Chapter 16
The Next Engineers—Equipping Industry for the Future of Construction

Dan Bergsagel and Phil Isaac

Abstract The construction industry is often classified as the world's largest ecosystem. Like other ecosystems, it must adapt to changes, such as the climate emergency and Industry 4.0. To ensure the industry can adjust dynamically to these drivers of change, we need to make sure that the next engineers are equipped with the necessary skills to manage the challenge. First, we need to understand which future skills these engineers will need. This chapter presents the key skills that we believe will be needed to respond to the coming changes of Industry 4.0 and the climate emergency. Second, we need to understand whether these skills are taught currently, and if not, how to introduce these skills into the next engineers' training. This chapter presents a review of contemporary and recent engineering curricula in the UK, the skills and content recently added to curricula and proposals for future additions on the longer-term scale. Finally, as the training provided to engineers changes, the workforce will begin to divide into an older cohort which received 'traditional' training and a younger cohort which received 'future-thinking' training. This dichotomy presents both intergenerational training opportunities and management challenges in organising a workforce with a non-uniform core skill set. This chapter proposes methods to navigate the changes within the industry to improve knowledge sharing, as well as opportunities to reframe engineering in the public mind set to expand and diversify the engineering workforce beyond its existing limited size and demographics.

Keywords Next engineers · Future of construction · Industry 4.0 · Skills · Teaching and education · Workforce

D. Bergsagel (✉)
Scale Rule, London, UK
e-mail: dan@scalerule.org

Schlaich Bergermann Partner, New York, USA

P. Isaac
Simple Works, London, UK
e-mail: phil@simple-works.co.uk

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1 Introduction

An ecosystem is a community of organisms that interact with their physical environment to form an integrated system, encompassing material flows and energy transfers. Ecosystems reach temporary states of equilibrium, but are controlled by internal and external factors and must respond reactively to these changes; whether short-term destabilising events—drought, hurricanes, wildfires, disease—or longer-term structural events, such as rising sea levels and climatic shifts.

The complex network of relationships that an ecosystem describes can be in our natural world, or the human-controlled world. The global construction industry is perhaps the world's largest ecosystem (Ribinheiro, 2020). As compared to natural ecosystems, our man-made construction ecosystem operates on material flows, energy transfers and information. This information is parsed by engineers, and engineers act based on this information. In this sense, engineers are the primary regulatory mechanism of the construction ecosystem; who they are, what they know, and how they respond to this flow of information is crucial to the success of the construction ecosystem.

Just as with a natural ecosystem, the construction industry ecosystem must adapt to short-term factors—recessions, government policy—and longer-term changes, such as the climate emergency and Industry 4.0. To ensure the industry can adjust dynamically to these drivers of change, we need to make sure that the next engineers who are part of the construction ecosystem—the future operators who will navigate the change—are equipped with the necessary skills to manage the challenge.

Society has seen significant change since the First Industrial Revolution, which brought about widespread economic and social reorganisation (Kuznets, 1955), as well as the birth of modern construction materials and practices (Taussig, 1900) and the founding of learned societies to formalise the design and construction process of the revolution's necessary infrastructure endeavours (The Times, 1890). During the subsequent three centuries, society has continued to be reformed, yet whilst our contemporary lives are fundamentally shaped by the electronics and digitization of the Third Industrial Revolution which began in the 1960s (Robinson et al, 1997), civil engineering practice has changed comparatively little since the Second Industrial Revolution.

The core work of a civil engineer was established in the early 1800s and modernised rapidly between 1870 and 1920 (Bonshek, 1988); however the project types, construction materials, design processes and construction methods of the 1920s largely endure in our work in 2020. Figure 1 graphically approximates when key changes in engineering occurred, and the general trend of development and change. The graphic is split into construction materials, project types and design and construction processes. Clusters of significant change have been circled. Three occurred during the Second Industrial Revolution and are interconnected: the industrialization of reliable and mass-producible construction materials, the refinement of engineering theory and associated change in scale and ambition of project types. These

