Integrating Urban Ecodesign in French engineering curricula: an example at École des Ponts ParisTech

Dr. Natalia Kotelnikova, Université Paris-Est (UPE), LVMT, Ecole des Ponts ParisTech, natalia.kotelnikova@enpc.fr

MSc Anne De Bortoli, UPE, LVMT, Ecole des Ponts ParisTech, France, anne.de-bortoli@enpc.fr
Dr Adélaïde Féraille, UPE, Navier, Ecole des Ponts ParisTech, France, Adelaide.feraille@enpc.fr
Dr Fabien Leurent, UPE, LVMT, Ecole des Ponts ParisTech, fabien.leurent@enpc.fr

Summary

In the era of climate change and energetic transition, industrial players are driven to adapt their activities. Eco-design has emerged as a major approach to enhance the environmental performance of products as well as services. Yet it still needs to be developed for complex issues such as neighborhood development and urban planning. This is the very objective of the academic Chair on the Eco-design of building sets and infrastructure that was established in 2008 by ParisTech and Vinci, the well-known leading group in construction and infrastructure operations. The chair involves three schools with different specializations within ParisTech: “Mines” deal with energetics, “Agro” with biodiversity and urban agriculture and “Ecole des Ponts” with transportation and urban development. The paper presents a one semester full-time specialization training for master students which was launched in 2014 at Ecole des Ponts. The curriculum, targeted to the “eco-design of sustainable cities”, is in two main parts: on the first hand, four specialist courses deal with spatial design, evaluation, urban modeling and big data, respectively; on the other hand, an intensive group project targeted to eco-design a sustainable neighborhood. The paper presents first the context of engineering education in France and its orientation towards sustainable development of cities, then the principles of the education program; next, details are provided about the specialist course in evaluation, which is based on Life Cycle Analysis, then on the intensive group project and the topics it addressed in years 2014-2015 and 2015-2016. Lastly some lessons and perspectives are drawn.

Keywords: eco-design, engineering curriculum, industry-academic partnership, LCA, built environment, transportation

1. Introduction

Ecodesign is an approach to designing a product or service that focuses on greater economy of resources which is gradually spreading into all sectors of economic activity, reflecting a general and growing awareness of sustainable development issues and an extensive commitment to energy transition and the fight against climate change. Training student engineers in the concepts and methods of ecodesign, in order to prepare them for their careers serving companies and society, is an aspiration that is particularly crucial at École des Ponts ParisTech (ENPC). It even poses a major challenge to the school: training students in ecodesign in its traditional city related sphere requires recognition of its hyper-complexity and of the need for this to be recognized in the design methods taught.The challenge was taken up in 2014 with the creation of a specialist subject, the “Ecodesign of the sustainable city” (EVD) specialization, in the second year of the Masters program in urban (including mobility) and environmental engineering. This article describes

the course, in terms of its knowledge and skills objectives, as well as its pedagogical architecture, with a project playing a central role. The rest of this article is divided into five sections: the previous situation with regard to sustainable development in the ENPC curriculum (Section 2), principles of the EVD specialization (Section 3), a more detailed description of a dedicated support course (Section 4) and of the intensive group project (Section 5). We conclude with a provisional assessment and suggestions for further avenues of development (Section 6).

2. Training in sustainable development in an engineering school

Every year in France, around 20,000 student engineers are awarded degrees by appropriately qualified schools. École des Ponts ParisTech (ENPC) belongs to the elite schools. Since its foundation in 1747, it has trained students to become civil servants in the ministry responsible for public works and transportation infrastructures, then for urban planning. Since 2007, the ministry's remit has been expanded to include sustainable development. What still needed to be taught was a hard core of concepts and methods relating to the economy, society and the environment. That has been the ambition of the Ville-Environnement-Transport (VET, standing for City-Environment-Transportation) faculty department in the Masters program, since its formation in 2002 at ENPC to deliver an in-depth curriculum focusing on sustainable development.

