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How to Integrate Sustainability in Technological Degrees: Robotics at UPC

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Abstract**—**Embedding Sustainability in technological curricula has become a crucial factor for educating engineers with competences in sustainability. The Technical University of Catalonia UPC, in 2008, designed the Sustainable Technology Excellence Program STEP 2015 in order to assure a successful Sustainability Embedding. This Program takes advantage of the opportunity that the redesign of all Bachelor and Master Degrees in Spain by 2010 under the European Higher Education Area framework offered. The STEP program goals are: to design compulsory courses in each degree; to develop the conceptual base and identify reference models in sustainability for all specialties at UPC; to create an internal interdisciplinary network of faculty from all the schools; to initiate new transdisciplinary research activities in technology-sustainability-education; to spread the know/how attained; to achieve international scientific excellence in technology-sustainability-education and to graduate the first engineers/architects of the new EHEA bachelors with sustainability as a generic competence. Specifically, in this paper authors explain their experience in leading the STEP program, and two examples are presented: Industrial Robotics subject and the curriculum for the School of Architecture.

Keywords**—**Sustainability, curricula improvement, robotics.

I. Introduction

AT the Technical University of Catalonia (UPC), the efforts to embed sustainability in the curriculum started in late nineties, with its first (1996-2001) and second (2002-2005) environmental plans followed by the last Sustainability plan [1]: UPC Sustainable 2015 (2005-2015). All these plans focused not only on embedding sustainability into education, which was always taken as a priority, but also into all the activities universities are involved: research, campus management and society outreach.

For this next year 2015, the Technical University of Catalonia is expected to be a key reference in technology for the sustainable development at a local, regional and European level through its contribution in Education as well as research, development and innovation.

Embedding sustainability within the curriculum does not only mean including new contents. If engineers are to contribute truly to Sustainable Development, SD, sustainability must become part of their paradigm and affect everyday thinking. This, on the other hand, can only be achieved if SD becomes an integral part of engineering education programs, not a mere ‘add-on’ to the ‘core’ parts of the curriculum.

There are many drivers and barriers identified [2], [3] when trying to embed sustainability within the curriculum, and many attempts have been carried out at technological universities in order to achieve this goal. There are mainly four strategies applied: First, a compulsory course for all graduates at 1st Cycle (Bachelor) level; second, a minor track on SD in both 1st Cycle and 2nd Cycle studies; third, assuring the introduction of SD in the final thesis project of graduation and finally, and most challenging, intertwining sustainability in all the subjects/courses of the curriculum.

Despite all these barriers, UPC Sustainable 2015 Plan seeks for the excellence in sustainability education in its degrees, and a new program has been developed: Sustainable Technology Excellence Program 2015 “STEP 2015”. This program is supported by the strong commitment from the university board in Sustainability education (a new competence in “Sustainability and Social Commitment” is compulsory to all degrees at UPC), and takes advantage of the great opportunity that European Higher Education Area (EHEA) framework offers (all courses must be redesign in order to fulfil the EHEA requirements).

The STEP 2015 main goals are:

- To design compulsory courses in each degree.
- To develop the conceptual base and identify reference models in sustainability for all specialties at UPC.
- To create an internal interdisciplinary network of faculty and students from all the schools.
- To initiate new transdisciplinary research activities in technology-sustainability-education.
- To spread the practical knowledge attained.
- To achieve international scientific excellence in technology-sustainability-education and to graduate the first engineers/architects of the new EHEA bachelors with sustainability as a generic competence.