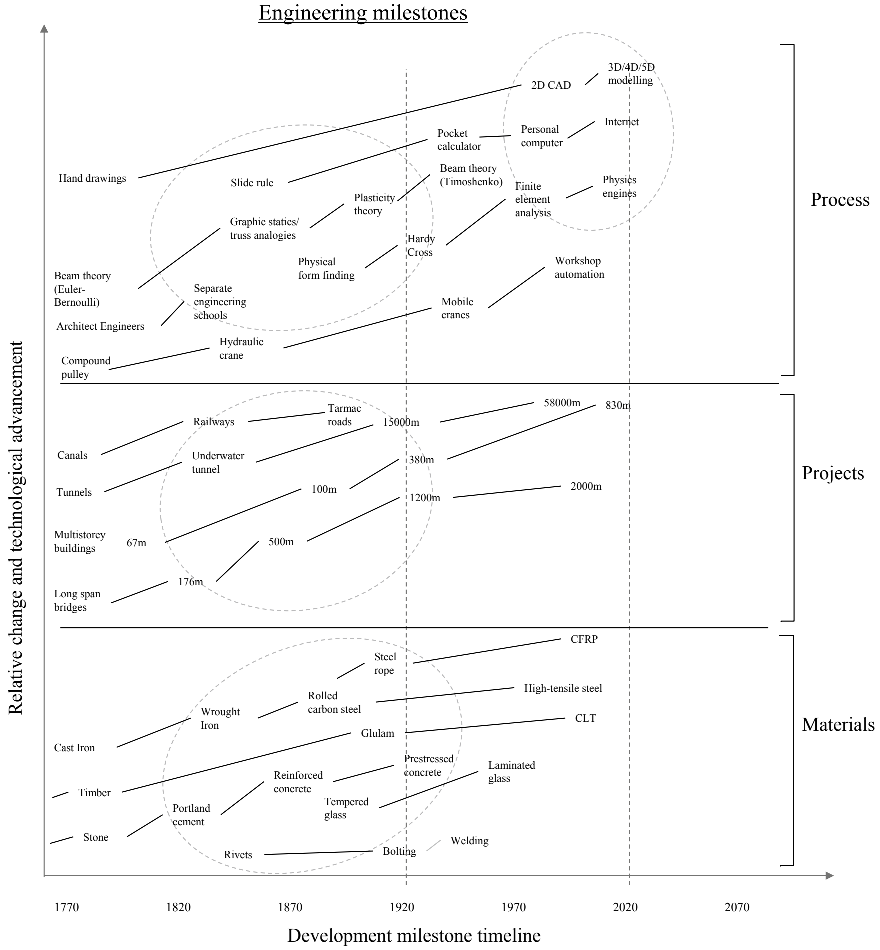

Fig. 1 Consistency and change during 250 years of civil engineering (Authors' Original)

moments of radical change were largely complete by 1920. The subsequent incremental development in engineering practice over the last century has been matched by a similarly consistent curriculum of skills and knowledge in which engineers are trained. University and construction-site skills have not needed to adapt significantly over this time.

However, the Third Industrial Revolution has had a significant impact on engineering practice in the field of design processes: particularly the development of personal computers, spreadsheet software and finite element analysis (the 4th and most recent cluster in Fig. 1). The significance of this change in engineering design is exemplified by the Sydney Opera House project completed by Ove Arup and partners and the change over the seven year project lifespan from physical modelling and hand calculations to computer processing (Trafas White, 2016). However, beyond a reactive recent emphasis on teaching computer coding skills and proficiency in 3D drawing and modelling—and parallel movements to ensure that qualitative analytical skills are not lost during these changes (Brohn & Cowan, 1977)—defining the required skills of the next generation of engineers has not been seen as an existential question. Today, we are facing two paradigm shifts in civil engineering—the climate emergency and the advent of Industry 4.0—and we must urgently update and redefine the necessary skills required to equip the next engineers to continue to work for the future benefit of society in this brave new world.

Whilst the civil engineering of the past 100 years may be comfortingly familiar, we expect the civil engineering of the next 30 years to be uncomfortably unfamiliar. To paraphrase L.P Hartley: the future is an unknown country; they will do things differently there.

The objectives of this chapter are to explore how the engineering community can prepare for this change. This chapter presents the key skills that we believe will be needed to respond to the coming changes of Industry 4.0 and the climate emergency. It then presents a review of contemporary and recent engineering curricula in the UK, the skills and content recently added to curricula and proposals for future additions on the longer-term scale. Finally, it proposes methods to navigate the changes within the industry to improve knowledge sharing, as well as opportunities to reframe engineering in the public mind set to expand and diversify the engineering workforce beyond its existing limited size and demographics.

2 Industry 4.0 and the Climate Emergency

The impact of Industry 4.0 is the continuation and expansion of the 4th cluster of change in Figure 1 related to digitization of the design process. Based on previous progress in the last 30 years, our dependency on technology is only going to increase in the next 30 years. However, this trend is predicted to broaden and lead to significant changes to the functioning of the industry (Ribineirho et al., 2020). Graduates will be entering a workplace demanding skills in areas such as digital design, coding and digital-based communication. Following the experiences gained during the Covid-19 pandemic, shifts in workplace practice and digital collaboration are already commonplace. However, to fully understand the skills required of the engineers of the future workforce—the next engineers—we must first understand the major changes that the engineering industry will face: demands for improved productivity and reduced risk, addressed by the many components which make up Industry 4.0; and the climate emergency, whose decarbonising impetus will affect every aspect of our work in the construction industry, and an engineer's place in the wider economy.

The construction industry has a reputation as a technological Luddite, lagging behind most other industries in adopting new methods of working (Hastie, 2019). Productivity growth in construction has remained at a third of that of the wider global economy (Barbosa, 2017). The overall slow rate of change in construction is in contrast to individual aspects of engineering which have adapted almost unrecognisably, such as the dependency of today's engineers on computational modelling, digital drawing packages and BIM. Construction is important: the construction sector is estimated to contribute 11% to global GDP, a figure that is only expected to grow (Roumeliotis, 2011). In the UK, construction is estimated to be worth 6.5% of the UKs GDP and to provide 6.3% of UK jobs (Infrastructure and Projects Authority, 2016). To counter this lack of progress, successive governments have sought to reform the industry through reviews and high-level policy statements. Of particular relevance is the farmer report 'Modernise or die' (Farmer, 2016) which focussed on the labour model for the construction industry whilst also touching on low growth in productivity in the sector, and the industrial strategy report 'Construction 2025' (HM Government, 2013).

