

# Drawing, Design and Building Information Modelling: Embedding Advanced Digital Tools in the Academy Programs for Building Engineers and Architects

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**Abstract**—This paper deals with the integration of advanced digital design and modelling tools and methodologies, known as Building Information Modelling, into the traditional Academy educational programs for building engineers and architects. Nowadays, the challenge the Academy has to face is to present the new tools and their features to the pupils, making sure they acquire the proper skills in order to leverage the potential they offer also for the other courses embedded in the educational curriculum. The syllabus here presented refers to the “Drawing for building engineering”, “2D and 3D laboratory” and “3D modelling” curricula of the MSc in Building Engineering of the Politecnico di Milano. Such topics, included since the first year in the MSc program, are fundamental to give the students the instruments to master the complexity of an architectural or building engineering project with digital tools, so as to represent it in its various forms.

**Keywords**—BIM, BIM curricula, Computational Design, Digital Modelling.

## I. ACADEMY CURRICULA AND BIM

AN up to date approach to Architecture and Engineering Academy courses, nowadays cannot neglect BIM: the new tools and methodologies have to be integrated in the syllabus since the first year of an Architecture, Civil Engineering and Construction Management (AECM) course. In terms of educational goals, there are two sides to take into account: the students have to approach and understand the basics of the construction world as well as of the disciplines useful to describe it (drawing and representation), and they have to comprehend how BIM and in general the parametric software can be leveraged for the constructions industry. It is important to give a broad overview of these topics, so that the students can learn to rationally identify, evaluate, choose and use the most suitable methods and tools along their university career and further.

That is why the school of Building Engineering MSc of the

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Politecnico di Milano did activate BIM courses organized according to an introductory and an intermediary level. Including BIM into the traditional educational programs has not been an easy task, though at the moment two courses have been implemented: a 2D and 3D Laboratory beside a mandatory first year course (Building drawing); an optional 3D Modelling course, among a wide offer of third year courses. The 90% of the eligible students did decide to opt for the 3D Modelling program. The high percentage of the students choosing the class and regularly attending the lessons, shows a great interest in the subject and that is why the course is likely to be continued in the future.

The paper is aiming to show the ground reasons and the consequent steps that have been taken in account in order to implement the new courses, as well as some of the outcomes obtained along the whole curriculum studiorum.

## II. TEACHING METHODOLOGY

### A. Literature review

CAD, BIM and other similar tools are already well known by the academy, and they are taught in several courses. Though, the goal of a better integration of such topics into the whole curriculum starting from the first year Architectural drawing courses, did require to investigate the available references on the existing experiences.

Therefore, a literature review has been done and it is here summarized.

The research was conducted using the "title/abstract/keyword" field on the search engine "Google Scholar" to get information about the trend in BIM teaching. In addition, articles contained in the Scopus® database (Elsevier B.V.) were considered.

Search keywords included Drawing Course, Drawing Teaching, BIM Education, BIM Course, BIM Teaching, BIM Curricula.

A brief review of the abstract was performed to make an initial selection. After this filtering, more than 30 articles with relevant contents about BIM teaching in the AEC programs were identified.

After an overview about the international trends for teaching BIM in AEC curricula, the approach adopted in the

“Drawing for building engineering”, “2D and 3D laboratory” and “3D modelling” curricula of the MSc in Building Engineering of the Politecnico di Milano is described.

Reference [15] analysed 45 Architecture, Civil Engineering and Construction Management (AEC) schools and they noticed that 9% of the universities and colleges has a BIM-related coursework and the 1% of those has dedicated BIM classes. These results underline the lack of a suitable BIM teaching even in those countries where BIM is used extensively.

References [1], [2] explained the international trend in BIM teaching, and they emphasized the importance of BIM learning in students' curricula. [6] analysed two case study to understand the effect of the BIM integration within the construction management curriculum and, in the same year, [7] suggested a collaboration between the industry and the academia world to develop a BIM curriculum in the Mechanical, Electrical, Plumbing and Fire Protection (MEPF) fields. This concept has been mentioned as well by [17], highlighting the importance of strong partnership between universities and industries, especially Software Editors.

