project-based research, international engagement, a focus on sustainability, and the development of transversal skills, programs like those at Mahidol University and THGA prepare students for both immediate professional roles and long-term growth. Ultimately, WIEE helps graduates become adaptable professionals who can meet the challenges of today while contributing responsibly to the needs of tomorrow.

Aspect	Mahidol University (Thailand)	THGA (Germany)	Lesson Learned
Context	Applied sciences program with industry-linked projects.	University of Applied Sciences with flexible structures and broad programs.	WIEE can be embedded at both program and institutional levels.
Flexibility	Mainly full-time study with project collaborations.	Full-time, part-time, and practical part-time formats.	Flexibility connects learning with work realities.
Industry Links	Projects with Peerapat Technology; product innovation and sustainability focus.	Co-created curricula with companies	Partnerships align skills with industry needs.
Applied Research	Practical projects (Wick-Burner efficiency).	Materials Conservation at heritage sites	Applied research bridges theory and practice.
Sustainability	Bio-Circular-Green initiatives; Biotech solutions.	Post-mining and sustainable resources focus.	Sustainability adapts to local priorities.
International Engagement	Yes	Yes	International exposure broadens perspectives.
Graduate Outcomes	Versatile careers	Various industrial applications	WIEE supports both adaptability and specialization.

6.WIEE in Universities with Resource-limited Settings

For universities in countries with resource-limited settings WIEE does not need to start with large-scale reforms—it can grow step by step in ways that make sense locally. Offering flexible study options, such as evening or weekend classes and blended learning, can help students continue working or supporting their families while pursuing their degrees. Building stronger links with local industries—whether in agriculture, textiles, Information Technology (IT), or renewable energy—can create valuable internships, small projects, and joint curricula elements that give students practical experience while also meeting industrial and community needs.

Even modest, low-cost research projects, such as developing clean water solutions, affordable building materials, or more sustainable farming methods, can have an immediate impact and show students how their knowledge leads to improvements. Regional partnerships can widen horizons without requiring major financial investment, for example through online exchanges or joint workshops. Alongside technical training, universities can nurture transversal skills like problem-solving, communication, and entrepreneurship through short courses, team projects, or student-led innovation challenges. Even small initiatives, such as setting up a career office or encouraging companies to host interns, can make a big difference. By taking these kinds of practical steps, universities in resource-limited settings can make WIEE a powerful, sustainable model—one that equips students to succeed in their professions, support students' local development, and build resilience in times of change.

Conclusion

Work-Integrated Engineering Education (WIEE) represents more than just a bridge between classroom learning and the workplace—it is an integrated, transformative approach that prepares students to thrive in a world defined by rapid change and complex challenges. By combining hands-on experiences, meaningful industry collaboration, and the cultivation of transversal skills WIEE can equip graduates "to use their knowledge and skills for the benefit of the world, in order to create engineering solutions for a sustainable future" (WFEO 2023).

The broad and sustainable framework of WIEE ensures that education is not just about immediate employability but also about long-term growth. Graduates are empowered to navigate nonlinear career paths, embrace emerging technologies, and contribute to sustainable development across multiple sectors. Case studies from Mahidol University in Thailand and THGA in Germany illustrate how integrating applied research, international engagement, and sustainability into education can produce professionals capable of creating real-world impact—from improving industrial processes to preserving cultural heritage. Ultimately, WIEE nurtures not only skilled professionals but also thoughtful innovators and engaged citizens. It shows that when learning is connected to practice, grounded in responsible ethical behavior, and open to lifelong growth, education becomes a powerful force for personal fulfillment, professional excellence, individual and societal resilience.

References

Boliden Aitik Company (2025): https://www.boliden.com/operations/mines/boliden-aitik/ accessed date (04.09.2025).

Hong, C. (2020): Introduction: Education 4.0: Applied Degree Education and the Future of Work, Springer Singapore May 2020 P. 1-12 (available) https://doi.org/10.1007/978-981-15-3142-2_1.

Kong, H., Yin, Z., Baruch Y. and Y. Yuan (2023): The impact of trust in AI on career sustainability: The role of employee–AI collaboration and protean career orientation, Journal of Vocational Behavior, Volume 146, 2023, 103928, ISSN 0001-8791, https://doi.org/10.1016/j.jvb.2023.103928.

Kretschmann, J. (2024): Work-Integrated Engineering Education – an Introduction, in: IDEAS, No. 22, October 2024, p. 11-15.

Makwa Z., Ismara, K. I., Sudira, P. and T. H. T. Maryadi (2025): "Career Adaptability for Sustainable Workforce Development: A Systematic Review in Vocational Education," International Journal of Research and Innovation in Social Science, International Journal of Research and Innovation in Social Science (IJRISS), vol. 9(3s), p. 3054-3070.

Peerapat Technology Public Company Limited (2025): https://peerapat.com/en/ (accessed date 16.09.2025).

PP-Green (2022): Sustainable Business Trophy 2022, https://www.francothaicc.com/fileadmin/thailande/user_upload/Peerapat_Technology_Sustainable_Development_-_myo_thiri.pdf (accessed date 16.09.2025).

Quote Investigator® (2018): https://www.quote investigator®2018/04/14/theory.

School of Materials Science and Innovation (2025): https://scme.sc.mahidol.ac.th/en/ (accessed date 16.06.2025).

THGA (2025): https://www.thga.de/en/studying-at-thga/our-study-programmes/bachelor-programmes/applied-material-sciences (accessed date 16.09.2025).

TICCIH Congress (2025): https://ticcih2025-kiruna.se accessed date (04.09.2025).

University of Technology (Yatanarpon Cyber City) (2025): https://en.wikipedia.org/wiki/University_of_Technology,_Yadanabon_Cyber_City (accessed date 16.09.2025).

WFEO (2023): World Federation of Engineering Organizations, WFEO MODEL CODE OF ETHICS, WFEO_Code-of-ethics_2023-10-14.pdf, (accessed date, 30.09.2025).

Engineering Tomorrow: Shaping a Sustainable Future

Prof Dr Rodrigo Pérez Fernández

CEng CMarEng FRINA FSNAME FIMarEST Universidad Politécnica de Madrid

rodrigo.perez.fernandez@upm.es

1. Introduction

Engineering plays a pivotal role in addressing the complex challenges of sustainability in the 21st century. As global populations grow and environmental constraints tighten, the demand for innovative, sustainable solutions has never been greater. This paper explores how modern engineering disciplines are evolving to prioritize sustainability through green technologies, renewable energy systems, sustainable materials, and ethical design practices. It analyzes the integration of sustainability into engineering education, policy, and industry practices and highlights successful case studies where engineering has led to impactful, long-term environmental and social benefits. Ultimately, this paper argues that the future of engineering lies in a holistic, interdisciplinary approach to sustainability, demanding new ways of thinking, designing, and implementing solutions that balance economic viability with ecological stewardship and social equity.

Humanity stands at a pivotal moment in history. The world today is confronted with an unprecedented convergence of environmental, economic, and social challenges that transcend borders, cultures, and generations. Climate change, resource depletion, biodiversity loss, pollution, and rising inequities are no longer distant concerns relegated to scientific models or future projections; they are unfolding in real time, disrupting lives, destabilizing economies, and threatening the very systems that sustain civilization. From intensifying natural disasters and diminishing freshwater supplies to widening global wealth gaps and unsustainable patterns of consumption, the evidence is undeniable: the current trajectory of human development is not sustainable. The urgency of these challenges demands responses that are not only rapid but also systemic, forward-looking, and equitable.

Within this context, the role of engineers has never been more critical. Engineering, at its core, is the discipline of problem-solving, innovation, and the translation of scientific knowledge into practical applications that shape the built and natural environments. Engineers design the infrastructure that underpins societies, develop technologies that drive economies, and influence patterns of resource use that affect ecosystems worldwide. Yet, traditional approaches to engineering have too often been driven by priorities such as short-term efficiency, technical optimization, and cost minimization.

While these approaches have enabled extraordinary progress in industrialization, urbanization, and technological advancement, they have also contributed to unintended consequences: rising greenhouse gas emissions, resource-intensive industries, environmental degradation, and systems that lack resilience in the face of global change.

Reframing engineering as a central force for sustainability requires a fundamental shift in mindset. Rather than treating environmental and social concerns as secondary considerations or constraints, sustainability must become the foundation upon which engineering decisions are made. This involves adopting a holistic perspective that recognizes the interdependence of human and natural systems, the need for long-term resilience over short-term gains, and the ethical responsibility to safeguard the well-being of both current and future generations. By embedding sustainability into the very fabric of engineering education, practice, and innovation, engineers can serve not only as technical experts but also as stewards of planetary health and social equity.

The principles of sustainable development, balancing economic growth, environmental protection, and social equity, provide a framework for this transformation. In practice, this means designing systems that minimize waste and emissions, prioritize renewable and regenerative resources, and promote inclusivity and access. It also means recognizing that engineering solutions must be adaptable to diverse cultural, political, and ecological contexts, and that collaboration across disciplines and sectors is essential. The integration of these principles into engineering is not an abstract aspiration but a practical necessity, as demonstrated by emerging innovations in renewable energy systems, circular economy materials, resilient infrastructure, and sustainability-focused curricula in engineering education.

This paper seeks to position engineering not as a passive contributor to unsustainable development, but as a proactive force in building a sustainable future. We begin by examining the theoretical underpinnings of sustainable development and their relevance to engineering practice. We then explore how engineering is evolving within key sectors, energy, infrastructure, materials, and education, to meet sustainability goals. Through a combination of case studies, critical analysis, and discussion, we illustrate how forward-thinking engineering approaches are not only possible but also essential to addressing the complex crises of the 21st century.