The program has been structured in 4 phases. First, the curricula of all Schools have been analyzed within the UPC (2008), and benchmarked with other technological universities in order to develop a feasible and effective program; those external universities are TU Delft (Holland), University of Chalmers (Sweden), Tokyo University (Japan) and ETH Zurich (Switzerland). Second, a pilot implementation of the STEP program in 5 Schools has been carried out for a period of two academic years (2009-10 and 2010-11). These Schools participated voluntarily. Third, the program has been spread for implementation to 10 Schools of UPC taking advantage of the

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lessons learnt in the pilot experience (2011-12 and 2012-13). Fourth, the program is going to be applied to all UPC Schools and departments (2013-14 and 2014-15). Fig. 1 shows the logo that STEP program has been using in the promotion plan and even some merchandising has been created with it (pens, T-shirts…) together with some brochures containing information (Fig. 2) for advertising the plan among students and faculty. The key values that STEP program want to promote are reflected in Fig. 1 (right).

Fig. 1 STEP logo and key values for the Program

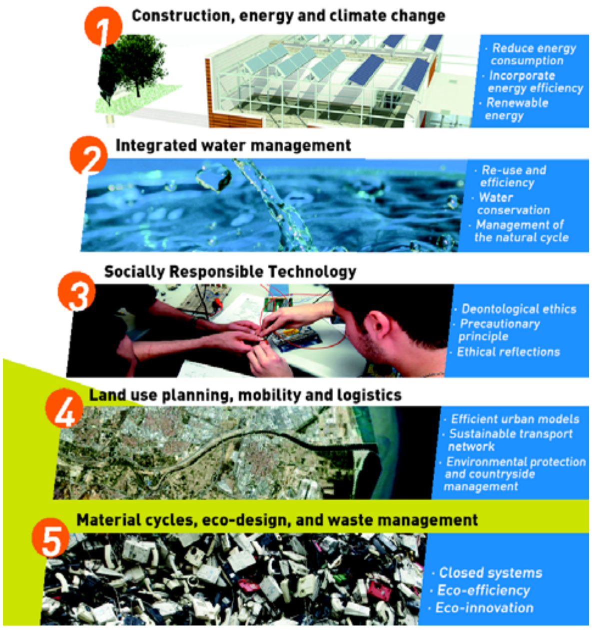

Fig. 2 UPC Sustainable 2015 Plan Challenges

This paper presents the STEP program, its implementation, development and evaluation highlighting the process recommendations to export the program to other Universities. Specifically the full process will be explained and the results up to the third phase will be shown, where the collected experience already covers ten technological schools of UPC (over 16 schools). This third phase has been the most exciting and creative one and for this reason authors want to share the enriching experience, the fourth phase (which is just beginning this academic year) will consist in enlarging and replicating the third phase. In this period, the basis of a methodological set-up has been developed preparing formative courses for lecturers in Education for the Sustainability in order the faculty are able to integrate sustainability in their regular subjects. This learning step has been led by the paper's proposers. The global process has been undertaken by each school independently with its own specific goals, action plans and activities, organized internally and coordinated from the program. This participatory approach has shown to be very successful in terms of faculty involvement, teaching material development and creation of internal and global networks for embedding sustainability. As a clarifying example, the process, results and assessment of integrating Sustainability in the Robotics subject taught at the Industrial Engineers School in UPC will be described.

II. Sustainable Technology Excellence Program: Methodology

The STEP program has four phases, described in more detail in this Section. Three out of four phases have been finished, but it is enough to ensure that this program has a great impact in our university.

A. Phase 1 - Design of the Program (2008)

To design such a program, first the situation in the university was analyzed in order to identify the internal drivers and barriers, and the above objectives were set for the program. There will be a Coordination team responsible for stimulating and encouraging the network, to ensure coherence of actions promoted and always has an overview of context, both internal and external, that allow evaluating the progress of the program based on the goals previously established. The members are the Vice-rector of Sustainability, and four experts on engineering and sustainability education, one leading the team. Then, the goal of the STEP network is to generate a critical mass of people interested and qualified, who can positively influence the consolidation of knowledge networks, to stimulate the intellectual capacity and to promote interdisciplinary dialogue. In this network each school is represented by to members, one from the school board and the other an interested and qualified teacher/professor. They will be responsible for stimulating/promoting/organizing activities within their school. Moreover, two interns will support the activities and open possibilities of active participation of the students of the school.

