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Integrated Design Concept in Civil Engineering Education*

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The current difficulties in the Construction Industry have confirmed the urgent need for interdisciplinary between all the design disciplines, from engineering to architecture. The requirement for high levels of building efficiency and the optimization of the building process is making increasing demands on the accuracy of designs. The project is no longer a sum of contributions, but a design methodology that combines the answers to all the different requisites of the building, an integrated design project. This multidisciplinary approach to design problems is only possible if it is present in the design process from the outset. This implicit complicity is only possible if it starts in university education, searching for a unique common language of construction. This article shows an example of the implementation of integrated project delivery (IPD) methodology to the project based learning in civil engineer education. Exploring the experience undertaken in last year's in one of the courses of the Integrated Master in Civil Engineering (MIEC) of the Faculty of Engineering of the University of Porto, the implementation of the IPD methodology along lectures and studio classes, proved to be a more efficient learning performance among students in what concerns to the understanding of the relation between the design process and the convergence of all engineering disciplines that have to work together with the architecture design practice. Therefore, the methodology implemented in the architecture course in the 2nd semester of the 2nd year (1st cycle) of the MIEC, described in chapter 3, allows students to learn the design methodology as an integrated disciplinary project and to become able to access the available work tools, from project design to construction process. As a result, the improvement in the students 'ability to acquire knowledge' was clearly visible in the increase of final grade average since the IPD methodology was implemented in the course (2010/11). Also, student's motivation for developing extra homework became higher due to their initiative and commitment.

Keywords: Integrated design concept; integrated project delivery; civil engineering education; project based learning

1. Introduction

The concept of integration is understood not as a stylistic architectural concept, but as a method of organising the steps and players involved in developing the design to optimize the construction process: a working methodology [1]. The Integrated Project Concept as a methodology is researched in-depth by the professional associations of architects in particular in Anglo-Saxon countries. Within RIBA (Royal Institute of British Architects), procedures and tools are created to systematise and optimise the designs of the different specialities and the relationship between the decisions of the various disciplines [2]. The Architect's Handbook of Practice Management is part of the library of every British design office, both architectural and engineering; therefore, the communication between these areas becomes more fluent. The principals are the same, the methodologies follow the same steps, and hence the result is more coherent and complementary.

The AIA (The American Institute of Architects) Integrated Project Experiences in Collaboration, discloses the relation of the impact cost of the design in a conventional project or in an IPD project. The focus of this methodology lays in frontloading the work effort to the design phase, as shown in the Macleamy Curve (Fig. 1).

There are substantial differences when the effort in each phase of the design and the construction process in a traditional design methodology is compared with the process using the integrated design. As in the IPD the project is brought to a deeper level of detail, eventual changes to be made in the construction period will be significantly lower, which translates into a lower overall investment. On the other hand, the same benefit can also occurs in the Construction documents phase when using the IPD, thus any change in a conventional project involves a larger endeavour from the different disciplines involved to reach the final solution. In fact, in the IPD methodology the team of architects and engineers invest more time in the earlier phase where the design solutions and the detailed drawings have to be carefully defined. In this phase the design is coordinated within an integrated concept—each decision is articulated with the other members of the team. This method involves less cost if in this first phase any change in the design proposal has to be made, because the construction process is not getting started yet [3]. Also, as the IPD brings the project to a deeper level of detail, eventual changes in the construction period will be signifi-