Ultimately, this work underscores that the pursuit of sustainability is inseparable from the practice of engineering and that the choices engineers make today will shape the quality of life for generations to come.

2. Engineering and Sustainability: Foundational Concepts

2.1 The Three Pillars of Sustainability

Sustainability is most often conceptualized as resting upon three interdependent pillars: environmental protection, social equity, and economic development. Together, these dimensions provide a holistic framework for understanding how societies can thrive within planetary boundaries while ensuring human well-being across generations. For engineers, this triad is not merely theoretical but serves as a practical compass guiding design decisions, material selection, system optimization, and project evaluation.

The environmental pillar emphasizes the preservation of ecosystems, biodiversity, and natural resources. In engineering practice, this requires minimizing pollution, reducing carbon footprints, and promoting the use of renewable or recyclable materials. It also involves anticipating long-term environmental impacts through tools such as *Life-Cycle Analysis* (**LCA**) and environmental impact analysis, ensuring that today's solutions do not compromise the ability of future generations to meet their needs.

The social pillar highlights the role of sustainability in advancing human well-being, justice, and inclusivity. For engineers, this entails ensuring that technologies and infrastructures are accessible, safe, and beneficial to all members of society, particularly marginalized or vulnerable communities. Social sustainability also requires that engineering projects respect cultural contexts, enhance quality of life, and promote equity in resource distribution and opportunities.

The economic pillar underscores the necessity of financial viability and economic resilience. Sustainable solutions must be affordable, scalable, and adaptable to changing conditions, thereby enabling both businesses and communities to prosper without overexploiting natural or human capital. In engineering, this means designing systems that balance initial costs with long-term value, factoring in maintenance, durability, and adaptability.

Crucially, these three pillars are deeply interconnected. A project that excels in one dimension but neglects the others cannot be truly sustainable. For example, an infrastructure project that is cost-effective but environmentally damaging, or one that reduces emissions but excludes community input, undermines the balance needed for long-term success. Engineers, therefore, must embrace integrative thinking, recognizing that sustainability is achieved through synergy, not trade-offs.

2.2 Sustainable Engineering Defined

Sustainable engineering can be defined as the practice of designing, innovating, and operating systems in a way that responsibly uses resources, safeguards ecosystems, and strengthens social structures without compromising the needs of future generations. It is an evolving discipline that extends beyond technical efficiency, requiring engineers to integrate ethical responsibility, systems-level thinking, and long-term foresight into their work.

At its core, sustainable engineering is guided by several key approaches:

- **LCA**: engineers evaluate products, processes, and systems across their entire life cycle, from material extraction and production to use, maintenance, and eventual disposal or recycling. This method identifies hidden environmental costs and enables informed decision-making that minimizes waste and emissions.
- **Systems Thinking**: sustainable engineering views problems not as isolated challenges but as components of larger, interconnected systems. By analyzing how energy, materials, information, and human behaviors interact within a system, engineers can identify leverage points for meaningful and lasting change.
- **Resilience-Based Design**: recognizing that uncertainty and disruption are inevitable in a rapidly changing world, engineers are increasingly adopting resilience principles. This involves designing infrastructure and technologies that can adapt, recover, and continue functioning in the face of climate shocks, resource scarcity, or social upheaval.

Importantly, sustainable engineering does not imply a rejection of progress or technological innovation. Rather, it redefines progress by aligning technological advancement with the broader goals of ecological stewardship, social justice, and economic prosperity. It demands that engineers think beyond immediate technical specifications, embracing long-term consequences and intergenerational responsibilities.

In this sense, sustainable engineering is not a niche or emerging specialization but a necessary evolution of the profession itself. By embedding sustainability into design standards, industry practices, and educational curricula, engineers become central actors in advancing a future where human development is both prosperous and ecologically balanced.

3. Key Areas of Sustainable Engineering Innovation

3.1 Renewable Energy Technologies

One of the most transformative areas of sustainable engineering lies in the advancement of renewable energy technologies. Once considered expensive and technologically immature, renewables such as solar photovoltaics, wind turbines, hydroelectric systems, and geothermal plants have become increasingly competitive with fossil fuels due to engineering innovations.

Engineers have played a pivotal role in improving the efficiency, durability, and affordability of these systems through advances in materials science, aerodynamics, thermodynamics, and digital monitoring.

For example, the cost of solar energy has fallen dramatically in recent decades, largely because of breakthroughs in photovoltaic cell design, modular systems, and large-scale manufacturing. Wind energy has seen similar gains, with engineers optimizing blade shapes, turbine height, and offshore platforms to harness more consistent wind patterns. Hydroelectric and geothermal energy, while geographically constrained, have benefited from engineering solutions that minimize ecological disruption and improve output reliability.

Beyond generation, engineers are tackling the critical challenge of integration and storage. Smart grid systems, enabled by digital sensors and real-time analytics, allow renewable energy to be efficiently distributed, balanced, and stored across large networks. Advances in battery storage technologies, such as lithium-ion, flow batteries, and emerging solid-state designs, are making intermittent renewables more reliable as base-load power sources. Together, these innovations not only displace carbon-intensive energy systems but also democratize access to clean, affordable power worldwide.

3.2 Sustainable Infrastructure and Urban/Marine Design

Sustainable infrastructure and urban systems are at the heart of reimagining how societies build and live. Cities, home to more than half of the world's population, and ships, which transport around 90% of global goods, are among the largest drivers of resource consumption and emissions. As a result, engineers are reshaping urban environments through green building design, sustainable transportation systems, and climate-resilient infrastructure.

Green buildings incorporate design features such as passive ventilation, efficient insulation, natural lighting, and renewable energy integration to reduce energy demand and environmental impact. Tools such as *Building Information Modeling* (**BIM**) allow engineers and architects to simulate a building's performance across its entire life cycle, ensuring optimal use of materials and energy. Certifications such as *Leadership in Energy and Environmental Design* (**LEED**) and *Building Research Establishment Environmental Assessment Method* (**BREEAM**) set benchmarks for sustainable design and encourage continuous improvement.

Transportation systems are another critical domain. Engineers are designing infrastructure to support electric ships or vehicles, mass transit, cycling, and pedestrian mobility, reducing dependence on fossil fuels while improving urban livability. Climate resilience is equally vital: modern infrastructure must withstand rising sea levels, extreme weather, and seismic risks. Engineers are employing resilient materials, modular designs, and nature-based solutions, such as green roofs and permeable pavements, to create adaptive and future-ready cities.

3.3 Circular Economy and Sustainable Materials

Traditional industrial systems operate on a linear model of take, make, dispose, which generates enormous waste and strains finite resources. In contrast, the circular economy promotes closed-loop systems where materials are continuously reused, recycled, and repurposed. Engineers are at the forefront of making this transition feasible by innovating sustainable materials and rethinking manufacturing processes.

Materials engineers are pioneering biodegradable composites, bio-based plastics, and high-performance materials with lower carbon footprints. Concrete, responsible for a significant share of global CO_2 emissions, is being reengineered with carbon capture additives, recycled aggregates, and alternative binders that drastically reduce its impact. Similarly, plastics are being redesigned for recyclability and biodegradability, with innovations in polymers that mimic natural decomposition.

Engineering also drives advances in remanufacturing and recycling technologies, enabling the recovery of valuable materials

from waste streams such as electronic waste, automotive components, and construction debris.

By embedding circular economy principles into product design, engineers ensure that items are easier to disassemble, repair, and recycle, extending their useful life and minimizing landfill contributions. These practices not only conserve resources but also open new economic opportunities through sustainable manufacturing and green jobs.

3.4 Sustainable Engineering Education and Ethics

For sustainable engineering to flourish, the profession must undergo a cultural and educational transformation. Engineering education is no longer confined to technical mastery; it must integrate systems thinking, ethics, and interdisciplinary collaboration. Universities and professional bodies are increasingly embedding sustainability into core curricula, ensuring that students are exposed to concepts such as life-cycle analysis, environmental impact assessment, and sustainable design frameworks early in their training.

Ethics is central to this shift. Engineers hold a profound responsibility to society, and sustainability requires weighing the broader consequences of their decisions beyond immediate technical feasibility. Questions of social equity, intergenerational justice, and cultural sensitivity must inform design choices. For example, a project may be technically efficient but socially unjust if it excludes marginalized groups from access to its benefits. Thus, sustainability education emphasizes not only what engineers can build but also what they should build.

In addition, the inherently global nature of sustainability challenges calls for interdisciplinary and cross-cultural collaboration. Engineers must work alongside policymakers, economists, ecologists, and communities to co-create solutions that are contextually relevant and inclusive. Through project-based learning, international exchanges, and industry partnerships, educational programs are preparing graduates to navigate the complex intersections of technology, society, and the environment.

Ultimately, sustainable engineering education and ethics foster a generation of professionals equipped to see beyond technical problems and embrace their role as leaders in shaping a resilient and just future.

4. Challenges and Barriers to Sustainable Engineering

While sustainable engineering has made remarkable strides, its widespread implementation continues to face significant challenges. These barriers are multidimensional, spanning economic, political, cultural, and technical spheres, and they underscore the complexity of transforming established systems into sustainable ones. Understanding these obstacles is essential for developing strategies that can accelerate progress and ensure long-term adoption.

One of the most persistent challenges is the financial barrier associated with sustainable technologies. Although renewable energy, green buildings, and circular materials have become more competitive over time, they often require higher upfront investments compared to conventional alternatives. For instance, installing solar photovoltaic panels or building a LEED-certified structure typically involves greater initial costs, even if operational savings accrue over time. In many cases, organizations and governments prioritize short-term economic returns over long-term benefits, deterring large-scale adoption. Access to financing, particularly in developing economies, further complicates the deployment of sustainable solutions. Without innovative funding mechanisms and supportive financial policies, the perception of high cost remains a significant deterrent.

