Orietta
Pedemonte

Mathematics for Architecture: Some European Experiences

Orietta Pedemonte studies how mathematics is taught in faculties or schools of architecture in Belgium, Portugal, France, Switzerland and Spain, comparing course organizations, subjects offered and entrance requirements. Which and how much mathematics for architecture? What kind of teaching? Is it better to have information on many aspects, or a deeper insight into only a few? Is it better to privilege a historical-philosophical overview, or to focus aspects of application that are current today? These are some of the questions that are raised by whoever deals with teaching mathematics in a faculty or school of architecture.

Introduction

Which and how much mathematics for architecture? What kind of teaching? Is it better to have information on many aspects, or a deeper insight into only a few? Is it better to privilege a historical-philosophical overview, or to focus aspects of application that are current today? These are some of the questions that are raised by whoever deals with teaching mathematics in a faculty or school of architecture. The problem is made more acute by a final question: what do we mean by “architect”? Rivers of words and paper have poured out in the attempt to define this term. The European Economic Community (EEC) directive EEC 384/85 (see Appendix 1) has provided some indications in this direction, but the means to achieve the objectives set forth there can be variously interpreted and understood; the debate continues.

What is meant by architecture? What are the possible future “professions” of an architectural graduate? What effect will the new world scene currently being shaped have? And further, is it better to prepare for one profession (which is revealing itself to be multifaceted, as has been shown by studies on the occupations of graduates), or to provide a methodological-cultural background that allows for future flexibility? The problem is further aggravated by the restructuring of university courses of study that are taking place on the European level and in the Italian universities as well.

From these observations arose my own study on the teaching of mathematics in European faculties or schools of architecture; a study I have not yet terminated and that, for now, has taken into consideration only Belgium, France, Portugal, Spain and Switzerland. The paper that follows does not therefore pretend to be exhaustive, not even in terms of the individual countries presented. It is only the fruit of some considerations, on the basis of conversations with educators and the consultation of articles, texts, dossier, course outlines, student handbooks and web pages of some of the schools or faculties of the countries mentioned above. Of special merit has been the consultation of *Architetti in Europa: Formazione e professione* [Masiero, Maguolo and Polese].

Belgium

The formation of architects is undertaken by both the ISAI, Instituts Supérieurs d'Architecture Intercommunales, (considered since 1991, in compliance with EEC directive 384/85, “institutes of superior instruction of long duration” at the university level, dependents of the Ministry of

Education, Scientific Research and Formation) and by the Technical Universities. The course of study lasts for five years, divided into two cycles. The first, of two years, provides the qualification for the title of “Kandidaat architect” (architect candidate), which allows an initial insertion into the professional world. The second, three-year, cycle leads to the title of “architecte/architect” or “burgerlijk ingenieur”. In all architectural schools the first cycle is primarily constituted of obligatory basic subjects; the second aims at specializations, with each school offering different options. There is no limit on the number of entering students and for inscription it is necessary to possess a diploma from a secondary school.

The Institut Supérieur d'Architecture de la Communauté Française La Cambre differs from other schools in that it is less technical and more focused on design (and thus closer to the French schools). In any case the first cycle offers a course in mathematics in which the first part teaches elements of differential and integral calculus and differential equations. In the second part “laws of harmony” are taken into consideration so that beginning with the history of mathematics the close relationship between architecture and mathematics are evidenced, through the science of proportion. The first cycle also includes a course in descriptive geometry and applications that comprise studies of solids and surfaces. A great deal of attention is given to computer science and its applications, one course being offered in the first cycle and two courses in the second. These courses not only concentrate on design and modeling, but also on the study of the properties of complex systems.

In other ISAI are found, in varying degrees, teaching modules of differential and integral calculus, probability and statistics, geometry of curves and topology, computer science (for example, at ISAI-Horta there is a total of 150 hours of these, while at the ISAI-Mons there are 240 hours) and descriptive geometry (150 or 120 hours). These courses are generally localized in the first cycle, but sometimes there are modules of computer science and statistics in the second cycle as well (as for example in the ISAI-Mons).

In the universities the biennium is usually common to the course of study of engineering. For the triennium there is the option to choose between a more technical formation or one more strictly tied to architecture. Inscription is free, but it is necessary to pass an entrance examination in which the exams in mathematics, regarding trigonometry, algebra, analysis, synthetic and analytic geometry are decisive. In order to pass the examination, usually it is necessary to have some reinforcement of the mathematical studies of the last year of secondary school. In the formation of the architect by the university, the teaching of mathematics and computer science is notably present with advanced courses even in the second cycle.

