The role of structures in architecture: the multidisciplinary experience of active learning in a master of science

Elsa Garavaglia
Department of Civil and Environmental Engineering, Politecnico di Milano, Milan, Italy
Noemi Basso
Waseda University – Waseda Campus, Shinjuku-ku, Japan, and
Luca Sgambi
Faculty of Architecture, Architectural Engineering and Urban Planning, Université catholique de Louvain, Louvain-la-Neuve, Belgium

Received 14 August 2019
Revised 27 February 2020
8 April 2020
29 May 2020
Accepted 5 June 2020

Abstract

Purpose – This paper aims to present the integrated teaching activity carried out in the Studios of the Master of Science "Architecture-Building Architecture" held at the School of Architecture Urban Planning Construction Engineering of the "Politecnico di Milano," Milan, Italy. The integrated teaching activity related to the structural disciplines was in Sgambi *et al.*, 2019; here the structure of the MSc training and its disciplinary synergies will be presented. Indeed, this type of activity characterizes all the Studios of this Master of Science and involves all the disciplines that contribute to the development of an architectural and cultural heritage preservation project.

Design/methodology/approach – In the Studios of the aforementioned Master of Science, teachers of different subjects are involved, working together to guide the student in the development of an architectural project sustainable in all aspects. The fundamentals of each discipline are taught using the best suited teaching methodology and the application phase of each discipline is carried out directly on the students' projects in the form of "learning by making." The students are thus stimulated to deepen their basic knowledge of each single discipline, making their design choices sustainable.

Findings – This experience, born in 2003 and still active, has also achieved good results in employment. Students train using the "learning by making" method to acquire proficiencies in various disciplines of design, giving them the ability to communicate competently with experts belonging to different construction sectors.

Originality/value – The approach illustrated in this paper does not represent the didactic experimentation of a single discipline, but it is typical of the study program of an entire Master of Science. Although this approach is entirely built on a "learning by making" and "active learning" philosophy, it maintains the teaching of the theoretical contents of disciplines at a significantly high level when compared with the contents of a frontal-taught theoretical course. The development of this structure required a strong commitment on the part of the teaching staff in their search for effective teaching methods in each individual discipline and aimed at the architectural project. The results obtained give an added value to the training of future architects.

Keywords Active learning, Architectural education, Multidisciplinary approach

Paper type Research paper

The authors thank their students for allowing to publish some figures of their degree thesis.

This paper is dedicated to Noemi Basso, a friend and esteemed colleague of Waseda University who recently passed away. A flower too delicate to overcome the storms of life.

Archnet-IJAR: International Journal of Architectural Research
Vol. 14 No. 3, 2020
pp. 469-488
Emerald Publishing Limited
2631-6862
DOI 10.1108/ARCH-08-2019-0187

Introduction

Nowadays, architecture is a professional field that requires specialized and avant-garde skills with the involvement of a team of experts, each with their own skills. The team must be built according to the needs of the project and must dialogue constructively with the designer to reach sustainable structural technological and plant engineering choices. At this point, the figure of the architect changes: the architects become an important figure and must have sufficient knowledge in all construction sectors that allow them to both dialogue competently and make choices in collaboration with experts from every such sector.

The architect was born as a generalist figure with a vast wealth of knowledge in the fields of Architectural Design, Construction and Technological Design, but in the field of Structural Design the situation becomes more complicated. It is common for architecture students to show indifference to everything related to structural subjects (Charleston, 2005) and to show difficulty in understanding the fundamental concepts of such (Chiuini, 2006). This aspect certainly represents a constraint on their professional work, the inability to dialogue with the structural engineer may lead to the architect's acceptance of the structural aspect up to the point of debasing the compositional aspect of their work. The need to train architects to be aware of the structural function, of the correct transmission of loads and adequate sizing of structural elements has led structural teachers to question themselves on what the best method to teach these disciplines to architects should be (Salvadori, 1958; Salvadori and Heller, 1986; Allen, 1997; Vassigh, 2005; Salama, 2008; Wetzel, 2012; Uihlein, 2013; Sgambi *et al.* 2013, 2019).

Over the years, various active learning experiences have been developed in Architecture courses and especially in Studios (Mohareb and Maassarani, 2018; Qureshi, 2019), where the teaching environment is more suited to the teaching of active learning, aimed at teaching structural disciplines. The approaches used are different, but all are intended to make the architecture students familiarize with a discipline that is not always acceptable to them, but essential to their training as future designers. Most of the documented initiatives seem those of individual teachers who, respecting the framework of the Study Program, modify their way of teaching in favor of experimenting new methods (Hadjiyanni and Zollinger, 2010; Mostafa and Mostafa, 2010).

Nevertheless, there do not seem to be any documented active learning experiences involving the many teachings of an entire BSc or MSc degree course as yet, if not some remarkable examples, such as the activities carried out at ILEK Stuttgart (Goldsmith, 2016), ETH Zurich (Department of Biology), IIT Chicago (Wetzel, 2012).

As previously mentioned, the approaches adopted in active learning are not all the same: some are more conceptual, others are more engineering. Finding a balance is not easy. Just as it is not easy to standardize the assessment procedures. The active experiences in this field of "teaching-learning" follow the Constructive alignment proposed by Biggs (2003, 2014) where the activity carried out is considered in many aspects: capacity in the theoretical development of a problem, propensity to the direct application to real cases, originality and creativity of the result and so on; in this way the evaluation that is formulated is more clear and fair (Taylor and Canfield, 2007).

It is in this framework of documented activities that we can insert the active learning initiative that involves all the disciplines of an entire curriculum of Architecture present in the Studios. The curriculum of Architecture – Building Architecture was born in the School of Civil Architecture, Politecnico di Milano, in 2003 and is now included in the Master of Science program of the School of Architecture Urban Planning Construction Engineering of Politecnico di Milano.

Unlike the "Studios and structures" model inserted in different master curricula for architects, the workshops created in the Master of Science in Architecture-Building Architecture are "studios with urban design, structures, building service design and technology" in addition to "landscape or restoration with structures and survey setting monitoring." Thereby rendering the students' experience not only more exhaustive but also more realistic.

The architect trained in this master will be able to manage design meetings in the presence of experts from different sectors of engineering and architecture and conduct constructive dialogues with each professional figure involved in architectural projects.

Needless to say, these workshops are a great financial commitment for the school, in order to be able to discuss the projects synergistically, four or five professors are required in the classroom.

Moreover, in the Studios each discipline follows a pedagogical approach based on learning by making. This approach has proved difficult to apply practically, in fact its development has required time and patience. Each discipline has had to find the right balance between the teaching needs of basic theory and their application to architectural design. This process has to be implemented and modified year by year consistent with the needs of the projects; consequently, the commitments are not only financial, as to offer an increasingly effective teaching of their subjects, the professors also pay the price of their commitments.

In this paper only the difficulties and results obtained by direct experience in the adoption of active learning in teaching structures are mentioned.