Both reports reached the same core conclusion: that the construction industry needed to embrace digital technologies if it is to be able to meet the needs of society in the coming years. 'Construction 2025' set the following specific targets for the construction industry: 33% lower costs, 50% faster delivery, 50% improvement in exports and 50% lower emissions. The farmer report (Farmer, 2016) made numerous recommendations covering the wider labour market and economic model of the construction industry, drawing particular attention to: on-site factories and pre-assembly, industry wide adoption of design for manufacture and assembly (DfMA) principles and pre-manufacturing capabilities and BIM-enabled collaboration.

The top-down call to embrace the tools and methods of work of Industry 4.0 was clear and to some extent successful. BIM has been mandated and implemented to varying degrees of success (HM Government, 2015), and some on-site factories have been piloted, such as the six-storey 'jump factory' developed by Mace—a moving canopy and gantry crane that provides the benefits of an indoor construction site at the top of a tower under construction (Byrd, 2020). However, the action has been less dramatic than might be expected. This is partially related to the lack of the bottom-up ability to do so, as the workforce of the next engineers is largely receiving training within a framework established with limited training to implement the industrial shift.

Both these industry reports must now be considered in the more recent context of the climate emergency and the building sector's outsized contribution of 38% of global carbon emissions (UN Environment Programme, 2020). As well as a moral imperative, there are new regulatory criteria to meet such as the UK's declaration of a climate change emergency and the related legislation that requires the UK to be net zero carbon by 2050 (Priestley, 2019) with a further target introduced in 2021 of a 78% reduction in CO_2 emissions from 1990 levels by 2035 (Committee on Climate Change, 2020). This has been met by a robust response from the construction industry, with architects (UK Architects Declare, 2019), engineers (Engineers Declare, 2019) and learned institutions all prioritising the demands of the climate emergency for the industry (IStructE, 2021; Thorniley-Walker, 2020). These are not only UK specific actions—globally legislation to bring countries to net zero by 2040 and 2050 is being adopted, and COP26 in Glasgow in 2021 is a further opportunity for the international community to affirm this.

Together Industry 4.0 and the climate emergency are external challenges to the status quo of engineering. They will have significant knock-on effects on the industry and the skills that will be needed. This relationship is summarised in Figure 2. These two shifts will lead to a range of new industry goals in response, such as reducing the embodied carbon of new construction or automating construction sites. These challenges and goals are shown in the first columns of Figure 2. To meet these goals, the next engineers must be versed in a range of new skills which are not currently core parts of a civil engineer's training. These skills are proposed for each industry goal and categorised into four groups: physics and mathematical skills, technological skills, communication skills and critical thinking and design skills. The skills in response to each goal are outlined in the body of Figure 2. The overarching theme is the expected broadening of skills and knowledge. This could lead to two types of engineers emerging: those with a broad overview of the varied and multi-disciplinary

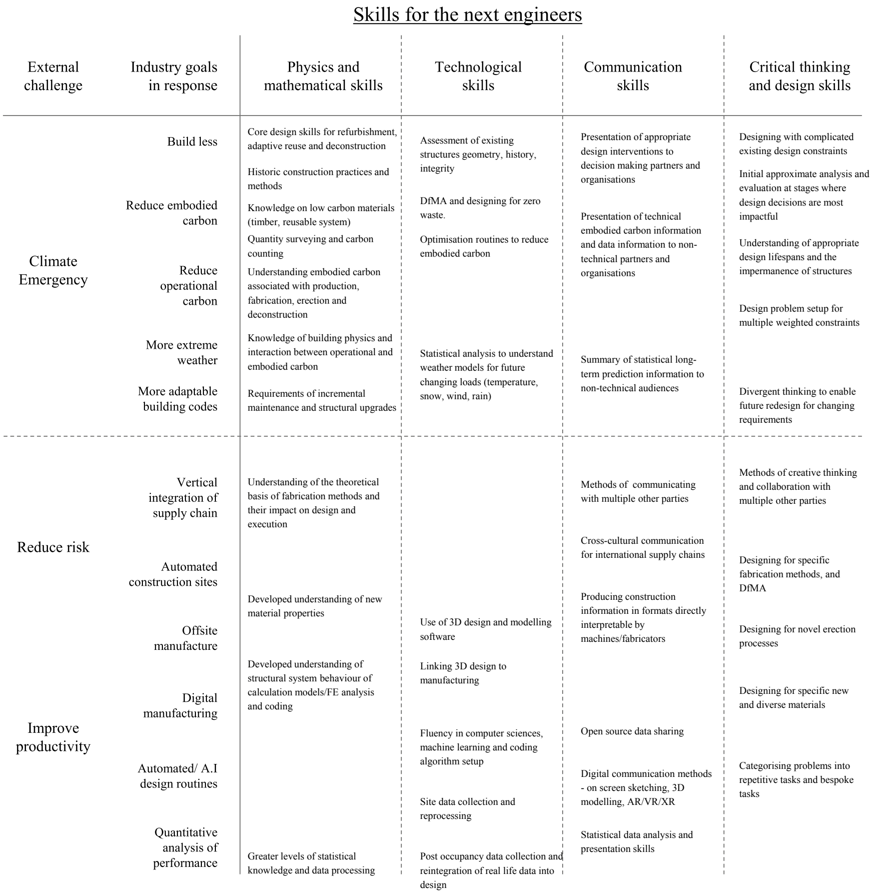

Fig. 2 Predicted required skills for the next engineers (Authors' Original)

aspects of the engineering profession, similar to the integrator role in the ICE's Project 13 framework (ICE, 2021) and specialists with a strong expertise in a smaller subset of the identified areas. It may also be that more T-shaped engineers emerge with a broad knowledge across the wider professional skills but with a deep knowledge of one particular area (Johnston, 1978; Neeley & Steffensen, 2018).