The results of this phase indicated that in general faculty is aware of the sustainability and recognize the need to integrate it in the technological studies but at the same time is unable to do so due to the lack of experience, leadership and teaching material. This analysis encouraged the program leaders to go ahead with the plan.

B. Phase 2 – Pilot Experience (2009-2011)

Phase 2 lied on creating internal networks of sustainability education at the schools, which deal with the short term goals of the program. At this stage it was decided to reduce the number of participating schools in the program in order to have a closer supervision and assessment of the process. A call to all UPC schools was made and finally there were 5 schools selected taking into account their application and trying to have a diverse spectrum of schools from UPC. The University has

17 schools and 6 attached centers with similar degrees but placed in different campuses. Fig. 3 shows the internal structure of the network and the relationship among Schools and the Coordination team.

The definitive action that pushed STEP program has been the implantation of the generic competences at the UPC. Among those competences, the most related one is the "Sustainability and Social Commitment" (SSC) competence that is compulsory in all the University Schools, together with other six competences. Then, the task of each School has been to decide which subjects will include SSC competence in their syllabus. That means that a seventh of all subjects have in average the SSC competence mandatory pioneering this competence at a European level. From that moment, the word "sustainability" sounds different and students and faculty take into account when preparing the concerning subjects.

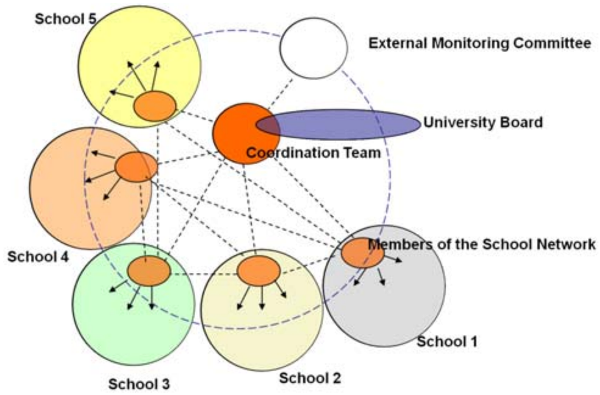

Fig. 3 Initial STEP Program structure in phase 2

C. Phases 3 and 4 – Spread Out of STEP Program

From the lessons learnt in the 5 pilot schools, Phases 3 and 4 aimed to spread out all the know-how attained in the process to all schools in order to ensure that all UPC graduates acquire the competence in sustainability and social commitment. Phase 3 (2011-2013) is the phase of expansion, which started in September 2011 selecting new schools to participate in the program and maintaining the schools from the pilot phase as consolidated schools. In Phase 3, 10 new Schools were engaged in STEP program. Finally in Phase 4 consolidation (2013- 2015) all 23 UPC Schools are involved (Fig. 2). Nevertheless, the total implantation is not working at full throttle; there exist some reluctances among a part of faculty that consider that the generic competences in general (and SSC in particular) can divert the attention of students from the more classical taught in some old-fashioned subjects. However, promoters consider STEP as a huge success for the acceptance among students and a big portion of faculty members. Fig. 4 tries to show the integration of more Schools to STEP program where the leading team remains with the same structure that had in previous phases. At least, this structure demonstrates soundness to lead such a project.