Sustainability efforts also face obstacles in the realm of governance. Inconsistent policies, fragmented standards, and lack of enforcement create uncertainty for engineers and industries attempting to integrate sustainable practices. For example, varying building codes, conflicting environmental standards, or inconsistent subsidies for renewable energy can discourage investment and innovation. Moreover, some regulations are outdated and fail to address emerging challenges such as e-waste management or carbon accounting. Without coherent, long-term regulatory frameworks, sustainable engineering struggles to scale beyond isolated pilot projects.

Beyond economics and policy, social and organizational culture can act as barriers. In many industries, institutional inertia, the tendency to maintain established practices, slows the adoption of sustainable innovations. Stakeholders may perceive sustainability as an added burden rather than an opportunity, leading to skepticism or outright resistance. Additionally, cultural attitudes toward consumption, waste, and resource use vary across societies, influencing how sustainability is perceived and prioritized. Within organizations, a lack of leadership commitment or insufficient training can prevent sustainability initiatives from being fully integrated into engineering practice. Overcoming this resistance requires not only technical arguments but also effective communication, education, and change management.

Although technological progress has been significant, many sustainability solutions remain at an early stage of development. Energy storage technologies, biodegradable composites, and advanced recycling systems, while promising, face hurdles of scalability, durability, and performance. For instance, battery technologies must overcome limitations in cost, lifespan, and raw material sourcing before they can fully support renewable grids. Similarly, sustainable concrete alternatives are still being tested for structural performance and long-term viability. Engineers must grapple with these limitations, balancing innovation with the practical realities of implementation and reliability.

Addressing these challenges requires collaboration across multiple sectors. Engineers cannot act alone; their innovations must be supported by policymakers who establish coherent regulations, by educators who prepare the next generation of sustainability-minded professionals, and by communities who embrace new ways of living and consuming. Cross-disciplinary partnerships, public-private initiatives, and international cooperation are critical for overcoming systemic barriers. By aligning economic incentives, regulatory frameworks, cultural norms, and technological innovation, sustainable engineering can transition from isolated success stories to a mainstream approach that defines the future of development.

5. Future Directions: Engineering for 2050 and Beyond

To achieve the ambitious but necessary goals of climate neutrality and global equity by mid-century, engineering must undergo a fundamental transformation in both practice and philosophy. The profession is uniquely positioned to shape technological, infrastructural, and social systems that determine humanity's relationship with the environment. However, meeting these goals requires not only incremental improvements but also bold rethinking of how engineering integrates with other domains of knowledge and society. To fully appreciate the underlying dynamics, it is necessary to examine several fundamental pathways, including the following:

- **Embracing Interdisciplinary Collaboration**: sustainability challenges do not exist in silos. Climate change, economic inequality, and resource depletion are deeply interconnected, requiring solutions that cross traditional disciplinary boundaries. Engineers must work in concert with scientists, economists, policymakers, and community leaders to design interventions that are technically feasible, economically viable, and socially just. Interdisciplinary collaboration ensures that engineering solutions account for ecological limits, market dynamics, and governance structures while aligning with community values.

- **Focusing on Resilient Design**: as climate change accelerates, resilience must become a cornerstone of engineering practice. This involves creating systems and infrastructures that not only minimize environmental impact but also anticipate and withstand climate shocks, resource fluctuations, and social transformations. Resilient design incorporates redundancy, modularity, and flexibility, enabling infrastructures to adapt to uncertain futures. For example, urban drainage systems designed to handle extreme rainfall events or energy grids capable of redistributing loads during outages exemplify resilience in action.

- **Scaling Nature-Based Solutions**: engineers can draw inspiration from ecosystems through biomimicry and green infrastructure, creating systems that work in harmony with natural processes. Nature-based solutions such as wetlands for flood management, urban forests for cooling, and green roofs for stormwater retention provide cost-effective, multifunctional benefits. These designs not only enhance ecological health but also improve human well-being by fostering cleaner air, greater biodiversity, and more livable urban spaces. Scaling these approaches requires engineers to rethink traditional hard infrastructure in favor of hybrid systems that blend technology with ecological processes.

- **Advancing Digital Twins and Digitalization**: emerging digital technologies offer unprecedented opportunities to monitor, analyze, and optimize sustainability in real time. Digital twins, virtual models of physical systems, allow engineers to simulate and test the environmental, social, and economic impacts of projects before implementation. Combined with *Artificial Intelligence* (**AI**), these tools enable predictive maintenance, efficient resource allocation, and system-wide optimization. For example, AI can optimize energy distribution in smart grids, predict material fatigue in structures, or monitor carbon emissions across supply chains. These digital innovations provide engineers with the precision and foresight needed to accelerate progress toward climate neutrality.

- **Fostering Inclusive Innovation**: finally, sustainable engineering must be inclusive, ensuring that solutions do not exacerbate inequities but instead empower marginalized and underserved communities. Engineers must center human well-being in their designs, incorporating local knowledge and prioritizing equitable access to technology, resources, and infrastructure. Inclusive innovation recognizes that those most affected by climate change often contribute the least to its causes, and it seeks to correct this imbalance through participatory design and community-driven development. By embedding equity into engineering processes, the profession can ensure that the benefits of sustainability are shared universally.

6. Conclusion

Engineering is not merely a technical profession, it is an inherently moral, social, and environmental endeavor that continuously shapes the trajectory of human civilization. The bridges we build, the energy systems we design, the materials we develop, and the technologies we deploy collectively define how societies interact with each other and with the planet. In an era of mounting environmental degradation, deepening inequities, and accelerating climate change, engineers face both an urgent challenge and an unprecedented opportunity: to reimagine the very foundations of progress through the lens of sustainability.

The preceding discussion has demonstrated that sustainability is no longer a peripheral concern but a core responsibility of

engineering practice. The three pillars of sustainability, environmental protection, social equity, and economic viability, demand that engineers move beyond short-term optimization and adopt systemic, long-term perspectives. Emerging fields such as renewable energy technologies, resilient infrastructure, circular materials, and digital innovations highlight that the tools to build a sustainable future are already within reach. At the same time, educational reform and ethical reflection are reshaping the profession, ensuring that future engineers are equipped not only with technical expertise but also with a deep sense of social and ecological responsibility.

Yet, progress is far from automatic. Significant challenges and barriers remain economic constraints that deter adoption, regulatory inconsistencies that slow innovation, cultural resistance that impedes change, and technical limitations that must still be overcome. Confronting these obstacles requires collaboration across disciplines, sectors, and nations. Engineers must work hand in hand with policymakers, educators, businesses, and communities to align innovation with justice, resilience, and ecological stewardship.

Engineering must embrace a transformative vision. This includes advancing renewable energy and smart grids to achieve climate neutrality, designing cities that are adaptive and inclusive, scaling nature-based solutions inspired by ecosystems, and harnessing digital tools such as artificial intelligence and digital twins for real-time optimization. Most importantly, it requires fostering inclusive innovation, ensuring that marginalized voices are centered in design processes and that the benefits of sustainability are shared equitably across societies.

Ultimately, embedding sustainability at the heart of engineering practice, education, and governance allows the profession to serve not only as a driver of technological advancement but as a steward of human and planetary well-being. The decisions engineers make today will reverberate for generations to come, determining whether humanity inherits a future defined by scarcity and crisis, or one characterized by resilience, justice, and opportunity. The time to act is now, and engineering must not simply participate in the transition to sustainability, it must lead it.

A Closer Look at the Global Engineering Capability Review (GECR) 2025 – Second Edition

MEng. MBA. Wahid Azizi

Royal Academy of Engineering, Prince Phillip House

3 Carlton House Terrace, London, SW1Y 5DG

United Kingdom

Introduction

Why does national engineering capacity matter? And how do we measure it? This article presents the structure and findings of the **Global Engineering Capability Review (GECR) 2025 – Second Edition**, a study produced by Engineering X, a growing collaboration founded by the **Royal Academy of Engineering** and **Lloyd's Register Foundation**, with support from **S&P Global Market Intelligence**.
The GECR presents a new framework for understanding engineering capacity and capability across countries and regions. It shows that strengthening these areas benefit not just engineers, but whole systems, further strengthening the evidence base for investing in global engineering capacity, capability and safety.

While the GECR 2025 does not provide specific solutions, acknowledging that these must be developed locally and tailored to each country's context. It can be used as a diagnostic tool, which can serve as a starting point for analysis, dialogue, and context specific planning by countries seeking to assess and strengthen their engineering capacity and capability.

Building on the GECR 2019 edition, the GECR 2025 includes:

1. Engineering Capacity Index (ECI) 2025 Framework
2. Capacity gap analysis & Regional examples
3. A series of thematic spotlights.