3. The new specialization in Ecodesign of Sustainable Cities (ESC)

It has been created at ENPC at the beginning of academic year 2014-2015, and consists of specialist modules (support courses) and of an intensive group project, about one half each in the first semester of the second-year Masters program (M2). There are four support courses, each of which cultivates a particular skill: The ACVMU course on Life Cycle Assessment of Urban Transportation Modes (see Section 4), the MMAUR course on Modelling Methods and Urban Applications, the CSIUR course on Spatial Design and Urban Integration, and the GRAVED course on Data Management, Collection, Analysis, Visualization and Enrichment. As for the intensive group project, it is conducted in teams ideally comprising 4 to 6 members and aims at pooling sectoral skills around a joint application. In 2014-2015, the first project was simplified to test the students' ability to handle an extended range of knowledge input. The task was to design an overall assessment for the concepts, products and services focused on the theme of the Sustainable City by organizations and companies located at Cité Descartes, a scientific campus in Greater Paris: that was the "Descartes showroom project". On the basis of the first year only, the assessment of the ESC specialization is very largely positive: the researchers who taught the courses and the intensive group project are very satisfied with the high level of student commitment and the quality of the results, and students commented on the very heavy workload while stating they would still choose this specialization if they had to start over. Each student produced their Masters assignment on a subject very well aligned with the specialization. We infer that the young engineers who have experienced this new training can more quickly access responsibility as heads of development projects, and therefore as operation coordinators. Indeed, it would seem that the course has helped them discover the diversity of possibilities in a cooperative perspective, by overcoming mutually imposed constraints and showing ways of reconciling them harmoniously. According to the design offices which recruit engineers trained by ENPC, this coordinating engineer profile is nowadays only too rare, and therefore much in demand. By adopting it, our young engineers will make themselves useful not only to their employers, but also of course to society, by reinforcing the effectiveness of public action

Space for notes

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Summary

In the era of climate change and energetic transition, industrial players are driven to adapt their activities. Eco-design has emerged as a major approach to enhance the environmental performance of products as well as services. Yet it still needs to be developed for complex issues such as neighborhood development and urban planning.

This is the very objective of the academic Chair on the Eco-design of building sets and infrastructure that was established in 2008 by ParisTech and Vinci, the well-known leading group in construction and infrastructure operations. The chair involves three schools with different specializations within ParisTech: “Mines” deal with energetics, “Agro” with biodiversity and urban agriculture and “Ecole des Ponts” with transportation and urban development.

The paper presents a one semester full-time specialization training for master students which was launched in 2014 at Ecole des Ponts. The curriculum, targeted to the “eco-design of sustainable cities”, is in two main parts: on the first hand, four specialist courses deal with spatial design, evaluation, urban modeling and big data, respectively; on the other hand, an intensive group project targeted to eco-design a sustainable neighborhood.

The paper presents first the context of engineering education in France and its orientation towards sustainable development of cities, then the principles of the education program; next, details are provided about the specialist course in evaluation, which is based on Life Cycle Analysis, then on the intensive group project and the topics it addressed in years 2014-2015 and 2015-2016. Lastly some lessons and perspectives are drawn.

Keywords: eco-design, engineering curriculum, industry-academic partnership, LCA, built environment, transportation

1. Introduction

Ecodesign, which has developed in industrial engineering since the 1980s, is an approach to designing a product or service that focuses on greater economy of resources: parsimony, recycling and more generally a minimization of negative environmental impacts, in terms of the consumption of materials and energy, emissions of pollutants and damage to natural environments, impairment to biodiversity and human health.

Ecodesign is gradually spreading into all sectors of economic activity, reflecting a general and growing awareness of sustainable development issues and an extensive commitment to energy transition and the fight against climate change [1].
Training student engineers in the concepts and methods of ecodesign, in order to prepare them for their careers serving companies and society, is an aspiration that is particularly crucial at École des Ponts ParisTech (ENPC). It even poses a major challenge to the school: training students in ecodesign in its traditional city related sphere – urban engineering, construction, transportation systems, urban services, environmental engineering – requires an understanding of the complexity of the urban environment, or at least a clear recognition of its hyper-complexity and of the need for this to be recognized in the design methods taught.
The challenge was taken up in 2014 with the creation of a specialized training, the "Ecodesign of Sustainable Cities" (ESC) specialization, in the second year of the Master program in urban (including mobility) and environmental engineering. The purpose of this article is to describe the course, in terms of its knowledge and skills objectives, as well as its pedagogical architecture. The project plays a central role, as it does in any curriculum related to urban design, combining with support courses dedicated to engineering methods, respectively for design, evaluation, modelling and simulation.
The rest of this article is divided into five sections. We begin by describing the previous situation with regard to sustainable development in the ENPC curriculum (Section 2). We then go on to present the principles of the ESC specialization: aims and priorities, pedagogical objectives and methods (Section 3). Next we give a more detailed description of a dedicated support course on evaluation which tackles the Life Cycle Assessment of an urban mobility mode (Section 4), together with the intensive group project dedicated to the design of a sustainable neighborhood (Section 5). We conclude with a provisional assessment and suggestions for further avenues of development (Section 6).