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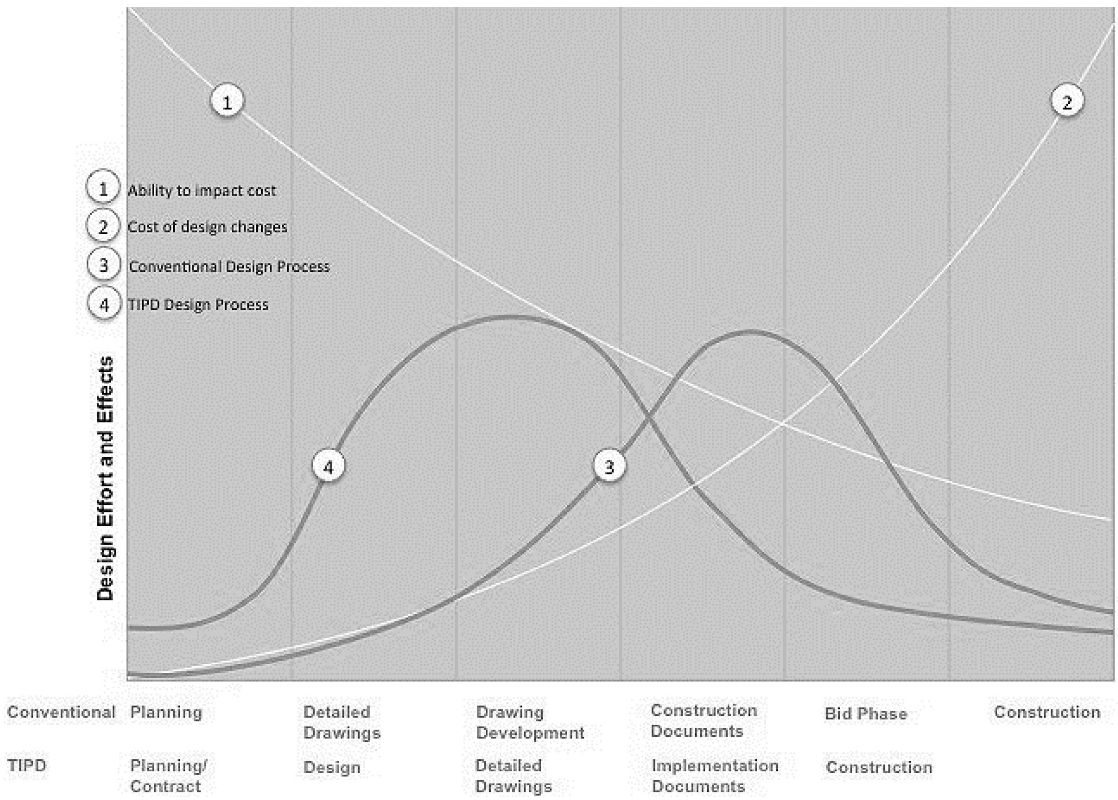


Fig. 1. Macleamy Curve [3].

cantly lower, which will translated into the mentioned lower overall investment. It is evident that as bigger is the effort to deeply define the project less problems one can have in the construction process [4].

However, information technology tools are insufficient to establish these relationships, so it is essential that future architects and engineers be aware of the importance of the decisions of others to substantiate their own solution. It is therefore inevitable that a huge methodological complicity among the various designers in finding a joint response could exist [5].

In recent years, in the Master Programme in Civil Engineering, important assignments have been showing to future engineers this (inevitable) common field of sustaining the Integrated Project Concept. Thanks to practical exercises based in real constructed buildings, students are stimulated to work as if they were in a professional studio [6]. They have to understand the complexity of decisions that have to be made in the different project stages. Using a hands-on approach, they realise the importance of the communication flow of those decisions between all members of the team, from the different backgrounds of civil engineer to architecture, building models to understand the structural systems of a constructed building [6].

2. Literature review

Recently, a transformation in teaching and learning methods in European universities has taken place, aiming at increasing active learning [7–9]. The transformation has been mainly driven by the creation of the new European Higher Education Area (EHEA) [10]. The model proposed by EHEA involves the transition from an education system based on teaching to a system based on learning, making the student the center of the educational process. The application of these new learning models particularly benefits engineering education, because training in engineering has an essential technical/practice component [9]. In particular, courses in the second cycle of graduation, which have a very technological and systematic nature, are more suited to implement active learning methods such as Project Based Learning (PBL) [11–14]. PBL enhances not only the students' acquisition of competences specific of each subject, but also the development of generic competences, such as communication, team work, leadership, etc., that are increasingly valued in the professional field [9].

