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# EXPERIENCING ARCHITECTURAL GRAPHICS LITERACY

# EXPERIMENTANDO A ALFABETIZAÇÃO GRÁFICA DE ARQUITETURA

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**Abstract**: Since 2011 the revised *Unesco UIA Charter for Architectural Education* recommended to include digital literacy among the relevant criteria for evaluating and ranking the Schools of Architecture. Not only in the field of Graphics, as one could easily expect, but in all the disciplinary fields forming the curriculum, either belonging to science and technique, or to humanities and art. Digital itself was then holistically considered as a linguistic environment, where the various contributions could converge and and be integrated. What was admirably summarized in the hope to achieve *digital fluency* as an educational goal. This seemed in accordance with the for long time coveted idea of a *semiosphere* proposed by Jurij Lotman (LOTMAN, 1984). In 2019 the Dean of the School of Architecture of Politecnico di Milano, and the Coordinator of the Bachlor Program in Architectural Design asked the author to prepare and to coordinate a program for the Academic Year 2020/2021, addressed to 19 classes, that is, to the about 1.000 students enrolled in the Second Year.

**Keywords:** Digital graphics literacy, architectural Drawing, architectural Geometry, architectural graphics.

**Resumo:** Desde 2011, a revisão da *Unesco UIA Charter for Architectural Education* recomendava incluir a alfabetização digital entre os critérios relevantes para avaliação e classificação das Escolas de Arquitetura. Isso não só na área Gráfica, como facilmente se poderia esperar, mas em todas as áreas disciplinares que constituem o currículo, seja das ciências e da técnica, seja das humanidades e das artes. O ambiente digital foi então holisticamente considerado um ambiente linguístico, onde as várias contribuições poderiam convergir e ser integradas. Isso foi admiravelmente estruturado na esperança de alcançar a fluência digital como meta educacional, o que pareceu estar de acordo com a idéia, por muito tempo cobiçada, de uma esfera proposta por Juri Lotman. Em 2019, o Reitor da Escola de Arquitetura do Politécnico de Milão e o Coordenador do Bacharelado em Projeto de Arquitetura pediram ao autor que elaborasse e coordenasse um programa para o Ano Acadêmico 2020/2021, dirigido a 19 turmas, ou seja, aos cerca de 1.000 alunos matriculados no segundo ano.

**Palavras-chave:** Alfabetização gráfica digital, desenho arquitetônico, geometria arquitetônica, gráfica arquitetônica.

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## 1 Introduction

Since 2013, when with the occasion of the 150° anniversary of our University the author organized a cycle of three international seminars on *The Visual Language of Technique Between Science and Art*, educating to the digital was already on stage as a relevant point to discuss. Among the participants to the event some keynote lecturers, who are also members of the International Society for Geometry and Graphics (ISGG) pointed out some key issues inherent to the links between Geometry and Graphics education, and digital education, with reference to various technical fields and applications. Other international Universities were already on the way, and we could also count on our international academic network, including our Erasmus programmes, for exchanging ideas and proposals. The School was hesitant to immediately include digital based courses in the Manifesto, so that it was decided to activate extra curricular short courses finalized to offer students basic technical skills in the field of the digital for architecture.

This program was called *Digi Skills* and it was initialy dedicated to the Master programme, consisting of courses and contributions, even on-demand, to the architectural design studios. Over time, it became an advanced program Parametric Design and BIM oriented, which required that students already had a background to follow. But nothing was proposed in terms of a properly said *digital graphics literacy*, and Bachelor students were totally left without a systematic basic training in that field.

In 2019, the need for some changes in the Bachelor programme, and some financial supports allowed to also look in this direction. It was finally proposed a *Digi Skills* programme for the Bachelor, and it was decided to offer it in the first semester of the second year, after the basics of architectural representation taught in the first year.

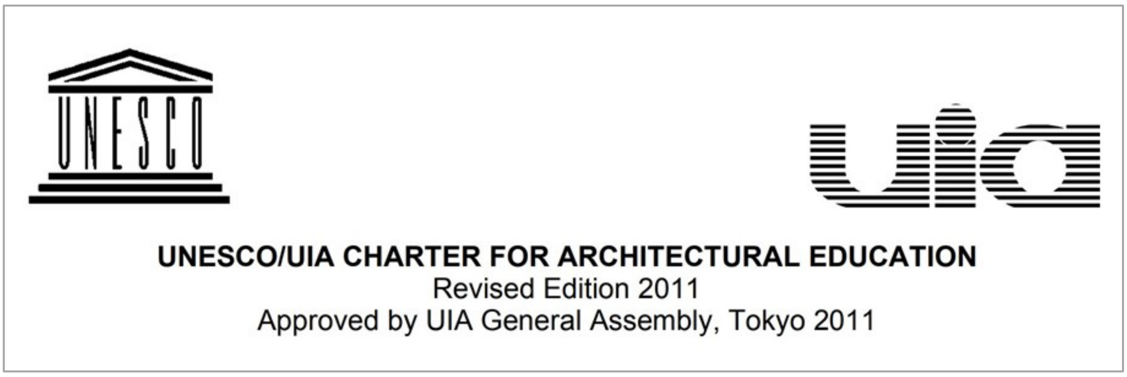


**Figure 1 -** Detail of the front page of the *UNESCO/UIA Charter for Architectural Education* (Tokyo 2011). Source: https://etsab.upc.edu/ca/shared/a-escola/a3-qualitat/validacio/0_chart.pdf.

As a teacher in the field of Architectural Drawing, and in the vest of Deputy Coordinator of the Bachelor, in 2019 I was asked to organize a *Digi Skills* programme for the Bachelor course. As an architect as well, I knew that spatial abilities shoud be at the core of the program, and since my research field is about Descriptive and Projective Geometry, I also knew that priority in this program must be given to three-dimensional modeling. However, the program could not be based on shape modeling only, but modeling activities should be integrated in the didactic simulation of a real architectural design workflow. By the way, the collocation of the course in the second year needed some insights about technology construction and the urban scale. These were the fishes on the table, now a program was to be drafted.

As reminded in the abstract, insipiration on that point was offered, as well as from my past educational and (limited) professional experience, from the recommendations of the revised *UNESCO/UIA Charter for Architectural Education* (Tokyo 2011) (Figure 1). In this document a holistic approach to digital education in the schools of architecture was encouraged, which should involve all the disciplinary fields, not only the technical ones, as probably expected, with profound implications on teachnig and learning styles compared with tradition. More than on specific digital skills, the document focused on the need of a new unitary language through which the various disciplinary fields, and the specialist behind them, could talk each other and collaborate in the design process much easier than in the past.

*Digital fluency* is the fascinating formula proposed in the document to indicate this aim, which is considered as important that it is proposed to use it as a relevant parameter for the overall evaluation of the Schools of Architecture and their placement in the national and international rankings.