2. Training in sustainable development in an engineering school

2.1 Specificities of the training of engineers in France

Every year in France, around 20,000 student engineers are awarded degrees by appropriately qualified schools, institutions that are independent of the universities (though often in partnership). Most of these schools recruit by examination following two years of preparatory classes, which succeed the scientific baccalaureate.
École des Ponts ParisTech (ENPC) is well positioned amongst the twenty or so most prestigious schools, France's elite "grandes écoles d'ingénieur", which educate a total of some 6000 student engineers a year. These schools share the same recruitment pool and all seek a certain versatility, by each offering a fairly wide spectrum of engineering specialties. This spectrum typically includes a branch of physics, applied mathematics and computer science, as well as system management. The balance between mathematics and physics is a major feature of the earlier stages in French education, right from secondary school. Up to the scientific baccalaureate, French language and philosophy constitute a third block, and history-geography combined with foreign languages a fourth, all taught within roughly the same number of hours.
In all, a French engineer is more versatile than specialized when leaving school, a semi-finished product for the professional world.

2.2 The sustainable development ministry school

Since its foundation in 1747, ENPC has trained students to become civil servants in the ministry responsible for public works and transportation infrastructures (roads and hubs such as ports, airports, etc.). Since 2007, the ministry's remit has been expanded to include sustainable development: the technical tradition of building solid structures and operating infrastructure and service networks (water distribution, sewerage, transportation), now encompasses environmental management, i.e. the sustainable management of resources, water quality, air quality.

Former students of the School have become illustrious scientists: in the 19th century, Navier in civil engineering and fluid mechanics, Vicat in concrete, Belgrand in sanitation, Dupuit in the eco-

nomic and social valuation of goods and services [2]. Closer to our time, Jean-Paul Lacaze in urbanism and housing policy, Bernard Hirsch, Jean Poulit and Pierre Veltz in spatial planning, were masterly embodiments of public action, upholding the values of technical solidity, economy of resources, the satisfaction of citizens' needs [3]. These values are precisely the three pillars – respectively environmental, economic and social – of sustainable development.

2.3 What education in sustainable development?

The versatility of French style scientific education, delivered up to the baccalaureate, pursued through a balance between mathematics and physics-chemistry during the two years of preparatory classes (L1 and L2), is maintained in France's elite engineering schools by compulsory education in economics (micro- and macroeconomic theory, business management) and in social sciences (organizational theory, history of technology, law).
These core economic and social disciplines have recently been joined by an initiation into environmental issues: major environmental challenges, natural and technological risks.

However, even with classes relating to each of the core subjects, and a dedicated seminar on the challenges and risks, education in sustainable development remains superficial and somewhat passive. In order to inculcate an in-depth understanding of the issues and principles, specific methods need to be taught and practiced by the students in an active role, from the designer's perspective. This is now well recognized in engineering programs for particular technical specializations, notably taught through project-based courses. It still needs to be applied for a specialization in "sustainable development".

2.4 The VET department: seeking to integrate the three core elements

What still needs to be taught is a hard core of concepts and methods relating to the economy, society and the environment, including analytical methods that can be used in design offices, together with operational methods that are applicable in the field.

That has been the aspiration of the Ville-Environnement-Transport (VET – City-Environment-Transportation) faculty department in the Masters program, since its formation in 2002 at ENPC to deliver an in-depth curriculum focusing on sustainable development:

The City component relates to social issues and spatial planning principles: design, coordinated decision-making, public action, urban services.
The Environment component is divided into the hydrological and the atmospheric environment, each with its physics, its chemistry or its biochemistry. Environmental engineering also includes system evaluation and management methods.
In Transportation, the basic courses deal respectively with systemics and modelling, traffic engineering, transportation economics.

In the VET Department's first five years since its formation, the student program included a compulsory hard core in each of the three components, in addition to the seminar dedicated to interactions between them. This very tough combination was based on a set of more easily combinable short courses (18 hour modules), put together through a breakdown of pre-existing courses [4].