Therefore, in the sections of this paper the regulatory situation from which the course was conceived and in which it is framed is presented. This is followed by the presentation of the current study program and by some results obtained from the experience of active learning carried out in the Studios of Architectural Design of the curriculum in Architecture-Building Architecture with reference to Structural Design.

European and Italian legislation

In 1985, the European Community issued a Legislative Decree (85/384/E.E.C.) with the aim of adapting master curricula issued by the Countries of the European Community to levels of common knowledge and considered essential in the higher preparation of future professionals. Among these qualifications, the degree in Architecture is also present.

The Directive highlights in 11 points the knowledge that students should acquire during their study path to be able to create quality architectural projects (Appendix 1). In addition to the knowledge deriving from the field of humanities (Fine Arts, Aesthetics, History and Theory of Architecture, etc.), the European Directive highlights the need, for an architect, to acquire knowledge also from the technical–scientific sector, in particular for management aspects of civil engineering related to structural analysis and building construction techniques.

Following this directive, the member countries began a profound revision of the regulations, and in June 1999, with the Bologna Process the construction of a European Higher Education Area (EHEA: European Higher Education Area) was realized, for which the governments of the community countries imposed some important reforms (Appendix 2) on the didactic organization of the respective schools of Architecture.

In Italy, with Ministerial Decree 24/02/1993 the modification of the didactic structure for the Architecture and Industrial Design degree courses began. The subsequent decrees, Ministerial Decree 509 of 3/11/1999, Ministerial Decree 270 of 10/22/2004 and subsequent amendments, in addition to regulating the didactic autonomy of universities, adapted the current Italian legislation to the requests of the European Community, drawing up new guidelines for the accreditation of curricula to the EU directive. It is during this phase that the architecture courses were renewed.

In this climate of change at the *Politecnico di Milano*, a Master of Science program was created in Milan (Italy) in 2003–2004, whose aim was to focus students' attention on the relationship between architecture, structure and construction. The Master of Science called *"Architecture-Building Architecture"* has the prerogative to introduce students immediately into the interdisciplinary environment of the "Studios" where the architectural design is developed and where they can practice their profession: all the technical and artistic disciplines are addressed as essential elements of the design and each solution is discussed and verified from a compositional, structural and technological-constructive and plant engineering point of view.

In the following paragraphs we will try to better clarify the didactic forms that characterize this curriculum.

Structure of the curriculum

The Master of Science in Architecture-Building Architecture is a two-year program. The required amounts of credits for each year is 60 ECTS for a total of 120 ECTS. The core of the course is represented by the Architectural Design Studios and by the elective Studios of Architectural Preservation and of Architectural Constructions. In total, these Studios cover 62 ECTS, that is, 50% of the available ECTS (Appendix 3, Study Program). Each Studio has an educational module of structures.

The training offered also includes in-depth thematic courses, general culture courses and courses useful to the profession of architect.

As can be seen from this program, the entire Master of Science focuses on workshops. Theoretical courses that take place outside of the studies use the work developed by the students in the same studios as a basis on which to apply the theory. On the one hand, this encourages students to work with more interest on the application of the theoretical course, because it is known that the results will be useful for their studio project/design; on the other hand, it makes the theoretical courses more anchored to the curriculum program. An example is the "Structural Modeling in Architecture and Numerical Computation," a theoretical course in numerical mathematics, which, thanks to an active teaching exercise carried out around the workshop project, manages to stimulate the interest of the students of architecture.

The study program is completed with an internship, to be held at professional offices of Architecture or Engineering, and the final exam consists in developing an architectural design: from the master plan to the executive design, to the structural and plant engineering sizing up to the technological detail.

At the end of the curriculum in Architecture-Building Architecture the students will have acquired 28 ECTS of architectural design and 24 ECTS of structures, which is definitely an uncommon baggage for architecture students. But it is not so much the number of ECTS of provided structures that counts as rather the didactic form with which they have been provided: four ECTS in an integrated course of structural modeling in architecture and numerical computation that introduces students to use structural calculation models; four ECTS in a risk-based design course that introduces the students to the knowledge of design in seismic and hydrogeological risk conditions; 16 ECTS are provided in the laboratories, where students "*learns by making*."

Teaching structures by working on a project: the experience of the architectural design studio

Purpose

The students of Architecture have a less analytical mind than the engineering students, so the traditional approach to structural subjects often puts them into trouble. They are usually reluctant to understand the phenomenon if it is described using mathematical formulations, but are insightful in perceiving the physical phenomenon itself, if observed in an experimental form; the subsequent codification in rigorous mathematical terms is easier for them since it is perceived as the description of something that they have well understood and therefore know how to better manage it.

Another extremely important topic for architect students is to understand the close relationship that links the design of architecture with its construction: structural needs must not distort the architecture design/project but, on the contrary, they must contribute with the architectural design to create what can be called "architecture." In order for this to happen, the designer must know in depth all the problems of design and be able to converse competently with all the expert staff that an architectural project requires: structural engineers, installers, technologists, economists and so on. To achieve this goal and teach students to dialogue with the structural engineer, we decided to build an environment, the "Studio," in which students and teachers sit at the table and discuss on the same topic: the architectural project. The Studio environment facilitates this approach, in fact the number of students is smaller than that in the traditional (ex-cathedra) course and this allows the teacher to interact intensively with each of the work groups, discussing the choices that are proposed, the progress status of the project and the theoretical insights necessary for the continuation of the project.

Teaching methodology

Soliciting students' curiosity to the problems of load transmission, balance and structural sizing starting from a real problem: their own project has the advantage of capturing attention and stimulating the learning of a discipline that is not easy to understand for architecture students.

The risk is that students can proceed by trial and error, almost retracing the path of structural pioneers. Therefore, it is important to accompany each reflection on the project with a theoretical teaching phase of the science and technique of construction. The theoretical phase can be preparatory to the setting up of the design or it can be introduced after the emergence of a structural need not yet treated (Tables 1 and 2).

The experience carried out in the Studios of the degree course in Architecture-Building Architecture has allowed us to articulate the module of structures always with a first phase of introduction to the subject of structures and with the theoretical explanation of the basic subjects. First, students must study the volumes to be included in the master plan, this will be followed by the modules of structures where students will have to analyze the characteristics of materials and their mechanical properties, their structural typologies and peculiarities. Moreover, during this phase they will have to analyze loads and sizing of the most common structural elements. During this phase theoretical lessons alternate with practical exercises.