France

The formation and research in the field of architecture in France appertain to the Ministry of Culture and Communication. The title of architect in France is conferred by either the “diplôme d'architecte diplômé par le gouvernement” (DPLG) awarded by the twenty-two Ecoles d'Architecture, or by the “diplôme d'architecte de l'ENSAIS” awarded by the Ecole Nationale Supérieure d'Architecture of Strasbourg or by the “diplôme d'architecte DESA”, awarded by the Ecole Spéciale d'Architecture of Paris, a private institution.

The Ecoles d'Architecture originated from the Ecoles des Beaux Arts and some of the French schools are still tied to the method and the type of education of the Beaux Arts, in the sense that the greatest emphasis is placed on the artistic formation of the student. Reform was begun in the academic year 98/99 that provides for a course of six years' duration subdivided into three

biennial cycles. At the end of the second cycle a first diploma is conferred, the DEUG, which allows for admission to the university. The reform confirms the centrality of architectural design, and to a lesser degree (in the first two cycles), urban design; in the third cycle courses specializing in urban design and computer science for architecture are offered. In the first two cycles, teaching is articulated through interdisciplinary modules and is based on the relations between “architecture and knowledge for architecture”.

The French situation regarding mathematics education is, among all the countries in this study, perhaps the most distant from the Italian. The reason for this must be sought in the origin of the schools from Beaux Arts and therefore in their having privileged the artistic formation of the students up until recent years. It can be seen then how the teaching of differential or integral calculus would be reduced to a minimum if not completely nonexistent, while placing more emphasis on descriptive and projective geometry, the study of solids and surfaces, topology and on their use for morphogenetic studies and as a theoretical basis for the construction of models (see, for instance, [Delarue] and [Delarue 1998]).

There are integrated courses in geometry, computer science, construction of models, which may be accounted for by the fact that the study of the relationships between architecture and the computer sciences is a central subject for some of the French research centers.

The debate on what should be taught in a school of architecture is still a very lively one in France (see [Violeau 1999]), but it is agreed that in order to maintain architectural design as a central and fundamental discipline, it is necessary to integrate studies of “knowing and knowing how” through ateliers either within the school or coordinated between various schools (Grands Ateliers de l’Isle-d’Abeau); in these cases as well mathematics has something to contribute ([Delarue 1998; Sakarovitch 1998a]).

With the activation of the new reforms projects for urban design has been given more attention, and therefore courses of statistics and geographical information systems have been introduced.

Portugal

It is only since 1983 that the education of architects is no longer entrusted to the Academies of Fine Arts, but rather to the faculties or departments specifically constituted for that purpose. Nevertheless, there has been a split between the technical-constructive emphasis of some faculties and the artistic-humanistic emphasis of others. The debate has been quite heated, arriving finally at the European Consulting Committee. Actually, thanks to a more balanced composition of a program of study, the conflict seems to have been resolved.

In order for inscription in a faculty of architecture, it is necessary to have a diploma from a secondary school and to pass a national examination for admission to the university in the specific subjects that are required by individual faculties. Generally, for architecture these subjects are mathematics, descriptive geometry and art history. The courses last six years at the faculty of Lisbon and Porto, and five years at Coimbra and the private universities of Lusiada. These courses of study are not subdivided into cycles and it is only in the fifth year that various options are made available.

Spain

The profession of architect is only open to those who have a university diploma of a superior degree conferred by the “Escuela Técnica Superior de Arquitectura”. The five-year courses,

subdivided into two cycles, that lead to award of the title of architect are supplemented, in almost all universities, by shorter three-year courses that lead to the qualification of “Arquitecto tecnico”.

It is possible to vary the education through the selection of optional courses that correspond to approximately 10% of the total hours. The rest of the hours are divided between fundamental obligatory subjects that are set by directives of the Ministry, and other obligatory subjects that are set by the each school on the basis of its own specific characteristics.

In Spain, the authority attributed to architects goes decidedly beyond that set by the European directives, and because of this some universities lament the six-year course, offering and preparing a continuing education that is superior, from a scientific point of view as well as that of duration, to that of other countries.

For admission to the university, once secondary school has been completed it is necessary to attend a one-year Course in University Orientation with a final examination (*Selectividad*); the score obtained determines admission to a university course of study that accepts only a limited number of students, such as the School of Architecture.