Reference [13] focused on the benefits of using BIM models in AEC programs while [18] analysed the several BIM teaching approaches across the world taking into account a real case at the Hong Kong Polytechnic University. [11] describe the importance to increase the efficiency of BIM teaching programs, considering in the first place the major BIM tools used by the industry sector. Therefore, they were identified via a questionnaire survey administrated to the BIM practitioners. Furthermore, the authors asked which were the most popular BIM software.

With regard to the BIM tools, the questionnaire results revealed that the first one is Clash detection and coordination, followed by Scheduling and 4D visualisation, Quality control and Quantification/Estimation. Concerning the BIM software, the most popular ones are Autodesk Revit Architecture and Autodesk Navisworks (for modelling, coordination, and clash detection), Google Sketch-up, DProfiler, Innovaya, and Synchro.

There are several theories about how to teach BIM concepts and tools. On the one hand, [8] supports the Constructivism theory based on two approaches: Problem-Based Learning (PBL) or Design Based learning (DBL). Basically, the students construct their models from a project that is under construction and then they focus on topics such as budgeting, scheduling, energy analysis, etc. On the other hand, [2] identified four macro-areas that are common in the major international schools such as Virginia Tech, California State University, University of North Texas, Penn State University, Israel Institute of Technology, etc. as from [1], [2], [17]. These are: (1) several strategies for teaching BIM, (2) different ways for introducing BIM in the curriculum, (3) obstacles encountered in BIM courses, (4) good examples in BIM teaching.

One of the major obstacles revealed in the literature is the lack of sufficient space in the curriculum to include a new course in the traditional programs of AEC schools. The BIM

philosophy requires a collaborative attitude, indeed, too often, the construction industry is showing its interests in Integrated Project Delivery. A solution could be the interaction between BIM tools within traditional classrooms and laboratories but this requires a solid structure of the school because the coordination is not easy to apply and handle. [2] demonstrated that the method of BIM teaching evolved over the two decades 1990-2010. The authors underlined the case study of Virginia Tech that developed an Inter-level and interdisciplinary program involving students from other subject-areas external to the AEC sector. The case was not successful because of different students' backgrounds and goals. The weak point was that they created poor and inaccurate models.

Reference [2] basically identified two approaches: the first one is teaching BIM in one (or at maximum two) course, the last one is teaching BIM in different courses. For the first approach, the BIM is taught at the beginning or at the end of the programs. For the second approach, the BIM tools are integrated into eight courses such as Drawing, Digital Graphic Representation, Building Technology, Construction Management, Specific BIM courses and Workshops, Thesis and Internships.

The purpose of BIM courses is the knowledge of the BIM skills for creating the potential future BIM Modeller and/or BIM Facilitator. In light of these considerations, three skill levels are identified: introductory, intermediary and advanced.

At an introductory level, BIM can be taught via lessons and labs. The students learn BIM tools making modifications on existing models such as the development of new components, the addition of information for construction sites, the detection of interferences, etc. Usually this level refers at the beginning and at the last phase of the AEC courses [1], [3]. In Intermediary level, the students, grouped in teams and promoting the rotation of roles, build a BIM model of an existing small building within Drawing and Building Technology Courses. In order to give more time to the students, the teachers should provide a complete documentation in CAD or PDF and a description of the project to be modelled. The grade may take into account the submission of files in CAD, IFC, tool integration and Clash Detection, and PDF [2],[8], [9].

For the advanced level, the requirement is a good background in Building Science and Technology and be experienced with BIM tools. The content of the BIM teaching is similar to the intermediary level but, at this level, the students are more independent and they assign the role upon to their experiences and skills.

The literature review made evident the importance of teaching BIM at each level of AEC programs. The demand for qualified BIM student increases day by day and year by year. The academic world plays a significant role and its duty is to insert BIM tools in students' curricula thanks to specific courses and BIM curricula where professors should be both academic figures and BIM specialists. Another aspect that should be underlined is the importance of a good knowledge of the Building technology and Building science. This knowledge has to be joined to the BIM tools such as Clash

detections, Scheduling, Quality control, etcetera.

### III. EXPERIENCES AT POLITECNICO DI MILANO

#### *A. Architectural Drawing Innovations between Theoretical methodology and BIM*

The route to introduce and integrate BIM in the Building Engineering MSc Curriculum, starts within Architectural Drawing courses, with the Design Theories applied to the digital representation, during the first year of studies. The next step is the presentation of the most advanced BIM tools, and the final step is the parametric modeling of a project for the development of MSc and PhD thesis.

