ANDRÉS VALDERRAMA, SØSSER BRODERSEN
AND ULRIK JØRGENSEN

4. ENVIRONMENT AND SUSTAINABILITY CHALLENGES TO ENGINEERING EDUCATION IN DENMARK

INTRODUCTION

In this chapter, we discuss the practices of planning for sustainability in engineering education by examining the ways environment and energy and later sustainability issues have been incorporated in the educational programs at the Technical University of Denmark (DTU) and at Aalborg University (AAU) since the 1970s. These are the two most important research universities providing engineering education in Denmark, measured by numbers of programs and students. At these institutions, engineering educators and students undertook a variety of different initiatives covering a range of possible responses: from in practice no response, to the inclusion of new topics, to reforming the structure of engineering programs, to the transformation of the thematic and disciplinary content of the educational programs. These various responses observed at DTU and AAU are also found at other engineering institutions around the world (Sterling, 2001).

How to respond to the sustainability challenges is debated at engineering universities in Denmark as well as in other countries – for example, such questions as: Should sustainability penetrate all educational programs as a fundamental aspect or is it new subject matter that must be addressed specifically through new curricula elements or in dedicated programs (Interview HB, 2013; Segalas et al., 2009). What should engineering students learn in order to be able to cope with sustainability? A comparison of bachelor engineering education competences at three European universities demonstrates how fundamental this challenge is assessed to be in relation to engineering knowledge and practice (Holmberg et al., 2008). It also opens for new perspectives that transcend the top-down approaches that in many fields dominates engineering training (Mulder et al., 2010).

Promoters who view sustainability as a fundamental aspect believe that it provides a new and crosscutting set of values that should explicitly frame all types of engineering activities in line with the existing quality, efficiency, ethics and service provision. It is not clear, though, how these values are linked to specific methods or topics or maybe implicit in the values taught. However, although agreement exists

U. Jørgensen & S. Brodersen (Eds.), Engineering Professionalism, 61–83.

about the need for a general re-orientation of engineering engagements towards sustainability, there are profound controversies over how to do this in engineering teaching and learning.

The discussion of how to respond to the sustainability challenge is in several ways a repetition of similar controversies that started in the late 1960s over how to respond to the environment and energy crisis, which related to societal concerns, formation of new government bodies, and the first global UN conference held in 1972 in Stockholm.

The three sets of challenges – environment, energy and sustainability – are tightly connected in several ways. Mulder (2006) argues that there have been two waves of incorporating environmental issues in Europe's traditional engineering schools: the first has focused since the 1970s on environmental pollution, water issues and energy; and the second wave started in the 1990s when the Brundtland report was taken up at many institutions. This resulted at first in sustainability issues being conflated mainly with traditional environmental issues, but increasingly it has included issues crosscutting impact on growth, inequality and resource use. In both cases, traditional engineering universities have provided more room for specific scientific and technique-oriented research programs such as water and waste management, Life Cycle Analysis (LCA), chemical processes, emission control and so on. In contrast, broader environmental and sustainability issues like environmental justice and social justice have regularly been left out of the engineering curricula, as they do not cohere with dominant disciplines within these educational programs (Mulder, 2006).

The broadening focus on the strategies for the development of new programs constitutes a contribution to the literature on engineering education and sustainable development that has otherwise focused in discreet courses (Kamp, 2006) and on incorporating sustainability in single existing programs (Chau, 2007; Costa & Scoble, 2006). Whole institutional initiatives that incorporate sustainability in all university programs (Kamp, 2006; Mulder, 2006), requirements for incorporating sustainable development in the education of engineers (Barry, 2007; Sterling & Thomas, 2006), and focus on learning through problem- (and project-)based learning (PBL) (Kamp, 2006; Mulder, 2006) have been part of this development. In this chapter, we present the methodological approach behind the research. Then, we account for how environmental and energy issues have been taken up at DTU in the practices of education and in the organisation of research, followed by the parallel, but also rather different practices carried out at AAU. To be able to trace the practices, we focus on codes of meaning and translations. This leads to a discussion of how especially AAU has been incorporating new educational programs and practices as a response to sustainability issues. Finally, we discuss the different responses and disciplinary practices within engineering, when confronted with the new societal challenge of sustainability.

METHODOLOGICAL APPROACH

To investigate response practices, we have conducted a historic study of how educators, managers and students at DTU and AAU, during a period from the 1970s to the 1990s, exhibit contrasting practices concerning the changes in educational programs and the structuring of research. The chosen period represents the first wave of responses to the environmental and energy challenges that during the 1970s were regarded as a societal crisis concerning pollution and depletion of resources. This serves as background for the analysis of contemporary controversies and response practices that reflect the second wave, which deals with the sustainability challenge initiated since the 1990s.

Our methodological approach builds on two developments in the anthropology of science, technology and engineering, which put forward the following two concepts: codes of meaning and translation. Engineering educators react to internal institutional signals and outside contextual developments by developing educational projects (courses, modules and entire programs). These are ‘codes of meaning’ (as suggested by Downey & Lucena, 2004) in the sense that they are complex objects that propose particular ways of coupling knowledge, institutional arrangements, students’ interests, research results, future expected work demands and institutional and disciplinary traditions. Therefore, codes of meaning are not stable objects but the result of several translations. According to this view, translations are understood as proposed by Callon (1986, 2004) as the process by which actors are interested, enrolled and mobilized to support a given initiative or code of meaning. Therefore, a given innovation in education, for example the idea of educating engineers in the fundamentals of ecology, is not merely a proposal to train future engineers in a particular body of knowledge. It is also a proposal to re-think what kind of knowledge engineers should be able to command; how they should be trained; what their role in society is; and how the institutions that train them should evolve. Depending on the ambition of the proponents of a given initiative, engineering educators have to interest, enrol and mobilize others, such as the head of the department in which they work, the committee responsible for a specific educational program, the accreditation bodies, influential external partners, or sometimes all of them.

These processes are not only about creating new alliances between existing actors, however, but also about interrupting relations and even challenging established or competing codes of meaning. For example, those who proposed training engineers in the fundamentals of ecology challenged the idea that engineers’ core disciplinary foundation should only be mathematics and physics.

Thus, our methodological approach builds on the theoretical developments of ethnographical and historical accounts of engineering cultures. Following Downey and Lucena (2004), we consider engineering educators not as passive agents that react to external social influences or to institutional top-down strategies.

