Paper 47. How is sustainability incorporated into the engineering curriculum? The case of DTU and AAU

Andrés Valderrama, Ulrik Jørgensen, Brian Vad Mathiesen and Arne Remmen

Department of Development and Planning, Aalborg University

afvp@plan.aau.dk

Abstract

Currently, the main concern among engineering educators is how to include sustainability in engineering education. But this is not the first time engineering educators have attempted to bring social and environmental issues into the engineering curriculum. As the point of departure for a discussion of how sustainability can and should impact engineering, this paper examines two different approaches. First, we account for the ways environmental and energy issues were incorporated in engineering education at the Technical University of Denmark and at Aalborg University from the 1970s until today. Environment became a broad societal concern already in the 1960s, and together with energy issues its importance grew during the 1970s into a concern that needed to be addressed in all engineering education. Environment and energy technology became established engineering disciplines on their own, but they tended to focus only on partial and sector-specific technical topics such as water provision, waste and solid waste management, or new energy technologies. Thus, rather than understanding environment as a broader social concern that should be reflected in engineering in general, the dominant conception has been that the environment is nature (outside society). Energy, on the other hand, has been conceptualized as renewable energy and has remained in the physics and electricity-related research groups and departments. Now that engineering educators are focusing on sustainability as a societal concern, we face the same kind of challenge. Is sustainability going to become a narrow set of physical indicators and metrics (emissions, fossil fuel consumption, energy efficiency, temperature increase), or will it be a broader social concern? To further this discussion, this paper then examines how environmental, energy and sustainability issues came into the engineering curriculum at Aalborg University.

1 Introduction

At Aalborg University – as at many other engineering universities – there is currently an internal debate: Should sustainability be a fundamental aspect of all educational programmes or is it something that needs to be addressed specifically? The promoters of the former view believe that it should be a fundamental aspect and thus no single programme should use the notion sustainability in its name. With time, it should become obvious to anybody inside or outside the institution that sustainability is a core value in all educations, just as quality, ethics and service are at the moment (interview with Henrik Brohus). However, several programmes do use the word sustainability in their titles – more precisely, four master programmes and one bachelor in engineering: Master in Sustainable Energy Planning and Management (SEPM); Master in Environmental Management and Sustainability Science; Master in Sustainable Cities (SusCi); and Bachelor and Master in Sustainable Design (SD). All these programmes are offered at the Department of Development and Planning at Aalborg University. How these programmes came into being is a discussion that needs to be understood in the context of a

broader historical development. Which social concerns (social, environmental, safety, energy, health) have been brought into engineering education? In which way do they cohere to a common sustainability perspective? Have they been translated into specific technologies that students should be familiar with, or specific solutions they should be capable of developing; or a set of criteria, methods and metrics that must be used to assess solutions; or a set of skills and competencies for making certain types of developments? Or is something else at the core?

To investigate these questions, we first use a historical approach to account for the ways environmental and energy concerns were incorporated into the education of engineers from the 1970s until the present at two institutions: Technical University of Denmark (DTU) and Aalborg University (AAU). This research has been part of the Project on Opportunities and Challenges for Engineering Education in Denmark, which set out to assess engineering education initiatives, traditions and indicators in Denmark (www.proceed.dk). The project focused on three challenges: the first related to environmental and climate challenges; the second to the increasing complexity of technology (design); and the third to the blurring boundary between science and technology (high-tech: bio-nano).

This article focuses on the challenge related to the widely recognized need for societal responses to resource depletion, environmental deterioration and new energy technologies. We have conducted an ethnographic analysis based on semi-structured interviews with 25 engineering educators at DTU and AAU. We applied the general principles of situational analysis to guide our research choices (Clarke, Leigh Star 2008, Clarke 2005). During our interviews and discussions, we found that environment issues are understood and translated in diverse ways at different times and in different institutional settings, and in the main text, we present the specifics of those translations. We also found however that since the 1970s, environmental issues go hand in hand with concerns about energy supply, and since the 1990s with management issues, production processes and sustainability issues.

The text is organized in three sections: First, we account for how environmental and energy issues were taken up at DTU; second, we do the same with AAU; and third, we go into some detail regarding the contemporary process of bringing sustainability issues into the design of the engineering programmes, Master in Sustainable Cities and Master in Sustainable Design at the AAU Copenhagen.