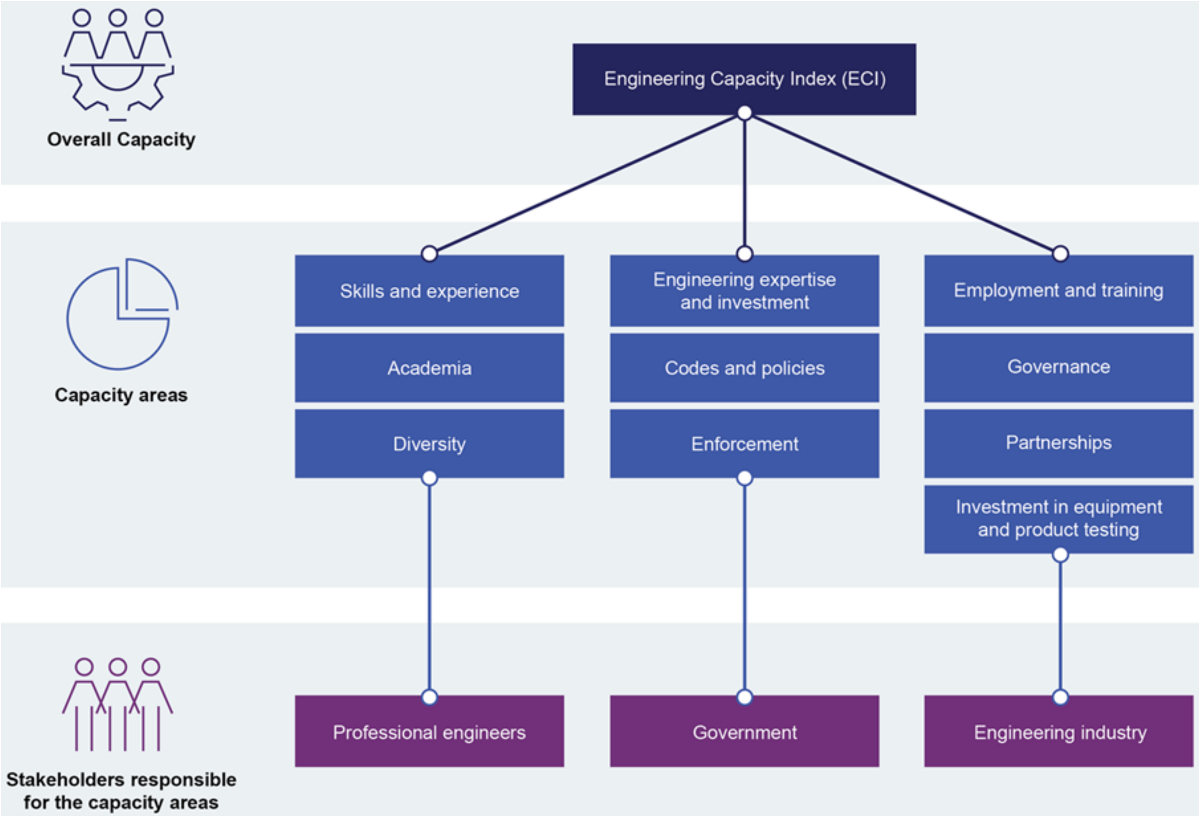
1. Elements of the study including results and insights

1.1 Engineering Capacity Index (ECI) 2025 Framework

To measure the overall engineering capacity of a country or geography, the GECR 2025 introduces the Engineering Capacity Index (ECI) 2025 framework. The ECI 2025 framework measures a country's capacity to safely and effectively conduct engineering activities across disciplines and sectors.

Using a systems-based approach, the ECI 2025 assesses engineering capacity by: i) recognising the interdependencies between capacity areas; and ii) highlight the roles of key stakeholders in strengthening them.

Through this lens, the ECI 2025 framework defines a geography's overall engineering capacity in terms of **10 capacity areas**, aligned under **3 key stakeholder groups** that hold primary responsibility for their development. These are outlined in the ECI 2025 framework below.



The Engineering Capacity Index (ECI) 2025 (GECR 2025, p. 21)

To measure the overall engineering capacity of a given geography, the ECI draws on **76 individual indicators** ranging from five to eleven indicators per capacity area. The scores are based on a range of reliable and internationally recognised datasets.

By appropriately aggregating and weighting these indicators, the ECI 2025 presents a multidimensional measure of each capacity area, providing a comprehensive view of engineering capacity within a geography.

One of the key challenges in constructing the ECI 2025 was the limited availability of internationally comparable data. While data was initially gathered for **137 geographies**, only **115** were included in the final scoring, those for which data was available for at least **two-thirds of the 76 indicators**.

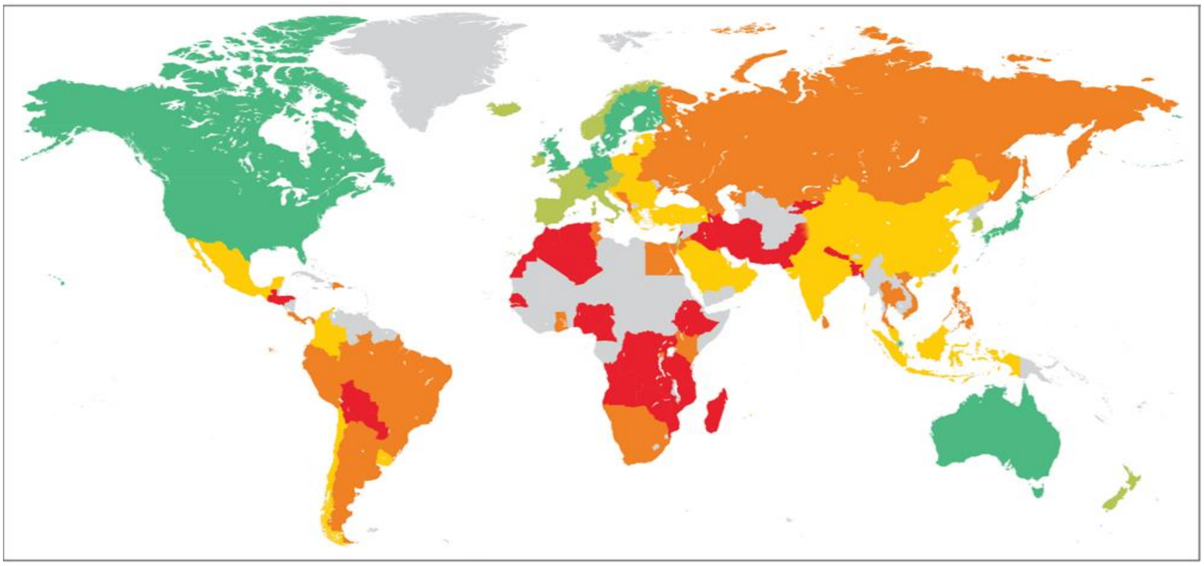
1.2 Engineering capacity versus capability

Engineering capacity is defined as the **inputs** and resources – such as technical skills, industry training, standards, and policy frameworks required for a geography to carry out engineering activities in a safe and effective way across disciplines and sectors. This is measured using the **Engineering Capacity Index (ECI) 2025**.

In contrast, **engineering capability** is defined as the **outputs and outcomes** that demonstrates the ability of a geography to conduct engineering activities in a safe and effective manner that minimises harm to people and the environment. To measure **engineering capability** a second index was developed: the **Safety and Quality Index (SQI) 2025**. The engineering capability is measured by comparing the **SQI** against the **ECI** to evaluate whether the current engineering capacity is showcasing the safe and effect engineering practices. The **ten proxy indicators** used in constructing the SQI provide insights into whether engineering capacity is being utilised safely and effectively in a given geography.

1.3ECI 2025 overall scores results

The ECI 2025 groups the engineering capacity of 115 geographies into five categories - advanced, high, adequate, low and inadequate. This categorisation enables comparisons and mutual learning between regions. It also serves as an analytical tool for further analysis and exploration of engineering capacity globally.



ECI* category and rankings

Advanced capacity
1 United States
2 Australia
3 Finland
4 Canada
5 Sweden
6 Germany
7 United Kingdom
8 Japan
9 Netherlands
10 Singapore
11 Denmark
12 Switzerland

High capacity
13 Ireland
14 France
15 Norway
16 Italy
17 Belgium
18 Czechia
19 New Zealand
20 Spain
21 Luxembourg
22 Iceland
23 Austria
24 Portugal
25 Israel
26 Hong Kong (SAR)
27 South Korea

Adequate capacity
28 Estonia
29 UAE
30 Malaysia
31 Croatia
32 Greece
33 Chile
34 Slovenia
35 Romania
36 Taiwan
37 Hungary
38 Poland
39 Bulgaria
40 Mainland China
41 Slovakia
42 Latvia
43 Cyprus
44 Lithuania
45 Malta
46 Mauritius
47 Colombia
48 India
49 Saudi Arabia
50 Qatar
51 Indonesia
52 Oman
53 Uruguay
54 Serbia
55 Mexico
56 Turkey

Low capacity
57 South Africa
58 Botswana
59 Kazakhstan
60 Costa Rica
61 Jordan
62 Brazil
63 Philippines
64 Ukraine
65 Armenia
66 Bahrain
67 Georgia
68 Argentina
69 Dominican Republic
70 Thailand
71 Bosnia and Herzegovina
72 Montenegro
73 Tunisia
74 Albania
75 Panama
76 Sri Lanka
77 Kenya
78 Peru
79 Ecuador
80 Namibia
81 Kuwait
82 Ghana
83 Mongolia
84 Egypt
85 Vietnam
86 Rwanda
87 Belarus
88 Russia
89 Azerbaijan

Inadequate capacity
90 Bangladesh
91 Nepal
92 Pakistan
93 Senegal
94 Morocco
95 Nigeria
96 Guatemala
97 Uganda
98 Ethiopia
99 Algeria
100 Honduras
101 El Salvador
102 Bolivia
103 Tanzania
104 Lebanon
105 Zambia
106 Iran
107 Cameroon
108 Mozambique
109 Kyrgyzstan
110 Paraguay
111 Madagascar
112 Angola
113 Iraq
114 Zimbabwe
115 DRC

The Engineering Capacity Index Overall Scores (GECR 2025, p. 29)

As shown in the results, only twelve geographies scored in the 'advanced' category. They are the United Sates, Australia, Finland, Canada, Sweden, Germany, United Kingdon, Japan, Netherlands, Singapore, Denmark, and Switzerland. These geographies not only ranked in the top 10% overall for ECI 2025 scores but also placed in the top 10% in at least five out of the ten capacity areas, reflecting strong and consistent engineering capacity across disciplines and sectors.