Instead, engineering educators are active academic entrepreneurs who, through their practices in teaching and research, develop new engineering knowledge and curricular contents. These dynamics are what was characterized in the PROCEED project as response strategies. This project provided the funding and intellectual environment (see the introduction to this book) with its focus on how institutions, scholars, staff and students responded to the external pressures and challenges. The focus on practices led us to look into these actual responses and what they entail by framing challenges and engineering training instead of searching for a specific and essential identification of the challenges.

DTU and AAU have quite contrasting institutional and educational profiles. DTU, founded in 1829, is a traditional science-oriented engineering institution with strong disciplinary programs and ties to research-oriented industries in Denmark as well as internationally. AAU is a younger university, which also covers social science and humanities with a cutting-edge pedagogical approach where all educational programs incorporate problem- and project-based learning (PBL) as a principle, and where interdisciplinary education is the norm rather than the exception. Since its founding in 1974, AAU's engineering research groups and teaching programs have developed strong ties with the traditional product-oriented industries as well as fast-changing engineering industries, including small and medium-sized businesses (Jamison, 2012).

The historic analysis of the responses in the fields of environment and energy builds on semi-structured interviews with 25 engineering educators at DTU and AAU (carried out during the period 2011–2014) combined with document analysis. We applied the general principles of situational analysis to guide our research choices. We selected the interviewees using a snowball technique to identify relevant sources based on the first interviewees, and we completed the sample according to the saturation principle (Clarke & Leigh Star, 2008; Clarke, 2005).

The contemporary responses to the sustainability challenge are based on curricula documents, participant observations by the authors involved in the processes at both DTU and AAU, and four complementary follow-up interviews with actors involved in the sustainability discussion.

THE EMERGENCE OF ENVIRONMENT AND ENERGI AT DTU

One of the first 'wake up calls' in the Danish engineering field to focus on environmental issues was a series of discussions in the Danish Engineers Association (Dansk Ingeniørforening) in 1964. In four transactions presenting those discussions, environment was divided into issues related to air, soil, water and chemicals (one transaction for each of these items). In 1972, at the United Nations Conference on the Environment in Stockholm, these challenges were given international articulation and were further strengthened, making engineering professionals feel 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 at MIT concluded that the world was reaching a level of resource use that would deplete the planet in the course of a few years (Meadows et al., 2004). These attempts at framing environmental issues inscribed themselves within a code of meaning that conceived of the world as a set of physical elements to be handled by way of careful measurement, modelling and technical intervention.

To attend to these concerns, students, faculty members and administrators at DTU in the late 1960s and 1970s began the first activities to meet the increasing environmental challenges facing the country. The Laboratory of Technological Hygiene, which was established in the late nineteenth century and framed the environment in terms of controlling wastewater, began to take up new courses to broaden their scope from sanitation to environmental pollution. Prior to the reframing of focus, the Laboratory focus had merely been on water: *It was all about water in and out of urban areas – how do we get clean water, how do we treat it, how do we get rid of the water, including rain water, and how do we treat it* (Interview PK, 2012). The reframing the Laboratory's focus meant that the focus also began to include aspects of *...chemicals, metals, effects in the environment, human health not only related to bacteria and waste* (Interview PK, 2012). Nevertheless, the focus was on controlling pollution rather than means of prevention.

The Department of Fluid Mechanics and Water Constructions, an institute concerned with how water flows in general, began broadening its focus with how the flows of ground water could supply clean water and also prevent contamination of clean water wells. Another set of activities was conducted at the Chemical Department on the burning efficiency for the production of energy; at the same time, they developed a whole set of courses in Chemical Processes and Environmental Analysis for educating engineers interested in environmental issues. The professor in charge of this department had the perspective *that chemical engineers should learn about the effects on the environment with a focus on chemicals, chemical production and its effects. They also focused on non-urban issues; ecology* (Interview PK, 2012). PK, who was a student during this time, mentioned that during this period a disagreement existed between the Laboratory of Technological Hygiene and the Chemical Department, *because they had very different opinions about what was important when working with the environment* (Interview PK, 2012).

These activities all strengthened the code of meaning within existing domains of engineering knowledge and professional practices related to waste water handling, supply of fresh water, efficient use of fossil fuels, and chemical processes with emphasis on pollutants.

However, another new topic was introduced by a professor of physics after a visit to the system dynamics group at Meadows in the US. He started research and teaching in renewable energy. In contrast to earlier, teaching of these topics introduced a new perspective on energy compared to what had hitherto been included in mechanical, electrical and chemical engineering covering only specific energy technologies and fuels. The outlet for these new perspectives were new disciplinary elements presented in new as well as existing courses. Energy savings and systems teaching were the fields that introduced the most radical new elements (Interview JH, 2013). These new perspectives gave rise to conflicts at DTU, since at this time, becoming engaged in societal challenges was interpreted as being political. *At DTU, the rules of the game are that you don't interfere with politics. You are a scientist and you keep to science. I was accused of doing politics. My colleagues didn't like that. It is different now because people realized that DTU has something to do with society* (Interview NM, 2013).

At that time, DTU was organized in departments that cohered around research agendas defined by professors and depended highly on the leading professor. During this period, four classic engineering programs existed: Civil, Mechanical, Chemical, and Electrical (Jørgensen, 2007). Administrated centrally by study boards, faculty members from the departments were requested to teach their subjects according to their particular competences. Parallel to the dramatic increase of new topics, the entire educational curriculum was reformed in 1972 with the introduction of a modular structure, which gave students the freedom to choose elective courses and created room for an expansion of the number of topics and courses offered by the different departments. This educational reform also made the creation of new experimental courses much easier, and gave the students room to organize their own project activities as long as they could engage teachers as supervisors.

Engaged students wanted more than just the possibility of choosing between existing courses or adding their own project assignments. An outcome of students' active engagement at DTU, in collaboration with the broader student movement, was the Danish legislation of 1973 giving students mandates in the governing bodies of universities. Around 1976, a group of students and teachers engaged in the management board at DTU proposed a change in the university's budget management that broke with the tradition of incremental growth completely aligned with existing academic traditions at the university. Instead, a proportion of the new budgets could be negotiated to support the creation of new units of research and teaching that would attend to current environmental and social concerns (Interview JH, 2013). Due to this development and the students' influence, the Department of Ecology and Environmental Education (Miljølære) was established. *It was the students who asked for Miljølære. It was then when students had something to say, had influence* (Interview KC, 2013).