## 2 A quick look at the literature

Although application oriented, the programme must necessarily be developed on some theoretical bases, which will be synthetically mentioned here. First of all the idea developed by Michel Foucault in *Les Mots et Les Choses* (FOUCAULT, 1966) emphasizing that any representation is a medium between ideas and reality. In this sense, as it was also stated by Karl Popper in *Epistemology Without a Knowing Subject* (POPPER, 1968), it is a kind of *third world* allowing us to operate on the other two. Depending on the direction of the investigation, representations – in our case graphic representations - offer us the opportunity to shape models of things, or models of thoughts, and most of all, to integrate them. By managing representations, that is by projects, architects shape the construction according to specific ideas, or, try to recognize a design vision when analyzing construction. On the purpose, decades ago Massimo Scolari claimed for puttin Drawing at the center of architectural education. It was not a request for having more courses of architectural drawing to the detriment of other matters, but a wise suggestion to call into question the whole potentiality of drawing as a *way of thinking*, able to synthesize and relate by iconic codes the various aspects characterizing the architectural design processes. A task that in our case Digital Graphics was expected to take.

Quite paradoxically, despite the *intangibility* of the Digital, Digital Graphics seem even more inclusive than traditional Graphics. Instead of the several piles of drawings and documents produced by the expert participanting in a project, interoperability allows the several operators to keep the whole process in a unique digital workflow, and to relate information directly to the single points in space of a 3D model, which can also become a permanent *avatar* of the construction during and until after its lifecycle. As an integrated linguistic system, it realizes a properly said *semiosphere*, as Jurij Lotman would have stated from a philosophical podium (LOTMAN, 1984), where the coexistence of multiple disciplinary languages is not only possible, but operationally manageable, as a working tool.

This complexity at the level of representation seems appropriate to match the complexity of the real complexity of the body of architecture. Whose shape is the result of multiple processes, including *Fabrica et Ratiocinatione*, according to Vitruvius. To explain this complexity, in the book *Fondamenti della rappresentazione architettonica*, meaning fundamentals of architectural representation, Vittorio Ugo refers to the etimology of the word *form*, prsoposing as an example the *form* of a lens as the final result of integrating craftmaship or industry with raw material, proven construction processes, principle of Optics, design expertises, and other (UGO, 1994).

However, even in a digital environment the complexity level is not given in advance, it needs to be implemented according to the processes to carry out. A primary level is offered by spatial modeling, which can correspond to drawing in a three-dimensional space, then other information level can be integrated in order to establish the various properties and performances characterizing the architectural space that is to be built at the end, eventually including its mantainance and the recycle of its components and materials. However, each information step requires a specific software or a specific set of software programmes to be elaborated, as well as in the past one can say, when each pile of documents was for a specific aspect of the project, like structural calculation, technical systems, and so on. There is a crucial difference however, since the piles of paper documents we used in the past were static and included separated sets of information. Checking in one pile (i.e. in that of structural calculations) no informatin related to other piles could be get (i.e. to that of the furnitures), and any change in one of them, needed to be manually reported on all the others involved, as well as, last but not least, each pile was written in a language understandable by a type of specialist, and the communication among the specialists authors of the various piles involved in the project was sometimes no easy.

On the purpose, an interesting bibliographic chain was mainly provided by the combined reference to four books. First reference book was *Bilder der Mathematik* (GLAESER and POLTHIER, 2009), meaning images of Mathematics, whose clear text and the astonishing illustrations could engage students in the theoretical world of Geometry and in the sense of Space. Second book was *Architectural Geometry* (POTTMANN et AL., 2007) where the nexus between theoretical geometry and architectural space was discussed and investigated in detail, and explained with the help of a very rich and exhaustive series of examples referring to real architectures, like in a properly said tratise on architectural shape, using the updated language of computer graphics. Third book was *Beyond the Grid – Architecture and Information Technology. Applications of a Digital Architectonic* (HOVESTADT, 2010), showing the evolution and the new potentialities of the CAD systems, based on their links with computational design and prototyping techniques. Fourth reference book was *Informed Architecture. Computational strategies in architectural design* (HEMMERLING and COCCHIARELLA, 2018), where the role of information and of the articulation of its layers in the computational strategies addressed to architectural design is emphasized. This literature was selected to help students to correctly locate Digital Graphics inside the multifaceted network of the Digital.

A fifth book was finally considered from the side of the teacher, titled *How Learning Works. Seven Research-Based Principles for Smart Teaching* (AMBROSE et AL., 2010), focusing on the basics of pedagogy in education, which has been of great help for the overall design of the course and of the related activities.

The Digital indeed, allows to *link* sets of information in one model, easily accessible and consultable by the various specialists involved in the process, at least to see the impact of their specific contribution on the overall project, and to facilitate the communication with the other operators. To clear the field of naïve misinderstandings, this does not mean that we do not need specializations. Opposite, the higher accessibility to certain complexity levels compared to the past, requires even more specialized technical competences. These technical competences are over time migrating in containers of knowledge which are quite different from the traditional books. What makes digital competences and skills essential.

In an interesting and very clever book title *The Game*, Alessandro Baricco offers a contribution to the understaning of the digital turn, analyzing its development from the origins to the present (BARICCO, 2018). In his opinion, the *Apps* as software programmes embedding specific sets of data and operations, are nowadays replacing the books and the chapters of the books. They are kind of pre-packaged blocks of knowledge, each allowing us to carry out a limited set of operations, which can be combined with other sets. For those who are not familiar with basic computer programming, like architectis for instance, they represent the entry level of digital knowledge, as in the case of apps for math, apps for drawing, as well as for any other disciplinary purpose.

This means that in the digital world, including the Digital Graphics world, knowledge and operational routines have to be implemented taking into account this way.

## 3 The approach

The design of the course has begun from considering *space modeling* as the core of the programme and the main educational goal. All the other components would have been proposed as a constellation of issues orbiting about a planet. Aiming at simulating a real professional design workflow, data acquisition and prototyping were to be included in the program. This was also decided in order to give students a complete set of basic skills appropriate for the didactict demands of the second and third year of the Bachelor course. All in all, the overall program resulted composed on three blocks.

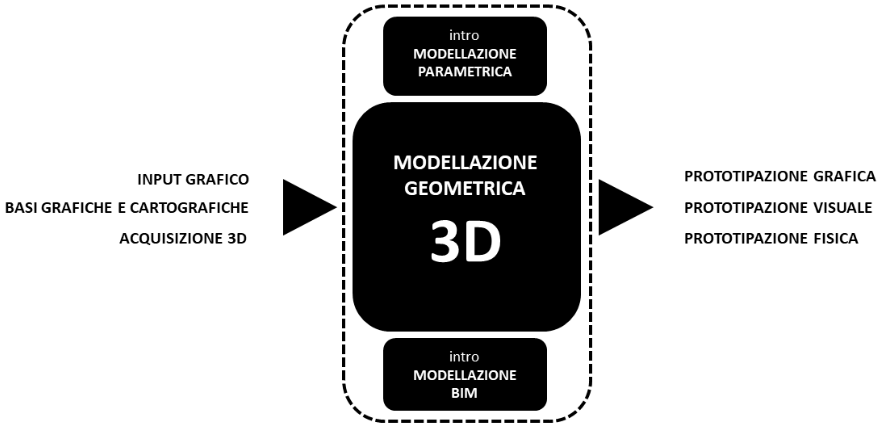


**Figure 2 -** Concep diagram of the *Digi Skills* program for Bachelor. Source: by author.

As we can see in the diagram above (Figure 2), given the role of *space* in architecture, *3D modeling* was the main subject, unequivocally. However, looking at the future expectations of the students, an early introduction to parametric modeling and to BIM has been included in this part. The idea was to emphasize parametric and information processes as a part of the design strategy in the field of Digital Graphics. In order to avoid a too abstract approach to the modeling, the program was integrated with lectures on data acquisition (*input*), that is, how to import data from the real world, and prototyping (*output*), that is, how to relate the model to the real world. Considering the typical operational routines in the implementation of an architectural model, the input phase has been splitted in three sections: graphic input, that is, direct input of data from keyboard or other devices; input from cartographic bases or databses; input from 3D acquisition by optical devices. Similarly, the output phase included: graphic prototyping, basically by printing; visual prototyping, that is, images and animations; physical prototyping by laser cutter or FDM.