Arguments /topics	**Preparatory and core**	**In-depth functional analysis of the design**
Structural typologies		
Transmission of loads		
Materials and their properties		
Loads analysis		
Sizing:		
Beams		
Pillars		
Walls		
Foundations		
Long-span beams		
Plates		
Domes		
Bridges		
Instability		
Seismic engineering		
Consolidation and preservation of existing structures		

Table 1.
Possible articulation of arguments/topics

I year Half yearly	1st month		2nd month		3rd month		4th month	
Studio activities								
Masterplan Scale from 1:500								
Scale project 1:200								
Executive project								
Structures								
Theory and training								
Structural choices on the design								
Thematic in-depth studies								
Structural axonometry								
Sizing of structural members								
Drafting structural report								

II year Annual	1st month		2nd month		3rd month		4th month		1st month		2nd month		3rd month		4th month	
Studio activities																
Masterplan Scale from 1:500																
Scale Project 1:200																
Final Proposals																
Elaboration of design thesis																
Structures																
Theory and training																
Structural choices on the design																
Thematic in-depth studies																
Structural axonometry																
Sizing of structural members																
Drafting structural report																

Table 2.
Example of organization of contribution of structure in studio activities

The objects of the exercises are architectural references useful to the design work to be carried out in the "Studio."

An attempt is made on these examples to develop all the topics foreseen in the structure module program, in order to link the theory as much as possible to the design practice. During the practical training phase, students are required to prepare calculation sheets for structural elements sizing that will be used during the design phase to have adequate structural sections both in layout and in elevation.

Direct application to the design

The most interesting phase is certainly the intervention phase on the project. In fact, it is there that the students must find the appropriate structural solutions for their design without distorting the architectural aspect. Teachers and students sit together at the table to discuss solutions, changes, insights. The development of the design always requires continuous tests and subsequent changes just as the structural choices require continuous checks and modifications. To better understand the construction of space, students are always asked to produce models of study of the volume of buildings, but also structural axonometries and structural models: these are useful tools to verify the structural skeleton (Figure 1) and the proper loads transmission (Plate 1).

The sizing phase is always the most delicate one. Students apply the acquired knowledge in the calculation of hyperstatic/redundant structures and in the sizing of the structural elements to the solution of a simple structural problem. The same is verified with the spreadsheets prepared with the teaching staff. The part that requires the most attention is the control of the result. Students are obliged to question themselves about the goodness of the result obtained and to continuously check the values used. This is an important aspect of their

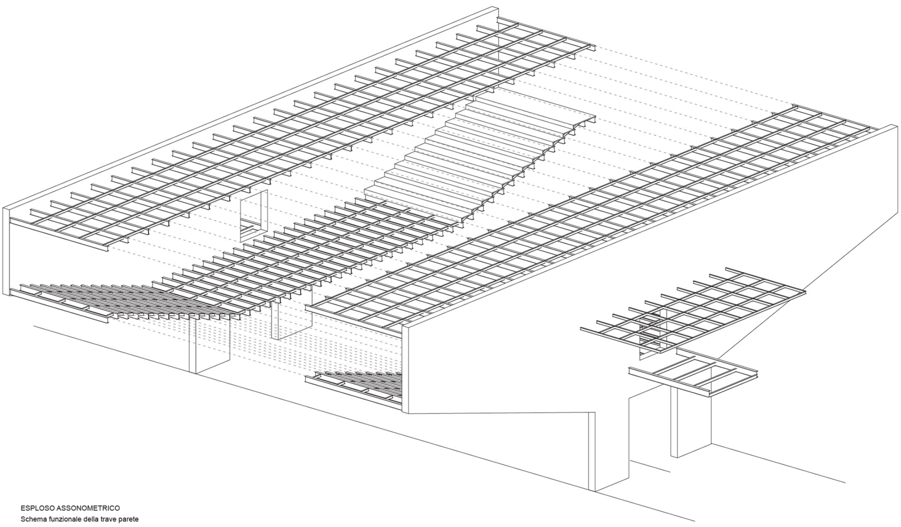


Figure 1.
Structural axonometry (Cerri *et al.*, 2017, MSc Thesis developed in Advanced Architectural design for complex construction II, 2016–2017)

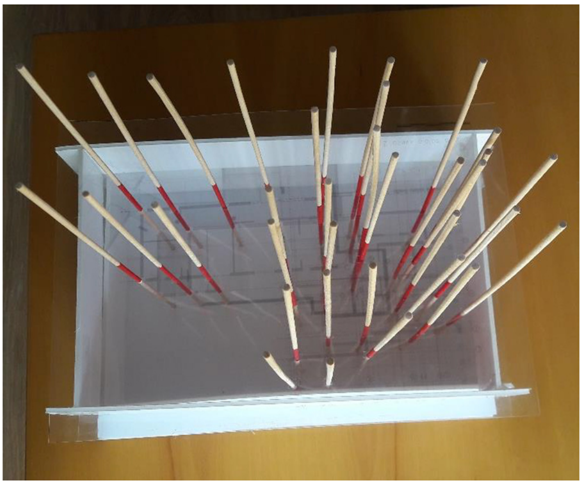


Plate 1.
Reflection on transmission of loads, model developed by students in a Studio of Architectural design of complex constructions I, 2016 (by Authors, 2016)

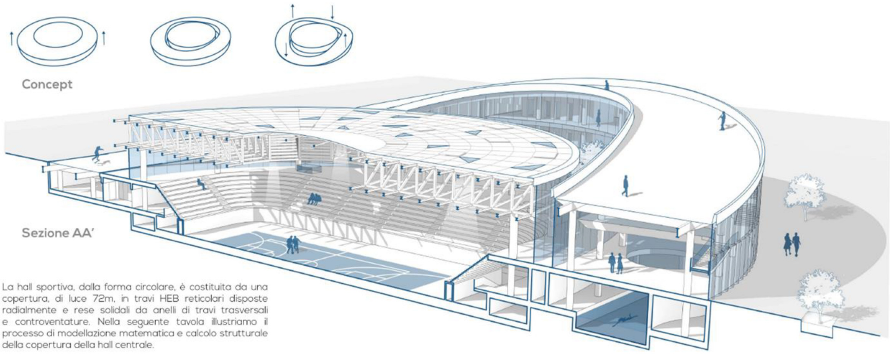
training and must be developed: for example, imposing manual calculation is a way to force students to face the government of numbers.

As mentioned earlier, the students of the Architecture-Building Architecture course have in their study plan the integrated course of structural modeling in architecture and numerical computation; therefore, in the laboratory it is also possible to perform the 3D structural modeling. In this way it is possible to deal with the insights related to horizontal actions of wind and earthquake and the sizing of two-dimensional elements such as slabs and plates.