The art of creating and developing a project in the Architecture, Engineering and Construction (AEC) industry is, in comparison with other industrial activities, very idiosyncratic and, in many aspects,

Table 1. Comparison between traditional project delivery and IPD [3]

Traditional Project Delivery TPD		Integrated Project Delivery IPD
Fragmented assembled on "just-as-needed" or "minimum-necessary" basis, strongly hierarchical: controlled.	**Teams**	An integrated team entity composed key project stakeholders, assembled early in the propose: open and collaborative.
Linear, distinct, segregated; knowledge gathered "just-as-needed"; information hoarded; silos of knowledge and expertise.	**Process**	Concurrent and multi-level; early contributions of knowledge and expertise; information openly shared; stakeholders trust and respect.
Individually managed, transferred to the greatest extent possible.	**Risk**	Collectively managed, appropriately shared.
Individually pursued; minimum effort for maximum return; (usually) first cost based.	**Compensation/ reward**	Team success tied to project success; value-based.
Paper-based, 2 dimensional, analog.	**Communications/ technology**	Digitally based, virtual; Building Information Modelling (3, 4 or 5 dimensional).
Encourage unilateral effort; allocate and transfer risk; no sharing.	**Agreements**	

the polar opposite [15]. The biggest indicator of this reality is the time-cost-dimension relation between project, execution and final product [15, 16].

Since there is no standard definition for the concept of Integrated Project Delivery, accepted by the whole industry, IPD is still used to describe significantly different contract arrangements and processes [17]. IPD is built on collaboration and encourages parties to focus on the project goals, rather than their own [3]. According to Ghassemi and Becerik-Gerber [18] the main characteristics that differentiate IPD from the traditional delivery methods are: a multi-party contract; early involvement of key participants; collaborative decision making and control; shared risks and rewards; liability waivers among key participants; jointly developed project goals. American Institute of Architects (AIA) has designed a table (Table 1) in order to list the mentioned differences more clearly.

3. Methodology implemented in civil engineering education (Porto—Portugal)

As said in the previous chapter, in the Master Programme in Civil Engineering, specifically in the Faculty of Engineering of the University of Porto (MIEC), important assignments have been showing to civil engineering students the inevitable common field of the Integrated Project Concept in the construction domain [19]. The objectives of the learning modules are focused both on learning the technical dimension integrating all the activity that takes place in engineering and architecture practices, developing their own critical and analytical ability. Students get the chance to assimilate the inevitability of the Integrated Project in the studio process development of any project. Whether in the theoretical or in the practical component of the programme, the language of architecture and engineering is gradually assimilated by students through the interpretation and investigation of constructive technologies, particularly, those associated with the structural systems. In the lectures of the Architecture course, the illustration of real cases from the history allows them to learn the design methodology as an integrated disciplinary project; and in practical classes, through the analysis of specific projects, the preparation of drawings and even model building, students are able to access the available work tools, from project design to construction process [20].

In this course, students understand that the design cannot definitely be a simple sequence of responses. By the contrary, from the initial sketches to the specifications of the various materials, they assimilate the design process as the result of a complex algorithm of the different responses of the various disciplines, the integrated design. The resolution of this algorithm, the design of the construction, lies in the common ground that underlies all the disciplines. Therefore, in determining the dimensions, the materials and the construction solutions, each member of the team must identify the solution that meets the requirements of each case study. The optimal solution corresponds to the weighting of the responses from each student [21].

From private buildings to public buildings, students learn, for example, that planning a museum, the designers cannot dimensioning the openings without knowing what is the ideal relationship between natural and artificial lighting. Architects/ designers cannot define the shape missing the acoustic technical implications that determine and "shape" the ideal volume for the interior space or design the finishing materials without knowing the desired degree of reverberation. Much less, scale the

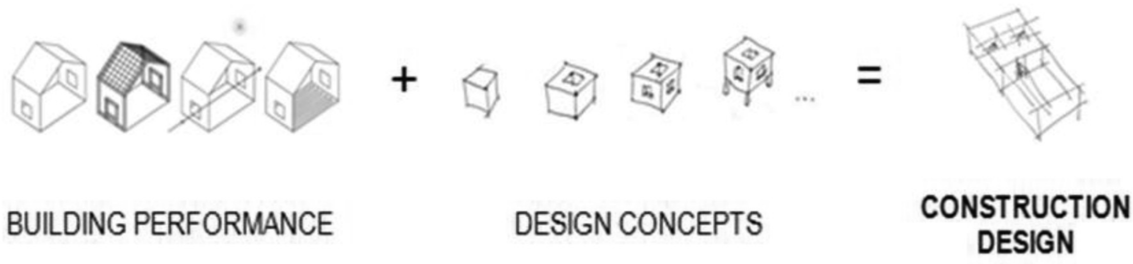


Fig. 2. Design Formula Scheme [21].

form without knowing the dimensions of the horizontal and vertical structural components needed to achieve a span of 15 m or 20 m. The final solution for the form, the spans, and the constitution of the envelope are therefore the result of the articulation of all these decisions. It is an algorithm that unites the optimal values of each discipline to find the suitable dimensions of the various components of the architectural form (Fig. 2) [6].