The broadening of skills is of interest in the historical context. If we take mathematical skills as an example, students graduating 30–40 years ago would have been entering a profession where much of the analysis was done by hand using advanced mathematics. The changes since the 1970s have reduced this hand calculation and replaced it with a greater reliance on technology and finite element analysis methods, such that these are now widely accepted as the primary analysis tool for all but the most simple of situations (Open University, 2016). With this rise in computational solutions, a continuing emphasis has also been placed on ensuring proper questioning and a qualitative understanding of the computational results (Brohn & Cowan, 1977). It is anticipated that this will further shift with a much greater emphasis placed on understanding and knowledge in coding, which will be required as processes become more automated, supply chains shorten, and there is greater integration of software. For many larger consultancies, this transition is already underway with in-house computational teams developing scripts and software to integrate various elements of processes which drives efficiencies in the design process.

Whilst the ubiquity of personal computers in society has carried through to an engineer's design processes, other recent societal shifts have been less well incorporated, such as the prevalence of big data as a tool: for design, informing design with large data sets; for evaluation, collecting data to verify the success of work and inform future work and for motivation, presenting results and information in a concise and comprehensible way to explain the logic for certain decisions. Engineers are not currently equipped with the skills to process large data sets—or pass judgement on the reliability of the collection method and contents of these data sets—whether it is meaningful statistical analysis or the presentation of data-based conclusions.

Technological skills are also expected to combine with a range of other skills such as management, leadership and communication as the engineering profession continues to adjust its role within the construction ecosystem. Management and leadership skills have always been required to found, grow and manage independent engineering companies; however, the scope of these skills may need to extend into other industries and fields as engineers work within more complex projects and provide technical leadership to ensure safe and efficient adoption of novel and unfamiliar technologies in design and on construction sites. As the industry changes, engineers will be required to communicate those changes clearly to other parties and partners, explaining without technical jargon why things are changing and how they will change.

Another key expected combination of technological and communication skills is in the closer link between design and manufacturing, harnessing the concepts of Design for Manufacture and Assembly (DfMA) or additive manufacturing (Ribineirho, 2020). At present, many engineers lack the skills and knowledge to fully embrace the fabrication and manufacturing aspects of DfMA, given that their education would typically focus on the design side. This will require engineers of the future to be trained in these skills, or workers with this experience will need to be recruited from professions where DfMA is more widely adopted, such as the automotive, aerospace or naval industry and product designers.

Industry 4.0 presents opportunities to improve productivity and execute design and construction in a more holistic and controlled fashion. The potential for change is significant; however, it is change that is largely motivated by the industry responding to competitive market pressures to reduce time, risks and costs and to improve quality of design, fabrication and erection. The climate emergency is an existential external challenge to the construction industry and civil engineering's primary occupation of building new structures. To meet society's net zero targets, we must build less, and what we do build must contain less embodied carbon. These twin requirements bring to the forefront a change in mathematical, physics and materials science knowledge and a significant focus on critical thinking and design. These skills will focus on analysis of existing structures, refurbishment and adaptation as we deal with more challenging, variable and unknown design constraints. New structures will need to utilise renewable and low carbon materials, and engineers will need to understand whole life cycle carbon assessment and the implications of circular economy principles on designs to allow for assembly, deconstruction and material reuse.

More broadly, there will be a demand for new innovative solutions. The industry has traditionally followed a route of incremental cautious development instead of entrepreneurial start-up change. In this regard, the industry must work harder to increase diversity in the profession and allow new ideas and innovations to flood into the industry and greater opportunities for knowledge sharing, collaboration and the potential for recombinant innovations. An example from a different sector would be the combination of photography and location mapping to create Google Street View, which revolutionised how we interact with unknown environments and route planning (Campanella, 2017). Achieving this will require companies to be less protective of their data, working methods and in-house knowledge and instead more open for sharing, collaboration and learning from those outside their traditional zone. Achieving innovation will also require flexibility and longer-term thinking from clients in their procurement. To facilitate innovation may require upfront resource investment for future benefits, instead of short-term minimal capital expenditure and always awarding contracts to lowest-cost providers without considering other benefits and parameters.

To confront the challenges, we face will also require a greater focus on solving larger and more complex problems which will require engineers to think creatively whilst working in larger and even more multi-disciplinary teams. This will require greater emphasis to be placed on communication skills where engineers will be required to interface with both the design team and the manufacturing team. Virtual and augmented reality have been trialled as ways of aiding team working, and the use of these technologies can only be expected to grow. The use of these technologies will require engineers to be proficient in 3D modelling techniques—either creating models as designers or viewing, tagging and editing models as constructors—potentially linked with parametric design, such that they can maximise the benefit of these working methods.