As far as mathematics education is concerned, the situation is rather similar to the Italian. Mathematics is present in the first cycle, but in the third year as well in some schools. In schools in which lesser emphasis is placed on mathematics, greater emphasis is placed on information sciences and applications, with ample space given to the geometric aspects of application. The arguments presented, in various proportion, are: infinitesimal calculus, integral calculus, differential equations, numeric methods, problems of maximum and minimum constraints, elements of statistics, geometry, linear algebra and descriptive geometry. Within courses of geometry and algebra are sometimes included proportional systems applied to architecture, isometrics and tiling. The subjects cited are certainly not new; the problem is the degree to which they are examined, their connections to other courses in architecture, and an engaging presentation. In this sense the formulation given in *L'art de calculer en l'architecture* [Alsina 1993] seems to me to be particularly interesting. Appendix 2 presents the outline of the book.

Switzerland

The situation in Switzerland is unique: the education traditionally provided for architects is strong technically. In order to design and construct buildings, only a diploma from a secondary technical school is necessary; but only those who have been awarded a university degree have the right to the title of architect. In any case, a reform is underway that seeks to adjust the architect's professional preparation in conformation with EEC 384/85, even though Switzerland is not part of the European Union. Thus, for example, the Swiss *Fachhochschulen* are modifying their systems of instruction so that they are comparable to the German *Fachhochschulen*.

Besides the superior technical schools, in modification, the degree in architecture can be conferred by the universities or the polytechnic institutions. In all but the University of Italian Switzerland, courses last four years, subdivided into two biennial cycles, with an extra obligatory year of apprenticeship. At the Polytechnic of Zürich (ETH), the institution of a year-long course of study of fundamental subjects that are either not presently taught or not sufficiently taught at the secondary level is being considered. The University of Geneva offers only the second cycle, and the first cycle must be taken either at the École Polytechnique Féd. De Lausanne (EPFL) or at the ETH. Geneva and Lausanne have sought, in the second cycle, to vary their specializations, Lausanne maintaining a technical/engineering specialty (besides a specialization in history). At the EPFL mathematics education is given both during both semesters of the first year and both

semesters of the second year, with special attention paid to geometry (descriptive, the study of curves and surfaces, proportions, the Golden Section, the Modulor and tiling) and graph theory. Also fundamental is a semester of computer science and two semesters of “informatique et dessin”, preparatory to a course of “modélisation informatique” of the second cycle.

The University of Italian Switzerland merits a discussion of its own. The diploma is awarded by the Academy established in 1995. The emphasis is purposely humanistic and less technical with respect to the other Swiss degree programs. Particular attention is given to interdisciplinarianism, to the fundamentality of design (intended in the broadest sense) and to the necessity of finding a common approach to other historic and scientific disciplines. The organization is unique (see [Alsina 1993]). The course lasts 6 years.

As regards mathematics education there is an introductory course in the first year, followed by these advanced courses following years: “Representation of forms”, “Geometric forms for visualization”, “Mathematic structures in architectural design”, “Mathematics in the history of architecture”, “Ecology”, “Structures”, etc. These are conceived as differentiated areas of study of a single field that are expected to “nourish” the complex process of design; the requirement for interdisciplinarianism is very strong.

The experiment is underway; the program is very stimulating. It is worthwhile to follow its development carefully, although the logistical situation of the Academy is so favorable that could be followed only with difficulty in our own schools and would be complicated to implement.

Conclusion

From this study I have formed the following impressions:

- that descriptive geometry, analyzed in its historical development and linked to stereometry, is a good point of intersection between the history of architecture, mathematics and the science of construction (see [Sakarovitch 1998b]). If it is united with the construction of models (for the preliminary design of which is indispensable a certain geometric capacity), the ability of the student to invent forms may be developed;
- the space dedicated to the interaction of computer sciences (geometry of forms) and architecture must be enlarged, as it is already in some other countries, and that, given the strong urban design component of our system of study, courses of geographical information systems need to be provided.

It is important that the students acquire the use of, or better, a “design” for the intelligent use of, the methods and instruments of computer science.

The central problem remains: what kind of education should an architect have? I share the opinion expressed by the director of the Academy of Meudrino during the presentation of a course of study, that the future architect must “know how to design a project, but a project of ideas, spaces, materials, forces, light, etc.; all designs, but not only drawings”.