Since all the assignments are seeking the same answers to the same equation, the same dimensions, materials and construction solutions, it is essential that, from the beginning of their training, they understand the importance of the decisions of others to substantiate their own solutions. To be able to understand this multidisciplinary approach, they must all master/establish a common language: the design of the construction. For future architects, how the mathematical language of engineering translates into compositional elements of the construction [22]. For future engineers how construction translates into architectural language. Before learning how to deal with the numerous computer programmes that can articulate the different projects (BIM), one must show first of all that colour, lighting, natural ventilation, spatial organisation are measurable and assessable "material", to be worked in an integrated way with the goal of creating a single body, the integrated system (Fig. 3) [23].

These concepts are translated in the structure of some assignments of the Master Programme of Civil Engineering (MIEC) at FEUP. The objectives are focused both on learning the technical dimension integrating all the activity that takes place in the production of Architecture and Construction, and the development of the students' critical and analytical ability when it comes to architecture, encouraging them in their reading and basic grammatical interpretation. Whether in the theoretical or in the practical component of the architecture course of MIEC, the language of architecture and engineering is gradually assimilated by students through the interpretation and investigation of constructive technologies, particularly those associated with structural systems.

The technical formative objectives are:

- understanding architecture as a creative act and as a system of subsystems, as well as its role in the practice of building in Portugal;
- read/interpret architectural designs;
- professional articulation between civil engineers and architects; and
- the challenges of architecture and engineering in the context of new European regulatory requirements.

The critical formative objectives are:

- interpreting the historical evolution of architectural space, articulated with constructive and structural innovations in engineering; and
- define the professional skills required to work in multidisciplinary teams.

The expected skills and learning outcomes are:

- describe the main concepts;
- manipulate and interpret a building project;
- categorise the various conceptual and constructive solutions;

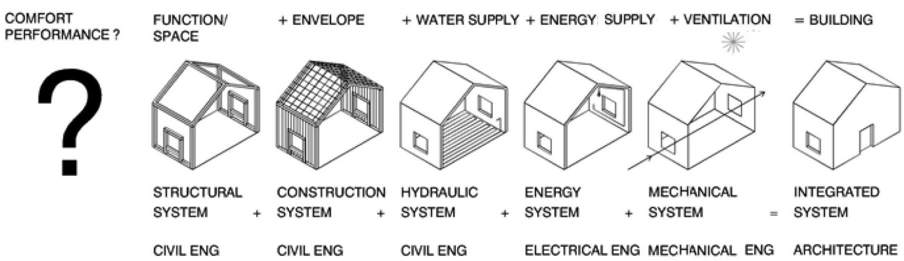


Fig. 3. Integrated Design Concept [21].

- compare and classify the results of different structural systems; and
- identify the common decisions between engineering specialties and architectural design.

Students are taught to understand how the choices made by each discipline at the various design stages and construction process can contribute to the functioning of the project team and even the performance efficiency of buildings. Different construction technologies imply specific design principals and rules. Different structural systems imply a different architectural design. In lectures, the approach of the history of architecture allows them to learn the design methodology as an integrated disciplinary project.

Considering that Civil Engineering students may go on in their careers to develop projects, particularly for buildings, such practice will involve the need to effectively articulate their solution with architects and other designers. It is therefore essential that during their training, students acquire the ability to read and interpret different projects, thus becoming acquainted with the specific language of technical representation drawings.