3 Teaching and Education

The engineering industry relies on two primary routes to train the next engineers: university and apprenticeship. Together, these paths provide students with the core knowledge and skills they need to perform design, construction and management tasks.

What is taught to the next engineers is partially decided by individual institutions, but largely regulated by national regulating bodies. If we take the UK as an example, the core requirements of accredited Bachelor's and Master's degree programmes are controlled by three documents and the groups which draft them: The UK Standard for Professional Engineering Competence (UK-SPEC), the Accreditation of Higher Education Programmes (AHEP) and the Joint Board of Moderators (JBM) additional guidelines. UK engineering apprenticeships are controlled by UK-SPEC and the Approval and Accreditation of Qualifications and Apprenticeships (AAQA). Together, these groups outline what knowledge and skills are required to be taught at university to become a Chartered or Incorporated Engineer (CEng, IEng) registered with the Engineering Council and define the core skill set of the profession. The Engineering Council represents the UK in organisations that facilitate mobility of engineering professionals internationally, such as the International Engineering Alliance (IEA) and the European Federation of National Engineering Associations (FEANI) (Engineering Council, 2021a, 2021b, 2021c).

Aside from variation amongst the forest of acronyms, this method of defining the training of the next engineers is globally accepted. Similar approaches are applied across the world, such as the National Council of Examiners for Engineering and Surveying (NCEES) in the United States of America. In summary, a group of regulatory institutions define the knowledge and skills content of an education to become an engineer, and rely on different institutions to implement that skill set. The goal is 'to meet the engineering and technological needs of today, whilst also catering for the needs of future generations'. (Engineering Council, 2021a, 2021b, 2021c). The remainder of this section will focus on the framework for training engineers through the university route; however, we would like to emphasise that the apprenticeship route is of equal importance to the industry, and many of the conclusions drawn from review of the university route are also applicable to apprenticeships. We expect a diversity of people working together to be a crucial aspect of the role of the next engineers.

The university accreditation guidance, by design, avoids being over prescriptive to provide leeway for educators to teach with different focusses and different teaching methods. The UK-SPEC and AHEP learning outcomes approach utilises a broad framework for general engineering with sufficient scope for interpretation structured around: knowledge and understanding; design and development of processes, systems, services and products; responsibility, management or leadership; communication and interpersonal skills; and professional commitment.

This approach also allows for innovation and diversity in how the teaching is provided, whether learning through physical experimentation and analysis such as at the University of Cambridge, through design exercises and industrial placements such as at the University of Bath, or through problem-solving learning approaches such as at University College London (Graham, 2018). Within this flexible framework, the approach functions well for already established and existing core learning topics that meet the needs of today, such as analysis and design of concrete and steel structures to existing codes of practice. This accreditation approach functions less effectively when discussing what new and developing content is needed to meet the needs of future generations of engineers, such as automated fabrication or a focus on adapting and upgrading existing infrastructure. The authors believe this lack of over-prescription in accreditation is a net positive—it allows educator's flexibility and independence—yet challenges with predicting and preparing for an unknown future tend to encourage universities to provide education overly based on the requirements of the past, and additional support could be provided in this field.

Out of the suite of guiding documents for engineering training at university, the JBM guidelines for developing degree programmes provide the most targeted guidance for civil engineering degrees, and the latest version of the guidelines (JBM, 2021) is applauded for its forward-thinking encouragement of knowledge and skills, in particular with regard to the climate emergency—exemplified by the introductory statement to place the 'Climate Emergency as a very necessary central cultural feature in the education of civil engineering students' and the accompanying guidance on the low carbon agenda. However, do these guidelines anticipate and prepare training for all the skills we believe the next engineers will need? And if not, what other skills should we add to close this skills gap?

Engineering education extends significantly beyond the UK and the JBM's purview: not all engineers complete degrees, and most of the world's engineers study outside the UK. However, if we use the existing UK University engineering education framework of the JBM guidance, we can highlight: which skills required for the next engineers are currently being taught, which skills required for the next engineers should be added to curricula, and at what stage and method of education these skills should be taught.

In Figure 3, we categorise the anticipated necessary new skills highlighted in Section 2 onto two axes: the first is the learning stage the skills could be introduced (from high school to early career), and the second is a timeline for when the skills are to be introduced in the training of the next engineers. The skills have been formatted based on which annex of the JBM's guidelines they are outlined in and placed on the timeline according to typical adoption in UK university engineering curricula. The resulting new skills are collected into six groupings, which broadly divide the new skills into categories related to either the skill type (column headings from Fig. 2,