In parallel, integrative courses were established:

- The basic environment program deals with the big themes (water, energy, life, weather and climate), each with its own course program. It takes place in the first year (Year L3).
- In the first semester of the first year of the Masters degree (M1), the MASYT course (Analysis Methods for Territorial Systems – 40 hours, 5 credits) teaches systemic analysis of an urban area successively through geography, demography, sociology, economics, the real estate system, the mobility system, environmental impacts. The theoretical courses are applied in supervised practical work based on a Geographical Information

System (GIS) supplied with a full set of thematic databases, and in a mini-project undertaken in pair-work on a case of territorial assessment and planning design [5].

In the second semester of the M1, the TAMUR course (Transportation and planning in an urban and regional environment – 80 hours, 8 credits) deals with methods of socio-economic evaluation and spatial planning in a deeper way. Half the course consisted of a team design project (e.g. eco-neighborhood design, company travel plan, territorial energy forecasting). [6]

Since 2010, the VET program has been reorganized with a stronger emphasis on the integrative courses, and the compulsory grounding in a hard core in each specialty has been replaced by registration in a singlwe specialization in order to achieve a more in-depth understanding. Thus, for a student engineer in the VET Department, the first year of the Masters program (M1) is a combination of integrative courses and a particular specialization.

3. The specialization in EVD (Ecodesign of the Sustainable City)

At the beginning of academic year 2014-2015, ENPC created a dedicated specialization in the Ecodesign of Sustainable Cities (ESC). It is administratively and pedagogically attached to the VET Department, but also open to other departments in the Masters program: Civil and Structural Engineering, Mechanical and Materials Engineering, Mathematical Engineering and Computer Science, Industrial Engineering, Economics-Management-Finance.

The aim is to draw on a sectoral specialization acquired in M1 and then to broaden it to the three areas of City-Environment-Transportation and thereby to the three core dimensions of sustainable development.

3.1 Thematic positioning

The title of the specialization states its purpose [7]:

- The City as a complex ensemble, extended in space, containing a population in buildings and open spaces for a diversity of activities: housing, production and consumption of goods and services, movement and social life in general. This space has been gradually developed through shaping and artificialization, with a variety of amenities, in particular the real estate stock and technical infrastructures.
- Sustainability in its three pillars – society, economics and the environment.
- Ecodesign in order to emphasize the environment and adopt the position of the designer, capable of identifying and exploiting synergies between the different pillars, and to convert constraints into opportunities.

Urban transportation reveals the synergies between the three pillars and the advantage of acting on systemic effects: there are both financial and environmental economies to be made by concentrating mobility in mass transit vehicles. High urban densities, which determine the scale of trip flows, reinforce the environmental stakes at local level and bring individual interests in line with collective interests, by making mass transit services efficient for individual passengers.

3.2 Knowledge and skills objective

The knowledge objective is to reach an advanced understanding of the issues, with their challenges, their respective whys and wherefores, and in particular their interactions and functional links. This advanced understanding is manifested in a capacity to express the phenomena and impacts qualitatively and to connect them together. A student engineer also needs to be able to translate a particular aspect into one or more indicator(s) that depict it with relevance and measure its state along significant dimensions.

The skills objective first concerns the ability to quantify the physical, economic, social and environmental aspects: modelling by variables and causes, simulation models applied not only as black boxes but also understood in their operational mechanisms.

Alongside evaluation and modelling, the skills objective also includes conception: the ability to propose configurations, scenarios, management processes for a particular case, in operational

regimes both regular and transitional (e.g. construction site) – which reinforces the importance of involving the system's different stakeholders in the conceptual process.

3.3 Course structure

The specialization consists on the one hand of specialist modules called "support courses" and on the other hand of an intensive group project, accounting for more or less equal parts of the student timetable in the first semester of the second-year Masters program (M2).