2 Environment and Energy at the Technical University of Denmark (DTU)

According to Jamison (2013), there are three types of approaches to engineering education: a science-driven approach, where the development is guided by engineering educator's own disciplinary concerns; a market-driven approach, where the contents of engineering education change according to pressures from the market for trained engineers outside academia; and a socially driven approach, where the educators actively translate and incorporate the social concerns that need to be addressed into engineering education, even if they do not have any commercial value to big traditional companies. These approaches are ideal types, often found to be mixed in the histories of specific educational programmes. To organize and present the wealth of material we have gathered on the case of DTU, we use Jamison's typology. Se www.proceed.dk for a chronologically oriented presentation.

The first wake up call to focus on environmental issues was a series of discussions in the Danish Engineer Union (Dansk Ingeniørforening, DIF) in 1964. In four transcriptions of those discussions, the environment was divided into issues related to air, soil, water and chemicals. This approach projected onto nature an elementary view of the natural aspects to be dealt with, even though the origin of these new challenges was from the growth and intensity of production, especially after World War II. In 1972, at the United Nations Conference on the Environment in Stockholm, this view was further

strengthened, and engineers felt the need to take action in order to "clean up the mess" produced by industrial societies. At the same time, researchers who were members of the Club of Rome and at MIT concluded that we were reaching levels of resource use that would deplete the planet in the course of a few years (Meadows et al. 2004).

To attend to these concerns, students, faculty members and administrators at DTU in the late 1960s and 1970s (at that time, Danmarks Tekniske Højskole, DTH) began the first activities to meet the increasing environmental challenges facing the country. The Laboratory of Technological Hygiene, established in the nineteenth century, framed the environment in terms of controlling wastewater. This laboratory's focus was on technical solutions for controlling pollution. The second set of activities was developed at ISVA, which was an institute concerned with how flows of ground water could supply clean water and also prevent contamination of clean water wells. The third activity was focused on food processing and pollution from burning coal and from chemical processes. Professor Østergaard started developing a notable research on burning efficiency for the production of energy and Professor Mosbæk developed a whole set of courses in Chemical Processes and environmental analysis for educating engineers interested in environmental issues. The fourth set of activities was lead by Professor Niels I. Meyer who was initially trained in physics with focus in microcircuit design. He turned his interest to renewable energy production after meeting Donella and Dennis Meadows at a congress in 1972. Professor Meyer was sent to the congress due to his position at DTH as vice president and as president of the Academy for Technical Science.

Unlike American universities and colleges, DTH was not organized in academic units that administrated specific educational programmes. DTH was a collection of many institutes that existed around research agendas. The institutes or laboratories were structured around professorial positions and depended highly on the leading professor. There existed four education programmes (the classic four programmes: Civil, Mechanical, Chemical and Electrical), which were administrated centrally and where faculty members from the institutes taught their subjects according to their particular competences. After 1972, the entire educational curriculum structure was reformed with the introduction of a modular structure, which gave students the freedom to choose elective courses.

The initial steps towards creating a new programme, Environmental Engineering, were taken in the mid-1980s. The programme was launched in 1987 and was headed by Professor Arne Villumsen, who originally appointed professor at Institute of Geology in 1983. His research focused on the contamination of soil and water sources. Prior to this, however, difficult negotiations took place about what should be included in the curriculum. The main aim of creating the programme was to structure some of the activities already being carried out at DTH. Due to an emphasis on operating with already existing courses framed by a science-based understanding of engineering, the focus in the new programme was on the physical environment (nature out there), and issues such as ground water pollution, chemistry, geology and waste management were given priority. The aim was to educate engineers who were better at exploring soil and surface and ground water and cleaning the output.

Not all activities related to the environment were included in the programme. Niels Meyer's developments in renewable energy remained outside. They were located mainly in the Physics Department and were first included only in the education of electrical engineers, but as elective courses. The explanation of these priorities is that the main affiliation of some of the core figures, like Meyer and Villumsen, who were engaged in departments with a strong, traditional disciplinary background that also defined the core of the environmental and energy courses and programmes, were all dominated by an interpretation of the environment within a natural science conceptualization. The management and societal perspectives on the environment remained at the margins in the

environmental programme, because they were perceived as not belonging to the core of engineering competences. These perspectives and topics were represented, however, in a few courses.