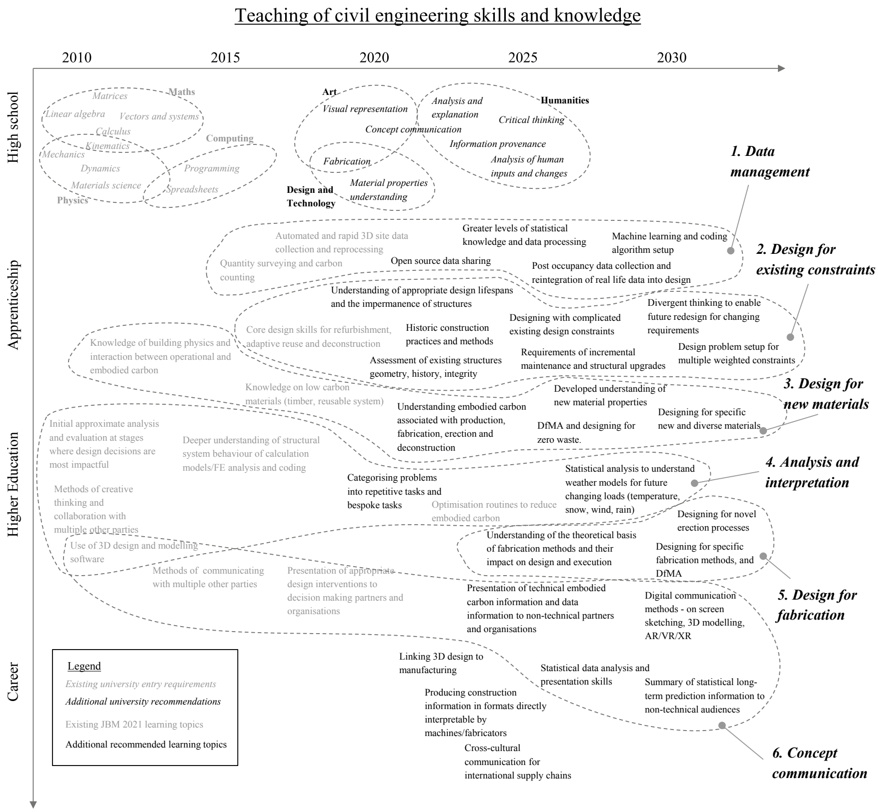

Fig. 3 Skills for the next engineers—current and future curriculum changes (Authors' original)

i.e. Technological skills) or the industry goal (row headings from Fig. 2, i.e. build less or with less embodied carbon).

Of the core skills, we anticipate will be important in the developing engineering industry; a number have already been emphasised in an engineer's training recently. The last decade has seen the continuing importance of an understanding of concepts of system behaviour, interpretation and understanding of calculation models, initial approximate calculations to facilitate design decision making (Ibell, 2019) and an emphasis on communicating in teams and creative thinking in collaboration with others (Reiter-Palmon & Leone, 2019), both in person and increasingly virtually, particularly post 2020. These skills are part of a general understanding in the engineering profession that the added value of engineers is shifting from situations where rigorous calculations are completed manually, and towards a scenario where engineers establish problem boundaries, seed different potential solutions and interpret and evaluate their outcomes (ASCE, 2013). This 'Analysis and interpretation' grouping (group 4, Fig. 3) must continue to develop, enabling the next engineers to decide on appropriate calculations, establish the key design parameters and interpret the results.

Of the skills that are being newly promoted in the training of the next engineers, many skills relate to the climate emergency. This includes the ability to evaluate embodied carbon and global warming potential of projects, the future importance of reuse, recycling and the possibilities of retrofit and the understanding of using new suitable materials. We believe these groupings of 'Design for existing constraints' and 'Design for new materials' (groups 2 and 3, Fig. 3) are crucial skills for the next engineers, and require significant priority and elaboration in training plans. An understanding of low carbon materials has been proposed as an important step for the education of engineers; we propose that this should be augmented to lead to more training in the design for renewable materials like timber, but also an understanding of the production and fabrication process of different materials and material systems to enable further reductions in embodied carbon and the integration of circular economy principles. Whilst there is some discussion of retrofit and reuse, we believe there is a need to have a better understanding of historic construction practices and how to work with existing structures for future development, as well as the associated critical, divergent thinking and creative problem solving that successful interventions on existing structures require. In a future world, where we must build less (Hurst, 2019), having a deep understanding of our existing structures is vital. We expect this to be a paradigm shift in the work of the next engineers (UN Environment Programme, 2020).

There are nascent proposals to better align the skills of the next engineers with changes related to Industry 4.0. The next engineers will require development in 'Data management' (group 1, Fig. 3) for collecting and processing large amounts of source data, whether that is through evaluating and sharing information about their own designs (carbon counting and benchmarking) or through evaluating data collected from construction sites or buildings in use to inform their future design processes (site surveying, algorithmic and statistical processing). A key aspect which is not a focus of current training proposals is a better understanding of new fabrication and erection methods related to offsite manufacture, digital and additive manufacturing, 'Design for fabrication' (group 5, Fig. 3). The fabrication process itself has a significant impact on material properties and what can be achieved in terms of design and erection, and we believe better theoretical understanding of the mechanics of these processes will be important, as well as opportunities to understand from real-life experience what can be altered.

The last grouping of necessary skills for the next engineer is 'Concept communication' (group 6, Fig. 3). This is a route which has been understood as a core skill for engineers for some time, related to an engineer's role as a manager and member of larger design teams. As the role of an engineer develops within a design and construction team, and as engineers gain more prominence in key early decision-making related to the climate emergency, the next engineers will need to be proficient in communicating their concepts to a wider audience. Future communication methods should develop skills such as presenting technical information to non-technical audiences, being equipped to use new visualisation techniques such as augmented reality, as well as explaining the results of large data sets in statistically meaningful ways.