Established in 1978, the Department of Social Science (Samfundsfag) aimed to provide engineering students with a better understanding of technologies' role in society. The initial role of this new unit was to introduce additional courses to the general modular structure of the educational programs, but not to organize new special programs and specializations within engineering. The research bases were disciplinary; one combined ecological perspectives with assessing chemical pollutants and climate change issues, while another brought sociological and economic perspectives on technology into engineering. The novelty of these initiatives is that they enforced demands and challenges articulated in the broader societal discourse over engineering education; and in this way, they departed from tradition: they challenged the instrumental engineering fields.

The two new departments (Dept. of Ecology and Dept. of Social Science) introduced new codes of meaning to engineering education that were not present within the existing departments and the dominant engineering domains of practice. The one was the crosscutting concern with environment as ecologies that also impacted climate, going beyond the separation in traditional media of pollution: water, soil and air. The other was the engagement of engineers through technologies with the social structures of society. These academic units grew and matured during the 1980s.

A number of new disciplinary courses emerged from these new departments. A specific requirement called the AMS points, equal to just a half-semester course load, was added to the modular structure and motivated engineering students to take a number of courses within the field of environment and social science. While the title of the Social Science department does not at first point to environmental or energy issues, the department soon became involved, not only with social impacts of technological change, but also questions of technology governance and economic issues in relation to pollution and resource use.

A NEW ENVIRONMENTAL ENGINEERING PROGRAM

An initial step towards creating a new educational program in Environmental Engineering was taken in the mid-1980s. It was initiated by the then pro-rector, because *we thought of doing something more formal and organized. We structured some lines of study, which were more aligned with students' needs. This was the background for structuring something in relation to environment education* (Interview KC, 2013). Even though there was a *conflict between the technicians and the more societally oriented* (Interview KC, 2013), the decision was made to establish the new Environmental Engineering program in the renamed Environmental Department, which had a long history with origins in the traditions of sanitary engineering, water engineering and soil pollution. The new program was launched in 1987 and was headed by a professor in engineering geology who was appointed in 1983. Besides teaching geology, his research was focused on the contamination of soil and water sources. The preparation of the program included difficult negotiations about what should be included and not included in the curriculum.

The main aim of creating the program was to structure some of the activities and courses already framed by a science-based understanding of engineering: *The art was to combine these (existing courses)* (Interview AW, 2013). This resulted in a focus 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 as well as surface and ground water and cleaning the waste water. They should have a background in natural sciences and at the same time be able to solve specific environmental problems.

The departments involved were dominated by the code of meaning that implied 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 program, because they were perceived as not belonging to the core of engineering competences. *Maybe we should have given more space to other aspects such as planning, but they were, I don't think we were ready to take that at that time – it was not considered to be really engineering* (Interview AW, 2013).

This meant that teaching covering societal and planning issues remained courses the students could choose as part of their AMS points. But also teaching within renewable energy remained outside the environmental engineering program. This also meant that students, scientists and professors who did not subscribe to a separate track on the environment, but rather to understanding the environment as part of broader societal issues, problems and developments were excluded from the negotiations regarding the Environmental Engineering program.

OTHER INITIATIVES AT DTU

Parallel to these institutional responses, questions concerned with the lack of integration and impact of societal issues and challenges on engineering competences led to the creation of additional but more temporary units (centres), which took specific topics under scrutiny in an attempt to build new interdisciplinary approaches as alternatives to departments' single-discipline portfolios. The two most important initiatives during the early 1990s were the Interdisciplinary Centre (Tværfagligt Center) and the Technology Assessment Unit (Initiativet for Teknologivurdering).

The Interdisciplinary Centre was mainly concerned with food contamination in the production process, new strategies for organic food production, and the overall pollution from industry by examining the lifecycle of materials and products. 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), including new approaches to understanding innovation, the history of technology and the relation of technology to society and nature; and in this respect also the study of transport systems and hygiene as well as the foundations of engineering knowledge and practices.

In the late 1980s, DTU was inspired by the first year's basic education established at Aalborg University from 1974 to organize the first years' curricula in topical teaching packages, still maintaining the modular and elective principles of the education programs. One of these packages focused on environmental issues. Another focused on energy systems and renewable energy (the Energy Package), offering students a coordinated set of courses and a project assignment that focused on energy issues. This new model for the introduction to engineering was terminated after some years however (Interview MG, 2013).

During the late 1980s and early 1990s, a different approach to the environment began taking shape at DTU. Due to frustration over the lacking effect of the enforcement of the environmental laws introduced in the 1970s, a number of professional engineers, consultants, regulators and engineering researchers in Denmark and elsewhere engaged in developing new codes of meaning related to the scope of environmental engineering. They began shifting the focus from pollution and emissions resulting from 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, and numerous projects and evaluations were carried out at both DTU and AAU, funded by the Danish Environmental Protection Agency (DEPA) (Interview MSJ, 2013). The most significant project in terms of funding was EDIP (Environmental Design of Industrial Products), which covered specific research activities such as Life Cycle Assessment (LCA) and Environmental Impact Assessment (EIA). Due to the new focus on industry and management, these topics were developed at the Department of Production and not the Department of Environmental Engineering.

In addition, topics of environmental management and environmental economy were developed at the Department of Technology and Society (a merger of the two temporary units and the Social Science Department). The department provided scientific support to these new and often more interdisciplinary course activities, which integrated technical and social science perspectives. The department also developed a professional, part-time Master of Environmental Management (Teknisk Miljøledelse), which was launched in 1995. The aim of this program was to provide an education in environmental and health issues for employees with more than five years of experience in industry and governmental institutions (Interview JH, 2013).

Summing up, at DTU all the activities related to the old sanitary engineering research group on water provision and wastewater treatment became over time the core of the Environmental Engineering Department and its education program. Other activities, which addressed environmental issues as an integral part of production, organizations and society at large, remained outside the framework of the Environmental Engineering program. 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 never a core part of the Environmental Engineering program at DTU.