During the late 1980s and early 1990s, a different approach to the environment began taking shape at DTU (DTH became DTU in 1994). Due to frustration over the effects of the enforcement of the environmental laws of the 1970s, a number of professional engineers, consultants, regulators and engineering researchers in Denmark and elsewhere began shifting the focus from pollution and emissions as results of companies' production activities, to the origins of these pollutants in the whole production process and how these processes and practices could be improved. A whole academic and social movement was developed around the concept of Cleaner Technology. These activities were translated at DTU into specific research activities, such as Life Cycle Assessment and Environmental Impacts Assessment, which were funded by among others the Ministry of Environment's programmes on Cleaner Technologies and developed at the Department of Production.

This resulted in new research-based courses first developed for the educational programmes in Mechanical Engineering and Chemical Engineering, which also included the teaching of topics within the field of production processes. These courses combined technical subjects on specific cleaner technologies with management courses focused on procedures and practices for improving the ways companies should handle environmental concerns. The disciplines of management and organisation provided scientific support to these new and often more interdisciplinary course activities, combining a technical and social science perspective. A specific educational activity blossomed in the professional, part-time Master of Environmental Management (Teknisk Miljøledelse, TML) programme, which was initiated by research groups organised in the Interdisciplinary Centre and the Unit of Technology Assessment in 1994/95 (later merged with the Social Science Department into the Department of Technology and Society). The TML programme was initiated as a result of the conclusions from a research project funded by the Danish Engineering Union and the Ministry of Environment. The aim of the TML programme is to provide an education in environmental and health issues for employees with more than five years of experience in industry and governmental institutions.

An outcome of the student movements at DTH in the 1970s was the influence they achieved on the university's general planning. Around 1976, students and young researchers proposed a change in the ways the university budget was negotiated. In this way, they broke a tradition of incremental growth completely aligned with existing academic traditions at the university. Instead, a substantial proportion of the new budgets could be negotiated to support the creation of units that would attend to current social concerns. Due to this development and the student influence the Department of Ecology and Environmental Education (Miljølære) was created and led by Professor Finn Bro-Rasmussen. Another called Social Science (Samfundsfag) was established in 1978 and later became one of the components in the Department for Technology and Society. The original role of these new departments was to introduce additional courses to the general modular structure of the educational programmes, but not to organise special new programmes. Their research bases were disciplinary; the one combined ecological perspectives with assessing chemical pollutants and climate change issues, while the other brought sociological and economic perspectives on technology into engineering.

A number of new disciplinary courses emerged from these new research and educational activities, but also questions concerned with the lack of integration and impact on engineering competences and approaches. This led to the creation of temporary units that took specific topics under scrutiny in an attempt to build new, interdisciplinary approaches. The two most important initiatives during the early 1990s were the already mentioned Interdisciplinary Centre (Tværfagligt Center) and the Technology Assessment Unit (Initiativet for Teknologivurdering). The Interdisciplinary Centre was mainly

concerned with the contamination of food in the production process, new strategies for organic food production, and pollution from industry. Its members promoted a comprehensive view of the environment and thus advocated educating engineers in the principles of ecology and organic food, and provided courses based on this perspective. During the 1990s, these scholars also developed courses, research projects and activities in environmental management, cleaner technology, and life cycle assessment. The Technology Assessment Unit was especially instrumental in introducing Science and Technology Studies (STS) at DTU, including new approaches to understanding technology, nature and the foundation of engineering knowledge and practices.

The contributions of these new approaches to the environment as a social concern were given a place in the Environmental Engineering curricula as well as in the Production Engineering programme, but they also remained in a marginal position in relation to the strong disciplinary character of engineering education at DTU. A specific requirement called the AMS points, equal to just a half-semester course, was added to the modular structure and motivated engineering students to take a number of courses within the field of environment and social science. On a general level, this requirement sustained these courses in the general curriculum, but also kept them in the role of add-on activities. Courses like Environmental Management, Environment and Society, Environmental Engineering in the Tropics, and many others became available to students; however, these courses were electives and only one or two became part of the core of the Environmental Engineering programme at DTU.

3 Environment and Sustainability at Aalborg University (AAU)

The several substantial differences in the histories of AAU and DTU have made their developments different and complementary in the small country that is Denmark. While DTU has been a successful engineering and science school and research environment with a long tradition (it was founded in 1829), AAU is a young university (founded in 1974) that combines the spirit of the social and environmental movements of the 1960s and the beginning of the 1970s with the disciplinary traditions of two institutions: the Engineering Academy and the Polytechnic School of Aalborg, which was integrated into the university. The founding idea behind the planning of the new university was to provide the country with a different pedagogical approach to higher education in general, including a stronger focus on the outreach to society and the professions. Three characteristics of AAU are salient to this analysis: the first is that interdisciplinarity was encouraged from the beginning; second, all educational programmes are structured on the basis of a problem-based and project-based learning concept; and third, the structure of departments was organised from the beginning to support interdisciplinary aspects of engineering education and research, as well as educations in other fields. In terms of engineering education, all these aspects provided Aalborg with a competitive advantage in relation to producing business and practice oriented professionals to feed into the dynamic, larger industries in Jutland and Denmark as a whole.