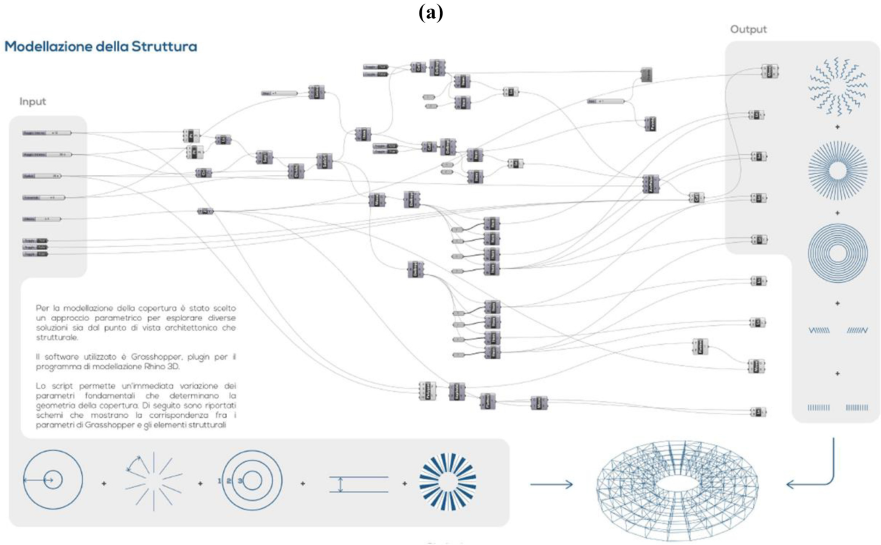
In Figure 2 an example of collaboration between the course of structural modeling in architecture and numerical computation and a Studio. In this case the students did a parameterization of the coverage of a stadium that is part of their project, to analyze the structural behavior and reach an optimized structure.

Verification of learning

The teaching of structural subjects in the studios cannot avoid facing the issue of learning verification.



(a)



(b)

Figure 2.
Example of collaboration between the Studio and the course of Structural Modeling in Architecture and Numerical Computation (Lorenzon and Tavanti, 2015)

The skills that are assessed throughout the duration of the course and in team with the other teachers of the Studio are reported in Table 3. They are the Dublin descriptors (or level descriptors) adopted in 2005 by EHEA, as the Qualifications Framework of the European Higher Education Area (http://ecahe.eu/w/index.php/Dublin_Descriptors). For each discipline, the levels of judgment are established as well as the tools with which to reach them (Table 4).

For the structural disciplines, the achievement of the first goal reported in Table 3 (knowledge and understanding) is assessed as the ability to solve simple problems and the ability to learn the fundamental theories of the discipline. Successive skills are verified at various times during the semester through continuous reviews of the design work. The final evaluation is the result of the progression of knowledge evaluated during the semester (Table 5). Combined with the judgments of the other disciplines, it contributes to the final evaluation of the Studio's work.

Examples of works developed in the studios

The integration and teaching of the structure modules in the Studios have had as the result, the drafting of structural tables, included in the package of presentation tables of the design, and the drawing up of a structural relationship describing the structural choices, from the concept, to the executive phase, showing the reference standards, the loads used and the size of the structural elements.

Following are some examples of designs developed in synergy between architectural design and structuring (Figure 3 and 4) plan, perspective drawing, section or details of sizing.

Conclusions

The teaching of structural disciplines in the Schools of Architecture has been the subject of educational experimentation for some time as it is difficult for architecture students to understand the structural subjects if they are taught in the traditional way at Engineering Schools. The approaches of active learning on the topic, and documented in the literature, are not few, but almost always represent the experience of the single teacher and not the teaching philosophy of an entire *curriculum*.

In this paper our intention is to show an integrated teaching activity between the disciplines of Architectural Design, Structural Design, Construction and Technological Design and Building Service Design, with specific reference to the relationship between architecture and structure, which the authors were able to experience in the course study in Architecture-Building Architecture held at the *Politecnico di Milano*, Milan, Italy.

Skills	Description
Knowledge and understanding	The student must demonstrate to know and have understood the basics of the discipline by solving simple problems proposed in practice and in skill tests
Applying knowledge	The student must demonstrate how to apply the knowledge acquired during the entire course to the architectural design he/she is developing
Making judgments	The student must be able to support the structural typological choices adopted and express a critical judgment on them
Communication skills	The student must be able to communicate the reasons for his/her choice in a clear and comprehensible way (sustainability, economy, design requirements, plant requirements, etc.)
Learning skills	In the final design/proposal the student must demonstrate to have understood the importance of teamwork, of the role of structures in design and of knowing how to dialogue with competence on all the structural aspects of the design

Table 3. Definition of the skills to be achieved

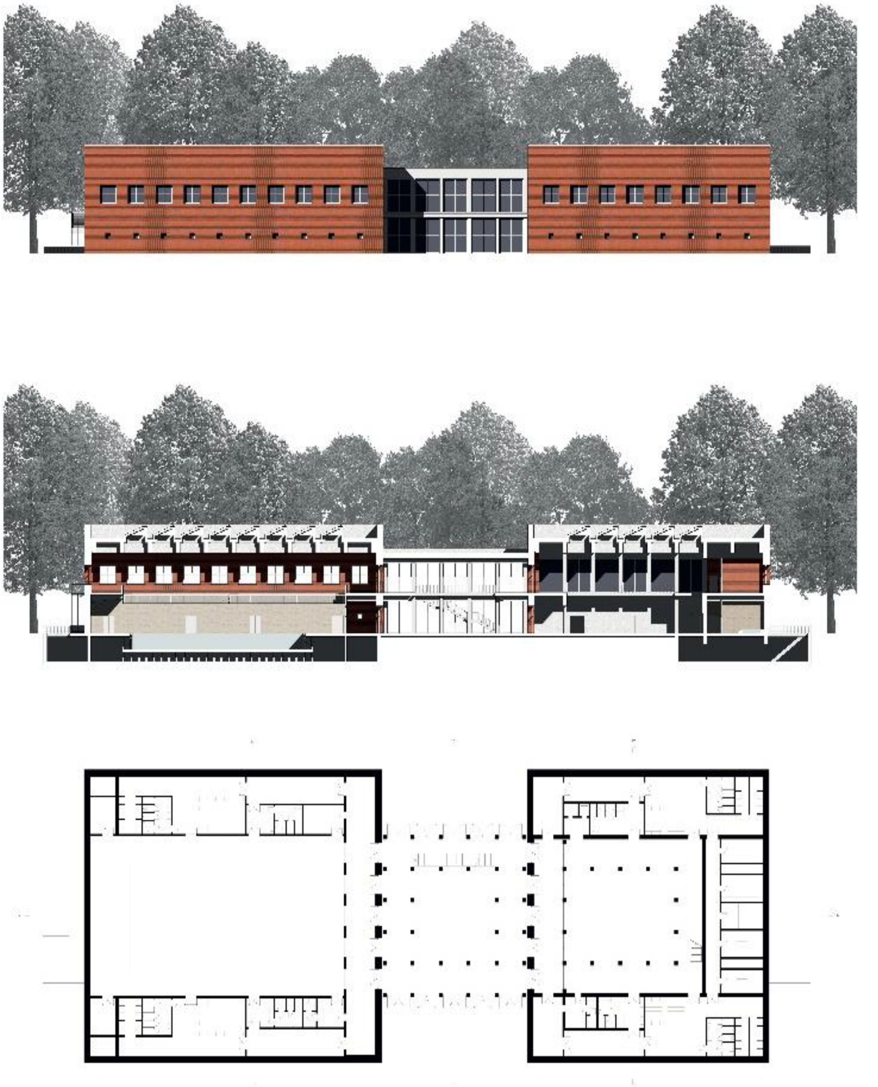
	Knowledge and understanding	Applying knowledge	Making judgments	Communication skills	Learning skills
Not acceptable	Conceptual errors in setting a problem. Inability to find a resolution	Inconsistency in the relationship, architecture structure and between architecture and structural apparatus, transmission of loads and sizing	Failure to justify the structural choices in relation to the design needs	Lack of clarity in exposing the choices made	Minimum learning levels are not achieved. The basic concepts are few and confused
Insufficient	Simplistic approach to the problem, lack of resolution skills	Definition of structural elements and transmission of loads, but inconsistency with architectural design	The justification of the choices is simplistic and with little relevance to the needs of the design. Lack of critical judgment	A little confusion in the presentation of the choices made	The basic concepts are acquired but not mastered in the application phase
Sufficient	Correct setting of the problem, difficulty in solving	Consistency in the relationship, architecture structure but difficulties in sizing the elements	Adequate justification of the structural choices adopted but not critically supported	Sufficient expository and organizational clarity of the design motivations	The level of learning allows the management of simple structural components
Good	Correct setting of the problem remarkable capabilities in the resolution	Excellent structural choice according to the project needs. Correct sizing of the elements	Clearly motivated and critically discussed choices	Good mastery of design arguments and adopted choices	The acquired knowledge makes it possible to deal critically with the structural problem at different scales
Excellent	Personal and critical approach to the problem, remarkable ability to resolve	Original and consistent structural solutions. Correct sizing even of two-dimensional elements	Choices supported with in-depth and critically commented arguments	Clarity of language, complete mastery of the themes exposed. Prompt response to the clarifications requested	The acquired knowledge allows the management of original structural choices with awareness and critical spirit