The perspectives of environmental management, product design, life cycle assessment and production were further developed within the programs of mechanical and production engineering. In addition, the perspectives of renewable energy were excluded in the Environmental Engineering Program. The explanation for this seems to be that environment is translated into being 'the nature out there'. This reflects the strong impact of existing codes of meaning maintained through the departmental organization of disciplinary knowledge. While the main focus on environmental issues remained within the framework of pollution (especially water-related), some new field of engineering concerns and domains of practices entered the realm of production and management engineering. As a general concern, the environmental discourse remained a topic for specific courses and a single, specialized educational program, but it did not enter the engineering educational programs at large as a crosscutting subject that was first introduced with the Department of Ecology and Environment. A broader ecological perspective did not survive as a separate department and even not as a prioritized disciplinary topic. Nor did the broader focus represented by the Social Science Department on societal perspectives of technology survive. These subjects, which had a crosscutting perspective linked to specific engineering challenges and competences, appeared over time to become subsumed into the perspectives established within specific codes of meaning related to engineers' instrumental problem solving. The actual result was that these new departments were not able to survive at DTU in the longer run. Instead, these new groups of researchers and their teaching were re-located into more well established fields of engineering such as on the one hand, management and product development with a focus on industry (private sector), and on the other, the handling of pollution and waste water in relation to public works (public sector) and engineering consultancy and construction. Still, a few general courses about the role of engineering in society were maintained to raise environmental issues, thus demonstrating that they are a general concern for engineering.

Our argument is that the tradition of disciplinary dominance was re-enacted at DTU as the code of meaning for engineering, as the science concerned with measuring and modelling natural resources and impacts was successfully up-scaled. In contrast, the codes of meaning related to social issues were located within the perspective of management or remained as single elective course activities that remained at the margins of the formal engineering curricula.

ENVIRONMENT AND PLANNING AT AAU

Due to several substantial differences in the histories of AAU and DTU, their developments have differed but are also in some aspects complementary. While DTU has been a school for engineering science and a research university with a long tradition (founded in 1829), AAU is a relative young university (founded in 1974) with a full academic program, even though dominated by the engineering faculty. AAU combined both the spirit of the social and environmental movements from the beginning of the 1970s with the disciplinary traditions of two existing polytechnic institutions: the Engineering Academy and the Polytechnic School of Aalborg (Christensen, 2000).

The founding idea was to expand access to and capacities of universities by building new regional universities that also provided academic educational programs with a different pedagogical approach, including a stronger focus of the educational training on outreach to society and professional practices. When completely new universities were started, the Danish student movement used the opportunity to become involved in changing the academic educational tradition with its focus on lecturing and disciplinary knowledge. This resulted in strong influence on the visions of AAU and its learning principles – an influence that later also lead to improvements and changes at DTU, as illustrated in the previous section (Interview JH, 2013). Four characteristics are salient in this respect: (1) interdisciplinary approaches were encouraged from the beginning; (2) educational programs included a problem- and project-based learning concept (PBL); (3) programs started with one year of basic education for each faculty; and (4) the structure of departments was from the beginning organized in cross-disciplinary units that were supposed to evolve through organic changes and support interdisciplinary aspects of engineering education and research, as well as interaction with other academic 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 larger industries in Jutland and Denmark as a whole. After an initial period of scepticism toward the new learning concepts, employers in Danish industry welcomed the graduates from AAU.

Like many other young universities, the educational practice at AAU in the 1970s was to award engineering degrees with specializations in different topics according to students' choice of project work. Thus, it was possible to earn an engineering degree with specializations in such various areas as Indoor Environment, Energy Planning or Environmental Technology, while the classic engineering programs in Sanitary Engineering and Energy Technology also continued to exist.

The Department of Development and Planning at AAU was established in 1974. It hosted mostly engineers working on issues of physical planning, including Surveying. With the founding of AAU, this was moved to Aalborg from the Royal Agricultural and Veterinary School in Copenhagen for the deliberate purpose of adding social science perspectives to the hitherto rather technical curriculum. This was a result of the Danish municipality reform in 1970 and the subsequent legislation on spatial and infrastructure planning (Christensen, 2000).

With time, this department became more interdisciplinary and inclusive, especially with emphasis on a more comprehensive approach to planning in the fields of environment and energy with focus on the needs of both industry and government. Its roots in spatial planning had been setting its course with an emphasis on the role of legislation and public sector planning; consequently, it has played an important role in grounding the codes of meanings established, also when it comes to the variety of new topics that were taken up by the department in the following decades.

From 1980, changes accelerated as the one-year basic education in engineering at AAU aspired to a crosscutting introduction to issues concerning the role of technology in society and the environmental challenges. These topics were formally part of the curriculum from the university's very first days, but were most often secured through the students' choice of topics that required a societal perspective for their project assignments. To support supervision and provide introductory lectures, new staff members were employed who were competent in these emerging topics. As we found at DTU, the technical disciplines at AAU took up new technical issues and priorities following the emergence of new environment and energy technologies. This also implied a broadening of the classic idea of planning, from its focus on land use, cities, and infrastructures to more specific topics related to the emerging societal challenges from environmental pollution, water use issues, cleaner technologies in industry, and new renewable energy technologies and systems.

By institutional design, the Planning Department became fertile ground for the up-scaling of new codes of meaning in relation to the issues engineers should address as professionals. These new codes of meaning included a stronger mix of technical and social issues as planning became increasingly understood as the capacity of engineers to influence decisions and projects in established and emergent institutions, rather that just providing technical support.

The open structure of large departments made it possible to establish new disciplinary groups such as FATS (Faggruppen for Teknologi og Samfund) in 1982. This group was instrumental in organizing the introduction to issues concerning the societal use of technology and the impact of technology on society and environment (Interview AR, 2015). The argument was that *... without a critical reflection of society it is not possible to explain the exploitation of humans and nature that the development and use of technology leads to ...* (Müller et al., 1984:21).

Teachers and researchers in the new department, as well as at the existing more classic department that focused on sanitation engineering, related closely to and worked on issues affecting the local society and the municipalities in North Jutland, in line with AAU's outreach principles. These topics included agriculture processes; use of fertilizers and pesticides; contamination of local lakes, rivers and fjords; heating of houses, offices and shop floors, and indoor climate in general; infrastructure for water provision, wastewater and solid-waste treatment; and many others (Interview KI, 2013). Because the teachers and researchers worked on such problems, and the students developed their curriculums around these problems every semester, the students became engaged in practice-oriented studies/research that also included consultancy and client-related work experiences. In this way, the traditional separation of teaching and research disciplines from engineering practice domains was to some extent overcome – or at least reduced – through institutional design and an improved alignment between societal priorities and engineering education.