These were considered as the minimum set of skills needed in the toolbox of a student of the second year. Even if, as a basic *literacy* programme more advanced topics were not included, it was intended to give students an overall strategy for approaching Digital Graphics, and some access keys to enable them to independently explore more advanced levels of the digital enviromnent. In few words, it was intended to give them basic assumptions for achieving *digital fluency*.

**Figure 3 -** A view of the expected outcome. Design inspired by *Archaeological Pavilion*, Kadawittfeldarchitektur, Aachen Germany 2013. Source: by author's teamwork.

Considering the educational goals it was decided to propose a small architecture as a theme, placed in a small urban context. The small architecture was generated as a variant of the *Archaeological Pavilion* designed by the group Kadawittfeldarchitektur for Aachen in 2013. It has been chosen because of the possibility to set some gometrically non usual details behind the apparent simplicity of the overall configuration. The close urban context around it is that of the urban area in front of the entrance of our School of Architecture, including façades with a particular volumetry as well as some flower beds and saplings, appropriate for testing specific issues of data acquisition and modeling (Figure 3). The course has taken place online because of the COVID-19 pandemic spread, then that place was also supposed to be well-known by most of the students attending the second year. The limited size of pavillion and place would have permitted some targeted insights on modeling technology details and spaces at the urban scale in the short time of the lectures.

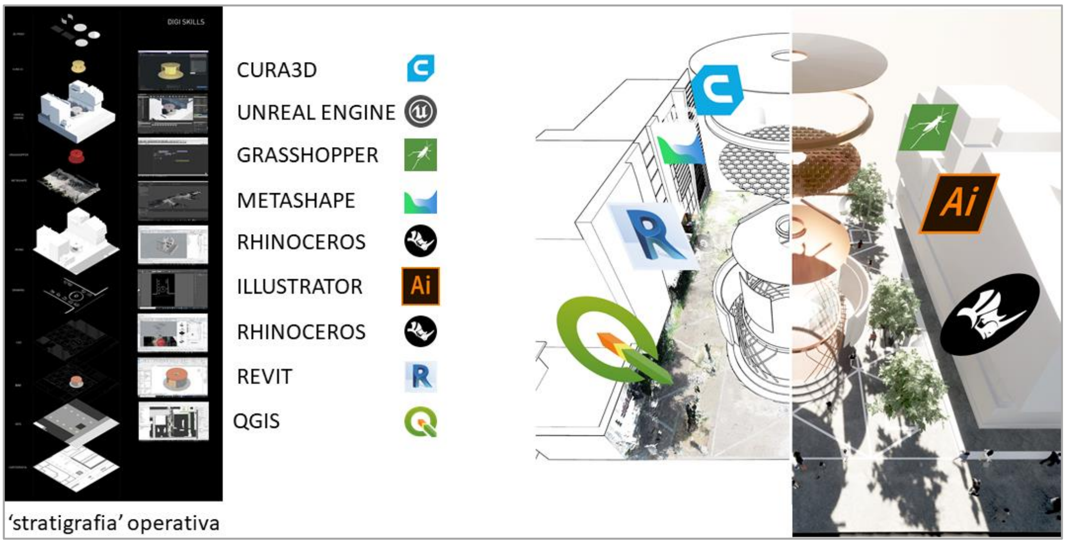


**Figure 4 -** Final view of the case study (right) and modelling process behind it (left). Source: by author's teamwork.

In this perspective, the course aimed at focusing on the multilayered process behind the construction of an architectural model of medium complexity, integrated in a small urban context. In the figure above (Figure 4), used to present the program to the students, the various steps are displayed in the column on the left, where the phases of modeling are related to the corresponding software environments, represented with the miniatures of their dashboards, together with icons and names of the programs. It was of course underlined that the real architectural modeling work is hardly as linear as it appears in that column, but that in real life one often goes back and forth among those layers, according to how the design process proceeds.

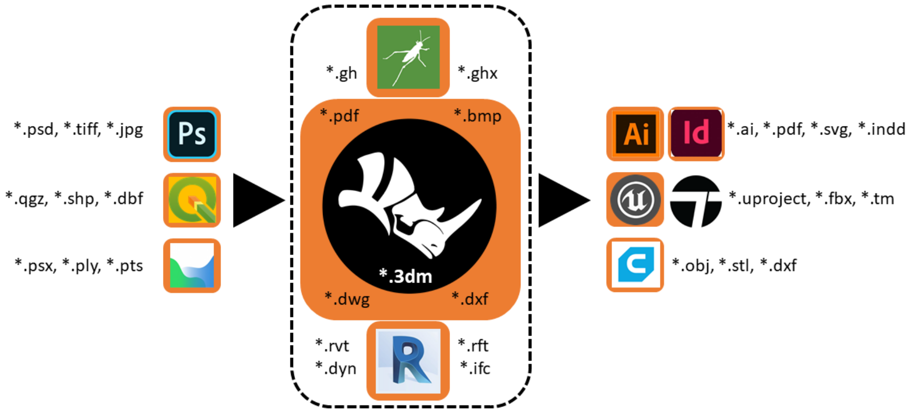


**Figure 5 -** Detailed concept diagram of the software used in the *Digi Skills* programme. Source: by author.

Back from the suface of the model to the roots of knowledge necessary to achieve that result, the initial didactic concept diagram was turned in the map of *Apps* shown in the figure above (Figure 5). Pivotal in that map are the extensions of the files related to the icons of the software programmes compatible with them, which were to be exchanged with the CAD environment at the core of the process. By this way the *digital fluency* recommended by the UNESCO/UIA charter was intended in terms of Digital Graphics *interoperability*.

## 4 Digi Skills for Bachelor: activities and outcomes

Due to the pademic spread, it was decided to plan the course as an online courses, which was compatible with a relevant component of the Digital, that of allowing design worflows from distance. Out of the 14 weeks of the course, 3 hours per week, only the last 3 days, dedicated to final review and exam, were planned as face-to-face classes. But due to the new increase of the pandemic spread, they were anyway turned into online classes.

The about thousand students involved, were distributed in 19 classes, 3 of them taught in English, having about 50 students per tutor, that is, the same standard used for the architectural design studios, given the interaction expected during the class activities. At our University, in fact, theoretical courses have mediumly hundred students per class.