The course of the first year is highly demanding, due to several factors such the heterogeneous students' background, the lack of knowledge in the design discipline and the lack of knowledge in terms of architecture, buildings technology and construction processes. It is a difficult educational environment but at the same time exciting because the integration between drawing theories and BIM tools is challenging.

The dialectic between traditional drawing disciplines and the use of digital tools is constantly changing. It is noteworthy reminding that [10] already underlined the need to upgrade the descriptive geometry, translating all complex graphic products into mathematical algorithms and drawing them via software.

On the other hand, it has been noted that, without setting clear goals, the software skills are not enough to support building engineers and architect's needs. Indeed, the students must first acquire deep competencies about drawing techniques and how to communicate the project. Therefore, a careful selection of the traditional drawing theories content has been done, in order to highlight the aspects that are synergic to BIM. Among these, the most important techniques are (1) the essential representations for the different stages of the project development, (2) the different scales of detail and graphical simplifications to be matched to the alphanumeric database, (3) the notation and the representation methods allowing to determine what kind of information is useful at each step of development and implementation of the project. At an introductory level, the theoretical lessons are accompanied by the activities within the drawing laboratory such as those of the 2D and 3D Laboratory.

The last ones are here presented.

#### *B. Traditional CAD to BIM approach*

The current educational paths aiming to teach how to represent buildings and constructions elements can follow two different ways. A first one is usually focusing on learning first how to use the CAD tools in order to support the project representation. With such an approach CAD tools are used mainly for their 2D aspects. The 3D comes later, to transform the 2D representations in a model that is of support for producing rendered images and sometimes to realise physical models through 3D printers or other devices. A second approach – more innovative - goes from 3D to 2D. The first steps of the representation start with 3D CAD tools in order to model at first a 3D virtual representation of a building that is

the source used to produce 2D drawings. This is the privileged path that has been, until recently, the standard track for the “2D and 3D laboratory” course at the MSc in Building Engineering of the Politecnico di Milano [5]. The pupils of this course are at their first year of university studies, and they come from different backgrounds. Some of them do already know 2D and 3D CAD tools, some others do not have any specific preparation, not even about building representation. Therefore, the course has to introduce them gradually to such topics, starting from the drawing standards up to how to use 3D and 2D CAD software. The classical projections techniques – orthographic projections, isometrics, perspectives, sections – and the graphical conventions of the architectural drawing language, are presented always starting from 3D modelling. The model realised by the students is organised in a hierarchic way useful to produce 2D representations that are set according to the proper drawing standards.

The 2D representation is executed taking into account the three different project levels – preliminary, definitive, executive - according to the Italian rules for the public works procurement.

As a further step, BIM can be introduced after both approaches – from 2D to 3D or from 3D to 2D - though this revealed to be a not obvious process. Students moving from 2D/3D CAD to BIM frequently do find the new instruments awkward to manage. While certain aspects of CAD still do apply to BIM, it is true that the habits acquired using 3D and 2D CAD often do not help to learn BIM in the proper way and sometimes are a real obstacle to understand the philosophy and the method that should accompany the modern instruments.

It has been experienced that a number in between 50% and 60% of the students attending the course do prefer to stick to the software they already know, instead of learning a new tool. This is true mainly for those students coming from previous CAD experiences, though it happens also for some of the students that approached CAD for the first time. Many of them find the effort to learn one tool so demanding, that it is discouraging the transition to a new software, despite the dramatic advantages they might obtain. Of course, this implies that the students avoiding BIM will not be able to leverage the opportunities that the new technologies can offer them. Therefore, the course approach based on the sequence from CAD to BIM has been recently changed adopting a BIM centric concept that has been first experienced into the third year course 3D modelling and then put in practice also into the first year courses.

#### *C. BIM based path*

OO tools, In the last few years, it has been possible to set up and test an educational path alternative to those discussed in the former paragraph. This has been done into the 3D Modelling course which is a 3<sup>rd</sup> year optional module of the MSc in Building Engineering. The path proposed to the students is involving the use of several 3D CAD among the other ones Autodesk Revit, Bentley Architecture, Graphisoft

ArchiCAD and Nemetschek Allplan. The majority of the students attending such course already have a basic knowledge of 2D CAD and some of them also 3D, as well as a fair understanding of issues related to the constructions, therefore the test bed course for BIM can focus just on acquiring the workflow fundamentals rather than insisting also on construction industry specific issues. The students come from an education based on a traditional CAD 2D to 3D approach, and this - opposite to what happens for the 1st year pupils - does not hamper them to quickly acquire the BIM basics. This is probably due to the maturity of the learners in terms of IT skills already acquired as well as in terms of specific knowledge about the building industry and processes.