This meant, in turn, that Aalborg graduates are appreciated for their capacity to search for and identify new knowledge and solve problems, rather than for being particularly well versed and established within traditional academic and engineering disciplines (Interview TP, 2013). This has also fostered their entrepreneurial capacity and their ability to step into the practice of engineering firms and consultancies more easily than is often the case with new engineering graduates. Still, some initiatives that grew out of the engineering school that pre-existed at the university also had an influence in maintaining a focus on wastewater treatment with the classical technical hygiene perspective, as well as energy educational programs focusing on specific types of energy technologies and their optimization. In these parts of the AAU engineering programs, the pedagogical reform has provided understanding of contemporary challenges and practices within existing engineering endeavours.

During the 1980s, two different strands of engineering educational programs developed. On the 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 technologies. The focus in these programs was on technical issues and on the provision of services or end-of-pipe solutions, as in the case of wastewater handling. These programs followed an engineering science tradition, but focused on new challenges like renewable energy technology and low-energy buildings.

On the other hand, the scholars at the Department of Development and Planning became concerned with urban, energy and transportation planning. In both cases, engineering students met the same core engineering topics, including mathematics and physics (Interview AR, 2015). Thereafter, during their graduate years and in what is equivalent today to the master degree program, they developed special competencies within the fields that research groups could support.

A restructuring in the department also reflected the focus on planning. In 1986, the Energy and Ecology group was established as a spin off from the FATS group and the new staff hired to meet the demand from growing numbers of students. Later, in 1989, the Cleaner Technology group was added (Handberg, 2014). The creation of the Energy and Ecology group reflected the emergence of grassroots-based experiments with renewable energy; the establishment of the first wind turbine industries resulting from energy crisis in 1973; the critique of nuclear power; as well as the involvement of academics from AAU and DTU since the mid-1970s in alternative energy strategies. This development is illustrated by the first alternative energy plan for Denmark from 1976 (Meyer, 2000; Sørensen et al., 1976). The Cleaner Technology group reflected the changes in environmental governance that led to law enforcement to engage companies in proactive environmental protection. It was also engaged in turning government's cleaner technology focus from industrial processes to an increased focus on product regulation and design standards, including energy efficiency and reduced material consumption and pollution.

In their own understanding, many of the educational programs within the engineering science tradition are interdisciplinary, since they deal with several different engineering disciplines and in this way apply a solution-oriented approach that mirrors how the problems are perceived in the practical world. A general viewpoint is that working with problems from practical settings makes it necessary to work across traditional engineering disciplines and have an interdisciplinary understanding, both in the students' project work and in research. This viewpoint among the staff at the Department of Development and Planning goes further to emphasize the inclusion of societal perspectives and social science (and topics from the humanities) as a precondition for interdisciplinary research. Still, the grounding of research engagements and projects and the problem definition outset for students' project assignments must come from practical problems that transcend the traditional borders between disciplines at different faculties. This was reflected in the curriculum initiative taken in the late 1980s with the Planning Year, which received students from both the social sciences and a few different engineering programs, though mainly civil engineering. This is partly also the case with the specialization in International Technology Planning from the early 1990s, which gave students the opportunity to apply engineering knowledge in an international context – quite often in developing countries – taking up the use of cleaner technology in production or environmental assessments in industries and areal planning (Handberg, 2014).

Specializations within the single master program in Planning were especially due to the students' own projects. They included choices related to energy, transport, urban and environmental planning. Except for the Surveyor program that was run by the Department of Development and Planning, all other teaching obligations had hitherto been organized around course contributions, supervision and the mentioned specialization years. Further growth in the number of students, the adoption of the Bologna regulations, and the internationalization of master programs in Denmark encouraged engineering educators to attract more students. Thus, after a few years, separate master programs in Environmental Management (2000), Urban Planning and Management (UPM) (2000), Sustainable Energy Planning and Management (SEPM) (2004), and Sustainable Cities (2012) were developed. These programs were all taught in English and gave Danish bachelor students the opportunity to become part of an international study environment that in the beginning attracted students from several continents, and later on mainly from Europe, due to the restrictions of overseas students set by the Danish government. The significant participation of students from Asia and Africa in the beginning was also due to the established collaboration with universities in Thailand, Malaysia and South Africa within the Danish University Consortium for Environment and Development – Industry and Urban Areas (DUCED-IandUA), a program that also included the participation of the social science and environment departments at DTU.

Until 2000, the Department of Development and Planning was related to both the Faculty of Social Science and the Faculty of Engineering, which formed a platform for several interdisciplinary research projects and educational programs between social science and engineering – also partly including traditional subjects from the humanities such as history of technology. Motivated by AAU management's wish to streamline the faculties organizationally and due to its size, the department was split into three in 2000. One group of academics went to the Social Science Department; a new Department of Architecture and Design was formed leading to the creation of a new educational program in Architecture and Design; while the largest group of academics continued in the Department of Development and Planning. These departments were now located solely under the Faculty of Engineering, although several research groups still had and recruited professors and other researchers with a social science background. Without changing the strategic focus on interdisciplinary cooperation, AAU reverted to more traditional divisions based on faculties (Handberg, 2014).

In short, the institutional design of AAU has provided a favourable selection environment for the up-scaling of different kinds of codes of meaning, especially those that are more interdisciplinary within the traditional engineering fields, but also across other disciplines. These institutional environments have also allowed the creation of programs that address energy and environmental issues from a planning and modelling perspective that includes aspects from social science in the educational programs and engages students to work with contemporary societal challenges. The dominant code of meaning has still been in favour of a societal and company-planning perspective, emphasizing assessment methods, governance and modelling as the disciplinary outcomes.

FINDINGS CONCERNING THE UPTAKE OF ENVIRONMENT AND ENERGY

At both DTU and AAU, the uptake of environment and energy topics has resulted from the challenges to society recognized from the 1960s and onwards. Engineering has become a far more diverse and multifaceted endeavour. This development has led to the inclusion of a number of new educational programs and a focus on environmental challenges and energy issues of savings, optimization and modelling as new disciplines. At the same time, the institutional responses show rather different patterns and demonstrate the influential role of differing codes of meaning among the existing staff as well as the structure of educational programs and departments. These codes of meaning have staged the institutionalization of the challenges and the translation of the challenges into specific disciplines and matters of concern. Over time, they have also framed the translations of topical approaches as well as prioritized which formal, departmental structures were able to survive.