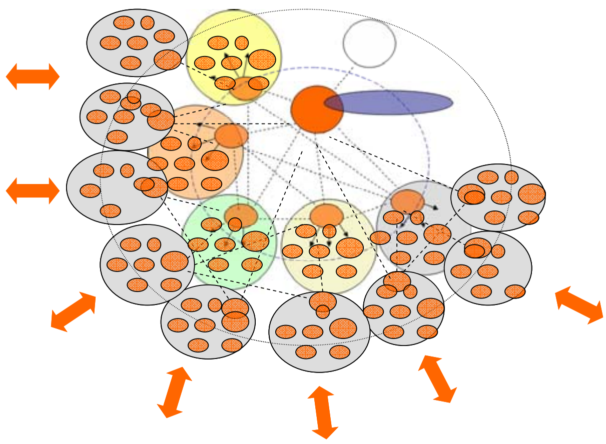

Fig. 4 Consolidated structure of Schools in STEP phase 4

An example of integration of the Sustainability and Social Commitment competence in the School of Architecture (ETSAV) curricula is shown in Table I. This School was engaged in STEP program during the ºPhase 3. In this table, the different subjects (with their credits) taught to achieved the new degree in Architecture are presented together their credits.

Obviously, one of the keys of the success in integrating the SSC competence is the commitment of the School management team.

TABLE I
SUBJECTS WITH THE SSC COMPETENCE INTEGRATED IN THE ARCHITECTURE SCHOOL (ETSAV)

Semester 1.
- Technical Fundamentals (6 ECTS)
- Theory Fundamentals (6 ECTS). Examples and Application References.

Semester 2
- Physics I (4+2 ECTS). Introduction to Structures.
- Architecture and Cities (4+2 ECTS)

Semester 3
- Technology I (4 ECTS). Building Environmental Design
- Physics II (6 ECTS). Applied Thermodynamics.

Semester 4
- Technology II (6 ECTS). Constructive Systems basis.
- Structures II (4 ECTS). Identification of the resistive behavior.
- Project workshop for Semester 4 (8+4 ECTS). Systems and Construction

Semester 5
- Technology III (7 ECTS). Indoor space.
- City Planning II (5 ECTS). Cities and residencial projects: exemple in the XXth century.
- Project workshop for Semester 5 (7+2+3 ECTS)

Semester 6
- Structures IV (3 ECTS). Structure design in concrete.
- Composition III (3 ECTS). Architecture history.
- Project workshop for Semester 6 (8+4 ECTS).

Semesters 7-12
- Pending of approval.

Note of the School Dean: "From the School we insist in the need and opportunity to act with determination with the SSC competence.

The evolution of faculty members involved in this new approach for the degree of Architecture is well worth to be mentioned. In Table II some figures are presented regarding the evolution before and after STEP program entered the School of

Architecture. Lecturers and instructors have been involved in the transformation with great delight because those that were aware with the sustainability had a new arena to explain their skills and know-how, and those that were new in the competence had very good examples to learn from. The most important lesson learnt in this School is networking among those faculty members with more experience and those more inexpert in Sustainability. Students accepted surprised the implication of some faculty members that in past years were skeptical with SSC competence.

III. Integration of Sustainability and Commitment Competence in Industrial Robotics Subject

A. Framework for Industrial Robotics Subject

The subject "Industrial Robotics" is taught in the Industrial Engineering School. This school entered STEP program in phase 3 and the commitment of the management team was absolutely though some faculty members were initially reticent to both the program and the SSC competence. This subject is taught in Semester 9 and students have achieved good skills in SSC competence at that level. Robotics has 6 ECTS with 4 classroom hours a week and 2 hours in the laboratory every week too. The syllabus is based on the classical subject of industrial robotics: robot morphology, kinematics, control, trajectory and path planning, sensors and robots programming. The novelty is not in the syllabus, and this fact is the key also of the integration success of SSC: the syllabus is not modified and the competence in integrated within the classical theory, problems, exercises, real applications and practices. To not modify the syllabus is the key to convince reluctant faculty to introduce SSC competence because their classical conception of the subject is not modified.

TABLE II
Evolution in the Implication of Faculty Members at the Architectural School

Figures about SSC competence	Year 2010	Year 2015
Faculty members involved	36	180
Students at the School	-	2000
Books published in the SSC competence	2	6
PhD Thesis related to SSC competence	2	10

The authors of this paper belong also to the faculty team of Industrial Robotics subject and a special teaching material has been created to help to integrate the SSC competence with clear examples and exercises [5], even though a classical book [6] is used at classroom.