After one semester - around 60 hrs of training - the pupils did acquire a basic understanding of modelling, they learned the fundamental tools useful to produce a complex building model and to manage it in order to obtain by-products such as the flat 2D representations: projections, perspectives, details, rendering and so on. It has to be highlighted here that the course does not interpret *Modelling* just as a geometrical reproduction of the building, it is instead presented as the integration of geometrical and information aspects of a construction: the students are stimulated to understand modelling activities as a synergy of information and geometrical content, therefore they are requested to plan their models according to the outcome they are expected to obtain from them. Indeed, the basic tools to provide further analysis - computational design software, quantity take off, energy, structures, etc. - are presented as well in order let the pupils face the issues related to the different kind of analysis that can be done with the model. Along the term, the students can then take on board those basic skills allowing them to start using BIM proficiently also for other courses, in order to perform different analysis (Clash detections, Scheduling, Quality control, Energy simulation, Structural analysis etc.) without being hampered by the lack of experience within the modelling environment.

The consequent step has been the introduction of a similar path for the 1st year students, taking into account certain differences due to the maturity level of the learners. While the 3rd year students are able to understand how to organise and structure the building model, the 1st year students do not have the same knowledge, therefore the BIM has been used as a tool useful to understand at the same time how a building is organised and how it has to be modelled and represented. In order to achieve such a goal, the faculty had to prepare sample files and templates that would facilitate the task for the students. In order to unify the language of the representation, it is necessary to identify graphical standards that can be efficiently organised using the IT tools. Such standards are made available to the students through the sample models and through the templates: analysing and interrogating the files given to them, the students acquire the basic organisation and representation rules, that later they will apply into their models. In a further phase, students are taught how to modify the given templates and standards or how to define their own according to their design needs.

Once the students are familiar with standards, templates, model organisation, they are requested to produce the virtual models of some selected buildings that allow to experience different modelling strategies.

In terms of 3D model detailing, the students refer to the standards about the Level of Development as interpreted by the Italian research Innovance [4] though at this stage of the learning process (1<sup>st</sup> year course), the expected outcome to be obtained by the model are just simple representations of the same building at different scales, according to the Italian standards:

- 1 : 200 preliminary design - site definition
- 1 : 100 preliminary design - building
- 1 : 50 definitive design - building
- 1 : 20 execution plan - building detailing
- 1 : 5 construction details - building detailing

Such a course structure allows the students of the 1<sup>st</sup> year course to understand the meaning of the different design levels and the kind of information and representation required for each of them, and to get on board those basic skills that are the support of a BIM based process. The ground competencies so established can be then pushed to a further level in other courses of the Building engineering curriculum as well in MSc and PhD thesis.

#### D. Some sample results

The images here presented show some of the outcomes of the Architectural Drawing courses, 2D e 3D Laboratory, 3D Modelling course, MSc Thesis and PhD thesis.

At the introductory level, the students explore pre-set building models and later on they reproduce simple constructions as well as existing contemporary buildings (Fig. 1).

At an intermediary and advanced level, BIM activities proposed to the students become more and more complex and sometimes can end up in MSc Thesis or specific research projects, such as the case of a sustainable building, or green skyscraper (Fig. 2 and Fig. 3) that was modelled in BIM, calculated using FEM, 3D printed and tested in the wind tunnel of Politecnico di Milano [14].

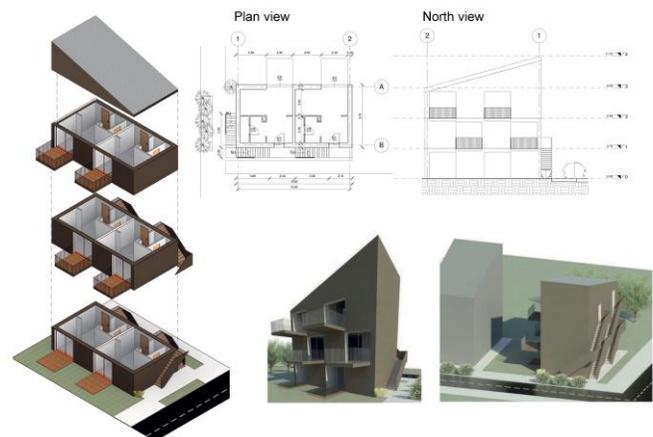


Fig. 1 “Canal homes” (Do Architects), modeled by the students of the 3<sup>rd</sup> year course