Many of these skills are well-suited to being taught in an academic environment in higher education institutions. However, there are two constraints which limit how this can be done: the limited duration of a training programme—whether that is a degree or apprenticeship—and the available skills and experience of the instructors of the training—whether academic at the exclusion of applied skills, or applied skills at the exclusion of academic. One approach would be to spread the acquisition of the skills of the next engineers over a broader time-period, starting in high school and continuing into early career stages. At the high school level, this would encourage engineers to have a broader educational background, encompassing design and technology, arts and humanities (Isaac & Bergsagel, 2020). This would provide the next engineers with the key skills in communicating and representing information, as well as an understanding of practical construction methods. This would have a direct impact on the 'Data management' and 'Concept communication' skill groupings. The early stages of an engineering career are an excellent opportunity to continue to develop skills in the 'Concept communication' grouping based on real examples of team and client interaction, with the support of engineers with some practise in this field. An earlier focus on computer programming skills at high school could liberate time for teaching other things at university. By spreading the teaching of some of these more general skills over a broader time-period, universities can still commit time to specialisation in technical content streams.

The limited duration of training opportunities also leads to demands of prioritisation of study. The impression is that the standard engineering curriculum is always full, and to allow for teaching, new skills would require removing important topics. Whilst a solution to this is challenging, we would suggest that change is coming. In some instances, re-prioritisation is straightforward, and a focus on new and natural materials could be at the expense of a partial reduction in focus on traditional materials like steel and concrete. The promotion of embodied carbon assessment can be as an alternative to a focus exclusively on weight reduction or simplicity in construction. A shift to using new digital representation techniques can be at the expense of traditional draughting training. Another approach could be to consider the training of the next engineers as a longer process which links across these three learning stages—high school, further education, career—and continues in a structured format into the early stages of a career, not dissimilar to an architectural part II. There is also the opportunity to specialise in a subcategory of engineering earlier, or to extend the academic training stage to be longer than the current 3 + 1 Master of Engineering (MEng) qualification.

4 Existing Workforce

Thus far, we have highlighted the coming changes to the industry and their novelty in the context of the last century of civil engineering practice; we have discussed the range of skills that the next engineers will need to deal with these changes, and we have reviewed which of these changes are already being introduced in the UK, and which can be further promoted in the UK and abroad. However, it is clear that if these new skills are only being introduced into an engineer's training now, the existing engineering workforce which has not received this training will not possess these skills sufficiently and broadly. This will lead to a stratified workforce and will present both challenges that the industry must mitigate, but also real opportunities that the industry can exploit.

The primary challenge of a stratified workforce is the lack of shared experiences between the next engineers trained in these new skills, and the teams and managers that they will join in industry. The existing workforce may not understand how best to take advantage of the new skills set (Wallace & Creelman, 2015); managers may be disheartened when noticing that some previously taught skills and knowledge are no longer covered in an engineer's training. If teams and team leaders are not aware of the value of new skills that embrace Industry 4.0 and address the climate emergency, then the skills will not be effectively applied to help solving engineering team problems.

In addition to a stratified workforce, if training in these new skills is only provided to the next engineers starting today, then there will be a delay of 20–30 years before these engineers are in positions to make informed industry decisions. This generational cycle of knowledge can lead to delays in the industry responding robustly to the external challenges, and slower adaptation could bring long-term degradation to an engineer's position in the design and construction process. Without contemporary leadership, understanding the industry changes and potential application of new skills in response, engineering as we know it could see reduced investment, a loss of influence and job flight into adjacent construction industries, in a manner similar to the collapse of the New England Whaling Industry in the 1860s when faced with international competition, technological development and increased competitor productivity and the advent of petroleum products (Thompson, 2012).

Some reports indicate that the engineering industry is already in decline, with skills shortages and skills mismatches in STEM subjects a recurring challenge in the UK (National Audit Office, 2018). Many business leaders already rank their ability to recruit skilled staff as their number one concern when growing their business (Cappelli, 2019). Ensuring that the next engineers feel welcomed and valuable in an industry which may be out of step with their skills may be crucial.

The mix of young engineers with new skills and older engineers with more traditional skills and knowledge presents a significant opportunity for cross-education. If an atmosphere of mutual learning is fostered, then young engineers can continue their education during their early careers through project interactions with their team members on real design challenges, and older engineers can realise efficiencies and maintain a breast with newly developed technologies and processes (Bersin & Chamorro-Premuzic, 2019). Indeed, with so much technology at their disposal, the next engineers will need assistance and perspective in assessing the appropriateness of the information, systems and technologies at their disposal—whether through the reliability of raw data or the suitability of computational outputs. This will require a deep understanding of engineering principles which can be provided by mentorship with members of the existing workforce.

To avoid workforce stratification and instead achieve workforce stability, a concerted industry effort should be made to ensure that an atmosphere of openness and continuous mutual learning is provided. This can be done in a number of ways:

4.1 Internal Company Training

Large organisations have the resources and facilities to invest in retraining staff, to both understand the impact of the changes in the next engineer's skill set, as well as to promote some of these skills. This can be done through structured learning between new career entrants and existing team and group leaders or through hiring external trainers to facilitate sessions. Companies have incentives to do this to maintain market position and to demonstrate a willingness to adopt new work methods to their new recruits. Indeed, many large consultancies are already beginning to embed aspects of Industry 4.0 in their workflow (Cousins, 2021; Mann, 2018; Rolvink et al., 2010).