We have mentioned tutors and not teachers up to now. Technically speaking, in fact, these courses were offered as *tutorships*, it means the 19 classes were taught by *tutors*, coordinated by the author, as the teacher responsible of the overall program. This made possible to attribute the mandatory 4 ECTS to the students by a final validation of the work done, without a grade. Even if we initially thought that passing the exam without a grade would have weakened students' motivation, the lack of a final grade resulted in a more enthusiastic participation of the students in the programme instead, since they knew that they could fully experience learning and practice training without any stress for the impact of the results on their curriculum. It is not said that this could have worked in the same way with any other course, but Digital Graphics was something strongly attractive for the students, who for decades have claimed for having fundamentals in this field since during the Bachelor programme.

## 4.1 The *Digi Skills* programme for Bachelor

Given the organization of the courses in form of a tutorships, the interaction between teacher coordinator and students was necessarily mediated by the *tutors*. Apart from some special events, like the welcome to the course and the final greetings, it would have been impossibile for the teacher coordinator, as one teacher, to follow about thousand students. Nevertheless, as the programme was aiming at achieving a literacy level, it was clear that contents and activities should have been as homogeneous as possible in all the classes.

Two levels of interaction were consequently planned: one between the teacher and the tutors, one between each tutor and her/his students. Educational materials were prepared in advance by the teacher, closely supported by two of the tutors, here mentioned in the *acknowledgements*, who have also worked as reference persons for the other tutors during the semester.

The ambition was also that of stimulating the activation of a network in the community of the tutors, based on the constant sharing of information.

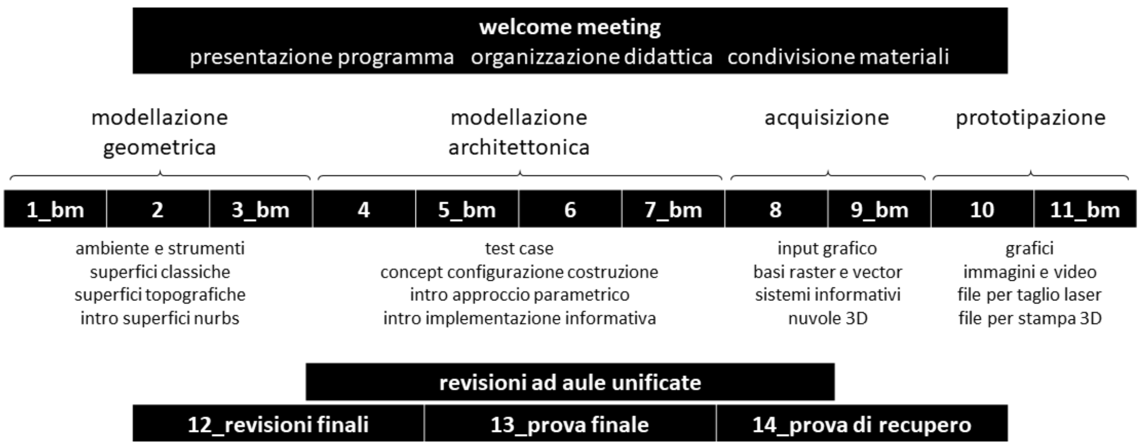


**Figure 6 -** Synopsis of the *Digi Skills* programme and related activities. Source: by author.

A *welcome meeting* with all the tutors was organized before the start of the course, in the presence of the Coordinator of the Bachelor Program, in order to discuss approach and strategies, and the organizational aspects. Other meetings followed during the smester, every two weeks, each one in order to present and share the digital files prepared for the following two lectures. These class materials worked as homogeneous bases to be used in all the classes, appropriately designed to allow tutors and students to develop the topic in the 3 hours assigned to each lecture. In the figure above (Figure 6), the plenary meetings with the tutors appear as "_m" in the schedule.

Concerning the contents, the first three lectures were about properly said geometrical modeling, focusing on the recognition of the software options finalized to development and editing of classical curves and surfaces and to basic elaborations concerning NURBS, both intended as fundamentals for the architectural modeling. Four lectures were then addressed to architectrual modeling, and to the approach to it in the various phases of a design process, including an intro to parametric design and an intro to BIM modeling. This first group of seven lectures defined the deep core of the educational activities, that at the very base of what a Bachelor student in Architecture should learn, offering at the same time a first proof of what *digital fluency* could mean in the field of Digital Graphics.

In order to complete the process, and to give students a more complete set of tools, consistently with the educational training they were expected to attend in the Studios (be it architectural design, technology design, interior design, conservation, urban design studio), other two lectures were planned, dealing with the *input*, that is data acquisition by cartography or point-clouds, followed by the final two, dealing with the *output*, that is visualizing, printing and rapid pototyping.

However, form an educational point of view, given the participation of so many tutors, even the sense of a teaching community should have been exploited by the students. Then, according to the availability of tutors, some office hours for reviews were planned in a large virtual room able to host all the classes at the same time. There the added value of questions and answers posed and proposed by teacher and students of all the classes was experienced, so offering different points of views about approaches and processes on the topics covered.

At the end of the 11 lectures, three face-to-face days were planned: the first one for the final review of the students homework by their own tutor, the second for the final test, the third one for students who needed a recovery test. As already mentioned, due to the pandemic spread these three meetings took place online at the end. A further input given to students was that of doing their best in the preparation of the final fairy copies of the work. Among those, some in each class woud have been selected as the *best of* inherent to the topics developed, which would have been published on the website of the Bachelor.

## 4.2 Early gym: exploring digital space

First three lectures were dedicated to a remind of some key abstract spatial configurations and properties, carried out through a tour inside the software programme *Rhinoceros*. Educational goal at this stage was that students started becoming familiar with moving and making spatial transformations inside a digital CAD environment. Like astronauts in this new environment they were assigned modeling tasks that forced them to move in all the space directions withouh loosing the orientation. This was considered as an essential prerequisite to correctly approach architectural modeling (Figure 7).


**Figure 7 -** Overview of some outcomes from the three lectures of the first educational block, dedicated to basic of *geometrical modeling*. Source: selection from the students' homework.

In the aim of establishing stable links with a consolidated tradition of the School of Architecture, the acquisition of space abilities was based on targeted exercises concerning generation and editing of some classical surfaces and curves, mainly *quadrics* and *conics*, widely recurring in the history of architecture as well as in treatises and manuals. These abstract configurations were then linked to architectural forms, especially vaults and staircases. The introduction to the NURBS, presented as a generalization of curves and surfaces, was initially carried out by an exercise focusing on modeling a small landscape by *contour lines* and *contour planes*, in which a simple architectural volume was integrated.

Further details like vegetations and little trees, gave students the opportunity to explore the world of the online libraries, and to make early tests about importing and exportin files. At this point the basics for setting and managing rendering properties were also considered. Finally, the parametric plugin *Grasshopper* was softly introduced to automatize the generation of scaled templates of the contour planes for the model making based on laser cutting and assemblage process. This early parametric test was also of help to introduce and emphasize the relationships between design process and Mathematic transformations, even from a digital and operational point of view. At the end of the three weeks studens were supposed to be ready for approaching architectural modeling.