At DTU as well as at AAU, the energy challenge has been translated into a much stronger focus on renewable energy technologies like wind turbines, biofuels, solar cells etc. Parallel to this, a new discipline of energy system modelling has also emerged. Both cases replicate classic engineering codes of meaning assigned to technical objects and the use of models as the way to represent the need for coping with future changes. While an aspect of the focus on energy savings has become integrated into existing engineering disciplines within building construction, optimization of products, processes and machines etc., only at AAU has it survived as an interdisciplinary engagement that combines technical innovation with an engagement in household practices, policies and standardization. The early, common engagement in energy governance and public involvement is transformed at DTU into a focus on energy networks and systems, while the broader focus at AAU on planning and social sciences has maintained an interest in understanding practices, ownership and involvement.

Different patterns, resulting from existing institutional structures and codes of meaning, have emerged concerning the translation of environmental challenges. DTU responded to the environmental challenge with a perspective based on engineering divided between dealing with waste handling and the cleaning of water and soil based on public sector obligations and investments – classic emission-related topics. In addition to this, a rather different focus has developed in relation to improving processes in production and product development on other approaches dominantly relating to industry and the private sector. Existing disciplinary approaches from either chemical and sanitary engineering or from manufacturing and management engineering have proved to be dominant. The environmental challenges were translated into either a focus on pollution and waste handling (a reactive approach to environmental change) or a focus on improved products and processes of industrial production, followed by an involvement with environmental management in companies.

In comparison, while the translation at AAU also demonstrated the classic waste-handling dimension, due to the dominant and already existing focus on societal planning and this field's interdisciplinary grounding, there has been a stronger focus on the social and governance processes. This brought the institutional and organizational aspects of environmental protection to the fore and gave priority to communication and strategic assessment tools like EIA (environmental impact assessment) and product standards and legislation. It also emphasizes the study of consumption practices and how these can be made objects of change, as well as a focus on reuse and recycling strategies.

SUSTAINABILITY CHALLENGES AND RESPONSES FROM DTU AND AAU

Sustainability, as a broader issue than environment and energy, has gained attention in research and teaching activities since the publication of the Brundtland report (1987). The notion has not least become a core part of the climate challenge debate with its deliberate take on multiple and conflicting goals covering not only the environment/energy challenges, but also balancing these in relation to local and global economic, social and influence/equity challenges. However, the meaning of the notion of sustainability and its conflicting elements is contested. When used as a qualifier in relation to educational programs, it is quite important to identify the more specific meanings applied and how they are translated into educational topics and practices.

No doubt most universities today have a reference to sustainability in their strategies and visions – sustainability has become a dominant discourse, an 'obligatory passage point', for universities to demonstrate their commitment to contemporary societal and climate challenges (Christensen et al., 2009). While this may be valued from a rhetorical point of view, it still does not tell us much about what this generalization and broadening of societal challenges does to engineering and educational training.

DTU's current strategy states: "DTU's educational programs must be designed so that sustainability is an integrated part of all programs. Also, all students have to accomplish curriculum elements that provide skills in innovation and entrepreneurship" (DTU, 2013). Similarly, at AAU, the new strategy states that AAU is "hosting a prestigious UNESCO centre for Problem Based Learning in Engineering Science and Sustainability" (AAU, 2015). In both cases, no further guidelines or learning goals are established for how to meet these visions. At DTU, there is already a glitch in the wording that turns the focus from sustainability to more classic engagements of engineering with innovation and entrepreneurship. Attempts to produce common guidelines for the 'integrated part' has failed so far, not least due to the concern with 'watering down the technical competences of engineers'. The result is that these topics tend to end as extra-curricular activities, for example at DTU in the 'Green Contest', where students can take study projects outside the grading system and enter them to win a prize. At AAU, the expectation is that this obligation is covered by the introduction to PBL principles, which includes taking outset in societal challenges in the problems to be solved. In the current interpretation, this includes issues of sustainability – which at best results in current debates being reflected in the students projects, because these introductions have no room for further qualification.

Aside from these general but limited references to 'sustainability', this notion appears in the titles of a few educational programs. At DTU, sustainability appears only in one master program that focuses on 'Sustainable Energy', while environment still appears as mentioned earlier in the Environmental Engineering program title. This program has its focus on energy systems, and the reference to sustainability is motivated by the program's topical focus on sustainable energy technologies, which implies that the notion refers to features of renewable energy technologies: biofuels, fuel cells, wind turbines and thermal energy per se, due to their potential reduction of climate impacts.

At AAU, the master program in Environmental Management had its name expanded to include Sustainability Science (EMSS) after a couple of years in order to give more attention to the social dimension of sustainability. Another relevant example is the reason for using sustainability in the name of the Sustainable Energy Planning and Management (SEPM) program from 2004. Research and planning in relation to energy systems has for several decades been an interactive endeavour in Denmark, especially involving grassroots movements and authorities at the municipal and regional level, as well as ministries and regulatory bodies. Even the new trends to construct markets for infrastructure services build an interactive model of governance. Therefore, when the possibility to make separate master programs arose, educators sought a translation that captured this interactive character and chose 'sustainable energy planning and management'. At the same time, they opened their energy systems model focus to include institutional aspects of how the energy infrastructure is structured. In this sense, the use of 'sustainable' differentiated the Danish type of participatory planning from the strategic top-down planning, which is popular in other parts of the world. In addition, as already mentioned, 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 (Interview HL, 2013). In addition, a program in Sustainable Biotechnology was initiated with emphasis of biotechnical refining of substances and materials as the motivation for using the notion of sustainability. This again mostly refers to the environmental expectations related to the technology.

Recently, a new generation of engineering educators used a window of opportunity to develop an engineering master program in Sustainable Cities (SusCi) at AAU. The window was linked to an expansion of AAU with a new campus in Copenhagen. The program 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 program has been that independent planning activities in isolated sectors are not feasible in the long run. Instead, a cross-sectoral perspective must be developed. 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 et al., 2010).

During the process of designing and obtaining accreditation for the Master in Sustainable Cities, 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 program graduates were especially encouraging about the prospect of having engineers who are capable of integrating and working across sectors, as well as 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 as to what made this an engineering program and not a social science program. The argumentation finally relied on maintaining that students, aside from receiving training in issues such as resource measurements, climate change processes and urban development, would also become technically competent in the development and use of modelling tools, such as life cycle assessment, carbon and environmental footprints, eco-design and energy system analysis. The Sustainable Cities program is based on a combination of courses presenting existing methods and metrics, including some of their disciplinary background. Its take on sustainability lies in the combination of topics and project assignments defined by the professional perspective of engineers working in cross-sector planning (Interview BVM, 2013).