However, as much as 80% of the registered engineering enterprises in the UK have four or fewer employees (Engineering UK, 2017). These small businesses do not have research development and continuing development budgets to tackle further retraining, and changes to working methods may be unaffordable or incompatible with the existing staff skill set. Reaching these companies and individuals is therefore essential if the industry is to fully witness the benefits of Industry 4.0.

4.2 New Targeted Continuing Professional Development (CPD)

Smaller enterprises may not be able to organise their own internal training; however, they can take advantage of available CPD to ensure lifelong learning. Learned institutions such as the ICE and IStructE can emphasise these new skills in their training development and promotion to ensure that all practicing engineers understand the importance of these changing skills, even if they are not proficient in them. This emphasis has begun to emerge recently with regards the climate emergency, with the IStructE's commitment to provide freely available technical resources, and the ICE's 157th President Rachel Skinner's focus on Net Zero (Skinner, 2020). In this regard, more can be done to promote Industry 4.0, and we expect to see further development in training packages offered to practicing engineers that provide introductions to key developments in technology and fabrication techniques to allow engineers to stay abreast of new opportunities in design and construction.

4.3 Knowledge Sharing Facilitation

For small and medium enterprises (SMEs) who are unable to provide in-house retraining to their staff, institutions could facilitate sharing of knowledge within the industry by developing platforms and local training forums that are beyond those organised by themselves. This could be in the form of greater incentives for knowledge and skill sharing through grants and awards or through enabling pooling and sharing of resources that allow SMEs to reduce their exposure to risk when investing in new technologies or working procedures. The onus to share knowledge related to tackling the climate emergency should already be familiar to signatories of UK Engineers declare as one of the key commitments of the manifesto.

4.4 A Return to the Classroom

A more structured approach that would allow for the partial retraining and learning of new skills instead of the high-level awareness of them could be provided by longer-term training courses. This could be realised through government funding for intermittent training in a classroom, technical school or university environment. This would allow for a more coordinated adult-learning curriculum to be developed in these new schools and might also provide opportunities to develop closer ties between industry and academia.

Courses which are completed entirely through evening study—such as at Birkbeck, University of London—provide a long-term successful template for managing part-time training (Birkbeck, 2021). The Open University has successfully led the field in distance learning for over 50 years (Open University, 1969); however, previous barriers to online learning have been overcome, and acceptance of online learning has been widely gained by students and society during the COVID-19 pandemic (Lockee, 2021). Training providers that are not directly linked with academic institutions—massive open online courses (MOOCs) such as Coursera or LinkedIn Learning—have seen significant growth in use over the last year as working patterns shifted online (Shah, 2020). Remote learning courses of both academic and MOOC types are expected to expand in number rapidly and may be able to address key topics related to Industry 4.0 and the climate emergency in more depth in the near future.

4.5 Public Acknowledgement

Organisations that respond to the changes of Industry 4.0 and the climate emergency are expected to be rewarded through growth and development in their competitive market. However, in addition to these organic rewards, additional acknowledgement can be provided to engineers that retrain and apply these new skills at a holistic level to new projects through industry awards and accolades. Annual company rankings such as the NCE 100 can prioritise specific technological innovation in design and construction methods and embodied carbon and refurbishment. This process has begun with the new Structural Award categories for Zero Carbon and Minimal Structural Intervention (IStructE, 2021).

If this environment of continuous mutual learning is provided, there are opportunities for more serendipitous effects to come about. When changing the skills of the next engineers and retraining the existing workforce, there will exist more opportunities to retrain engineers from other adjacent industries. New engineers from a diverse range of other industries can reinvigorate engineering through cross-pollination and actively develop the adoption of change. This retraining approach could learn from other industries such as journalism, who bring in staff with specialist skills and knowledge in a certain industry and retrain them to perform journalistic analysis of that industry.

Broadening the potential core training of the next engineers at high school to incorporate arts and humanities may lead to a more diverse range of people becoming the next engineers. This will lead to better representation within the industry and consequently more equal and just decision-making by the industry. As with the infiltration of new skills into the existing workforce with the arrival of the next engineers, this process may take decades. The opportunity to retrain new engineers into the workforce at a later stage in life can provide a shortcut to reforming the workforce to be more representative in the shorter term and to serve as valuable role models for future students considering entering in the industry.

5 Conclusion

Engineering faces two paradigm shifts in civil engineering—the climate emergency and the advent of Industry 4.0—and what we teach future engineers will determine whether the industry is able to adapt to the changing world that we anticipate. The next engineers will be the future operators of the construction ecosystem, but only if they are prepared. If we do not prepare, then we are at risk of being repositioned within the construction ecosystem; as with all ecosystems, organisms that adapt will survive, and those that do not will perish.

This summary of the skills requirements of the next engineers can be considered a broad outline for potential changes to training and curricula that could be adopted throughout the world engineering community and beyond the scope of higher education. These conclusions can be seen as a guide checklist for industry input on engineering education.

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