Robots are devices with a notable impact in some common productive processes and their activity cannot be dissociated from some aspects like energy consumption, the constructive materials (steel mainly, but other rare or pollutant elements), the atmosphere around the processes where robots are located or even the own process (welding, painting, pollutant atmospheres…), the social impact (or social acceptance) of the robot in the immediate working place and the activity it develops, the incidence of robots presence in the environmental audits, tangible and intangible costs associated to the robot or its activity [9]. These are, at a glance, the elements that could allow a rational use of the robots that have to be undoubtedly introduced to students in the Industrial Robotics subject.

B. Pedagogical Methodology

The lecturers of Industrial Robotics have focused the integration of SSC competence in the subject in: the scope where robots are deployed, the set of elements that integrate robots (environment, activity, productive process, energies involved, and materials that robot handles, etc.). Regarding those points, there are different problems to analyze:

- Generic problems inherent to the industrial activity.
- Problems related directly with the robot and relative to its mechanical structure, its controller and all the elements that integrate the robot.
- Problems related indirectly with the robot that can be: i) problems derived from its activity in the productive process, ii) social problems derived from the presence of the robot [10].

Ethical problems related with robots really concern a part of the society [7], [8] and they are treated in the classroom in order students know where and how robotics has to be applied and integrated in the working places.

The main drawback that faculty encounter when the competence has to be integrated in any particular subject is the lack of examples and didactic material to use. For this reason, and in order to encourage other colleagues, authors propose a set of systemized examples, as if they were recipes that could be used to prepare lectures with practical and real applications where the sustainability is present. This is the best way that authors have found to encourage colleagues that "do not know what students expect from the SSC competence" (in their own words).

The recipes have the following contents (as tags):

- Title: Every recipe has an explicit title that identifies its contents.
- Other subjects that could be using the recipe: Apart from the Industrial Robotics, other subjects can share specific fields or areas where the same example (or with slightly modifications); this tag encourages other faculty members to use the recipes in their subjects (for instance, Advanced Robotics, Electronics, Automated Manufacturing, Industrial Processes…).
- Description: Beneath this tag, a large and complete explanation of the activity is contained. This part is closely related to robotics areas presenting a practical framework in an industrial and real environment. Lecturer explains how robots cover and solve a specific activity or industrial process.
- Problem area: After the mere description of the robotic activity or industrial process, problems arise when lecturer creates a debate about the environmental or social problems related with the activity. At this point, students try to respond to those questions, with a clear comprehension of the problem (analysis), and then with a set of solutions to the specific problems. The participation is important and the lecturer's task is to moderate the

debate, proposing also some solutions or sometimes even posing more problems to the students' solutions. This part of the class is highly enriching because the brain storming of ideas leads to a taxonomy of the problem-solution pair. Students value very positively this part of the class at the final semester questionnaire.

- Multimedia material: The description and problem area are always accompanied with multimedia material; mainly videos of real industrial applications, in order students understand the description.
- Related links: Some links for a further reading are presented to students.

For instance, some real applications are related to: handling, pick and place, packaging, palletizing, machine tending, spot welding, arc welding, painting, laser cutting, waterjet cutting, polishing, deblurring, assembly, among other less usual.

Although the subject is closely related to Industrial Robotics and real industrial application, lecturers dedicate a class to discuss other non-industrial robotic applications: service robotics, robots at space, underwater and autonomous robots, humanoids, and the star issue: unmanned aerial vehicles (drones). Those applications have important and even catastrophic consequences in society and the debate is very well rated for students after the class. Authors understand that without this kind of debates the SSC competence should be incomplete.