There are four support courses, each of which cultivates a particular competence:

- The ACVMU course covers the Life Cycle Assessment of an Urban Transit Mode, combining methodological inputs and team-based practical application to a study case. The case concerns an urban travel mode, so that both infrastructures and vehicles are involved [8]. Details of this course are set out in Section 4 below.
- The MMAUR course deals with Modeling Methods and Urban Applications. It develops around two complementary axes: the first direction delivers a range of modeling approaches, the second direction spans different urban subsystems. Each axis encourages comparative analysis, critical examination and critical distanciation [9].
- The CSIUR course, Spatial Design and Urban Integration, focuses on design. Space is treated both as a resource and as a node at which different constraints connect together. Technical intervention on space, the use of space, its arrangement and artificialization through infrastructures and superstructures, is taught by a consultant engineer. However, the teaching team is primarily made up of architects who talk about their professional practice and present theoretical strategies for acting in and upon space. In particular, in the urban environment the negotiating power of citizens governs the notion of compensation: this forces an expansion in the development project, so that it becomes a genuine urban project and therefore provides greater value, even if at higher cost [10].
- The GRAVED course on Data Management, Collection, Analysis, Visualization and Enrichment, teaches the representation and handling of large datasets, with applications to transportation and real estate [11].

As for the intensive group project, it is conducted in teams ideally comprising 4 to 6 members. The objective is to pool sectoral skills around a joint application. Collectively, the primary aim is to manage intersectoral complexity and to conceive a development operation that is satisfactory in all aspects of sustainable development. Further benefits come from the learning of teamwork methods and external communication in interaction with outside actors, some of whom are potential clients.
In addition, there are individual learning objectives: (1) for effective sectoral design, (2) for working successfully in close cooperation.

Details on the process of the intensive group project and its results are set out in Section 5.

4. Course on "Life Cycle Analysis of Urban Transportation Modes"

4.1 Knowledge and skills objectives

This module teaches Life Cycle Assessment (LCA) methodology, particularly for transportation systems. It seeks to equip student engineers with the skills to handle evaluation studies and research on the environmental performance of urban transit modes.

LCA is an ISO 14040 and 14044 classified assessment methodology that is used to quantify the environmental impacts of a given system over its whole life cycle, from the extraction of the raw materials needed for its development through its use right up to end-of-life.

Currently, optimizations relating to transportation systems are highly sectoral, divided between vehicles on the one hand, infrastructures on the other and, between them, traffic optimization. However, an urban transit mode is a complex system in which numerous interactions can take

place: “optimal optimization” necessarily requires the mode to be assessed as an integrated system, over a larger than usual physical perimeter.

The complexity of transit systems reaches its apogee in urban environments, where the density of demand – which supply seeks to fulfil – entails a diversity of modes and therefore a multiplicity of possible combinations within an itinerary, generating substitutions and/or intermodality on the part of travelers, and lane juxtapositions and traffic mixes within the system, which themselves generate conflicts between mobile units.

The objective of this module is both to pass on the theoretical and practical elements of LCA, and to teach students how to apply them in a close-grained way to transportation systems. This second aspect constitutes the state-of-the-art in the environmental assessment of transportation systems, since LCA methodology was initially developed for the ecodesign of simple manufactured products.

As regards the pedagogical structure, the module is built around 13 sessions of 3 hours, comprising an initial series of lectures followed by a project-based case study.

4.2 Lectures

The first four sessions provide the essential theoretical grounding, in a very restricted timeframe: first the environmental issues associated with the transportation sector, LCA methodology, and its sectoral use in application on the vehicle side and on the infrastructure side in France, continually punctuated with exercises in application to promote the practical assimilation of the concepts.

Conducting a LCA requires a certain technical knowledge of the system studied, without which there is a risk that the model will contain omissions, replications and errors and inaccuracies. For this reason, the two lecturers sought to put across the rudiments of the construction of the systems constituting a transportation mode. The lectures were combined with two sessions of bibliographical reading (individual work) followed by class feedback.

4.3 Case study: eco-assessment of a BRT system

The project group is structured rationally to handle the case study. It followed the stages of a LCA:
1. Consideration of the study framework, selection of study objectives and the perimeter of the system studied;
2. Establishment of inventories based on documents supplied by our industrial partners (designers, constructors, suppliers and operators of the transportation system);
3. Implementation using the OpenLCA software, reflection on the environmental indicators chosen and acquisition of the potential impacts;
4. Study of the results and correction of modelling errors through close analysis.

