BIM and IPD as vehicle in the teaching and learning process of Project delivery in civil engineering

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Abstract

The spreading of the Integrated Project Delivery (IPD) has involved new concepts in the management of construction projects generating a new demand for trained professionals with deep understanding of their principles and collaborative skills. In this order of ideas, a query arises as a non-negligible concern about how to teach and prepare students for this challenge. This paper presents a teaching and learning proposal for project development in the subject of final design project (8th-semester civil engineering - Universidad de los Andes), through the adoption of integrated project delivery (IPD) principles for their professional development through the project-based learning (PBL) methodology in accordance with the needs of the industry. The main objective of the course is to promote the professional and personal skills needed to thoroughly develop a design project, in order to solve a tangible social need identified in the municipalities and communities across the country and aligned with their development plans. It is a requirement that the students explicitly and holistically frame their project under the three dimensions of sustainability: social, economic and environmental, and the project has to be ambitious enough so that it can involve all areas of the Civil Engineering program. The students develop and deliver the project in the real phases of the design lifecycle of an integrated civil project during the course: conceptual project, basic project, project draft, design project and the final deliverable which includes a complete and detailed descriptive-constructive memory, a complete design memory of all systems, the financial viability and construction schedule established to a high level of precision and a 3D BIM model with complete details. Students often take a step further and perform 4D and 5D simulations, as well as virtual reality applications. As a result, the students recognize the value of this methodology that allows a full rapprochement to a real world situation with innovative solutions and multidisciplinary teams.

Keywords: Teaching and learning process, Action Learning, Integrated Project Delivery (IPD), Problem-Based Learning (PBL), Building Information Modelling (BIM), Lean Construction.

1 INTRODUCTION

The Architecture, Engineering and Construction (AEC) industry demands graduates with practical experience in real projects, in such way that the learning process through experiencing has become one of the most important objectives for professors, which directly benefits students education (Efstratia, 2014).

In the last century, new educational methodologies have been developed in the process of teaching and learning to apply some kind of empirical or experimental philosophy which allows students to understand their own progress in terms of general and individual performance, self-organized work and competencies (Enke , et al., 2015). In this line, the Project Based Learning (PBL) methodology arises to improve the quality of the education in order to produce innovative individuals with ethical principles and capacity of critically thinking.

The core idea of PBL is that real-world problems capture the student's interest in acquiring and applying new knowledge in a problem-solving context (David, 2008). PBL encourages the motivation of the students, generating an environment of collaboration and active learning, as well as developing problem-solving and group-working skills with innovative solutions, improving the competitiveness of the graduates on a global market. However, construction projects have become increasingly complex and specialized which are developed in real environments by segregated processes that can cause high levels of fragmentation and inefficiency, and high costs of inadequate interoperability (Kent & Becerik-Gerber, 2010).

To deal with the fragmentation and inefficiency on the traditional project delivering systems, new complimentary tools, methodologies, and philosophies, have arisen in the academic and industrial

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environment as Lean Construction (LC), the Integrated Project Delivery (IPD) and Building Information Modelling (BIM).

Recently developed trends, such as Lean and Integrated Project Delivery (IPD) aim to address the issue of mistrust by creating an environment of mutual trust and respect (Pishdad-Bozorgi & Beliveau, 2016). On one hand, IPD can be defined as “a project delivery approach that integrates people, systems, business structures, and practices into a process that collaboratively harnesses the talents and insights of all project participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction” (AIA California Council, 2007) and does so by aligning the incentives and goals of the project team through shared risk and reward, early involvement of all parties, and a multiparty agreements. Finally, BIM is argued to be the catalyst for the integration of product and process modelling, to radically improve collaboration among the wide-ranging and expertise needed to design and construct a building and to increase efficiency, generating a “methodology to manage the essential building design and project data in digital format throughout the building's life-cycle” (Penttilä, 2006).

BIM is the principal tool to support the IPD approach due to its ability to combine, among other things, the design, fabrication information, erection instructions, and project management logistics in one database, that is to say that like IPD, it provides a platform for collaboration throughout the project’s design and construction (AIA California Council, 2007).

At the Universidad de los Andes, the Department of Civil and Environmental Engineering offers a course of last year undergraduate program, called “Final Design Project” that was created to respond to the need for building competencies in the students, as well as to comply with industry demand. In this course, lecturers promote to students in the developing of a real project under the Colombian context, applying IPD methodology enhanced with BIM tools and, applying a PBL training process for real world problems under the three pillars of social, environmental and financial sustainability.