Table 4.
Skills assessment criteria

Scale of assessment	Knowledge and understanding	Applying knowledge	Making judgments	Communication skills	Learning skills
Not acceptable					
Insufficient					
Sufficient					
Good					
Excellent					

Table 5.
Example of evaluation of a students' performance in the structural field for study modules

The experience of the Master of Science in Architecture-Building Architecture, with the experience carried out at the IIT of Chicago and the ILEK of Stuttgart, seems to be one of the few experiences of true integration between the disciplines of architectural composition, structuring and construction of architecture.



Plan and cross section

(a)

Figure 3.
Design of a sports center (Farrauto *et al.*, 2018 MSc Thesis developed in Advanced Architectural design for complex construction II, 2017–2018)

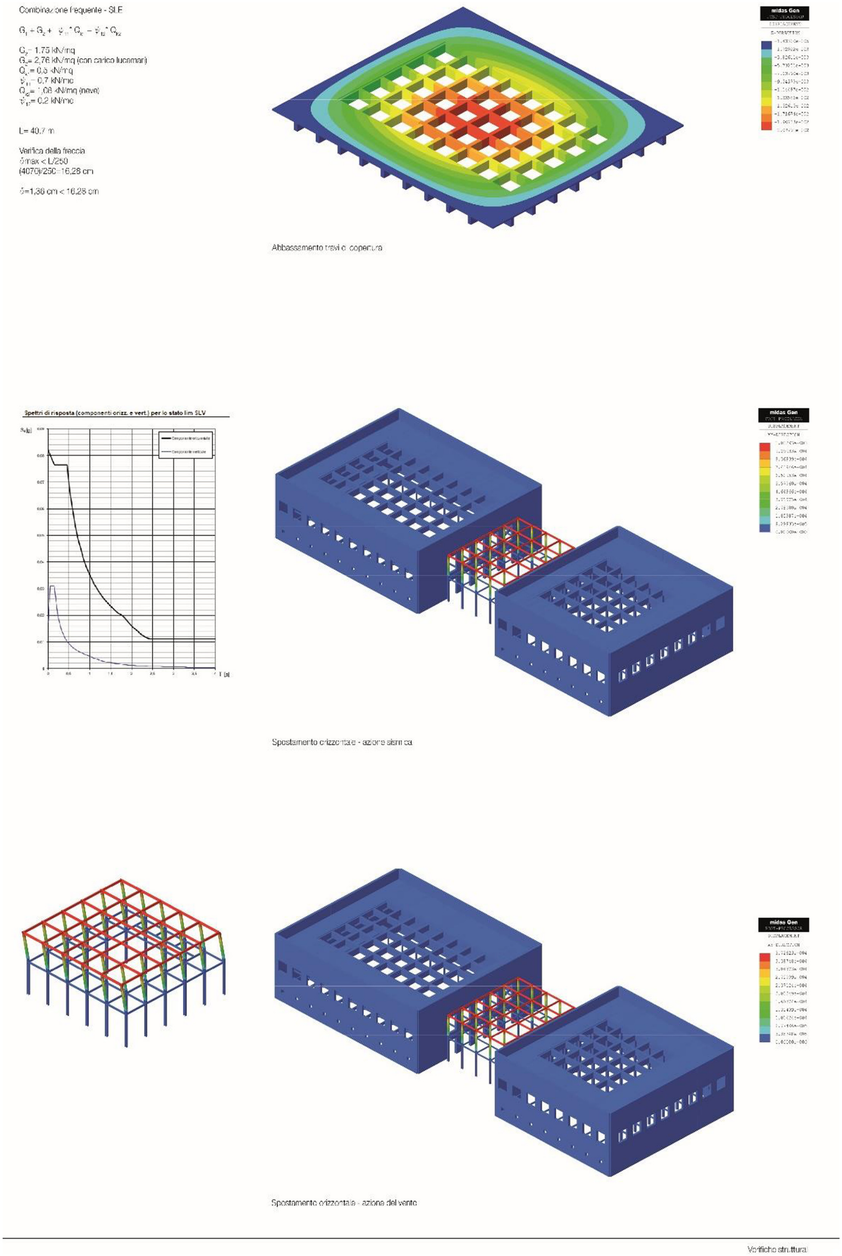
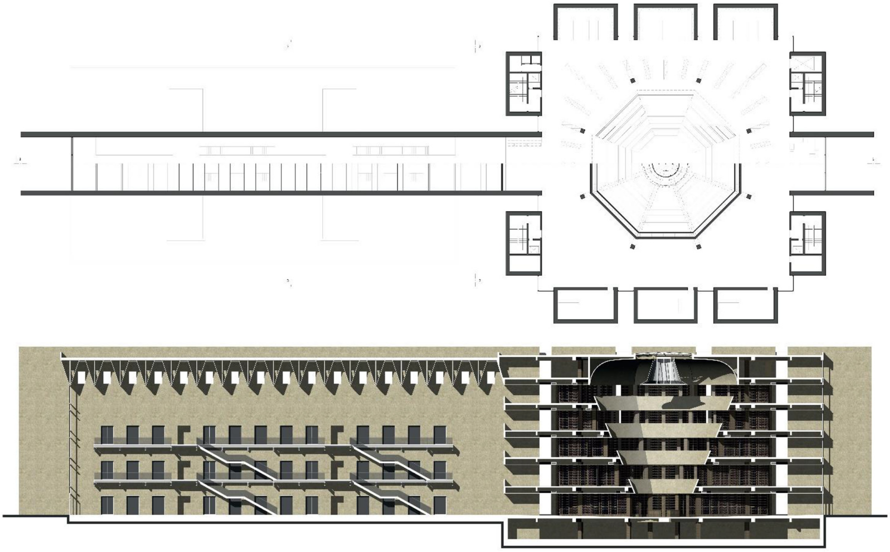