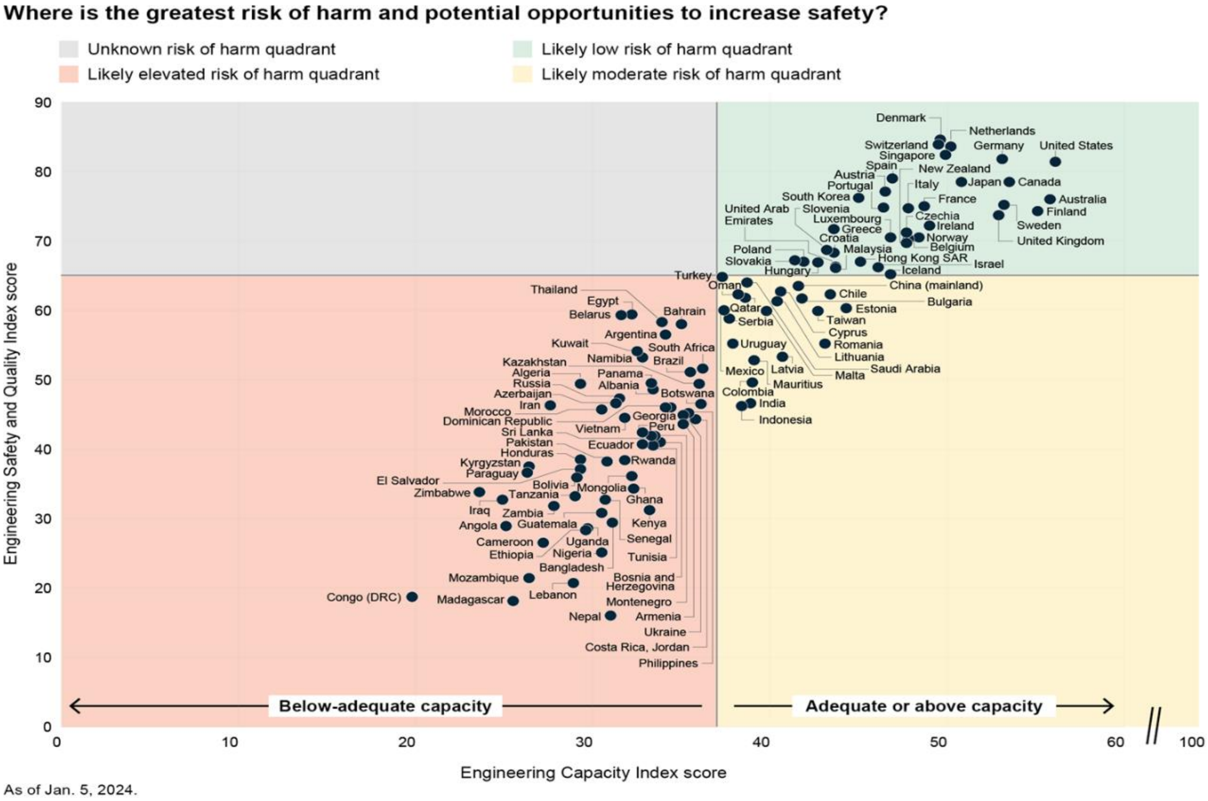
2. Effective application of the GECR 2025

The GECR 2025 introduces tools that geographies can use to better understand their own engineering capacity and capability. However, it is important to mention that capacity and capability are context specific. Therefore, further locally led research is necessary to develop tailored analytical tools that can more effectively measure and improve engineering capacity and capability within each unique context.

2.1 Global view of greatest opportunities

To identify the greatest opportunities to minimise harm to people, infrastructure, and the environment, the comparison of the ECI 2025 with the SQI, led to the development of an additional analytical tool - the **Engineering Capability Matrix (ECM).** The ECM highlights areas where both capacity (inputs) and capability (outputs/outcomes) are low, indicating a high risk of harm due to unsafe engineering practices.

The **Engineering Capability Matrix** can be used to identify and prioritise areas with greatest risk of harm from unsafe engineering practices as outlined in the following figure.



The Engineering Capability Matrix (GECR 2025, p. 33)

In the Engineering Capability Matrix, geographies shown in the upper-right quadrant demonstrates both high capacity and high capability, indicating a low risk of harm due to strong and safe engineering practices. Geographies in the lower-right quadrant demonstrates adequate or high capacity but scores low in some capacity areas, suggesting moderate risk of harm. These countries may benefit from targeted improvements in specific capacity areas to enhance safety. The lower left quadrant represents geographies with both low capacity and low capability, and thus an elevated risk of harm due to unsafe engineering practices. In these geographies, key stakeholders must collaborate and invest in strengthening multi capacity areas to reduce the risk of harm and improve safety outcomes.

2.2Engineering capacity gap analysis

To better understand engineering capacity gaps across the ten capacity areas, the report introduces the Capacity Gap Charts – a tool designed to help users use the ECI 2025 for gap analysis.

Two benchmarks were established to support the gap analysis:

1. The Global benchmark - the highest score across all 115 geographies
2. The Regional Benchmark - the highest score within each specific region

These benchmarks allow users to identify where a country falls short relative to the best-performing peers globally or regionally.

Capacity Gap Charts for all 115 geographies can be generated using the ECI 2025 interactive dashboard. The main report includes six detailed regional examples and additional analysis for 33 countries, all available for download from the Skills for Safety webpage.

As an example, this section looks at the United Kingdom’s capacity gap analysis.

United Kingdom – Capacity Gap Analysis:

United Kingdom's overall engineering capacity falls within the Advanced category based on the ECI 2025, ranking 7th out of 115 geographies. The UK is positioned in the upper-right quadrant of the Engineering Capability Matrix, indicating high capacity and high capability, and therefore a low risk of harm from unsafe engineering practices.

According to the ECI 2025:

Professional engineers (UK):

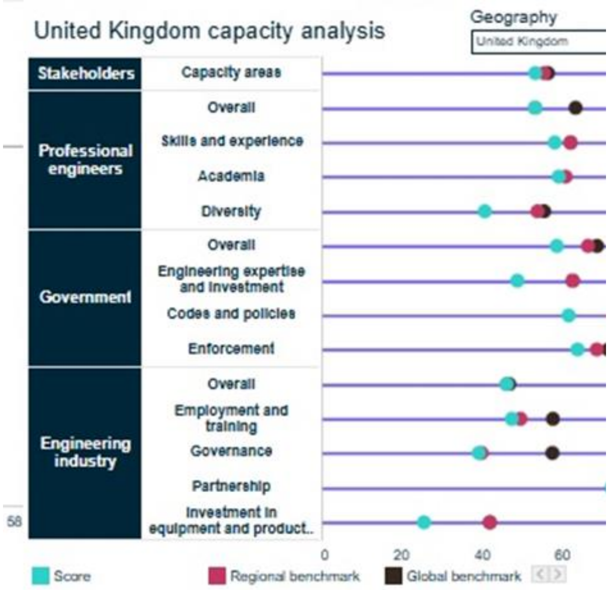
- The largest capacity gap in the UK's professional engineers stakeholder group is in diversity, where UK scores lower than both regional and global benchmarks.

Government (UK):

- The largest capacity gap in UK's government stakeholder group is in engineering expertise and investment, where UK scores lower than both regional and global benchmark.

Engineering Industry (UK):

- The largest capacity gap in UK's Engineering Industry stakeholder group is in governance, compared to global benchmark.
- The UK also scores low in investment in equipment and product testing compared to both regional and global benchmarks.



Capacity Gap Charts (ECI 2025, Interactive dashboard)

The analysis indicates that, despite the UK being ranked in the advanced category, there is still a need to invest in specific capacity areas to further strengthen and sustain safer engineering practices.

It is important to note that the ECI 2025 is a relative index, based on comparisons among the 115 geographies scored. Therefore, the identified capacity gaps need to be interpreted as relative rather than absolute, given limitations in data availability. However, using the ECI 2025 to analyse a country's capacity gaps offers valuable insights into potential areas for improvement. It also serves as a starting point for further discussions on data challenges and the need for locally led, country specific studies and plans to further strengthen their engineering capacity and capability.

2.3Thematic spotlights

The Engineering Capacity Index is also used to examine specific engineering challenges through a series of thematic spotlights. These thematic spotlights highlight how engineering capabilities can contribute to sustainable solutions in an increasingly complex and fast-changing world. Through the lens of the ECI 2025, the spotlights showcase the value of a systems-based approach, revealing how each stakeholder group –professional engineers, government, and engineering industry - relies on collaboration with the others to build capacity and drive progress collectively.

The first three spotlights focus on challenges related to the energy transition:

1. **The mining industry** spotlight examines its evolution in response to the demand for critical minerals, highlighting various engineering challenges.

2. **The energy transition** examines the engineering challenges and the skills needed to enable sustainable energy transition.

3. **Decommissioning and end of life planning** – addresses the end of life of sustainable energy infrastructure and equipment.

The next two spotlights examine:

4. **Artificial Intelligence (AI)** investigates the engineering skills needed to develop and apply AI technologies ethically and effectively.

5. **Continuing education for engineers** considers the issue of continuing professional development that balances the theoretical knowledge and practical application.

3. Key findings and insights:

- The ECI 2025 serves as a **diagnostic tool** for governments, industry, and professional engineers to identify strengths and priority areas for improvement within their engineering ecosystems.
- There is a clear **need for collaboration** across all stakeholder groups to build capacity and reduce the risk of harm from unsafe engineering practices.
- The GECR highlights the **urgent need for investment in engineering capacity, particularly LMIC's pursuing on sustainable development goals.** Strengthening capacity is critical to ensure safe and sustainable development.
- **Every region** of the world has **successful engineering practices examples** that offers valuable lessons and opportunities for shared learning.
- **Improved data collection and reporting** are essential to support better **evidence-based decision-making** across engineering ecosystems.