The student body proposes the project course earlier before the teaching-learning process begins, in contrast from the conventional teaching method whereby the problems are given at the end of each section being taught in the classroom (Ahmad Basri, et al., 2012). Students have autonomy in their learning process and in the development of the project along the course, because the teacher plays the role of facilitator working with them to frame worthwhile questions, structuring meaningful tasks, coaching both knowledge development and social skills, and carefully assessing what students have learned from the experience (David , 2008).

PBL has been applied in various disciplines including business, education, architecture, law, engineering and social work (Savery & Duffy, 1995), but, to the best of the authors’ knowledge, the reviewed literature does not include works about PBL methodology improved with BIM and IPD. For that reason, the principle objective of this paper is to present and analyze a course proposal for enhancing the adoption of lean and integrated project delivery (IPD) principles to university students in their academic and professional development through the project-based learning (PBL) methodology in order to justify that this approach significantly improves the student experience and learning process, and at the end develops the intended professional competencies of the graduates.

The remaining of this paper is organized as follows: First, a conceptual framework is carried out on the PBL in higher education, the IPD and BIM concepts and explicitly implementation for education. Then, the proposed course methodology is described with the deliverables in the differents phases. After, the results and continuous improvement process are disclosed with the objective of corroborating the expectations and experiences of the students, and finally, conclusions and recommendations are drafted.

2 THE PROJECT BASED LEARNING (PBL) METHODOLOGY

The PBL methodology grows out of the need to promote the autonomy and self-propelled of the students, being defined as an activity in which students develops an understanding of a topic or issue through some kind of involvement in an actual real-life problem in which they have some degree of responsibility the learning process. That is to say, the student has some freedom in designing his own learning activities, boosting the learning through experience, in which the instructor helps the student to learn how to formulate problems, find answers and evaluate his progress himself (Dixon & Taylor, 1979).

Moreover, the PBL is an innovate strategy for problems that cannot be solved by applying a technical solution alone. The introducing and integrating of non-technical aspects of problems requires innovative approaches to handling sustainability-related problems, the education needs to allow for interplay, mix and diversity, which are aspects that can be achieved with PBL (Lehmann, et al., 2008). Furthermore, the PBL application on sustainable development encourages the interdisciplinary work as well as the opportunities and challenges inherent in involving students in authentic research with communities (social impact); this means that students can solve wicked sustainability problems in the real world.

In recent years, the PBL has become an important methodology learning for the introduction to engineering design and professional practice (Palmer & Hall, 2011); especially in civil engineering for the simple reason that this industry demands interdisciplinary working groups and different emphasis. One of the facts that verifies the success of this methodology is the integration of core construction curriculum subject matter (scheduling, estimating, controls, and contracts) (Barlow, 2011), it reflects the perceptions and opinions of students that demonstrated satisfaction because key skills required by industry, namely, group work, time management and the development of technical competence, were enhanced. Summary, the students perceived that the main positive elements of the PBL process were the application of design skills, teamwork and the development of their teamwork and communication skills in the context of real-world design problems (Gavin, 2011).

The research shows that PBL answers to the challenges of engineering education that require approaches that promote scientific, technical, design and complementary skills while fostering autonomy, innovation and responsibility (Malheiro , et al., 2015). Nowadays, this methodology has a positive impact on the students' learning of course concepts allowing them to apply theoretical knowledge in solving real-world problems. This research takes a step further and relates PBL and project management methodologies partially filling the gap identified by Kanigolla, et al. (2015).

3 THE INTEGRATED PROJECT DELIVERY (IPD) AND BUILDING INFORMATION MODELLING (BIM)

Current practices and integration trends were increasing the demand for the implementation and deployment of integrated project delivery systems aligning the incentives and goals of the project team through shared risk and reward, early involvement, and multiparty agreement (Kent & Becerik-Gerber, 2010). The IPD emerged as a new model-based design that aims for the collaboration between the architect, consultants and general contractor with the integration of sustainability in the projects (Ku, 2009). The American Institute of Architects (2007) defines eight Principles of IPD that enhance trust-based collaboration: Mutual Respect and Trust, Mutual Benefit and Reward, Collaborative Innovation and Decision Making, Early Involvement of Key Participants, Early Goal Definition, Intensified Planning, Open Communication, Appropriate Technology, Organization and Leadership.

Also in this decade, the theory about technology-supported collaboration arise with the first implementation of BIM in projects like a complement of the IPD methodology in a sense that the continued growth of BIM has promoted new contractual arrangements (Dossick, et al., 2009). The. BIM allow professionals to deal with a rapid pace of technological change, a highly interconnected world, and with complex problems that require multidisciplinary solutions. Moreover, "to ensure interoperability among different software, building SMART developed a neutral object-oriented data model called Industry Foundation Classes -IFC- that facilitates the exchange of information among compatible" (Prada-Hernández, et al., 2015), and even when there is still room for improvement, BIM stands as a tool to enhance IPD across the lifecycle of a project.