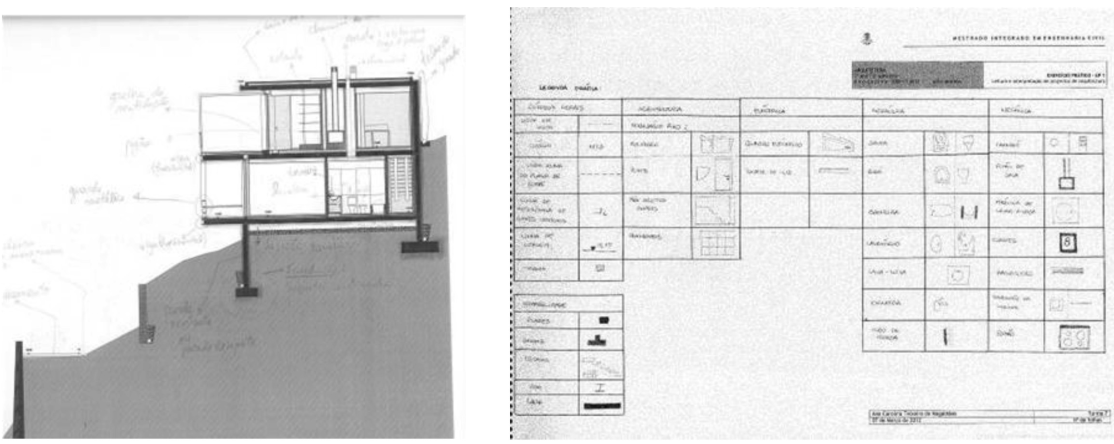
The students are given an introduction to the concepts of structure and composition, reflected in the context of standardised forms and spatial systems. In laboratory, through the analysis of specific projects, the preparation of drawings and even model building, students are able to access the work tools available, from project design to construction. Visiting real construction sites and talking with architects, engineers and other construction technicians, students get familiar with the design requirements and tools for this integrated project methodology.

In a first assignment, the general drawings of an architectural project being implemented are studied, focusing on its technical drawings, plans, sections and elevations. By analysing these drawings, the aim is that students assimilate the technical representation codes for the various architectural components (wall, floor or pavement slab, pillar, beam, load-bearing wall, roof, stairs, ramp, vault, lintel, arch, porch, etc.). After this interpretation, students are asked to organise this information in a subtitle graphic by project area (Fig. 4).

The aim of the second assignment consists in the reading and interpretation of an architectural design by the students focusing materializing it in the built work, by analysing the constructive system adopted, in order to gain an understanding of how the technological options determine the shape of the building. This exercise is conducted in group and individually.

Initially, each student reads the information provided alongside the drawings and pictures of the finished structure, supported by the drawings made to study the structure, the form and the space in the building. In the second phase, the group must organise research literature that complements the constructive analysis of the building. Using the information collected by each student, the group must prepare a new reading of the project pointing out the specific design solutions. The conclusions drawn from this analysis should be the point of departure for the group to make a model for the final presentation to the other students and teachers.

The aim of this phase is for the students to understand not only the potential that the development of the model offers for understanding the project, but also to have an approach to the constructive methodology of the system studied. The traditional construction techniques, analysed in the



a) Analyses of the architectural section. b) Subtitle graphic by project area.

Fig. 4. Categorized information according with different areas of engineering. Work developed by students at the Integrated Master in Civil Engineering (MIEC) 2012/2013.

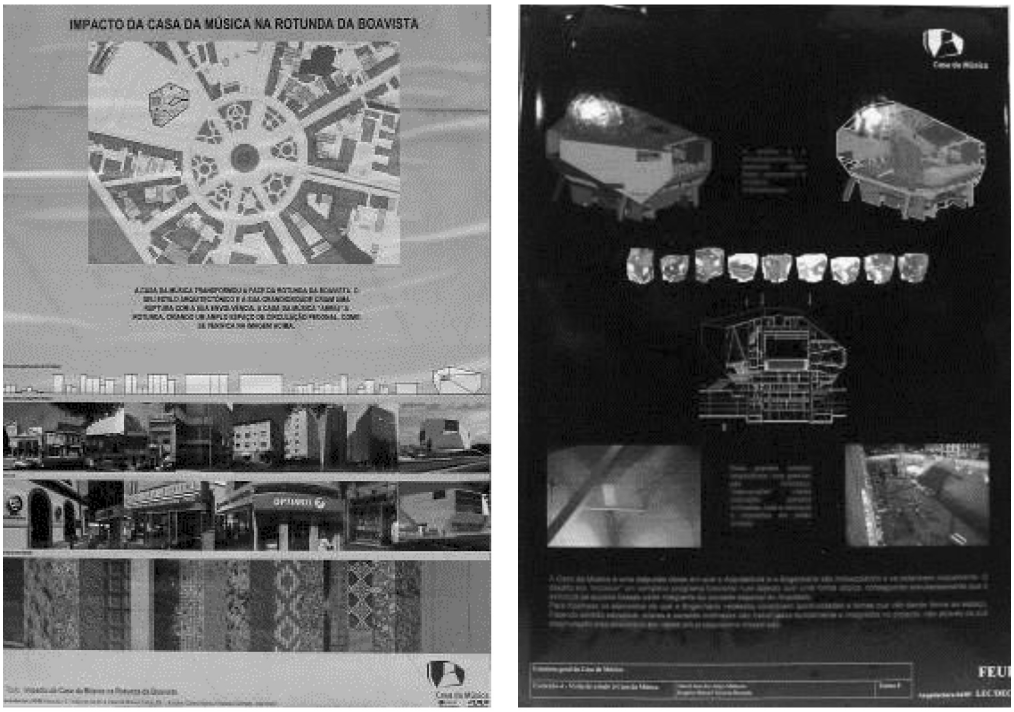
a) 3D Image of the Art Center of Guimarães. b) 3D Model of the cantilever.