Summary:

The GECR 2025 introduces an updated framework for understanding and strengthening engineering capacity and capability worldwide. At its core, the Engineering Capacity Index (ECI) 2025 provides a valuable diagnostic tool for analysing capacity gaps across countries and regions, enabling evidence-based action to enhance safety and resilience.

The review also highlights a key challenge: the limited availability of consistent, internationally comparable data, reinforcing the need for improved global data collection to inform future policy and investment decisions.

As a resource, the GECR 2025 can support a wide range of stakeholders, from researchers and educators to policymakers and investors, in identifying priorities and designing interventions that strengthen engineering systems.

We invite you to partner with us in supporting countries to adapt and apply the GECR 2025 to strengthen engineering capacity and capability needed for a safer and more sustainable world.

We also welcome you **input and feedback** on this edition to help shape future versions of the review. Additionally, we invite you join us in building a Skills for Safety Community of Practice, fostering collaboration and shared learning across the global engineering ecosystem.

References

1. Skills for Safety, https://engineeringx.raeng.org.uk/programmes/skills-for-safety/

2. Global Engineering Capability Review (GECR) 2025, https://engineeringx.raeng.org.uk/programmes/skills-for-safety/global-engineering-capability-review/gecr-report-2025/

Curriculum and Competency Transformation in Undergraduate Engineering Education

1. **Yashin Brijmohan, Faculty: Utah State University, VP: World Federation of Engineering Organizations (2014-2019), yashin.brijmohan@usu.edu**
2. **Anu Singh, Postdoctoral Scholar, Engineering Education, The Ohio State University, singh.2311@osu.edu**

Abstract

The global landscape of engineering education is undergoing significant transformation, driven by evolving technology, industrial shifts, and societal demands, including globalization and climate change. This research synthesizes recent developments influencing undergraduate engineering curricula, focusing on the historical evolution of specialization, the emergence of essential non-technical competencies, and subsequent challenges related to curriculum overcrowding. Key findings highlight the critical need for curriculum reform, utilizing universal competency frameworks to manage prioritization and integrating competencies across the entire engineering career pathway, rather than solely within the undergraduate degree. We explore various proposed models for structuring the "New Age" curriculum, emphasizing the necessity of a foundational common core while maintaining competencies of adaptability, lifelong learning, and interdisciplinarity to ensure longevity of the undergraduate curriculum outcomes.

1. Evolution of Engineering Qualifications & Specialization

The global requirement for engineers has been shaped by various contexts, primarily by shifts in industrialization and technological development. In contexts such as the United States, military progress and major innovations, including the space race, heavily impacted the evolution of engineering education (Martin et al., 2023). Engineering education degrees evolved to a timeline lasting three to four years full-time. A few of the factors that decided the program length include student preparation time and financial burden (Epstein, 1991). New disciplines within engineering evolved with their own unique breadth and depth, new core qualifications such as electrical, mechanical, civil, and chemical engineering were established. However, closer examination reveals that the push for more qualifications largely centred on what could reasonably be included within a three to four-year curriculum (Litzinger et al., 2011).

As technology advanced, new ideas led to the development of specialized fields in engineering. Specializations such as electronics within electrical engineering later emerged, introducing additional complexities, making it nearly impossible to design a single disciplinary engineering degree that covers all specializations within a discipline. This led professional societies and accreditation bodies to determine what an electrical engineering degree typically entails. To further complicate matters, some interdisciplinary degrees and some more specialized areas were also introduced as their fields also developed (Coy, 2004), such as industrial engineering, environmental engineering, biomedical engineering, metallurgical engineering, and computer. These new qualifications such as, chemical, biomedical, and electronics demanded their own depth and expertise, eventually evolving into distinct disciplines within engineering education (Messler, 2004). However, despite these evolutions, engineering qualifications generally retain core fundamentals across all engineering disciplines, such as science and mathematics, common across all fields, such as in ABET 30 credits are assigned for basic mathematics and science (ABET, 2023).

2. Post-Undergraduate and Practice-Based Specialization

The difficulty of comprehensive coverage of specialization areas within a discipline prompted ideas about utilising post-undergraduate programs (often called graduate programs) to develop further academic specialization. This approach combines a foundational discipline degree with a specialized master's degree to prepare engineers for discipline areas that encompass more depth in areas of specialization (Cranch, 1994). However, the specialization development of engineers did not always rely on academic qualifications; some disciplines develop expertise through practice, meaning specialization occurs during early career development or continuing professional development (CPD) through lifelong learning in the workplace (Chakrabarti, et al., 2021). This idea promotes the notion that the competency development of an engineer continues throughout their career pathways, rather than occurring solely at the undergraduate level (See Figure 1)

3. Emergence of Non-Technical (Professional) and Global Competencies

Over the past 20 years, a shift has occurred with the emergence of new ideas beyond purely technical qualifications (Prados, 1998), initially referred to as "soft skills". The profession soon recognised these as essential parts of professional development (Richter & Kjellgren, 2024), leading to their current designation as non-technical or professional skills, yet a required skillset.

a) Value-Based Aspects and Sustainability

While globalization has expanded the scope of engineering practice by connecting industries and markets across the globe, recognition of issues such as climate change, alongside the industry's role in global warming has highlighted the need that engineers must contribute broadly and holistically, rather than focusing solely on local product development. This led to the concept of sustainability and sustainable solutions, which incorporate environmental factors and value-based aspects, including considerations for people, communities, and cultural heritage(Arefin et al., 2021). Incorporating these aspects necessitates a new set of competencies for professional recognition, such as systems thinking, life cycle costing, and environmental impact assessment (Staniškis & Katiliūtė, 2016).

b) Technological and Global Recognition Pressures

Advancements in technology, especially the introduction of artificial intelligence (AI), blockchain technologies, and 4D printing, have sparked new discussions about non-traditional specialties and qualifications. In addition, the demand for qualifications aligned with sectors like energy and water is also rising. These debates are driven by students, industry, and societal needs, although these new qualifications are not yet officially recognized as engineering qualifications or credentials. Nonetheless, these needs have led to the regulation of microcredentials and continuing professional development (Kloos et al., 2025), enabling engineers to stay current with the latest technologies in their respective sectors.

The COVID-19 pandemic is another event that highlighted that engineers could work anywhere globally, raising questions about competency equivalence and whether qualifications would be substantively equivalent worldwide. Global recognition is often managed by bodies like the International Engineering Alliance through agreements such as the Washington Accord, which establishes accepted graduate attributes. Curricula meeting these attributes are often considered globally equivalent, allowing graduates to practice in multiple countries, upon meeting other mobility and practice requirements (Lucena et al., 2008). Furthermore, COVID-19 underscored the importance of few competencies such as communication and remote teamwork to work effectively in global and intercultural teams, and understand regional values and ethics.

4. Curriculum Overcrowding and Integration Strategies

The necessity of including diverse competencies required of practitioners has raised concerns about how to include these within a time-limited engineering curriculum. Consequently, efforts should be undertaken to distribute these competencies along the engineering career pathway (Figure 1), examining what should be included in undergraduate programs versus early career and professional development pathways. The challenge of fitting all requirements into the curriculum has been a major focus, following calls for change by the World Federation of Engineering Organizations (WFEO) and the International Engineering Alliance (IEA), such as the call for change by Brijmohan (2019) at the IEA meetings. Such competencies include Creativity, Innovation, Entrepreneurship, Interpretation and Reflection, Adaptability, Problem Identification, Systems & deductive reasoning, Intercultural Competence, Ethics, and Responsibility, as well as policy engagement.

5. Approaches to Competency Integration

The feasibility of incorporating people and value based competencies like those related to sustainability has not been fully assessed (Sabri, 2025), leaving it to universities to demonstrate how they achieve these competencies. Five approaches to integration of competencies have been identified:

a) **Specific Standalone Courses:** This involves including specific courses, such as ethics or sustainability, within the curriculum. The limitation is that these are often taught in isolation, making it difficult for students to see their relevance in various engineering contexts. Moreover, they consume curriculum space, leaving less room for other key competencies.

b) **Integrated Curriculum:** This approach requires faculty coordination and harmonisation across different existing courses to incorporate additional competencies, such as ethics, in a clear and measurable way. The challenge lies in achieving consensus and coordination to determine which courses cover these added competencies.

c) **Capstone Courses / Project:** Introducing capstone courses that integrate prior course outcomes, allowing students to combine learning into a single unit where additional competencies are developed. A significant drawback is that introducing skills only at the capstone level means it may be the first time students encounter these competencies, potentially limiting the time and experience necessary to fully grasp them practically. Another solution is to introduce capstone-type courses earlier in the curriculum.

d) **Formalized experiential learning**: Certain competencies may best be learned through experiential learning, which includes simulations and experience in industry through internships.

e) **Micro-credentials:** This layer could be introduced to address specific industrial and sectoral needs, and if well-regulated, could potentially lead to recognized credits or qualifications.

6. The Need for a Standard Framework

Guidance from professional societies, industry, and policymakers has led to a comprehensive set of competencies for engineers. While research has examined the incorporation of specific competency like teamwork, a standard framework upon which these non-technical competencies could be evaluated and assessed is still not clear. Curriculum designers have had to evaluate which competencies fit, risking over-prioritization that could unintendedly diminish the quality of the engineering qualification.

Recognizing the deficiency, Brijmohan (2023, 2024) called for a reclassification of engineering competencies. An international team was assembled to investigate the possibility of developing a framework encompassing different competencies into relevant dimensions. This taxonomy integrates both traditional competency and capability perspectives into a single framework [manuscript for journal publication submitted].