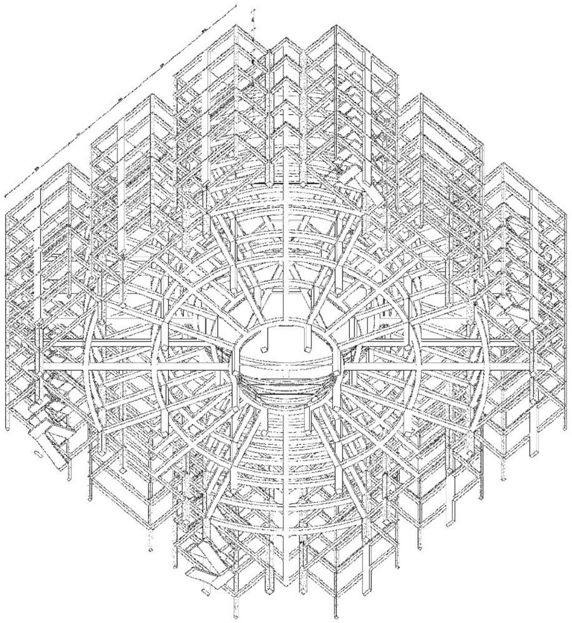
Figure 3.

sizing and structural verification
(b)



Plan and cross section

(a)



Structural axonometry

(b)

Figure 4.
Design of a university library (Marcandelli and Piatti, 2018, MSc Thesis developed in Advanced Architectural design for complex construction II, 2017-2018)

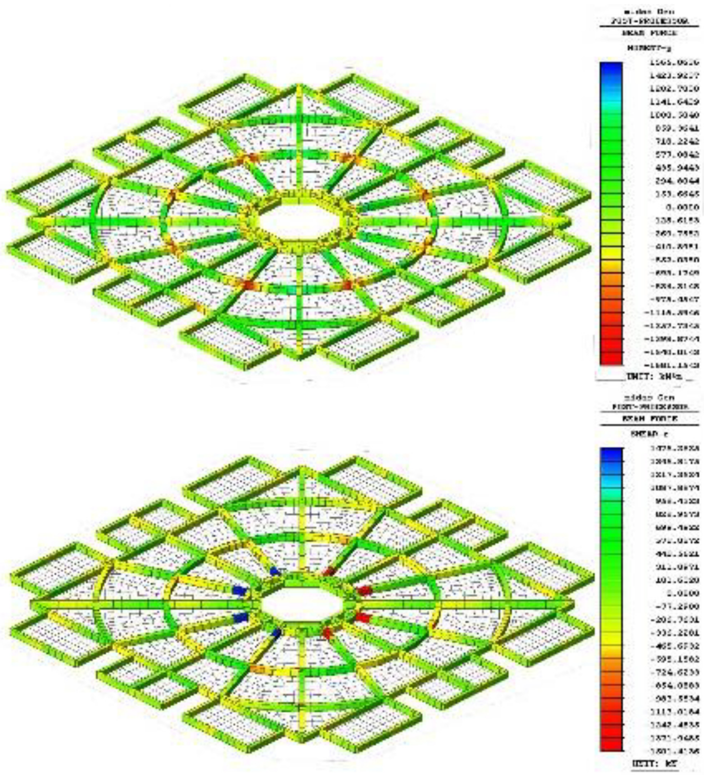


Figure 4.

Sizing and verification

(c)

The experience carried out in the *Politecnico di Milano* is certainly complete: students face the architectural design immediately, trying to keep all the essential components of the design under control. The training they acquire is the training of a competent professional, not an expert in any disciplinary field, but a professional able to dialogue with experts with language and competence properties. The figure closest to this architect's training is that of "the architectural designer and project manager" of his/her own team of experts.

With regard to the direct experience of the authors in the teaching of structural disciplines in the Studios, it can only be defined as positive. Surely the didactic commitment is greater than the didactic commitment required by a traditional (ex-cathedra) course, but being able to work side by side with the students, having the theoretical aspects of the discipline applied to the solution of their specific problem, leads them to better understand both the bases of the discipline and its application. Being able to support the manual calculation part (the calculation error is the most problematic aspect for the architect) with a structural software correctly taught to the architect students in a dedicated course stimulates the students' curiosity to understand the real prerogatives of a structural typology knowing that the calculation will not then represent an insurmountable problem.

The quality of teaching and the level of appreciation of the module are measured in the always positive judgments reported in the teaching questionnaires completed at the end of the course by the students. To complete this judgment there are the project results that always include complete and well-articulated elaborations of the structural design. Unfortunately, the course evaluation system is limited to a summary judgment on the quality of teaching from which it is difficult to extrapolate an in-depth analysis of the satisfaction and critical issues encountered by students during their learning activities. This aspect highlights how, in many universities, the teaching activity is still poorly valued, as well as the serious student feedback, a tool that the authors consider essential for the improvement of any teaching activity.

Note

1. Diploma Supplement is a document attached to the final academic qualification, aimed at improving international "transparency" and facilitating the academic and professional recognition of qualifications (diplomas, degrees, certificates, etc.). Its task is to provide a description of the nature, level, context, content and status of the studies undertaken and successfully completed by the person mentioned in the original of the qualification to which this Supplement is attached. It is based on an international scheme developed on the initiative of the European Commission, the Council of Europe and UNESCO.

References

Allen, E. (1997), "Second studio: a model for technical teaching", *Journal of Architectural Education*, Vol. 51 No. 2, pp. 92-95, doi: 10.1080/10464883.1997.10734756.

Biggs, J. (2003), "Aligning teaching for constructing learning", *The Higher Education Academy*, Vol. 13-16, available at: https://www.researchgate.net/profile/John_Biggs3/publication/255583992_Aligning_Teaching_for_Constructing_Learning/links/5406ffe70cf2bba34c1e8153.pdf.

Biggs, J. (2014), "Constructive alignment in university teaching", *HERDSA Review of Higher Education*, Vol. 1, pp. 5-22 Available at: http://www.herdsa.org.au/herdsa-review-higher-education-vol-1/5-22.

Cerri, A., Carone, D. and Gariboldi, E. (2017), *Un Nuovo Centro per Pavia: Progetto di Intervento per l'area Dell'ex-arsenale*, MSc degree Thesis, School of Architecture Urban Planning Constuction Engineering, Politecnico di Milano, MSc course in Architecture-Building Architecture.