## 4.3 At the core: architectural modeling

As already said, architectural modeling was *the* educational goal to achieve. Everything in the program was related to it. Reason why it was presented as something that grows together with the project, appropriately matching the specific needs of each design stage. It was intended to firmly contrast the misconcepted idea that digital modeling is just a transcription of a project in a digital format, after having developed it somewhere else and with somehow different techniques. As educators in the field of architecture we know that in real professional work analogue and digital can be strictly integrated. We only wanted to contrast the dogmatic idea that one comes *first* and the other comes *later*. We wanted to make students experiencing that they can come and run *together* (Figure 8).

In order to stress this crucial point, contrary to what one could expect, architectural modeling was introduced in a parametric way. Since we wanted to simulate a – more or less – standard design process, we planned to test digital graphics from the concept to the final construction model. Starting from the concept stage, some basic signs traced on a graphic tablet as a vector data and inherent to the early architectural inspiration were imported in the CAD environment and linked to the parametric plugin *Grasshopper*. Students could then modify in real time the *embryonic* shape outlined, in a three dimensional environment, in search for the final form. First step of a *think in 3D* training which would have flanked all the following steps of the work.

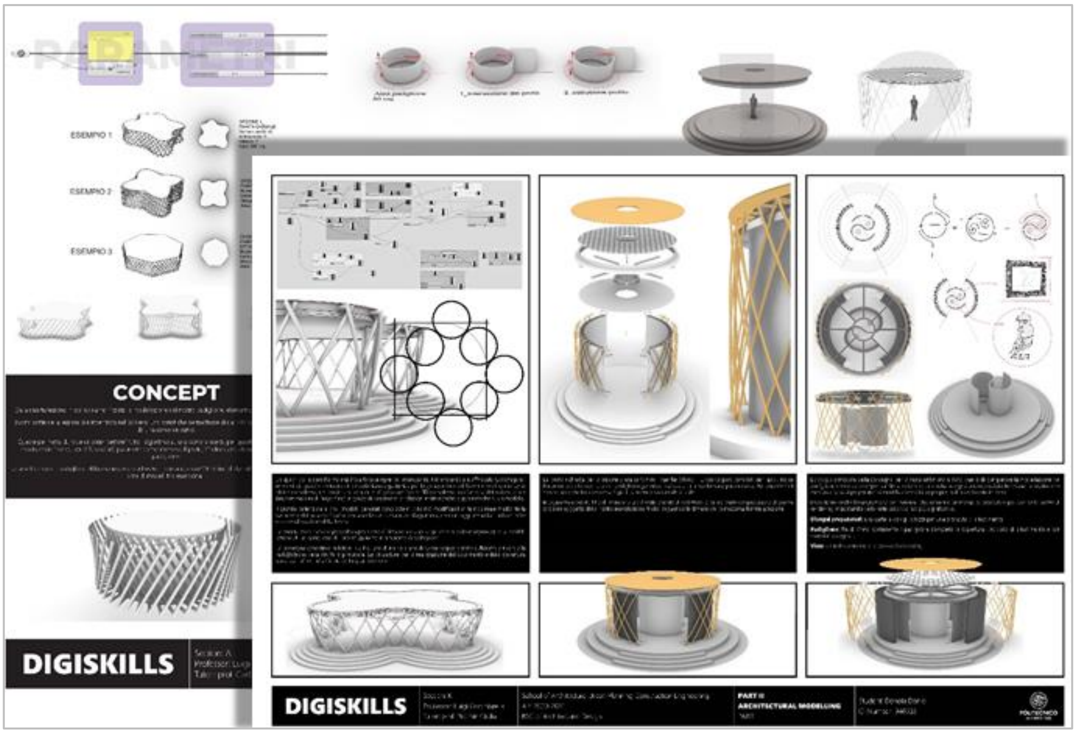


**Figure 8 -** Overview of some outcomes from the four lectures of the second educational block, dedicated to basic of *architectural modeling*, including an intro to *computational* and *BIM modeling*. Source: selection from the students' homework.

After training on *form finding*, students were asked to approach the *form definition*, based on teacher instructions that led students to solve some geometrical problems linked to the first groups of lectures. One of these was about the geometry of the crossing metallic supports, since to have a cylinder as the overall shape of the pavilion, they must be elliptical, and not linear as one could have initially supposed. This also had interesting consequences on the design of their connections with the base and the roof.

Construction technology was then called into question, in line with the program of the second year of our Bachelor. At this stage we wanted students work as sculptors, disassembling the overall volume initially elaborated as a concept space, and redesignign it element by element. Perhaps this was the most challenging part of the educational process, where the spatial abilities were put to the test and students had a real opportunity to improve in architectural modeling practice.

According to the aim of also linking the experience to the professional world, Building Information Modeling was introduced at this stage, using *Revit*, so that students could confront with the most shared standards and file formats normally used in the real architectural design and construction workflows. Some insights on parametric approach were also offered in this stage under a new light. Students had at this point an interesting journey inside *Digital Graphics*, having thread a path connecting various phases, from geometrical modeling to the threshold of informed design. They were somehow ready for approaching in the future advanced computational graphics and BIM modeling included in the Digi Skills program of the Master Course.

## 4.4 Feeding model: data from life and documents input

Back to the ideal initial stages of a design workflow, two lectures were dedicated to the *input*, that is, to how import vector and raster data in the CAD environment, and how to manage them. Frankly speaking, this is the first thing that students are required to do, when teachers give them files related to the project site. It was decided to focus on three lines. First, more insights about inputing data by keybord or graphic device. Second line concerned how to import and manage raster and vector cartograhic bases, and the related data from GIS databases. Third line of input was considered that of importing and managing 3D point-clouds generated by survey from life, including that carried out by mobile phones. Urban scale was then called into question, together with georefenencing and integrating the architectural project in this new digital information context (Figure 9).


**Figure 9 -** Overview of some outcomes from the two lectures of the third educational block, dedicated to basics of *data acquisition*, by *graphic and numeric input*, *GIS cartography*, *survey from motion* as input. Source: selection from students' homework.

The approach to the Geographic Information Systems was supported by the software program *Qgis*, with which students could learn another way of orgnizing sets of information, belonging to the quite heterogeneous world of the urban and territorial systems. As already seen with the BIM, but even more here, it was clearly perceived the role of Geometry and Graphics, in this case the geometry and graphics of maps, in bringing together thousands of layers of information – numeric, textual, alphanumeric – in a semantic system *shape-based* (or *shape-referred*) otherwise hardly referable to a real space.

In order to allow students to enrich, integrate and customize the territorial data available from the official geoportals, an introduction to *survey from life* was proposed, based on some targeted pictures, appropriately taken with a mobile phone, of a part of the assigned project site. Pictures have then been imported in the software program *Metashape* to obtain a 3D cloud of points of the part of the site analyzed. This work phase has required more mature space recognition skills to rationalize the geometry behind those 3D sets of points related to the project site, with interesting implications at the cognitive level.

Given the operational complexity of the work, it was necessary to avoid that students would be completely absorbed by the technical aspects of the software, so losing sight of the meaning of the job. On the other hand it was necessary that they did not confuse the levels of complexity involved. Therefore, they were asked to explicitly show the layers of the operational chain by clear exploded views of the several modeling steps carried out to generate the final model of the pavilion placed inside the proper urban site.