An advanced case, that is also an example of BIM for heritage buildings, is the survey and modelling of Villa Faccanoni, designed by the Arch. G. Sommaruga and built between 1912 and 1914. The students of the 3D modelling course, starting from a 3D laser scan model, did replicate in BIM the building and used the model for a number of activities, including rendering, solar simulation, quantity take off and others (Fig. 4).

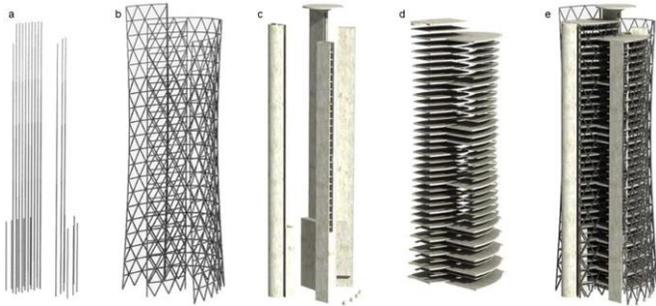


Fig. 2 Sustainable skyscraper, structural scheme: (a) steel columns, (b) steel diagrid structure, (c) concrete shear walls, (d) concrete floors, (e) full model [14]

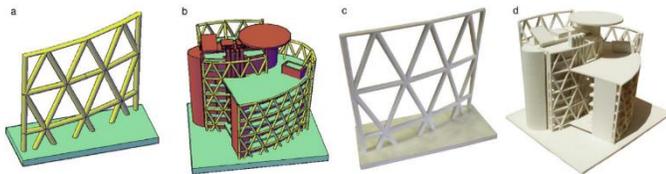


Fig. 3 (a) diagrid structure CAD model, (b) top of the tower CAD model, (c) diagrid structure physical model (1/100 scale) (d) top of the tower physical model (1/250 scale) [14]



Fig. 4 Building Information Modelling for heritage buildings (Villa Faccanoni) applied in the 3D modelling course: (a) quantity take off, (b) façade material survey, (c) images from the solar analysis

*E. Advanced experiences in PhD courses: the use of parametric software to create and analyse building shapes*

Beyond the MSc experiences, there are researches developed by PhD students that, starting from the skills achieved in the MSc, approach advanced modelling

applications and tools.

The current technological enhancements and latest generation software shifted the design process from static to dynamic, introducing new ways to conceive the architectural object. Nowadays parametric tools are used to increase building samples by modifying the base geometry in terms of proportions and dimensions. According to [16] the parametric design “corresponds to a set of rules or logical, geometric and parametric relations, set into a specific sequence, for solving a specific problem”. By using Grasshopper®, architects and engineers can deeply understand how shapes relate to their environment in terms of shape, movement and energy. Feasible geometries are thus found following a form finding approach, where wide ranges of shapes and deployments are described by generative algorithms defined by mathematical rules that relate with each other through existent components or customised scripts. In this way, these tools help to systematise the process, which is ruled by maths components run by numeric values change. Besides, the design of customised shapes is carried out by the combination of those algorithms, which enable step by step geometric changes adjusting some parameters while maintaining some of the others fixed. The parameters variation becomes thus a design driven methodology managed by numerical sliders that allow the alteration of dimensions and proportions by using vectors and planes to set up the shapes.

Aside from the shape exploration and the design of technical parts, parametric software can be connected to plug-ins to deal with the real indoor and outdoor conditions that interfere with the architectural object. Reference [12] exploit how to investigate building envelopes taking advantage from these tools. In their research, geometry, movement and environmental simulations are accounted at once, coupling different Grasshopper® plug-ins (i.e. Kangaroo®, Honeybee® and Ladybug®). Still under development, the Honeybee plug-in can be used to test in a feasible way building performance. The tool works as interface between Grasshopper® and simulation engines used at research level such as Radiance® and Daysim® for daylight simulations and EnergyPlus™ for the thermal ones. By collecting results in CSV files format or directly saveable as excel files, Honeybee® allows the user to manage inputs directly by changing the numeric values associated to the definition’s components. With these type of plug-ins each building component is interconnected

and totally adjustable in an incremental way. Besides, Grasshopper provides to design alterations working both in the parametric environment or by collecting geometries from Rhinoceros®.