C. A Class Example: Painting Robot

A typical example seen in class corresponds to surface coating by any kind of material (paint, varnish, metal particles…) for decoration or protection. This process is a critical part of many industrial processes such as automobile manufacturing, appliances, furniture…

In these procedures, a surface is coated with a blend of air and material sprayed with a pistol. The environment is a small hazardous space, with a toxic atmosphere, a high degree of noise and a high risk of firing. For those circumstances painting and similar operations are suitable for being robotized. With robots the environmental drawbacks are removed and the quality, homogeneity, paint saving and productivity largely increase. Those robots usually have special protections against suspended particles inside the painting cabinet and its possible consequences (blasts, firing, mechanical deterioration…). This sector is aware of its environmental influence and some problems are specially treated: reduction of solids and liquids waste, paint fumes…

The use of robots in painting processes can reduce the electrical consumption mainly in electrodeposition (metallic materials painting procedure) and electrostatic pistol painting due to their efficiency in such processes.

The drying processes are always linked to painting procedures. Those drying processes have to follow also some environmental rules, with hermetic cabinets for particle-free painting to avoid the dangerous consequences of such a process.

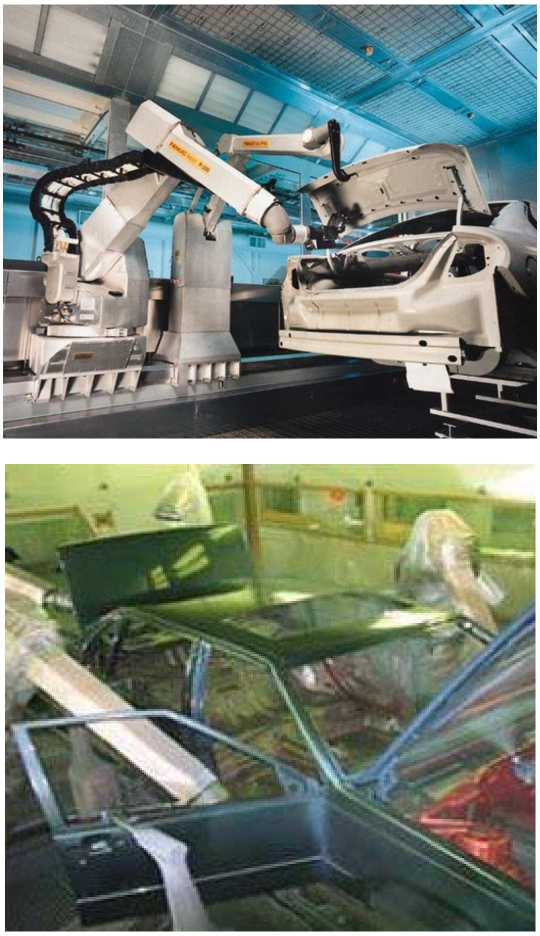

Fig. 5 Robotics processes in automobile production

IV. Conclusions

STEP program is now under development [4]. After the pilot phase and phase 3, we are currently applying the know-how to the remainder schools of engineering and architecture at UPC. From the conclusions of each school some lessons have been learnt:

- Leadership from the university board is necessary to support and to fund this kind of programs.
- Leadership at each school has shown to be very important in order to involve faculty in the networks.
- The strategy of not applying a top-down approach and let the schools to organize themselves and propose their own activities has shown to be successful (all school from the pilot phase wanted to participate in the second phase).
- The creation of internal networks linked to an overall network has facilitated the communication and spread of information.
- Students get really involved in the program, creating their own program.
- In every school there exist some faculty members (sometimes a reduced set only) teaching sustainability concepts, although basically related to soft sustainability: environment protection and energy efficiency.

- Some faculty members find STEP program very interesting and are eager to participate.
- The main barrier is to involve non-interested faculty due to lack of incentives.
- There is still a lack of transdisciplinarity within the schools that has to be overcome in phase 4.

The STEP program has been very successful in terms of making sustainability comprehensive to faculty and to catalyze the introduction of the compulsory competence of Sustainability and Social Commitment to all UPC degrees.

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