## 4.5 Testing model: visual, graphic, physical output

The last two lectures of the course have dealth with *prototyping*, intended in a broad sense. Again it was remarked that prototyping itself is not something happening at the end of a project. As data acquisition and modeling, it can be variosuly developed and implemented during the design process, working either as a tester either as a generator of a project. Also in this case the lines to follow were three. First of all visual prototyping, that is, the generation of digital images or animations. Second line referred to graphic prototyping finalized to printing on paper or on other kinds of graphic supports. Third was rapid prototyping, laser cutting and fused deposition oriented (Figure 10).

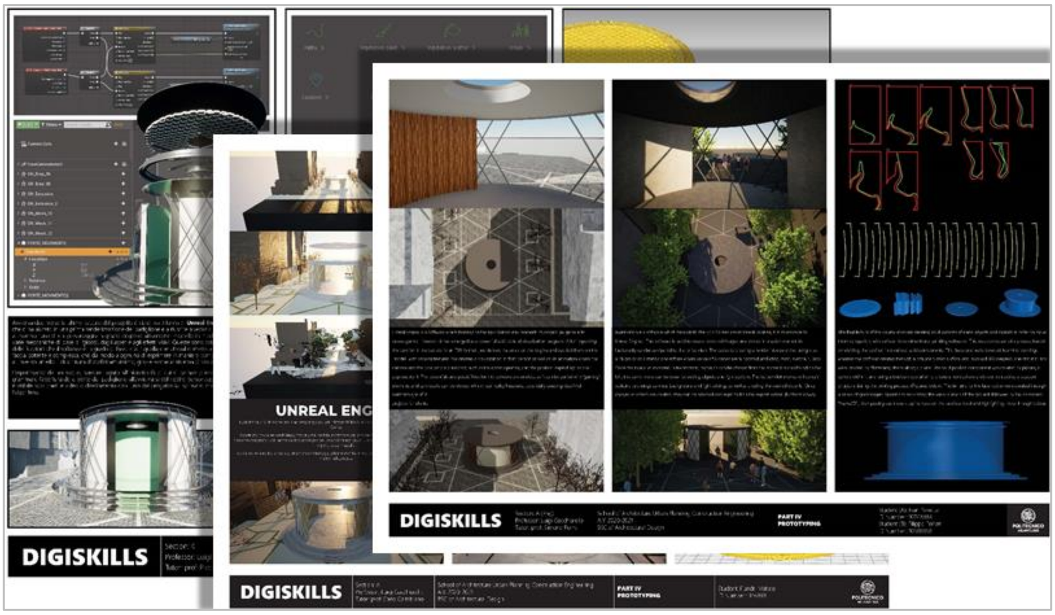


**Figure 10 -** Overview of some outcomes from the two lectures of the fourth and last educational block, dedicated to basics of *digital prototyping*, in the cases of *visual, graphic,* and *physical* output. Source: selection from students' homework.

In relation to the first line, that of *visual prototyping*, is was focused on the rendering as a way to consider the aesthetics of materials as an essential point in the real architecture, intrinsically related to construction, as well as an opportunity to test a new declination of parametric modeling. *Unreal Engine* indeed, the software programme choosed for creating images and animations, is a parametric based platform, not only for setting materials, but also for creating interactive scenarios in the video games, what makes it an interesting contact point with artificial intelligence.

Concerning *graphic prototyping*, it was discovered that refreshing some basic concepts about how to control the scale in raster and vector graphic files, as well as the weight of the printing files, was not unnecessary at all, even at the second year. By the way, the control of paraline as well as perspective cameras, together with lights and shadows, also offered a tangible validation of the theoretical contents of Descriptive Geometry learnt in the first year. Attention was then posed on graphic composition, basically develoed by *Indesign* and *Illustrator*, which were also used for realizing the final boards for the exam.

Passing from plane to physical space, *rapid prototyping* was addressed to the generation of CAD files to be sent to CNC laser cutter machine and to FDM machines, these latter by operating on CAD files with the software program *Cura*. Consistently with the overall approach of the course, finalized to enhance competences and skills to be used in the various steps of the design workflow, from the concept to the final project, the files for 3D printing were generated in different scales and levels of detail. Small rough models of the overall volume of the pavilion – considered as a kind of 3D concept models – were followed by bigger mokup, printed out as sets of separate detailed components which needed to be assembled manually, in the aim of simulating a real construction process.

## 4.6 Sharing results

Since the beginning of the class activities, tutors were recommended to collect some *best of* among the students homework. In order to keep the students workload acceptable, the layout for the homework delivery has been provided in due time. According to the organization of the program, and in order to make the classes homework comparable, all the classes used the same layout. Each lecture or topic was summarized on a predefined A3 board, where selected images and some paragraphs of text were to be included.

According to the approach characterizing architectural education, which integrates science and humanities, it was established that either iconography either writing shoud be used for presenting the outcomes, in order to foster a conscious reflection on the work done.

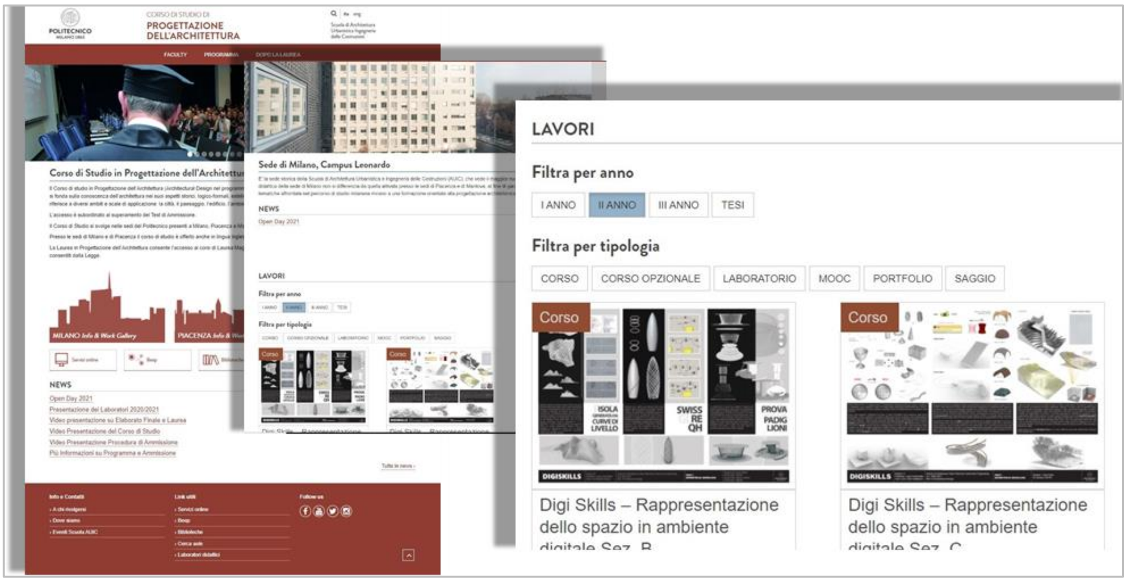


**Figure 11 -** Presentation of the outcomes on the webpage of the Bachelor in Architectural Design. Source: http://www.progettazionedellarchitettura.polimi.it/en/ (English version), http://www.progettazionedellarchitettura.polimi.it/ (Italian version).