A further step at AAU was the establishment of a new engineering program in 2013 with focus on Sustainable Design. At the core of this program is the inclusion of different societal actors who set the stage for sustainable change and broader transitions that challenge existing technological products, models and systems.

This provides the students with analytical tools to handle the uncertainties, the interdisciplinary and socio-material integration inspired by Science and Technology Studies, and the new models and solutions they need as part of their engineering design work. Again, the technical subjects' engineering core satisfies the demands set by the accreditation board. Besides defining the project assignments, sustainability is addressed in courses focusing on product service systems, system design, business models, and extended design criteria, including the social and political dimensions of sustainability. Sustainability within this educational approach is as much a part of the design challenge as the technical products and systems.

DISCUSSION OF THE FINDINGS

Sterling (2001) suggests that there are four response strategies to sustainability in education: no response; accommodating response; reformatory response; and transformative response. The majority of engineering schools and institutions in the world that either ignore or deny the challenges of sustainability fall into the first category. Those who follow the accommodating response have either developed new add-on courses to their curriculum (Kamp, 2006) or have attempted to incorporate sustainability in existing programs without fundamentally changing their nature (Chau, 2007; Costa & Scoble, 2006). Reformative attempts have been made to incorporate sustainability in all university programs (Kamp, 2006; Mulder, 2006) and by issuing requirements for incorporating sustainable development in the education of engineers (Barry, 2007; Sterling & Thomas, 2006). Finally, a few institutions have attempted a transformative strategy in relation to sustainability.

These considerations are in line with developments in engineering for sustainable development. Universities meet the sustainability challenge at all levels, but neither strategies using a top-down nor a bottom-up approach are satisfactory in changing the practices at engineering research universities. Researchers and lecturers cannot be motivated to incorporate sustainable development principles in their courses and research unless they develop a thorough understanding of its importance, and match their knowledge with considerable work on curricular development (Kamp, 2006; Mulder, 2006; Peet, Mulder, & Bijma, 2004).

Our analysis also differs from that of Holmberg et al. (2008) in distinguishing between internal and societal/contextual factors of resistance to change within engineering education institutions. Their analysis of three different institutions (Chalmers University of Technology – Sweden; Delft University of Technology – The Netherlands; and Technical University of Catalonia – Spain) shows that the incorporation of sustainability in curricular activities is the consequence of a mixture of strategies to deal with internal and societal/contextual factors at the same time. Our analysis shows that curricular development strategies fit the internal and societal/contextual practices of institutions differently. In other words, legitimacy is built and validated through different strategies, depending on the responses and curricula developed either in accordance with the existing paradigm or in pursuing a paradigm shift. As we have shown, both DTU and AAU have been loyal to their internal institutional paradigms and their established codes of meaning, but only AAU has departed on a long-term basis from the traditional, established science-based engineering and instrumental practice paradigm.

Kamp (2006) accounts for how Delft University of Technology in Holland has pursued a three-legged strategy for integrating sustainability in education: (1) a dedicated course for all students; (2) intertwining sustainable design in all regular disciplinary courses; (3) structure a specialization conducive to degree in each faculty. Kamp concludes that there has been relative success with the three strategies: "however, integrating sustainability fully into the curricula and changing the engineering paradigm requires support from leading scientists, lecturers and the university board. Therefore, without co-operation of the rest of the Delft University our efforts will not have a lasting impact". In line with this reflection, our analysis shows a contrast: At DTU, these issues were 'squared' in a classical tradition for educating engineers. Therefore, no noticeable paradigm shift can be observed at DTU. Conversely, at AAU, a paradigm shift can be observed as environmental and sustainability issues have 'broadened' what is normally understood as training engineers and led to experiments with new kinds of interdisciplinary research and education. This has been facilitated in great measure due to the university's experimental character and to the fact that the whole institution is PBL-oriented.

CONCLUSIONS

In this article, we have accounted for the ways in which new societal challenges in the areas of environment, energy, and sustainability have been articulated in engineering education at DTU and AAU. In both cases, we have observed a slow and careful negotiation of legitimate spaces for curricular development, rather than a clean top-down or a clean bottom-up approach (Mulder, 2006). Two different institutional paths of development can be observed in Denmark's two most important research universities with engineering programs.

At DTU, since the 1970s, environmental challenges have been gradually, narrowed down to specific problems, solutions, indicators, and metrics that reflected already established codes of meaning coming from existing disciplines, which strengthened historically established domains of engineering practice. Two parallel developments can be observed: one emphasizing different environmental technologies, and the other focusing on production engineering and the management of environmental issues within a company-dominated perspective.

At AAU, environmental issues have evolved around a perspective of interactive planning, emphasizing the role of public regulatory institutions and consultancy. This in contrast to the focus at DTU on methods and procedures to be used in management companies. Both institutions have focused on the identifying sources and solutions to environmental challenges on the one hand, and on energy systems modelling of renewable energy sources on the other; however, the fields of professional application have evolved differently. While engineering programs gradually have addressed sustainability issues more comprehensively, AAU's focus on students' problem- and project-based learning (PBL), in close collaboration with companies and municipalities, has opened for more innovative approaches. We regard this as a 'broadening' development.

In short, over a period of several decades, environment and energy challenges have been taken up in engineering education through the building of new engineering tools and metrics. These encompass life cycle assessment, environmental assessment, modified design principles for a wide range of technologies, energy savings, new renewable energy technologies, and system models that integrate energy technologies and savings. In this process, the broader analytical take on these challenges through ecology and social science approaches has been marginalized.

We can observe the same happening in the responses to climate challenges and sustainability. The solving of open-ended problems resulting from taking action in sustainable transformation is mostly represented in strategic rhetoric, while only a few dedicated and specialized educational programs and even fewer courses have been established.

One obvious major challenge is the difficulty in building a sustainability metrics that can provide answers from the outset on how to assess design solutions. Sustainability as such is an open-ended and path-dependent valuation framework that may guide and inspire, but which evades the demand to become instrumental and predictive. Alhough this follows from the idea often presented in discussions of engineering education about the importance of dealing with real world, wicked problem identification is not the priority of engineering departments and faculty, where the dominant focus is on providing technological solutions to societal challenges.

REFERENCES

AAU. (2015). *Knowledge for the world*. Aalborg: Aalborg University Strategy.

Barry, J. (2007). Spires, plateaus and the infertile landscape of education for sustainable development: Re-invigorating the university through integrating community, campus and curriculum. *International Journal of Innovation and Sustainable Development*, *2*(3), 433–452.