Charleson, A.A.W. (2005), *Structures as Architecture: A Source Book for Architects and Engineers*, Elsevier, Burlington, MA, ISBN 0750665270, available at: http://books.google.com/books?hl=en&lr=&id=mS8uVBWqjJoC&pgis=1.

Chiuini, M. (2006), "Less is more: a design-oriented approach to teaching structures in architecture", in in Oakley, D.J. and Smith, R.E. (Eds), *Building Technology Educator's Symposium*, ISBN 9780615249117, Building Technology Educator's Society, College Park, Maryland, US, 3-5 August, 2006, pp. 205-212.

Farrauto, L., Rossi, E. and Teruggi, S. (2018), *A Project for Bovisa, Milan, Italy: The Service Square*, Thesis, School of Architecture Urban Planning Construction Engineering, Politecnico di Milano, MSc course in Architecture-Building Architecture.

Goldsmith, N. (2016), "The physical modeling legacy of Frei Otto", *International Journal of Space Structures*, Vol. 31 No. 1, pp. 25-30, doi: 10.1177/0266351116642071.

Hadjiyanni, T. and Zollinger, S.W. (2010), "Stimulating student interest in design history classes. Special issue: design education: explorations and prospects for a better built environment", *International Journal of Architectural Research: ArchNet-IJAR*, Vol. 4 Nos 2-3, pp. 296-309, ISSN 1994-69612, available at: https://archnet.org/collections/34/publications/5320.

Lorenzon, F. and Tavanti, M. (2015), *Post-expo Loop Arena – Numerical Analysis. Structural Modelling in Architecture and Numerical Computation*, School of Architecture Urban Planning Construction Engineering, Politecnico di Milano, MSc course in Architecture-Building Architecture. available at: https://i0.wp.com/struandarch.com/wp-content/uploads/2016ModelliMatematici/Tavanti-Lorenzon.jpg.

Marcandelli, E. and Piatti, S. (2018), "A project for città studi", Milan, Italy: The Library, MSc degree Thesis, School of Architecture Urban Planning Construction Engineering, Politecnico di Milano, MSc course in Architecture-Building Architecture.

Mohareb, N. and Maassarani, S. (2018), "Design-Build: an effective approach for architecture studio education", *International Journal of Architectural Research: Archnet-IJAR*, Vol. 12 No. 2, pp. 146-161, doi: 10.26687/archnet-ijar.v12i2.1570.

Mostafa, M. and Mostafa, H. (2010), "How do Architects think? Learning styles and architectural education", *International Journal of Architectural Research: ArchNet-IJAR*, Vol. 4 Nos 2/3, pp. 310-317, ISSN 1994-69612, available at: https://archnet.org/collections/34/publications/5320.

Qureshi, H. (2019), "Collaborative architectural design studio environment: an experiment in the studio of Architectural Design-I", *Archnet-IJAR*, Vol. 14 No. 2, pp. 303-324, doi: 10.1108/ARCH-12-2018-0049.

Salama, A.M. (2008), "A theory for integrating knowledge in architectural design, education", *International Journal of Architectural Research*, Vol. 2 No. 1, pp. 100-118, doi: 10.26687/archnet-ijar.v2i1.180.

Salvadori, M. (1958), "Teaching structures to architects", *Journal of Architectural Education*, Vol. 13 No. 1, pp. 5-8, doi: 10.1080/10464883.1958.11102384.

Salvadori, M. and Heller, R. (1986), *Structure in Architecture*, Prentice Hall, Division of Simon & Schuster, Englewood Cliffs, New Jersey.

Sgambi, L., Basso, N. and Codazzi, M.E. (2013), "Conceptual structural design: an important topic in architectural education, structures and architecture: concepts, applications and challenges", in Cruz, J.S.P. (Ed.), *Proceedings of the 2nd International Conference on Structures and Architecture, ICSA 2013*, ISBN 9780415661959, CRC Press, Guimarãs, Portugal, 24-26 July, 2013, pp. 1271-1278.

Sgambi, L., Kubiak, L., Basso, N. and Garavaglia, E. (2019), "Active learning for the promotion of students' creativity and critical thinking: an experience in structural courses for architecture", *International Journal of Architectural Research, ArchNet-IJAR*, Vol. 13 No. 2, pp. 386-407, doi: 10.1108/ARCH-11-2018-0018.

Taylor, R. and Canfield, P. (2007), "Learning to be a scholarly teaching faculty: cultural change through shared leadership", in Sachs J, B.A. (Ed.), *The Transformed University: Scholarship of Teaching and Learning in Action*, Ch. 21, Sydney University Press, Sydney, pp. 233-247, available at: https://core.ac.uk/download/pdf/41230956.pdf.

Uihlein, M.S. (2013), *Architectural Engineering in the Curriculum: The Case Study on AE and its Relationship to Architecture*, University of Illinois at Urbana-Champaign, *Building Technology Educator's Symposium -Tectonics of Teaching*, pp. 3-10, available at: https://pdfs.semanticscholar.org/5853/6613205f2edc8b6373b73e7ee078680685af.pdf.

Vassigh, S. (2005), *Interactive Structures: Visualizing Structural Behavior DVD-ROM – May, 17, 2005*, Dvdr ed., Editore: John Wiley & Sons, ISBN-10: 0471705667.

Wetzel, C. (2012), "Integrating structures and design in the first-year studio", *Journal of Architectural Education*, Vol. 66 No. 1, pp. 107-114, doi: 10.1080/10464883.2012.715980.

Further reading

Bologna Process (1999), "Ministerial declarations and communiqués", *European Ministerial Conference*, Bologna, Italy, June, 18-19, available at: http://www.ehea.info/cid100210/ministerial-conference-bologna-1999.html.

Economic European Community (1985), "Eur-lex, legal-content 85/384/CEE", available at: https://eur-lex.europa.eu/legal-content/it/TXT/?uri=CELEX:31985L0384.

EHEA (since 1999), European higher education area, available at: http://www.ehea.info/pid34135/accueil.html.

European Community, (2005), Eur-lex, legal-content 2005/36/CE. available at: https://eur-lex.europa.eu/legal-content/IT/TXT/?uri=celex%3A32005L0036.

Ministero dell'Istruzione dell'Università e della Ricerca (1993), "Equiparazioni dei diplomi di laurea (DL) secondo il vecchio ordinamento alle nuove classi delle lauree specialistiche (LS), ai fini della partecipazione ai concorsi pubblici", Ministerial Decree February 24, 1993, available in Italian, available at: http://capdi.it/A_pubb/Rubriche/Doc_capdi/2006/luglio/decreto_interministeriale_5_maggio_2004.pdf.

Ministero dell'Istruzione dell'Università e della Ricerca (1999), "Regolamento recante norme concernenti l'autonomia didattica degli atenei", DM, November, 3, 1999, available in Italian, available at: http://www.miur.it/0006Menu_C/0012Docume/0098Normat/2088Regola.htm.