Currently, academics are beginning to realize that educating our future engineers in BIM and IPD, as collaborative and design approach, needs to be a forerunner of education with sustainability topics (Oswald Beiler & Evans, 2015).

4 COURSE METHODOLOGY

Final Design Project is a course of the last year civil engineering program at *Universidad de los Andes*. The methodology of the course involves a mixed educational system of individual and group work based on a single project using active and collaborative methodologies. The differentiated point is the autonomy the students develop, as they become the protagonists of their own learning while the teachers have the role of advisors and counsellors of the process throughout the course.

In fact, following the main principles of PBL and with the aim to enhancement of self-dependence of the students (Lasauskiene & Rauduvaite, 2015), the process in the course starts with a conceptual idea and goals and finishes with a detailed design that includes a complete and detailed descriptive-constructive memory, a complete design memory of all systems, the financial viability and construction schedule established to a high level of precision and a 3D BIM model with complete details. Students often take a step further and perform 4D and 5D simulations, as well as virtual reality applications.

The workgroup has the obligation to use innovative technologies, starting with BIM to model, simulate the project accurately, and enhance collaboration and teamwork. From the start, all the work teams materialize the conceptualization of the project in 3D models using the massing tool of different software, which are fed with information of all designers groups. The students develop and deliver the project in the first phases of the lifecycle of an integrated civil project during the course, as shown in Figure 1.

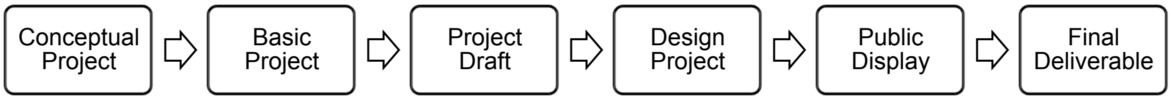

Figure 1. Deliverables of all phases of the project.

Previous to the final deliverable, students have to perform a public Display in InnovAndes fair organized by the Faculty of Engineering at Universidad de los Andes, where they have to step out of the technical aspects of their designs and translate them into valuable information anyone can understand, focusing on the sustainability issues of their deliverables, innovations in their proposals and value added by appropriated technology.

Focusing on the implementation of BIM, the workgroups encourage the model across all phases of the project. Considering the definition of the “Level of Development (LOD) Specification, that is a reference that enables practitioners in the AEC Industry to specify and articulate with a high degree of clarify that content and reliability of Building Information Models (BIMS) at various stages in the design and construction process” (BIMForum, 2015), the students develop the LOD on all phases as can be seen in Figure 2. This is a clear example of how this methodology provides opportunities for deep learning and introduces the student to resources and skills necessary for life-long learning (Gavin, 2011) because in the industry the LOD is the basis for built the legal contracts of the project contractors,

Throughout the process, teachers serve as guidance in the process and experts on each specific topic of the student’s selected projects are often invited to give a conference and are available for the students that seek their guidance. In addition, a BIM module is taught over the semester, making special emphasis in the tools they will most likely need given the project that is being developed.

The course proposal is completely aligned with IPD principles, as all the group members are encouraged to promote a trust-based collaboration from the start and throughout the semester, working in a collaborative environment regardless of the specific role each of them plays in the project. A mutual benefit and reward are promoted because the evaluation is based only on the group performance as a whole and not on each individual technical area. Collaborative Innovation and Decision Making is enforced with a competitive environment as all groups in each semester develop a project to solve the same tangible need. Early goal definition intensified planning, open communication and organization and leadership are stimulated from day one in each group and taken into account when grading each deliverable. Finally, appropriate technology is used for the integral development of their deliverables with BIM as the catalyzer of all previous items.