Fig. 5. Models prepared by students at the MIEC 2013/2014.

seminars module are built in the laboratory classes. The second assignment entails the analyses of the design and construction process leading to 3D discretization—3D images and models prepared by students (Fig. 5).

The third assignment offers an approach to the real context of the design and construction process, through the analysis of a building that is completed or still under construction. This time, the aim is that students become able to interpret the architecture in the light of different disciplines of Civil Engineering such as: acoustics; thermal; fire safety; structure; HVAC; and hydraulic infrastructure. After the project interpretation a discussion with the design team is promoted: the architect, the project manager, the structural engineer or the mechanical engineer. In a conference organized under the architecture course, they explain their projects and particularities to the students. In this class, students have the opportunity to understand how the team and the coordination between them work in order to achieve the integrated design. Then, after the conference, the designers make a guided tour of the building with the students. The third assignment entails the analyses of the design and construction process resulting in 2D organized information (posters)—Porto Music House, as an example of the studies carried out by MIEC's students (Fig. 6).

Back in the classroom, the group interprets the work according to one of the engineering disciplines, looking for the rules that this discipline has imposed on the building design, on its functional



a) Analyses of the construction materials. b) Analyses of the structure.

Fig. 6. Posters made by students at the MIEC 2011/2012.

and programmatic definition, on the spatial and dimensional definition, on its performance and construction.

At the end of each semester, a public exhibition of all the work done by the students is held in the Department of Civil Engineering. It is an important opportunity to show the academic community and future students of the course the potential of this interdisciplinary process between the various factors involved in the construction field, the positive outcome of the joint methodology for designing a building—the integrated design project.

4. Results obtained in civil engineering education (Porto—Portugal)

The implementation of PBL in the architecture course establishes the connection between the various units of the civil engineering programme. The teachers treasure complementarity on a multidisciplinary course and students find it easier to absorb knowledge and to understand the practice of the future profession.

It is given to students a variety of matters present in the construction process. The overview of civil engineering is essential for the comprehension of the whole process. Integrated project in project based learning gives the students important tools, such as: the ability to set attainable goals; organizational skills; concentration and motivation; and commitment.

The expected benefits of the implementation of the described methodology are engaging: critical thinking; problem solving; communication skill; collaboration; innovation; and creativity.

The graphic presented in the next figure (Fig. 7) shows the results obtained each year, between 2008/09 and 2012/13, by the students in the architecture course of 1st cycle of the FEUP's master programme—MIEC, where the PBL was implemented in 2010/11. Between 2010/11 and 2013 some improvements were made till the actual methodology previously presented (see §.3).

The number of students assisting that assignment (the architecture course) is more or less stable each year, approximately 200 students. As shown in Fig. 7, the average results increased since the implementation of the PBL, in 2010/11. The average rate, in a scale from 0 to 20, was 13.06 in 2008/09 and, in the academic year of 2012/13, the average reached 14.07. The improvement in the ability to acquire knowledge is visible in the final grade increase. Considering the scale from 0 to 20, the higher grade was 16 in the years before de implementation of the PBL (2008/09 and 2009/10) and the in the following years the higher grades registered was 17 and 18. Since the implementation of the PBL, in 2010/11, the student's results are becoming better. The percentage of unapproved students decreased and the rates are higher, contributing to the increasing of the average rate.