From phase 2 onwards, the students organized into pairs or individually for each system element in order to model the infrastructure. This organization arose quite naturally from the source documents conveying the basic information used in establishing the inventories: this document was the Indicative Bill of Quantities of the infrastructure constructor Eurovia, which was also organized into system elements. This was a very large document: 600 Excel spreadsheet rows in the basic document, with a further 7 detailed files containing up to 75 tabs, each with a few Excel rows. The process of establishing an inventory consisted in dividing up the so-called operations (i.e. lifecycle stages of construction, operation, end-of-life) for the whole system, conducting a materials assessment (materials, energy consumed in different forms), and then identifying the most appropriate modelling processes in the EcoInvent database. This required a very close analysis of EcoInvent.

The eight workshop sessions were headed by the module’s two tutors: their role was both to verify accomplishments as they occurred and to support the students, usually on request, in establishing working hypotheses and in progressively verifying the magnitudes.

The small number of students – just eight – meant that they could be closely monitored in classes and then in the project workshops. Their work was assessed on the basis of the quality of the bibliographic study and their communication in class, the relevance of their modelling, and the accuracy of the results obtained.

Not all the results could be exploited, even when the most significant mistakes were corrected by the tutors. For example, the "wastewater management" subsystem had to be excluded from the perimeter, pending revision. Out of a set of 13 indicators selected to cover the main categories of environmental issues quantifiable by LCA, the study gives the contribution of each subsystem to every indicator describing their types of impact. The subsystems can be more or less finely divided, depending on the information sought: infrastructure/vehicle or a more detailed level, focus on green spaces (per life-cycle phase), on street furniture, etc.

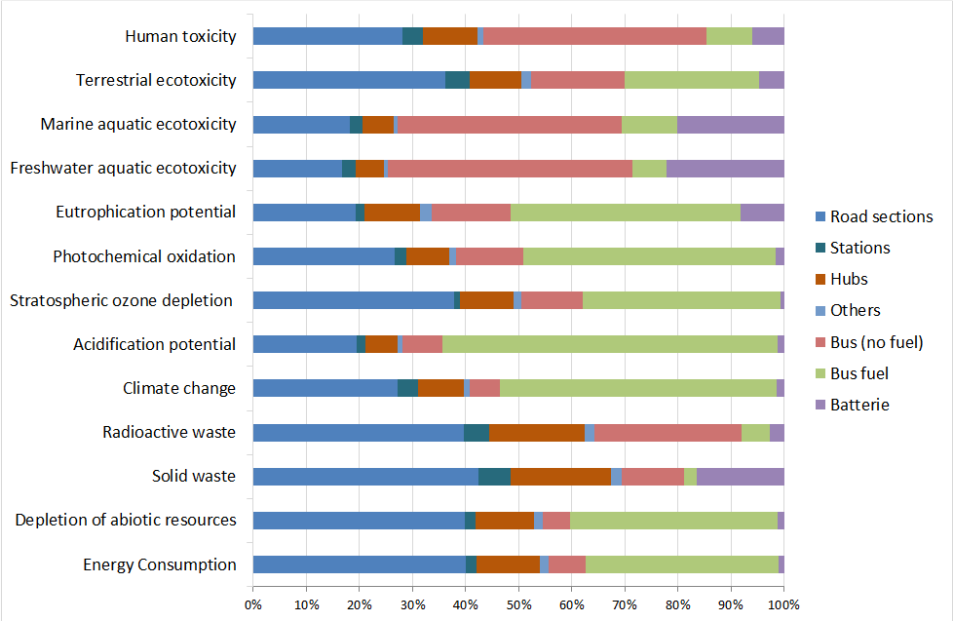

Figure 1 Example of results

4.4 Critical assessment

Although the LCA methodology claims to be global, it in fact provides neither the local environmental impacts that directly affect populations adjoining the transport infrastructure – air quality and urban ambience (noise, odors, landscape…) – nor the quality of the transportation system for users, which could be measured, amongst other things, by accessibility indicators.

In pedagogical terms, the module offers two advantages. First, it places the students in a complex professional situation – teamwork, data that are highly complex to handle and at first sight not very comprehensible/familiar, use of previously unknown software and database. Second, it places them at the heart an advanced subject with so far very little spread at national level, the development of an assessment methodology for an integrated transportation system, on a larger perimeter ([12], [13], [14]) or with more indicators ([15] than usually.

Since a detailed LCA (i.e. an ex-post assessment) is highly time-intensive and less useful for developing recommendations that are actually usable, it was decided to develop an ex-ante LCA and to conduct sensitivity analyses in order to place the students in a real-world situation of providing client advice.