Design is, however, complex and requires knowing how to conduct an interdisciplinary activity, understanding in some cases the insufficiency of one’s own knowledge and knowing therefore how to maintain a dialogue with experts. This does not mean merely asking an expert for the answer to a problem, as often happens, but knowing how to participate in formulating an answer, that is, knowing how to exchange ideas. It is therefore towards the construction of a common language that our attention ought to be focused, bringing to light the possible

connections between the knowledge of our own discipline and that of others that are useful for creating a design, but the participation must be complex, not unilateral. It is a difficult problem; to me it still seems an uphill battle.

Appendix 1: EEC Directive 384/85

According to EEC Directive 384/85, studies at the university level that lead to the title of architect must be divided in a balanced manner between theoretical and practical aspects of the education of the architect and assure that following objectives are achieved:

1. The capacity to create architectural designs that satisfy aesthetic and technical requirements;
2. An adequate knowledge of the history and theory of architecture, in addition to the arts, technologies and human sciences pertinent to it;
3. A knowledge of the fine arts in as much as they influence the quality of the architectural conception;
4. An adequate knowledge of urban design and planning and the techniques involved in the planning process;
5. The capacity to grasp the relationships between man and architectural creations and between architectural creations and their environments, as well as the capacity to grasp the necessity of revising architectural creations and spaces in accordance with human needs;
6. The capacity to understand the importance of the profession and of the function of the architect in society, particularly in elaborating designs that respond to social factors;
7. The knowledge of methods of enquiry and the preparation of a construction project;
8. The knowledge of problems of a structural nature, and of construction and civil engineering connected to the design of buildings;
9. An adequate knowledge of physical and technological problems, as well as of building functions, in order to render them comfortable and to protect them for climatic factors;
10. A technical capacity that permits the design of buildings that respond to the needs of the building users within the constraints imposed by factors of cost and construction materials;
11. An adequate knowledge of the industries, organizations, regulations and procedures necessary to realize designs of builds and for the integrations of planning.

Appendix 2: Preface to L'art de calcular en l'arquitectura [Alsina 1993]

A grans trets, podríem classificar els càlculs dels arquitectes en els tipus següents:

a) Càlculs constructius

Són els càlculs inherents a l'edificació en sentit estricte: la representació topogràfica del terreny, l'estudi de la mecànica del sòl, fonamentacions, moviments de terres, etc. fins arribar a la construcció efectiva de l'obra i el seu control de qualitat.

b) Càlculs estructurals

Són els propis de l'estructura de l'edificació i asseguren per sobre de tot la rigidesa de l'obra. En una subtil combinació de conceptes de mecànica, resistència de materials, equacions diferencials,

càlculs de moments, torsions, flexions, etc., és possible crear aquesta estructura que sovint apareix disimulada i maquillada per altres elements, però sense la qual res no romandria dret.

c) Càlculs de condicionament i serveis

Integrats a l'edifici, hom troba un món complex d'elements elèctrics, mecànics, acústics, lumínics, calorífics, etc. Cal fer càlculs relatius a la integració en la construcció i càlculs sobre el funcionament específic dels elements en qüestió. Matemàtica, física i enginyeria troben aquí un bon camp per fer-hi aportacions.

d) Càlculs projectuals

El projecte, com a element vertebrador de l'obra, ha de tenir en compte necessàriament la integració de totes les components i d'axiò deriven sovint càlculs específics: pilars, canonades, esteses de cables, envans, endolls, ascensors, etc. podrien esdevenir una barreja esperpèntica si no hi hagués un disseny global de l'obra.

e) Càlculs gràfics

Les tècniques d'expressió gràfica contenen, de fet, un bon gruix de càlculs que acaben permetent la resolució gràfica dels problemes. Marcar un punt de fuga, distingir les escales convenients per presentar els diferents elements o fer palesa la forma d'una volta o d'una escala de cargol pressuposen un joc geomètric fi, no mancat ni de mesura ni d'altres components matemàtiques.

f) Càlculs legals

Les obres són realitzades en un lloc precís tenint en compte una normativa legal que en fixa limitacions molt diverses. Calcular fondàries edificables, alçàries, patis de llum, ventilacions mínimes, plans d'evacuació, resistències al foc, etc. són problemes difícils de resoldre, però inexcusables.

g) Càlculs de planificació

La realització efectiva d'un projecte sempre porta aparellada una bona planificació respecte dels diferents equips i professionals que hi intervenen, una regulació temporal imprescindible, i un càlcul econòmic acurat que faci l'obra viable i, si pot ser, rendible (!). Organigrames, grafs, sistemes d'organització, càlculs financers, càlculs actuuarials, etc., són el nostre pa de cada dia; i càlculs d'assegurances per allò del «per si de cas».

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