In order to give a wide documentation of the class activities intentionally consultable by all the students, as well as to give the feeling of the impact of the program on the whole Study Course, the class results of all the 19 sections were published on the official website of the Bachelor (Figure 11). As expected, although based on the same assignments and developed from the same class materials, each student's work unequivocally reflects a recognizable personal sensitivity in the approach to the digital workflow. From the point of view of a teacher, it was a great success, meaning that skills had been metabolized, and that the overall educational experience did not result, at the end, in a superficial application of some modeling steps. In other words, we could metaphorically say that it was a sign that students were starting drawing the machine instead of simply being passengers.

## 4.7 Recruitment: the teamwork

It was clear since the beginnin that it could not necessarily be taken for granted that teachers and scholars with a consolidated curriculum supported by long experience and plenty of relevant publications would have been keen on such a program.

Reason for proposing to involve younger generations on stage. Which could have been a crucial point, since university teaching contracts normally require a PhD at leas in the curriculum. After a frank discussion, the call was finally also open to young graduates in architecture and civil engineering, as long as their final theses had concerned topics and operational skills required in the program. This allowed us to involve Master graduates, together with young Researchers and PhD graduates.

Some specific circumstances suggested to accept the proposal. First of all, by an administrative point of view, the courses were considered as tutorships, then the young graduates involved could sign a contract as tutors instead of as teachers, while, as it has already said, the didactic responsible for all the classes was the author, as an official teacher of the School (Figure 12). Second point in favour was the fact that teaching syllabus and materials were the same for all the classes, easier to monitoring. Third point, the distance-learning mode would have allowed kind of emergency intervention by the teacher responsible in the virtual rooms at any moment.

Other good reasons for supporting this idea were the immission of fresh energies in the university community, the challenging possibility for the young tutors to test their skills on the base of a systematic programme architectural design oriented, the opportunity to share knowledge and competences each other, and last but not least, an expected ease in the communication with the students. As the coordinator of the program, even author broke the mold, deciding to keep the communication with the tutors alive via some social network.


**Figure 12 -** The *Digi Skills* team work for the academic year 2020/2021.

All in all, the decision of enrolling young graduates together with more experienced tutors resulted in a good decision, and most of the tutors would have applied again for the next edition. From the academic side, this test experience has been presented and appreciated by the whole board of the teachers of the Bachelor programme, who have also encouraged to extend the experience to other courses in the aim of reaching one day a relevant digitalization of the whole Study Programme.

From the point of view of the author as the coordinator of the tutors, it is to be mentioned the enthusiam, the competence, the ability, and the resilience shown by the whole team, without which the mission could simply not have been possible.

## 5 Feedback from the students

After the exam, we decided to submit a targeted questionnaire to the students. Relevant to us was to understand pros and cons of this experience, in order to possibly update and improve the program in the future. Pivotal points in the questionnaire were the effectivenes of the topics proposed. First of all about the novelty of knowledge and software skills offered, since we know that many studens could have their own former backgrounds as self-directed learners.

The (in part unexpected) high percentage of positive answers, besides gratifyng us from a teaching point of view, clearly revealed a largely misconcepted approach to digital graphics in the self-directed community of the students users, often aiming at edonistic graphic performances more than to a responsible use of digital graphics for enhancing their spatial abilities as prospective architects.

This confirmed us that maybe we were working in the right direction, encouraging us to confirm the structure of the program for the next edition.

## 6 Feedbacks after exam

Concerning the course outcome, out of the 903 students enrolled in the courses, 752 passed the exam, that is 83%, 98 had to repeat the course, 53 were not admitted to the exam since they did not attend the lectures (Figure 13). Since we wanted students acquire and spend immediately their skills in other courses, one exam date only was planned. With one possibility for a recovery test, otherwise they had to repeat the course.

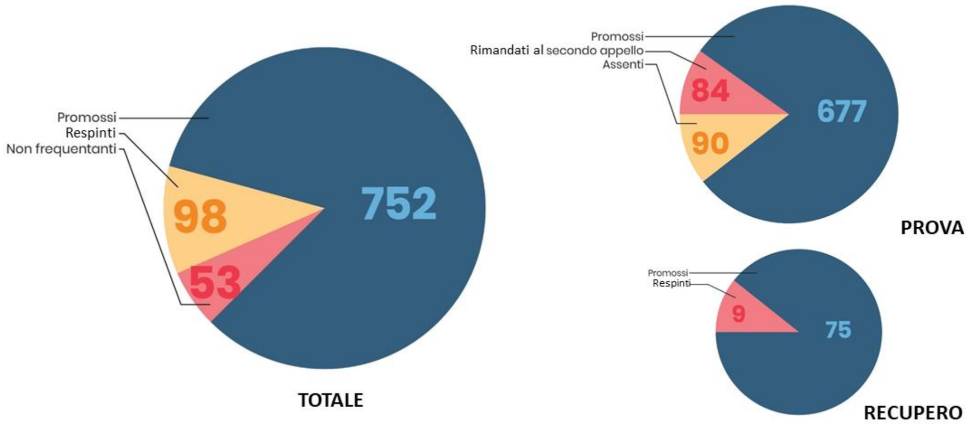


**Figure 13 -** Exam results: students who passed the exam (blue), students not attending the classes (red), students who did no pass the exam (yellow); the big diagram on left shows the total number, the two diagrams on the right refer to the validation test, that is, the final exam (above) and the recovery test (below). Source: by author.

Apart from the positive results, perfectly in line with the trend at our School, we wanted to know more about this experience from the point of view of the students. Although students had to answer an official and mandatory questionnaire before the exam, it was decided to submit them a new questionnaire after the exam, which was not mandatory in the aim of tapping interested students, and to have unconditioned and frank feedbacks. 547 students out of the 903, representing 61% of the whole cohort, corresponding to about 73% of those who passed the exam, responded to the invitation. The data here presented are based on this survey (Figure 14).

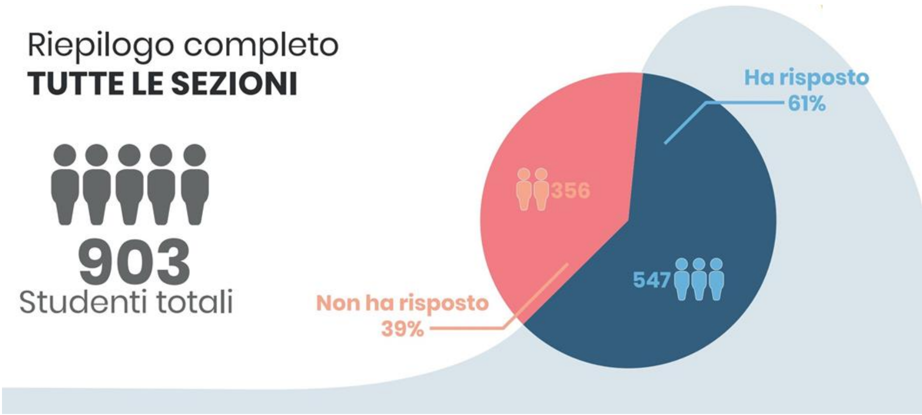


**Figure 14 -** The diagrm shows the participation of the students to the not mandatory questionnaire, submitted to them after the exam, in order to mainly tap interested students, who voluntarily would have decided to respond. Source: by author.