It can be also said that this assignment became more attractive and interest. Student's opinion about this methodology is absolutely positive. Even the motivation for developing extra homework became higher due to students' initiative and commitment.

5. Discussion

Architects and engineers were learned to discover the secrets of construction during periods of work experience. The ideas that were studied in the office were fine-tuned with the craftsmen who were doing the building. Construction was learned on site. However, this knowledge of construction, by getting their hands dirty, is no longer possible. There is no longer sufficient time nor construction sites to

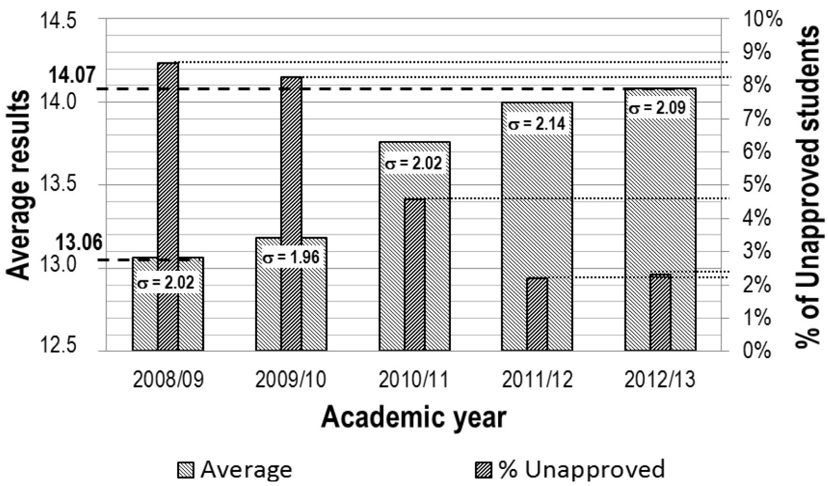


Fig. 7. Course results summary: average results and % of unapproved students.

ensure that future engineers and architects gain experience on the ground, both must be shown the importance of the decisions of other disciplines for the consistency of the solution that each presents. The participants in the design process must be aware from early on that each of their projects will be part of a unique solution in building an integrated project. It is time to look at the design of construction as a total solution bringing together various disciplines, to adopt a design methodology that can articulate the necessary information between them. This teaching methodology jointly seeks the solution to the design equation.

This article presented a case study where the application of PBL in Master Programme of Civil Engineering (MIEC—FEUP) was applied and observed. It can be said that PBL enhances the students' acquisition of competences specifically related with each subject, student's motivation, team collaborative work, leadership, student's communication skills and other important abilities that will increasingly worth their future professional practice. However, some limitations can be underlined such as the time required to gradually guarantee a better implementation rhythm of the PBL and the adequacy of the work progress (the phase of the construction work) of the buildings available to visiting in relation to the academic calendar.

6. Conclusions

Master Programme of Civil Engineering of the University of Porto (MIEC—FEUP), some important assignments have been recently introduced the Integrated Project, Project Based Learning (PBL).

The objectives were focused both on learning the technical dimension integrating all the activity that takes place in the production of Architecture and Construction, and the development of the students' critical and analytical ability when it comes to architecture, encouraging them in their reading and basic grammatical interpretation.

According to the performed study the following conclusions can be reached:

- Students acquire the ability to read and interpret different projects, thus becoming acquainted with the specific language of technical representation drawings.
- Students appreciate not only the potential that the development of the model offers for the understanding of the project, but also the approach to the constructive methodology of the system studied.
- Integrated project in project based learning gives the students important tools, such as: the ability to set attainable goals; organizational skills; concentration and motivation and commitment.
- The expected benefits of the implementation of the described methodology are engaging: critical thinking; problem solving; communication; collaboration; innovation and creativity.
- Since the implementation of the PBL, in 2010, the student's results are becoming better. The percentage of approved students is kept stable however the rates are higher, contributing to the increasing of the average results.
- The assignment became more attractive and interest. Student's opinion about this methodology is absolutely positive. Even the motivation for developing extra homework became higher not because of professors demanding but taking into consideration the commitment and students dedication.

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