Thanks to new software development and current new design strategies is thus possible to simulate in the digital environment what happens in reality. Setting the right parameters and having the ability to adjust them means to optimize the design process and act against physical prototypes costs and time. Despite their infinite possibilities, software can also be misleading. Several options can be made and not every choice is the best one to correctly evaluate each shape. With these regards, it is important to learn how to

investigate the parameters variations in order to comprehend every time which parameter act the most onto the analysed geometry.

Warning the students and making them aware of such issues is one of the tasks of the BIM foundations courses described in the former paragraphs.

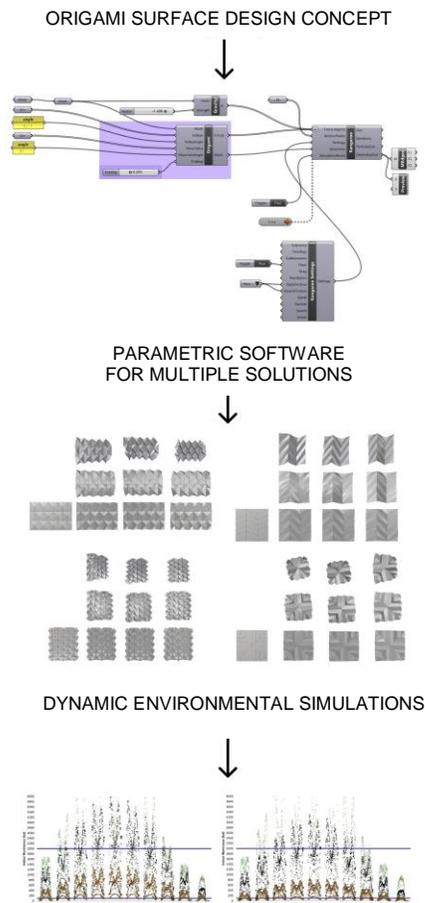


Fig. 5 PhD thesis: parametric software has been used to evaluate how different building shapes match the requirements.

#### IV. WHAT HAS BEEN LEARNED

The educational experiences about BIM methodologies and parametric tools that the authors have been conducting over more than ten years of courses, constitute a solid background for a better integration of BIM methods in Architecture, Civil Engineering and Construction Management (AECM) curricula.

Moving from the old pathways to BIM based courses, few lessons have been learned, and some of them are aligned to what expressed by the international literal review presented in this paper.

The authors believe that the approach to BIM must start since the early phases of the academic career. Due to the nature of the modelling tools involved, a strict integration between BIM courses and representation disciplines is highly desirable since the first steps of the educational curriculum.

It is important to point out that the learning process based on a traditional path going from CAD to BIM, can actually hamper acquiring BIM skills: as it has been highlighted, such an approach makes a high number of students reluctant to embrace the new methods, because they feel breaking the comfort zone they established for themselves with CAD, and they prefer to stick to it.

A second point is that there is need for allocating enough time for training in order to properly take on board the BIM processes: that means acquiring the basics of the constructions disciplines, as well as the skills for modelling geometry and information and consequently put that in practice in real cases.

Introducing BIM at a late stage of the courses, can be successful in terms of attitude and ability of the students to change their mentality and design approach: despite being already used to traditional CAD tools, the construction awareness they matured during the former years can be enough to let them perceive the advantages of learning the new methodologies, and they commit to that. On the other hand, as it has been highlighted also in the literature review, the space given to such topic is not enough: students at a late stage of their career, miss the chance to experience, train and apply the BIM skills to other disciplines since the start of their curriculum.

The introduction of BIM in the 1st year courses, instead, allows the student to face the new methodologies since the beginning of their career. This way, they have enough time and chances to apply and improve their BIM skills in other courses and in different situations. Furthermore, Building Models can be leveraged to introduce them to the complexity of the constructions and to the standards needed to model and represent the products of the industry, following a deductive approach. Pre-set models of buildings, prepared by the faculty at different Levels of Detail and/or Development, introduce the students progressively to different issues: what a building is, what are the elements it is made of, what are the representation and the modelling standards, what kind of information content is required.