Finally, the study was extensively publicized with industrial partners in the project and at a world-wide professional conference (25th World Road Congress), which gave half the year group – i.e. those who had delivered usable work – the opportunity to co-author a first article. Nonetheless, the tutors had to intervene extensively in order to verify and revise the models and obtain valid results.

5. The intensive group project on "ecodesign and planning"

5.1 Knowledge and skills objective

Let us recall here what was specified in paragraph 3.3: the body of knowledge to be acquired relates to subjects that are components of the sustainable city: (1) the built environment and urban morphology, (2) mobility and transportation, (3) energy and materials, (4) water and the blue infra-structure, (5) biodiversity and the green infrastructure, (6) stakeholders.

The skills for development are modeling and simulation through acquisition of the principles and implementation of simulation software tools, as well as evaluation and the design process [16].

5.2 Project structure and process

Here, the project aim is to design a sustainable neighborhood. This entails designing a layout plan (land-use and spatial arrangement in 3-D, at each of the locations within a demarcated perimeter), in terms of urban functions (housing, amenities, economic activities of several types), each of them in certain places and with certain intensities, with material amenities (buildings, networks) requiring proposals for form and scale, as well as fine-grained arrangement for elementary functions (e.g. layout of external access points and parking spaces for a given building). This plan must fulfil a set of functional specifications imposed by a commissioning client: typically, for the number of inhabitants and jobs to be contained, the areas of floor space to be built, land occupancy ratios; and, at the same time, it must offer good performances against multiple sustainable development assessment criteria [17].

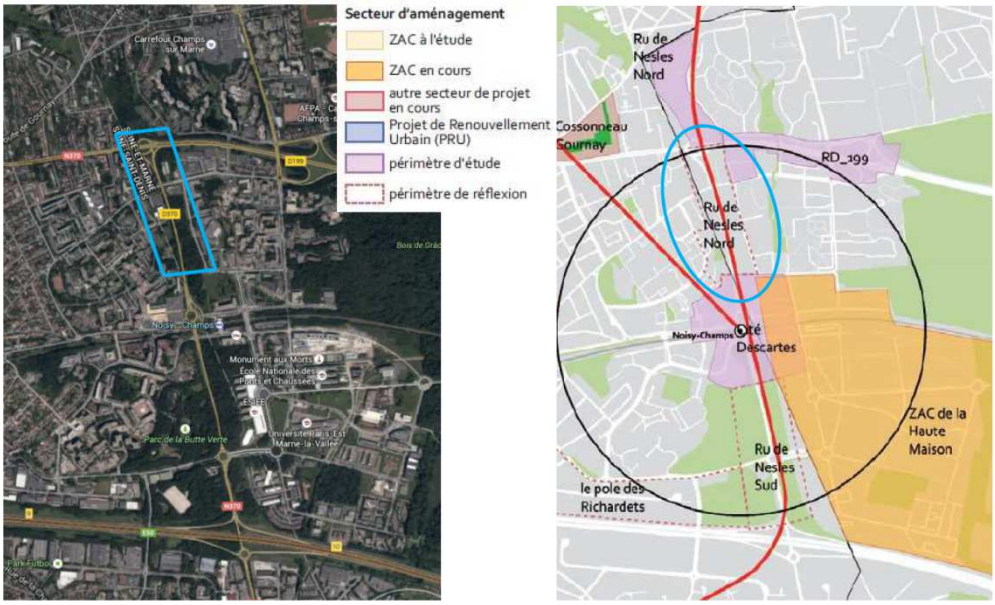

Figure 2 Neighborhood under study (a) Satellite view, (ii) Situation map

This standard project was implemented in 2015-2016, by a group of 8 students, for a district in Cité Descartes in the eastern suburbs of Greater Paris. This district will be served by the Grand Paris Express automatic subway system in 2025, and urbanization will be intensified. Figure 2 shows (a) a satellite photo of the site and (b) a site plan. Four topics will be studied in depth: the

buildings, mobility, energy and hydrology. Air quality will only be considered in terms of road traffic emissions.

The semester allocated to the project (in fact less than 5 months) is structured into four phases:

- First, revising and obtaining knowledge, together with the learning of simulation tools;
- Next, application to design, by modelling the study case and devising a planning choice (a "variant" of the project);
- Then the multi-criteria assessment;
- Finally, following an intermediate presentation to the stakeholders, a project redesign and the assessment of the new variant, for final presentation.