A universal framework for engineering taxonomies was subsequently created to assess how dimensions are prioritized and the depth to which they are integrated into curricula. The competency dimensions include: STEM Fundamentals, Practice Competencies, Value Competencies, People Competencies, Meta-Competencies, Learning Competencies, and Community of Practice Competencies . Research by Wasay and Brijmohan (2025) tested this framework with data from accreditation bodies, highlighting its completeness. Further work is necessary to assess the impact of how accreditation bodies stipulate competencies and whether implementation is consistent with the principles of maintaining substantive equivalence globally.

7. Distributing Competencies Along the Career Pathway

A new perspective suggests examining the entire engineering career pathway holistically, rather than focusing solely on the undergraduate curriculum. Including all required competencies at the necessary depth within an undergraduate program may be "quite impossible". The alternative involves sharing development across the pathway: certain aspects are included in graduate qualifications, others in early career development, and additional elements in later continuing professional development. This distribution strategy prevents overcrowding within the engineering curriculum and provides mechanisms for development to occur with appropriate levels of depth and complexity. Overcrowding may force educators to rush through concepts, limiting deep, transferable learning. It is critical, especially at this juncture, to engage in robust discussions regarding which competencies should be included in undergraduate studies and which should be reserved for early career development and other pathways, including micro-credentials. The universal competency taxonomy provides a foundation for these discussions. Future refinement of the model requires investigating constituent competencies within accreditation bodies and researching past and future competencies to assist in prioritization and reform of the "New Age" engineering curriculum.

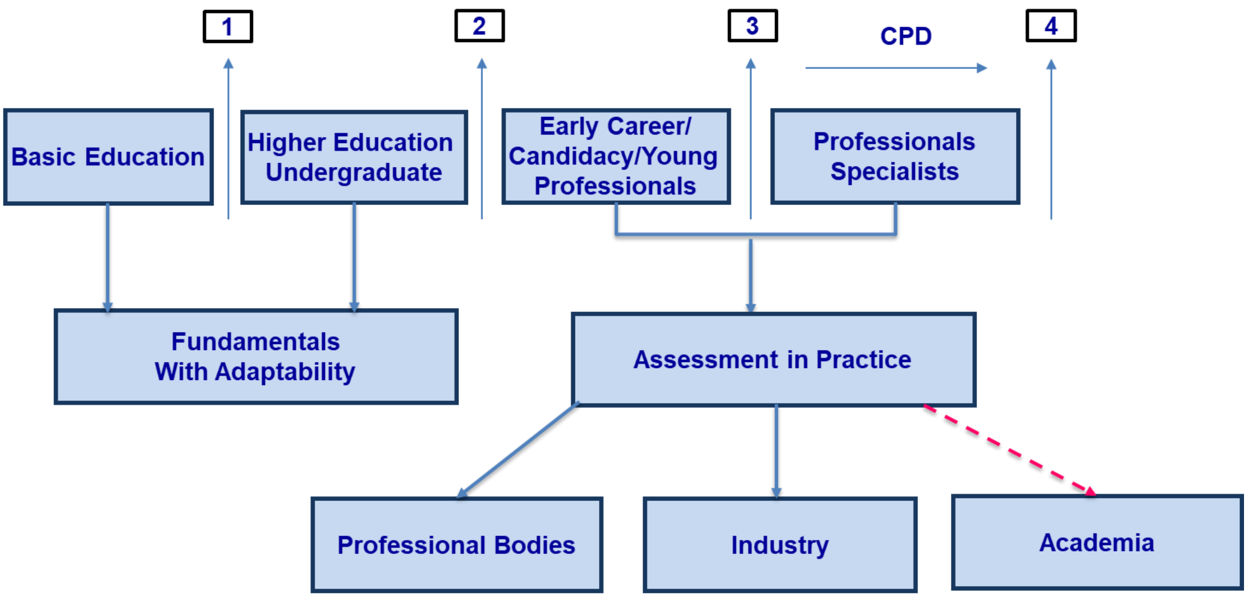


Figure 1: Engineering Career Pathway

Adapted from Desha et. al (2019) and Brijmohan (2018)

8. Consideration for Structuring the New Age Curriculum

The New Age curriculum must meet principal requirements, including adaptability, lifelong learning and interdisciplinarity. Given the intense debates, the need for a curriculum with longevity is clear, which must remain relevant for many years.

a) Common Core Requirements

A central consideration is whether a Common Core should exist across all engineering programs. This core should include fundamentals like science and mathematics, and, in the new age, potentially AI fluency and data science, given their essential role in the technological revolution.

b) Overcoming Challenges of Traditional Foundational Programs

Many programs have adopted a foundational approach, often incorporating core sciences and mathematics during the first year of study. However, traditional methods have limitations: individuals often feel uncertain in the first year regarding discipline choice, and motivation can decrease because engineers do not see the connection between basic sciences/mathematics and their engineering studies.

Alternative models have introduced an easing of the curriculum, teaching hard sciences and mathematics over two years in a way that avoids disrupting necessary follow-on courses. This requires careful timing and flexibility. Some foundational programs expose students to different types of engineering during initial years, allowing them to choose their path, combined with a gradual introduction to hard sciences and mathematics while maintaining appropriate depth. A key approach is ensuring that sciences and mathematics are taught not in abstract ways, but within engineering contexts, using examples and explanations. This requires engineering faculty backgrounds and industry involvement.

c) Curriculum Model Considerations

These evolutionary approaches have specific structural models:

• The 2 + 2 Model: The first two years focus on a set of Common Core elements. The remaining three years include specialization within a discipline. This model enables the integration of additional competencies introduced by the Industrial Revolution, sustainability, and COVID-19 within the first two years, with more in-depth topics introduced gradually later. Discipline specialists typically advocate for more room for specialization in the curriculum.

• The 1 + 3 Model: One year is dedicated to Common Core, while the remaining three years blend elements of Common Core with specialization. This offers flexibility for disciplines to determine the content of the three-year specialization period. A limitation is that the first-year Common Core area tends to become relatively fixed, and specialist faculty may reduce expected Common Core elements in the second year to include more specialization.

• Other Models: These include a three-year base curriculum consisting of three years of Common Core followed by a year of honours specialization (3+1), or an integrated master's program built upon this foundation to incorporate emerging competencies (3+2).

A major challenge across models is ensuring articulation and scaffolding so that foundational units lead to, or provide input for, higher-level units. Care must be taken to avoid over-alignment; for example, teaching mathematics solely to serve higher units might exclude essential mathematical elements needed for the broader engineering profession.

9. Conclusion and Future Directions

The debates surrounding the engineering curriculum necessitate a conscious decision regarding its structure and inclusion of

competencies. It is essential to consider the appropriate model for a university and its environment before implementing a specific curriculum, rather than relying solely on the natural evolution of existing curricula. Future work should investigate what competencies should be prioritized within an engineering curriculum, together with their breadth and specificity.

References:

ABET. (2023). Criteria for accrediting engineering programs. www.abet.org/wp-content/uploads/2023/05/2024-2025_EAC_Criteria.pdf#:~:text=curriculum%20must%20include%3A%20a,engineering%20and%20computer%20sciences%20and

Arefin, M. A., Nabi, M. N., Sadeque, S., & Gudimetla, P. (2021). Incorporating sustainability in engineering curriculum: a study of the Australian universities. *International Journal of Sustainability in Higher Education*, *22*(3), 576-598.

Brijmohan, Y., "Global Review of Engineering Competencies," presented at the International Engineering Alliance (IEA), Hong Kong, Jun. 2019.

Brijmohan, Y. "Balanced Perspective of International and National Accreditation and Pedagogical Approaches: A call for change" presented at the International Conference on Engineering Education Accreditation, Jul. 2023.

Brijmohan, Y. "What does preparedness mean in the context of engineering education in an inclusive and sustainable world." presented at the International Conference on Engineering Education Accreditation, Jul. 2024.

Brijmohan, Y. "Usefulness of the Universal Competency Taxonomy for Policy, Accreditation, and Curriculum Evaluation for a Sustainable Future." presented at the International Conference on Engineering Education Accreditation, Jul. 2025.

Forum-Global Engineering Deans Council (WEEF-GEDC)Coy, W. (2004). Between the disciplines. Acm Sigcse Bulletin, 36(2), 7-10.

Chakrabarti, S., Caratozzolo, P., Norgaard, B., & Sjoer, E. (2021, November). Preparing engineers for lifelong learning in the era of industry 4.0. In 2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC) (pp. 518-523). IEEE.

Cranch, E. T. (1994). The next frontier in engineering education: The master's degree. Journal of Engineering Education, 83(1), 63-68.

Desha, C., Rowe, D., & Hargreaves, D. (2019). A review of progress and opportunities to foster development of sustainability-related competencies in engineering education. Australasian Journal of Engineering Education., 24(2), 61–73. https://doi.org/10.1080/22054952.2019.1696652

Epstein, H. I. (1991). Why four years?. Journal of professional issues in engineering education and practice, 117(2), 150-154.

Kloos, C. D., Alario-Hoyos, C., Kemcha, R., Moreno-Marcos, P. M., Estevez-Ayres, I., Callejo-Pinardo, P., ... & Munoz-Organero, M. (2025, April). How Challenges Become Opportunities: Micro-credentials and Artificial Intelligence. In 2025 IEEE Global Engineering Education Conference (EDUCON) (pp. 1-10). IEEE.

Litzinger, T., Lattuca, L. R., Hadgraft, R., & Newstetter, W. (2011). Engineering education and the development of expertise. Journal of engineering education, 100(1), 123-150.

Lucena, J., Downey, G., Jesiek, B., & Elber, S. (2008). Competencies beyond countries: the re-organization of engineering education in the United States, Europe, and Latin America. Journal of engineering education, 97(4), 433-447.

Messler Jr, R. W. (2004). Growth of a new discipline. Materials Today, 7(3), 44-47.