The questions were formulated on the base of points considered relevant in relation to topic and organization, which could have been useful to understand, to propose a better program in the future. The results were collected in detailed reports course-by-course, where either answers and the free comments were downloaded and organized. Below in the figure the front pages of these reports are presented (Figure 15).


**Figure 15 -** Figure shows the analytics of the answers resulting from each of the 19 classes of the course. Source: by author.

Then, the resulting data were synthetically represented by a specific set of diagrams. In the figure below they have been assembled in an overall picture, wher blue represents the positive answers to the questions (Figure 16). The big diagram at the center of the page represents the results referring to question 5, which for us was the most relevant, where students were asked if the course had somehow influenced their approach to architectural design, which is the core of a School of architecture. The positive trend of feedbacks seemed to reassure us about the accomplishment of the educational mission.

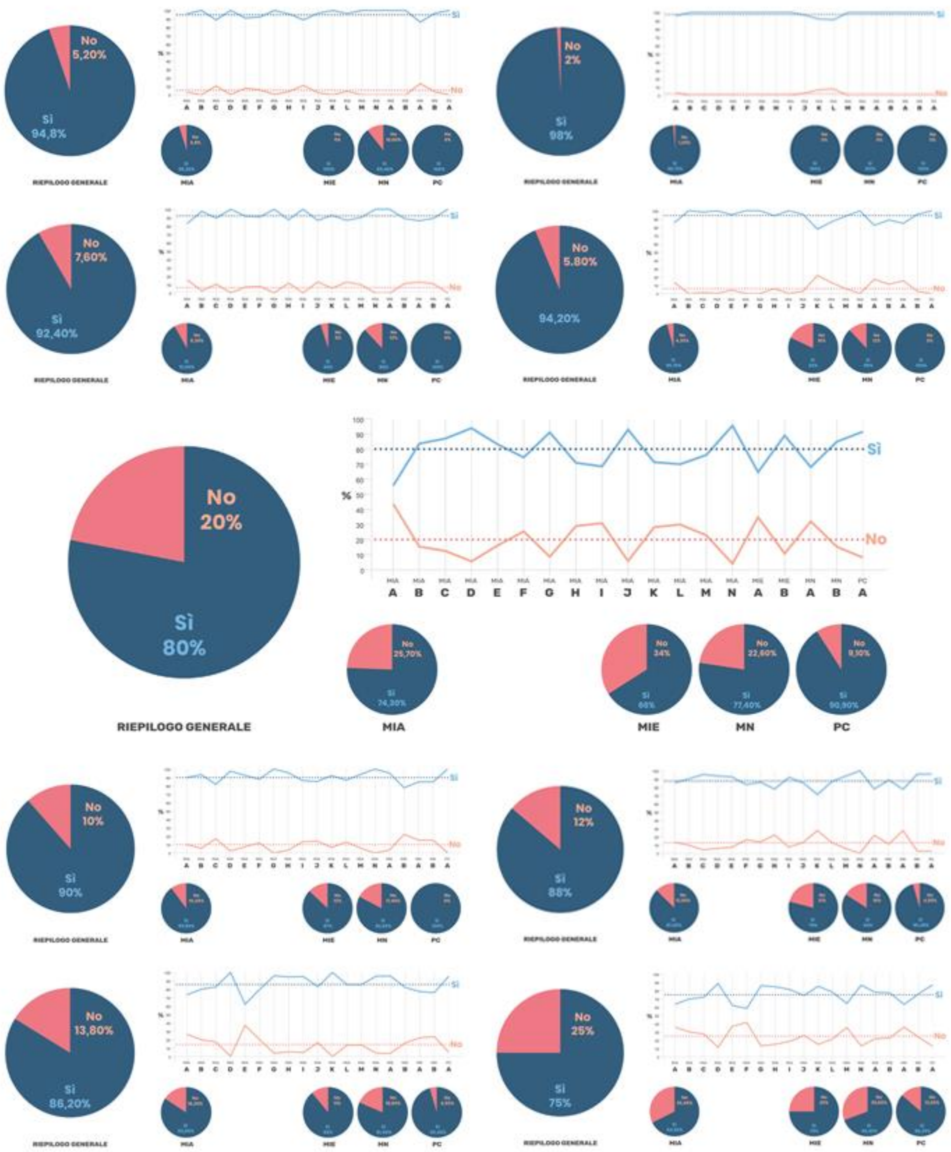


**Figure 16 -** The diagrams show the trend in the answers to the 9 questions submitted; big disks on left represent overall percentages; linear diagrams show in detail the data resulting from the 19 classes. The big figure in the center shows the results concernin one of the most relevant questions, whether the course has somehow influenced the students' approach to architectural design. The blue color represents positive answers. Source: by author.

In the figure, the upper group of diagrams refers to questions 1 to 4, the lower group to questions 6 to 9. More specifically, questions asked students about appropriateness of having this course in the study plan (question 1), real acquisition of new competences and skills (question 2), opinion about including several software programmes in the same course (question 3), effectiveness of the digital training proposed in enhancing spatial abilities (question 4), influence on their approach to architectural design (question 5 related to the big diagram in the middle of the figure), if competences and skills aquired resulted immediately and profitably usable in other courses (question 6), if the course has influenced students' vision of the Digital in relation to architecture (question 7), and finally, related to the specific circumstance of the pandemic spread, if distance learning has worked profitably (question 8), and if distance learning would be recommended in the future independently on the pandemic spread (question 9).

## 7 Final remarks

Mission of the course was to offer a digital literacy course to the students of Architecture at the Politecnico di Milano. It was offered to the about 1.000 students of the Bachelor in Architectural Design, enrolled in the second year. The 19 classes taught by tutors have been coordinated by one teacher (in the case also author of this work). Based on the *UNESCO/UIA Charter for Architectural Education*, as revised in Tokyo in 2011, *digital fluency* has been at the core of the educational mission, matching the specific goal of enhancing students' *spatial abilities*. A 4 ECTS program has been design where 3D spatial modeling was the gravity center, integrated by issues related to several related aspects, relevant in the architectural design processes, like an intro to *computational graphics* and *BIM*, to *data acquisition* (by direct input, GIS cartography, point clouds), to *prototyping* (visual, graphic, and physical by laser cutter and FDM). 90% of students passing the exam did it in the first exam date. Passing the exam resulted in a validation of the credits without grade, which allowed students to focus on the essentiality of topics more than on the curricular performance.

Results seemed encouraging, the course has been repeated in 2021/2022 and it is planned to be stably kept it in the Bachelor. Most interesting result, the course has been perceived as relevant for approaching architectural design education by students (Figure 17).


**Figure 17 -** Most frequent words detected from the free comments of the students, asked about the overall opinion (left), pros and cons (midst) and suggestions (right) on the course; it was interesting to notice that, some complaints for the workload appear together with enthusiasm for topic and grats to the tutors for the course done. Source: by author.

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