Beck, U. (1992). *Risk society: Towards a new modernity*. New Delhi: Sage.

Brundtland, G. H., & World Commission on Environment and Development. (1987). *Our common future*. Oxford: Oxford University Press.

Bulkeley, H., Broto, V. C., Hodson, M., & Marvin, S. (2010). *Cities and low carbon transitions*. New York, NY: Routledge.

Christensen, P., Knudsen, K., & Riberholdt, A. (Eds.). (2000). *Hvor vejene skilles – 25 år med instituttet*. Aalborg: Institut for Samfundsudvikling og Planlægning.

Christensen, P., Thrane, M., Herreborg Jørgensen, T., & Lehmann, M. (2009). Sustainable development: Assessing the gap between preaching and practice at Aalborg University. *International Journal of Sustainability in Higher Education*, *10*(1), 4–20.

Clarke, A., & Leigh Star, S. (2008). The social worlds framework: A theory/methods package. In E. J. Hackett, O. Amsterdamska, M. Lynch, & J. Wajeman (Ed.), *The handbook of science and technology studies* (pp. 113–138). Cambridge, MA: MIT Press.

Clarke, A. (2005). *Situational analysis grounded theory after the postmodern turn*. Thousand Oaks, CA: Sage.

Chau, K. W. (2007). Incorporation of sustainability concepts into a civil engineering curriculum. *Journal of Professional Issues in Engineering Education and Practice*, *133*(3), 188–191.

Costa, S., & Scoble, M. (2006). An interdisciplinary approach to integrating sustainability into mining engineering education and research. *Journal of Cleaner Production*, *14*(3), 366–373.

Downey, G. L., & Lucena, J. C. (2004). Knowledge and professional identity in engineering: Code-switching and the metrics of progress. *History and Technology*, *20*(4), 393–420.

DTU. (2013). *Strategy 2014–2019*, as decided by the board at the meeting 6th December 2013.

Handberg, S. (2014). *Mod det vi ikke kender*. Aalborg: Niche and AAU.

Hansen, I. B. (Ed.). (1979). *Polyteknisk undervisning og forskning i det 20.århundrede. Festskrift ved 150-års jubilæet*. Lyngby: Polyteknisk forlag.

Holmberg, J., Svanström, M., Peet, D. J., Mulder, K., Ferrer-Balas, D., & Segalàs, J. (2008). Embedding sustainability in higher education through interaction with lecturers: Case studies from three European technical universities. *European Journal of Engineering Education*, *33*(3), 271–282.

Jamison, A. (2012). *Turning engineering green: Sustainable development and engineering education*. Dordrecht: Springer Netherlands.

Jørgensen, U. (2007). Historical accounts of engineering education. In E. F. Crawley, J. Malmqvist, S. Ostlund, & D. R. Brodeur (Eds.), *Rethinking engineering education* (pp. 216–240). New York, NY: Springer.

Kamp, L. (2006). Engineering education in sustainable development at Delft University of Technology. *Journal of Cleaner Production*, *14*(9), 928–931.

Kemp, R. (1994). Technology and the transition to environmental sustainability: The problem of technological regime shifts. *Futures, 26*(10), 1023–1046.

Meadows, D. H., & Club of Rome. (1972). *The limits to growth: A report for the club of Rome's project on the predicament of mankind*. New York, NY: Universe Books.

Meyer, N. I. (2000). *Vedvarende energi i Danmark – En krønike om 25 opvækstår, 1975–2000*. Kobenhavn: OVEs Forlag.

Mulder, K. F. (2006). Engineering curricula in sustainable development. An evaluation of changes at Delft University of Technology. *European Journal of Engineering Education*, *31*(2), 133–144.

Müller, J., Remmen, A., & Christensen, P. (1984). *Samfundets teknologi – teknologiens samfund*. Gylling: Systime.

Peet, D. J., Mulder, K. F., & Bijma, A. (2004). Integrating SD into engineering courses at the Delft University of Technology: The individual interaction method. *International Journal of Sustainability in Higher Education*, *5*(3), 278–288.

Segalas, J., Ferrer-Balas, D., Svanström, M., Lundqvist, U., & Mulder, K. F. (2009). What has to be learnt for sustainability? A comparison of bachelor engineering education competences at three European universities. *Sustainability Science*, *4*(1), 17–27.

Segalas, J., Ferrer-Balas, D., & Mulder, K. F. (2010). What do engineering students learn in sustainability courses? The effect of the pedagogical approach. *Journal of Cleaner Production*, *18*(3), 275–284.

Steiner, G., & Posch, A. (2006). Higher education for sustainability by means of transdisciplinary case studies: An innovative approach for solving complex, real-world problems. *Journal of Cleaner Production*, *14*(9), 877–890.

Sterling, S. (2001). *Sustainable education*. Totnes, UK: Green Books Ltd.

Sterling, S., & Thomas, I. (2006). Education for sustainability: The role of capabilities in guiding university curricula. *International Journal of Innovation and Sustainable Development*, *1*(4), 349–370.

Sørensen, B., Blegaa, S., Hvelplund, F., Jensen, J., Josephsen, L., Linderoth, H., Meyer, N., & Balling, N. (1976). *Skitse til alternativ energiplan for Danmark*. København: OOEs forlag.

Wenzel, H., Hauschild, M., & Alting, L. (1997). *Environmental assessment of products, Vol. 1: Methodology, tools and case studies in product development*. London: Chapman & Hall.

Yin, R. K. (2014). *Case study research: Design and methods*. Thousand Oaks, CA: Sage publications.

INTERVIEW REFERENCES

HB: Henrik Brohus, 2013
PK: Peter Kjeldsen, 2012
JH: John Holten, 2013
NM: Niels Meyer, 2013
KC: Knut Conradsen, 2013
MG: Mirjam Godskesen, 2013
AW: Arne Willumsen, 2013
MSJ: Michael Søgaard Jørgensen, 2013
AR: Arne Remmen, 2015
LI: Klaus Illum, 2013
TP: Tjalfe Poulsen, 2013
HL: Henrik Lund, 2013
BVM: Brian Vad Mathiesen, 2013

Andrés Valderrama
Department of Development and Planning
Aalborg University Copenhagen
Denmark

Søsser Brodersen
Department of Development and Planning
Aalborg University Copenhagen
Denmark

Ulrik Jørgensen
Department of Development and Planning
Aalborg University Copenhagen
Denmark