Such base of knowledge can be proficiently applied in the rest of the students' career. When they approach other courses, such as Building Technology, Construction Management, etc., they do not need to learn something new: they just have to leverage the skills already acquired and take them further within the new situations they face.

As it has been noticed in the Building Engineering MSc, the pupils having developed the basic BIM skills since the start of their career, are those that have been the best at leveraging BIM and collaborative work practices along their whole curriculum studiorum and further, in the industry or in the PhD programs following the Master degree.

#### REFERENCES

- [1] M. B. Barison, E. T. Santos, "Review and Analysis of Current Strategies for Planning a BIM Curriculum", *Proc., CIB W78 2010 27th International Conference, Virginia Tech, Cairo, Egypt*, 1- 10
- [2] M. B. Barison, E. T. Santos, "BIM Teaching: Current International trends. *Gestão e Tecnologia de Projetos*. 6 (2), 2011.

- [3] N. C. Brown, R. B. Peña, J. Folan, "Teaching BIM: Best Practices for Integrating BIM into Architectural Curriculum?" Autodesk University 2009.
- [4] V. Caffi, B. Daniotti, M. Lo Turco, D. Madeddu, M. Muscogiuri, P. Novello, A. Pavan, M. Pignataro, BIM enabled construction processes: the InnovANCE approach, Proceedings of the congress Energy, Sustainability and Building Information Modeling and Management, Bari 2014.
- [5] V. Caffi, "Representing the architectural project: an educational CAAD program for building engineering and architecture MSc curriculum", Proceedings of the congress INTED2009, Valencia, 9-11 marzo 2009, Valencia.
- [6] C. Clevenger, S. Carey, "Industry-Academia Collaboration to develop a BIM-based MEPF Coordination Educational Module", EcoBuild Proceedings of the BIM-Related Academic Workshop, Washington D.C., 2010, Video material.
- [7] C. Clevenger, M. Ozbek, S. Glick, D. Porter, "Integrating BIM into Construction Management Education", EcoBuild Proceedings of the BIM-Related Academic Workshop, Washington D.C. 2010.
- [8] E. Hjelseth, "A Mixed approach for SMART learning of building SMART. eWork and eBusiness in Architecture, Engineering and Construction". ECCPM 2008. Org. Alain Zarli and Raimar Scherer. London.
- [9] R. Holland, J. Messner, K. Parfitt, U. Poerschke, M. Pihlak, R. Solnosky, "Integrated Design Courses Using BIM as the Technology Platform. Proc.", The BIM-Related Academic Workshop 2010
- [10] R. Migliari, La geometria descrittiva nell'era informatica. Edizioni Kappa, Roma, 2008 pp. 14-31.
- [11] A. Nejat, M. M. Darwish, T. Ghebrab, T., "BIM teaching strategy for construction engineering students". American Society for Engineering Education 2012.
- [12] M. Pesenti, G. Masera, F. Fiorito, "Shaping an Origami shading device through visual and thermal simulations". Energy Procedia 2015, 78, 346-351.
- [13] F. Peterson, T. Hartmann, R. Fruchter, M. Fischer, "Teaching construction project management with BIM support: Experience and lessons learned". Journal of Automation in Construction. 20. 2011 pp. 115-125.
- [14] M. A. Pignataro, G. Lobaccaro, G. Zani, "Digital and physical models for the validation of sustainable design strategies". Automation in Construction, 39, 2014 pp. 1-14
- [15] F. J. Sabongi, M. Arch, "The Integration of BIM in the Undergraduate Curriculum: an analysis of undergraduate courses". Retrieved from ascweb.org on January 3, 2012
- [16] L. Sanches, M. A. Hippert, G. F. Abdalla, "BIM as a support for the design process with fire safety regulations". Occupational Safety and Hygiene IV, 185, 2016.
- [17] S. Vidalis, J. Cecere, "Building Information Modeling/Vertical Digital Construction: Teaching Strategies and Preparing Students for the Workforce". Proc. of the 2015 Conference for Industry and Education Collaboration, ASCE.
- [18] K. A. Wong, K. F. Wong, A. Nadeem, "Building Information modeling for Tertiary Construction Education in Hong Kong". Journal of Information Technology in Construction, 16, 2011 pp. 467- 476.