5.3 The Descartes showroom project

In 2014-2015, the first year of the new program, the first project was deliberately simplified in order to test the students' ability to handle an extended range of knowledge input. The task was to design an overall assessment for the concepts, products and services focused on the theme of the Sustainable City by organizations and companies located at Cité Descartes, a scientific campus in the eastern part of Greater Paris. This group includes public education and/or research bodies (ENPC, IFSTTAR, CSTB, CEREMA, Université Paris-Est Marne la Vallée) as well as large companies associated with these public institutions and others within the Efficacity Institute for Energetic Transition (IET): EDF, Engie, IBM, Véolia, Vinci and an engineering consortium. The category also includes innovation companies, in particular MopEasy (different forms of car rental) and Moviken (mapping).

The assessment goal was gradually restricted to a fraction more easily accessible to the students: the work of the Chair in the Ecodesign of Buildings and Infrastructures (an association between ENPC and the schools of Mines and Agro ParisTech) [18], the EIT Efficacity projects, the Université Paris-Est Great Hall project, and a few private sector services.

This pedagogical framework enabled the students to grasp the major stakes and also the main engineering components of the Sustainable City. The students divided up the work to concentrate more specifically on each of the following six major components: (1) Urban morphology, (2) Transportation and mobility, (3) Energy, (4) Environmental assessment, (5) Biodiversity, (6) Stakeholders, and then brought the components back into interaction.

During the project, they produced:

- A report with their own presentation of the components together with their design approach [19].
- Posters explaining each component from a four-fold perspective: from Priorities to Prospects via Projects and Productions;
- A "7 Families Set" of the sustainable city, a discovery card game; each family contains six members, representing each of the six components. The families are "Functional and Socially Interactive City", "Circular Economy", "Smart and Connected City", "Resilient City", "Green City", "Renovated City", "Today's City".
- A "Board Game" for assessing the life cycle of a concrete wall.

Plans for the layout of a demonstration space: a layout map divided into circuits covering the major components.

The exhibition material was displayed for a week, from February 9-14, 2015, at the Bienvenue Building in Cité Descartes, in the central hall's so-called "green bean" room. In the event, it also included several loaned objects, notably provided by IFSTTAR to demonstrate the concept of 5th Generation Road, while ESIEE loaned several Sense-City equipment sensors.

5.4 Observations

The first year group and the beginning of the second have shown that the students are strongly committed to the project. The linkage between the support classes and the intensive group project facilitates and stimulates the team dynamic. The students work hard to understand the topics pursued by their colleagues and erstwhile classmates, as well as the themes they model and simulate themselves.

Contacts with the stakeholders are an opportunity to discover the need to communicate in a clear and targeted fashion, and conversely to deal with vagueness or even contradictions in the expectations and needs of the different stakeholders.

6. Conclusion

6.1 Assessments

On the basis of just the first year of implementation, the assessment of the EVD specialization is very largely positive.

The researchers who taught the course and the intensive group project are very satisfied with the high level of student commitment and the quality of the results. In several courses, the processes carried out and the results obtained formed the basis for a scientific paper presented at an international conference. The small numbers allow rich and fluid interaction between tutors and students.

The students commented on the very heavy workload, while stating that they would still choose to take the course if they had to start over. The group dynamic, driven by the strongest students, enabled the less advanced to gain confidence in their own technical capacities, and therefore to gain personal poise and self-assurance in their working relations.

Following the semester of learning, each student produced their Masters assignment on a subject very well aligned with the specialization. Their understanding and technical competence were very quickly recognized by their employers. As a result, the content of their employment roles has been enriched, to the benefit of both employer and student.

In all, the new training system opens up the students to a wider technical spectrum, and makes their learning more productive. In other words, the program itself is much more effective than the previous system.

6.2 Future developments

We infer that the young engineers who have experienced the new training can more quickly or deliberately access responsibility as heads of development projects, and therefore as operation coordinators. Indeed, it would seem that the education process has helped them discover the diversity of possibilities in a cooperative perspective, by overcoming mutually imposed constraints and showing ways of reconciling them harmoniously.

According to the design offices which recruit engineers trained by ENPC, this coordinating engineer profile is nowadays only too rare, and therefore much in demand. By adopting it, our young engineers will make themselves useful not only to their employers, but also of course to society, by reinforcing the effectiveness of public action.

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