Like many other young universities in the world, the practical educational choice at AAU in the 1970s was to award degrees in engineering, with some small specializations in different topics according to students' choice of project work. Thus, some of our interviewees who were trained at AAU hold an engineering degree with specializations in areas as various as Indoor Environment, Energy Planning, or Environmental Technology. In the 1970s, the new Department of Development and Planning housed mostly surveyors and engineers working on issues of physical planning. but with time it became more interdisciplinary and inclusive, especially with emphasis on planning in the fields of environment and energy with focus on the needs of both industry and government. Teachers and researchers in this department were closely related to and working on issues affecting the local society

and the municipalities in North Jutland, such as agriculture processes; the use of fertilizers and pesticides; contamination of local lakes, rivers and fjords; warming of houses, offices and shop floors and indoor climate in general; infrastructure for water provision, waste-water treatment and solid-waste treatment; and many others. Because the teachers and researchers worked on several such problems, and the students developed their curriculums around these problems every semester, it was practical and economical for the students to be engaged in research. In this way, the traditional barriers handed down through the history of the disciplinary ideas were overcome through institutional design, and an alignment between societal priorities and engineering education was achieved.

This meant, in turn, that Aalborg graduates have been traditionally appreciated for their capacity to find knowledge and solve problems, rather than being particularly well versed and established within academic disciplines. This has also fostered their entrepreneurial capacity and their tendency to innovate in engineering education. Still, some initiatives that grew out of the engineering school that pre-existed the university also had an influence in maintaining a focus on wastewater treatment with the classical technical hygiene perspective, as well as energy educations focusing on specific types of energy machines and their optimisation. In these engineering programmes, the pedagogical reform that focuses on student project learning favoured a focus on societal challenges.

Consequently, during the 1980s, two different strands of engineering educations developed. On one hand, there were the research groups concerned with the technical aspects related to energy and the environment, with focus on indoor climate, sanitary systems, energy technologies, and environmental technology. It could be said that the focus of all these programmes was on technical issues and on the provision of services or end-of-pipe solutions. On the other hand, the scholars at the Department of Development and Planning were concerned with urban, energy and transportation planning, which eventually, during the 1980s, also began to incorporate issues of environmental assessment and strategic planning. In both cases, engineering students were trained in the same basic core competencies of mathematics, physics and design; and thereafter, during their senior year and in what today is equivalent to the master degree programme, they developed special competencies within the fields that research groups could support.

During the 1990s, collaboration between the two strands of engineering outlined above continued, but due to the growth of AAU, both in the number of researchers and number of students, more specializations became possible. Up until around 2002, there were several specializations within this master programme, including Energy, Transport, and Urban and Environmental Planning. Further growth in the number of students, the adoption of the Bologna regulations, and the internationalization of master programmes in Denmark encouraged engineering educators to attract more students. Thus, separate master programmes in Environmental Management, Urban Planning, Sustainable Energy Planning and Management (SEPM) (2004), and Sustainable Cities (2012) were developed.

4 The sustainability challenge and agenda

Sustainability issues have been increasingly studied in both research and teaching activities since the publication of the Brundtland report (Brundtland, World Commission on Environment and Development 1987). However, the reason behind the use of the word sustainability in the name of the SEPM stems from a translation issue between Danish and English. Research and planning in relation to energy systems has always been an interactive activity in Denmark, especially with authorities at the municipal and regional level but also with the ministries and regulatory bodies. Therefore, when the possibility to make separate masters arose, educators sought a translation that captured this interactive character and therefore chose “sustainable energy planning and management”. In this sense,

they differentiated the more participatory Danish type of planning from the more strategic top-down meaning accepted internationally. In addition, the Department of Development and Planning has a tradition for substantial integration among levels and forms of knowledge and project work, which in many ways captures the spirit of what the journey towards sustainability is all about.