Ministero dell'Istruzione dell'Università e della Ricerca (2004), "Modifiche al regolamento recante norme concernenti l'autonomia didattica degli atenei, approvato con decreto del Ministro dell'università e della ricerca scientifica e tecnologica 3 novembre 1999, n. 509", Ministerial Decree October 10, 2004, available in Italian, available at: http://www.miur.it/0006Menu_C/0012Docume/0098Normat/4640Modifi_cf2.htm.

Appendix 1

Summary of European Community Legislative Decree (85/384/E.E.C.)

(1) The ability to create architectural projects that meet aesthetic and technical needs;

(2) An adequate knowledge of the history and the theories of architecture as well as the arts, technologies and human pertaining thereto;

(3) A knowledge of Fine Arts as factors that can influence the quality of architectural conception;

(4) An adequate knowledge in the field of urban planning, planning and techniques applied in the planning process;

(5) The ability to grasp the relationships between man and architectural creations and between architectural creations and their environment, as well as the ability to grasp the necessity to adapt between their architectural creations and spaces, according to the needs and size of man;

(6) The ability to understand the importance of the profession and the functions of the architect in society, by developing projects that consider social factors;

(7) A knowledge of the methods of investigation and preparation of the construction design;

(8) A knowledge of structural-design problems, construction and civil engineering problems associated with building design;

(9) An adequate knowledge of physical problems and technologies as well as the function of buildings, to make them internally comfortable and protect them from climatic factors;

(10) A technical capacity that allows the design of buildings that meet the needs of users, within the limits imposed by cost factor and by regulations in terms of construction;

(11) An adequate knowledge of industries, organizations, regulations and procedures necessary to carry out building projects and to integrate plans into general planning.

The 11 points present in Directive 85/384/EEC are also reiterated in Directive 2005/36/EC of the September 7, 2005, on the recognition of professional qualifications. They represent the prerequisites for the training of an architect.

Appendix 2

Summary of Bologna process:

(1) The introduction of understandable and comparable qualifications, based as uniformly as possible on a three-cycle system of first, second and third level;

(2) The transparency of the courses of study through a common credit system, based not only on the duration but also on the workload of each course and on the related learning results, certified by the Diploma Supplement [1];

(3) The recognition of qualifications and periods of study;

(4) A shared approach to quality assurance;

(5) The implementation of a shared qualifications framework and aimed at the European Higher Education Area.

Even nowadays such reforms are periodically verified in collegial confrontations among member countries and updated or reformulated if necessary.

Appendix 3

Study program of Master of Science curriculum in Architecture-Building Architecture; School of Architecture Urban Planning Construction Engineering, Politecnico di Milano

Courses title	Modules title	ECTS per module	Total ECTS
I *Anno*			
History of building construction			4
Planning for environmental risk management			4
Architecture and materials for historic heritage	Theories of restoration	4	8
	Materials in architecture	4	
Structural modeling in architecture and numerical computation	Structural modeling	4	8
	Numerical computation	4	

Studios title	Modules title	ECTS per module	Total ECTS
Architectural design studio for complex constructions 1	Architectural design	8	20
	Architectural composition	4	
	Structures	4	
	Technology and design in BIM environment	4	

(*continued*)

Elective studios (The student opts for one of these two studios)	Modules title	ECTS per module	Total ECTS
Architecture construction studio	Technological design	4	12
	Structural design	4	
	Site survey, setting out and monitoring	4	
Architectural preservation studio	Restoration	4	12
	Reliability and vulnerability	4	
	Site survey, setting out and monitoring	4	

Elective curses		ECTS per module	Total ECTS
Optional 1	Soft skills		4
			60 per year

Courses title	Modules title	ECTS per module	Total ECTS
II *Anno*			
Planning legislation			4
Risk-based design			4
Economic evaluation of project			4

Elective studios (The student opts for one of these two studios)	Modules title	ECTS per module	Total ECTS
Architectural design studio for complex constructions 2	Architectural design	8	30
	Structural design	8	
	Building services design	4	
	Innovative materials for architecture	4	
	Technology and design in BIM environment	6	
Architectural design studio for restoration and transformation of complex constructions	Architectural design	8	30
	Restoration	8	
	Structural design	4	
	Building services design	4	
	Materials for preservation	4	
	Technology and design in BIM environment	4	

Elective curses	ECTS per module	Total ECTS
Optional 2		4
Internship		*4*
Final exam		*12*
		60 per year

About the authors

Elsa Garavaglia received MSc Degree cum laude in Architecture from Politecnico di Milano, Italy, in 1984. Garavaglia was assistant professor and currently is associate professor in Solid Mechanics, Department of Civil and Environmental Engineering, Politecnico di Milano. Since 1996, Garavaglia is Chair of Static, Structural Design and Structural Reliability and Vulnerability at the School of Civil Architecture, Politecnico di Milano. From 2011 to 2016, Garavaglia was board director of Bachelor's and Master's Degree Programs in Civil Architecture, Politecnico di Milano. Garavaglia is author and coauthor of five didactic books concerning the structural mechanics and nearly 130 scientific papers concerning: uncertainty, probabilistic modeling, structural reliability, durability of materials and

structures, life-cycle assessment and seismic risk analysis, theory and practice of education. Elsa Garavaglia is the corresponding author and can be contacted at: elsa.garavaglia@polimi.it

Noemi Basso received MSc Degree in Civil Architecture from Politecnico di Milano, Italy, in 2007 and PhD Degree with highest honour in 2013. Basso was visiting scholar at Tokyo Denki University, Japan, teaching assistant in Building Reliability and Vulnerability, Structures, Theory and Design of Buildings and Structures, Department of Civil and Environmental Engineering, Politecnico di Milano. Basso was 2013 winner of JSPS two-year Postdoctoral Fellowship for Foreign Researchers (2013–2015 Tokyo Denki University). Since 2016, Basso is lecturer in Structural courses, Department of Architecture, Waseda University, Japan. Basso is author and coauthor of scientific papers concerning uncertainty, probabilistic modeling, structural reliability, durability of materials and structures, life-cycle assessment and seismic risk analysis, theory and practice of education.

Luca Sgambi received MSc Degree in Civil Engineering from Politecnico di Milano, Italy, in 1998; Second-level Specializing Master (2 years) in Concrete Structures from Politecnico di Milano, in 2001; and PhD Degree in Structural Engineering from the Università di Roma, Italy, in 2005. From 2003 to 2015, Sgambi was adjunct professor in Structural Design, School of Civil Architecture, Politecnico di Milano. Since 2016, Sgambi is assistant professor in Structural courses, Université catholique de Louvain, Tournai Campus, Belgium. Sgambi is author and coauthor of three technical books concerning structural engineering and nearly 100 scientific papers concerning: structural modeling, uncertainty, fuzzy and probabilistic modeling, durability of materials and structures, theory and practice of education.