Martin, D. A., Bombaerts, G., Horst, M., Papageorgiou, K., & Viscusi, G. (2023). Pedagogical orientations and evolving responsibilities of technological universities: A literature review of the history of engineering education. Science and Engineering Ethics, 29(6), 40.

Prados, J. W. (1998). Engineering Education in the United States: Past, Present, and Future.

Richter, T., & Kjellgren, B. (2024). Engineers of the future: student perspectives on integrating global competence in their education. European Journal of Engineering Education, 49(3), 474-491.

Staniškis, J. K., & Katiliūtė, E. (2016). Complex evaluation of sustainability in engineering education: Case & analysis. Journal of Cleaner Production, 120, 13-20.

Sabri, O. K. (2025). Rethinking sustainability in engineering education: a call for systemic change. In Frontiers in Education, 10.

Wasay, A. K., Brijmohan, Y, (2025, September). A Comparative Analysis of Engineering Accreditation Bodies Expressions of Curriculum Outcome Requirements: Proposal for the Universal Competency Taxonomy. In 2025 World Engineering Education

Building Sustainability from the Ground Up: Embedding Design for Safety (DfS) in Engineering Education

Professor Ir. Dr. Che Khairil Izam Che Ibrahim

Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia

Abstract

The construction sector continues to record high accident and fatality rates, with design decisions identified as a contributing factor to workplace incidents. Embedding Design for Safety (DfS), also referred to as Prevention through Design (PtD), in engineering curricula offers a transformative pathway to reduce risks at source while fostering sustainability. This paper explores the integration of DfS into engineering education by drawing on accreditation requirements, constructivist learning principles, and global best practices. It reviews current efforts, identifies gaps in Malaysia and other regions, and proposes a framework for embedding DfS into engineering curricula. Findings highlight that while accreditation bodies such as ABET and the Engineering Accreditation Council (EAC) mandate health and safety considerations, explicit coverage of DfS elements remains limited. The adoption of constructivist pedagogical approaches, active, experiential, and technology enhanced learning, is necessary to equip graduates with knowledge, skills, and attitudes required for safe design practice. The paper concludes by recommending structured curriculum integration, alignment with accreditation outcomes, and capacity building for educators to nurture future engineers who can contribute to safer and more sustainable built environments.

1. Introduction

Construction remains one of the most hazardous industries, consistently ranking among the top sectors for occupational accidents and fatalities worldwide. Research indicates that design decisions account for a significant proportion of safety incidents (Lorent, 1987). In response, the concept of Design for Safety (DfS), or Prevention through Design (PtD), has emerged as a proactive approach to eliminate hazards at the design stage (Szymberski, 1997). Beyond improving safety, integrating DfS contributes to sustainability by reducing life-cycle risks, costs, and resource wastage (Karakhan & Gambatese, 2017).

Education plays a critical role in advancing DfS adoption. However, PtD content in engineering programmes remains limited, often constrained by overcrowded curricula, lack of qualified instructors, and insufficient institutional emphasis (López-Arquillos et al., 2015; Din & Gibson, 2019). Recent studies in Malaysia and elsewhere highlight the need to embed DfS explicitly into engineering curricula to prepare graduates with professional competencies aligned with evolving regulations (Che Ibrahim et al., 2021; Ismail et al., 2024).

2. DfS Educational Landscape

Globally, the inclusion of DfS in higher education has been uneven. While the United States and Australia have pioneered curricular integration, Europe and Asia show sporadic adoption (Toole, 2017; Foley et al., 2016). In Malaysia, despite the introduction of the Occupational Safety and Health in Construction Industry (Management) [OSHCIM] regulations, awareness remains at an early stage, and explicit incorporation of DfS into civil engineering programmes is limited (Che Ibrahim et al., 2021).

Curriculum reviews reveal that current approaches emphasise hazard identification and risk analysis, but lack structured embedding of design safety principles across core engineering courses (Behm et al., 2014). The integration of DfS must move beyond elective or peripheral treatment towards systematic embedding in courses such as structural design, project management, construction safety, and professional ethics (Ismail et al., 2024).

3. Accreditation Framework as a Driver

Engineering accreditation standards provide a strong lever for embedding DfS. ABET explicitly requires graduates to design solutions with consideration of health, safety, and welfare. Similarly, the Malaysian EAC has integrated safety and sustainability into its programme outcomes under the Washington Accord framework. The latest EAC Standard 2024 introduces 11 graduate attributes linked to sustainability and the UN Sustainable Development Goals (SDGs), positioning DfS as a natural fit for curricular alignment. Institutionalising DfS through accreditation ensures compliance and creates systemic incentives for universities to adopt it (Din & Gibson, 2019).

4. Mechanisms for Integration

A constructivist approach offers a practical scaffold to embed Design for Safety across engineering curricula because it emphasises active knowledge construction and reflection on authentic design problems rather than passive content coverage (Terhart, 2003). Five learning principles guide the design content, learning outcomes, learning environment, learning domains, and pedagogical approaches (Ismail et al., 2024). Recommended mechanisms include:

- **Content**: Content should be sequenced to mirror the time safety influence curve so that hazard elimination is taught at the earliest design stages and then revisited through preliminary and detailed design. Rather than a single standalone course, embed short DfS units inside structural design, project safety management, construction law, construction technology, and engineers in society. Core topics include hazard prevention, design risk management, legislative duties and organisational roles, constructability, and the hierarchy of controls, with worked examples on drawings or three-dimensional models. This strategy aligns with your slides that list recurrent DfS elements such as hazard recognition, risk analysis, design activities and tools, collaborative delivery, and information technology enabled reviews.

- **Learning outcomes**: Learning outcomes need to make safe design explicit and assessable. Outcomes should progress from knowledge through application to judgement. Typical statements include the ability to explain the role of the designer as a duty holder under relevant regulations, to conduct a preliminary hazard analysis on a structural system, to recommend elimination or substitution choices using the hierarchy of controls, and to justify a design decision that balances safety, cost, constructability, and environmental performance. This progression supports alignment with accreditation outcomes that already require consideration of health, safety, and welfare and therefore turns compliance language into concrete learning.

- **Learning environments**: The learning environment should move beyond the lecture room toward applied studios and authentic exposure. The results showed lower satisfaction with learning environment than with content and outcomes, which signals a need for change. Start with a digital design review studio that uses building information models on desktops for viewpoint markups, rule-based risk tags, and short safety by design memos. Add structured site observations, practitioner case talks, and internships to connect classroom knowledge with real project contexts.

- **Learning domains**: Learning domains must be developed in an integrated way. In the cognitive domain, teach concepts and methods for hazard identification, assessment, and control, together with legal frameworks and ethical reasoning. In the psychomotor domain, require repeated practice in drawing and model markups, option appraisal, and the production of risk registers that

  track design changes. In the affective domain, use incident cases, role play in design meetings, and reflective writing to cultivate professional responsibility and a prevention mindset linked to public welfare and sustainability.

- **Pedagogical approaches**: Pedagogical approaches should privilege active, cooperative, and technology supported learning. Project based tasks that treat risk prevention as a design problem help students transfer methods like What if and checklists, failure mode effects analysis, and preliminary hazard analysis into real decision making. Flipped sessions free class time for collaborative problem solving on drawings and models. Serious games and simulation have shown measurable gains in safe design thinking and provide a low-risk environment to practise hazard recognition and safer design choices. Where feasible, virtual reality and building information models can deepen engagement, but early wins are possible with desktop tools and short scenario-based exercises.

Conclusion

Embedding DfS in engineering curricula is imperative to produce industry-ready graduates capable of designing safer and more sustainable infrastructure. Accreditation frameworks offer an institutional pathway, while constructivist pedagogies and digital innovations enhance the depth and breadth of learning. Future efforts must focus on capacity building for educators, curriculum alignment, and cross-stakeholder collaboration to ensure DfS becomes a mainstream element of engineering education.

References

Behm, M., Culvenor, J., & Dixon, G. (2014). Development of safe design thinking among engineering students. *Safety Science, 63*, 1–7.

Che Ibrahim, C. K. I., Belayutham, S., & Mohammad, M. Z. (2021). Prevention through design (PtD) education for future civil engineers in Malaysia: Current state, challenges, and way forward. *Journal of Civil Engineering Education*, *147*(1), 1–15.

Din, Z. U., & Gibson, G. E. (2019). Prevention through design accreditation requirements in engineering, architecture, and construction education. *Global Center for Safety Initiative Report*.

Foley, B., Howard, P., Toft, Y., & Hurd, M. (2016). Increasing safe design practice within the engineering curriculum. *Australasian Association for Engineering Education Conference Proceedings*.

Ismail, S., Che Ibrahim, C. K. I., Belayutham, S., Cheung, C., & Manu, P. (2024). Prevention through design (PtD) educational elements in engineering, architectural and construction domain: A review. *European Journal of Engineering Education*, 49 (6), 1265-1287.

Karakhan, A. A., & Gambatese, J. A. (2017). Integrating worker health and safety into sustainable design and construction. *Journal of Construction Engineering and Management, 143*(9), 04017069.

López-Arquillos, A., Rubio-Romero, J. C., & Martinez-Aires, M. D. (2015). Prevention through design in engineering and architecture university courses. *Safety Science, 73*, 8–14.

Lorent, P. (1987). *Les conditions de travail dans l'industrie de la construction*. Comité National d'Action pour la Sécurité et l'Hygiène dans la Construction.

Szymberski, R. (1997). Construction project safety planning. *TAPPI Journal, 80*(11), 69–74.

Terhart, E. (2003). Constructivism and Teaching: A New Paradigm in General Didactics?, *Journal of Curriculum Studies,* 35

Toole, T. M. (2017). Adding prevention through design to civil engineering educational programs. *Journal of Professional Issues in Engineering Education and Practice, 143*(4).

ISBN 978-99986-0-477-3