Nevertheless, this reflects the basic interpretative flexibility of the notion of sustainability, which does not include, per se, the integration of social, political and long-term issues into the perspective of specific ideas about improved environmental protection, energy systems not based on fossil fuels, or a more interactive planning process. As demonstrated in the historical cases, the content assigned to environment may entail quite different interpretations concerning the competences and knowledge needed by engineers to become environmental professionals, and this is also the case for the use of sustainability as a prefix. It may just cover a specific set of metrics, methods or technically preferred solutions; it may include a broader perspective on how planning can be performed in a more interactive and integrative fashion; or it may raise demands for engineers to be able to analyse societal challenges that include all facets of sustainable change so they are able to navigate, design and give advice on the choice of technologies and how they are to be implemented.

At DTU, like AAU, the management has been keen on inscribing sustainability in the core of their vision and strategy for research and education, but what this implies for the specific demands to programmes in general, to specific educations, and for research priorities remains rather open. In some educational programmes at DTU, as well as at AAU, sustainable is simply added to almost traditional engineering topics to improve their market credentials. In other cases, the perspective is transformed into a basic orientation and interest linked more to student preferences and competition from outside the core educational programme. But what can be identified when the sustainability challenge enters into the core of technological knowledge and the priorities concerning future societal change?

Most recently, a new generation of engineering educators used a window of opportunity to further develop an engineering master programme in Sustainable Cities (SusCi) at AAU. The window was linked to an expansion of the programme at a campus that AAU is developing in Copenhagen. The programme builds on the tradition of integrating knowledge from different disciplines bridging the social sciences and technology at the Department of Development and Planning. One of the arguments for the new programme has been that independent planning activities in isolated sectors are no longer feasible; instead, a cross-sectoral perspective is employed. In addition, cities and urban settings as locus for research and integration have become more and more important – in general economic terms, and also in the literature on transitions to sustainability (Bulkeley & Betsill 2005).

During the process of designing and obtaining accreditation for the Master in Sustainable Cities (http://www.sustainablecities.aau.dk), engineering educators underwent two critical moments. One was the very positive response from the panel of external partners that reviewed the proposal. The potential employers of programme graduates were especially encouraging about the prospect of having engineers capable of integrating and working across sectors, as well as being capable of navigating municipal administrative bodies and national regulations and able to innovate institutionally and technically. The other critical moment was an inquiry from the accreditation bodies on what made this programme an engineering programme and not a social science programme. The argumentation finally relied on maintaining that students would receive training in broader management issues such as resource measurements, climate change processes and urban development, and at the same time become competent in the development and use of modelling tools, such as life cycle assessment, carbon and environmental footprints, eco-design and energy systems. The Sustainable Cities programme is based on a combination of courses presenting existing methods and metrics, including

some of their disciplinary background, in combination with of project and problem-based learning. Its take on sustainability lies in the combination of topics and project assignments that are defined by the professional perspective of engineers working in cross-sector planning.

A further step is the introduction of a new engineering programme beginning in the fall of 2013 with focus on Sustainable Design (SD) (http://www.sustainabledesign.aau.dk). At the core of this programme is the inclusion of different societal actors in setting the stage for sustainable change and broader transitions, which challenge existing technological products, models and systems. This will provide the students with analytical tools to handle the uncertainties, the interdisciplinary and socio-material integration inspired by STS, and the new models and solutions needed as part of their engineering design work. Sustainability within this educational approach is as much a part of the design challenge as the technical products and systems that are to be designed.

5 Conclusions

What is going to happen to sustainability in the engineering education curricula in the coming years? Is sustainability going to become a core value that is integrated in all curricula and therefore not necessary to mention in any name, which is what many educators at AAU want? Or is sustainability going to become a discipline, or maybe better a challenge and an approach to socio-material analysis and design on its own? If it does, will it be a new discipline as narrow in scope as any other engineering specialization – including most notably Environmental Engineering? Or will this be an opportunity to reform engineering education as a whole from the inside? There are no easy answers to these questions, but from an intellectual point of view, it appears that a substantial reform of engineering education towards sustainability requires changes in research priorities, educational structures, accreditation criteria and institutional design. In the meantime, we can conclude from the material gathered for this paper that there are windows of opportunity in the existing institutional and cognitive settings. Particularly in Denmark, at AAU, before the official accreditation authorities, there has been space to innovate with programmes like SusCi and SD, at least at the educational level. The success of these programmes, however, is still to be seen, and a strategy remains to be conceived for scaling up the possible successes to other engineering programmes.

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