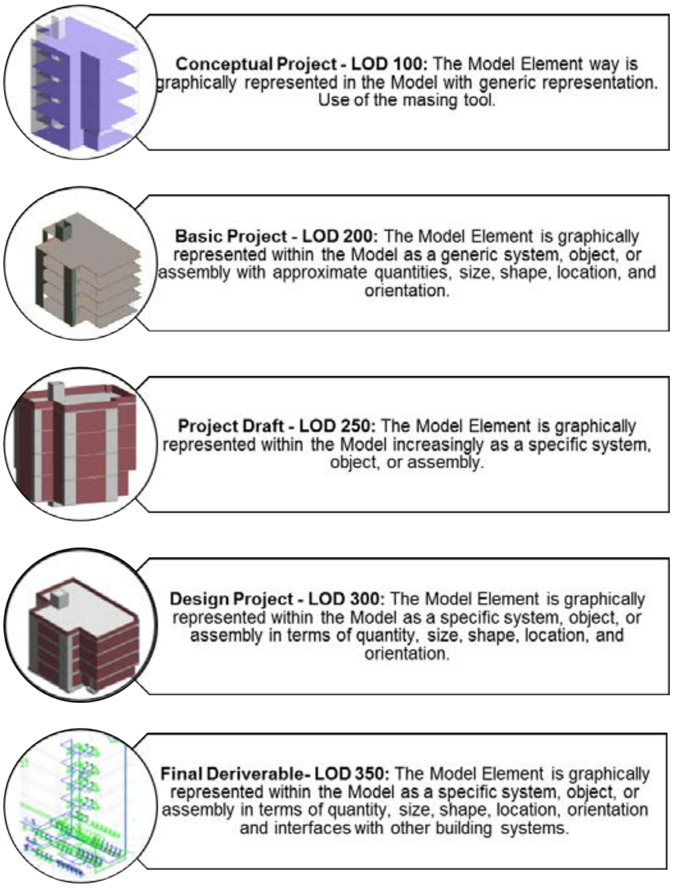

Figure 2. LOD across all phases of the project Definitions by (BIMForum, 2015).

The main objective of the course is to promote the development of the skills needed to thoroughly develop a design project in order to solve a tangible social need identified in the municipalities and communities across the country and aligned with their development plans. It is a requirement that the students explicitly and holistically frame their project under the three dimensions of sustainability: social, economic and environmental, and the project has to be ambitious enough so that it can involve all areas of the Civil Engineering program. Figure 3 shows a diagram of the course fundamental requirements.

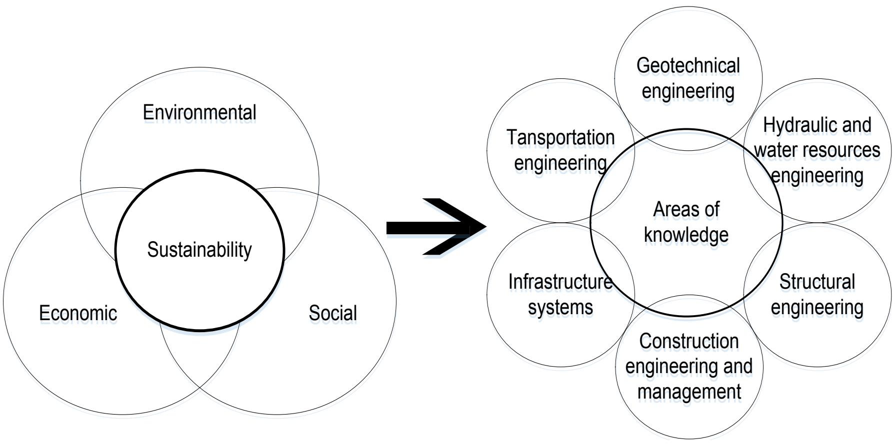

Figure 3. Course fundamental requirements.

In this order of ideas, inside the workgroup, thanks to the holistic forces and the complexity of the project, a role-playing is generated, in such way that the students choose an area of civil engineering that responds to their preferences and skills. On the other hand, there are others roles, not explicit, related with the develop higher-level cognitive skills, autonomy and self-direction which are the principal skills that promote PBL methodology. Taking in mind that with IPD all Primary Team Members (PTM) are responsible for all provisions of the prime contract with the client (Matthews & Howell, 2005), that is to say, the priority of all team members is the global objective and performance of the project, not the deliverables of each area of knowledge. In this order of ideas, the PTM share the risk and profit for total project performance (Matthews & Howell, 2005).

In addition to the technical and specific skills of the different areas, the course aims to develop interpersonal skills through the acquisition of a set of basic competencies to respond to the complex demands of industry, allowing them to make decisions in a collaborative manner with autonomy and responsibility in the labor and social environment of competitiveness in which the students are called to act.

The course is evaluated in two stages: (1) group performance evaluation given by the teachers, undergraduate and postgraduate teaching assistants and relevant external evaluators, and (2) a peer-and-self review. The first process is performed for all deliverables and is based in the overall continuous work performed by the group, the technical aspects of the written product and the accomplishments noticed during an oral presentation. The peer-and-self review itself has two components. The first one is a confidential evaluation of the individual performance of other team members in terms of their commitment, attitude, availability, collaboration, teamwork skills, proactivity and tasks fulfilment. The students grade their mates on a discrete scale from one (1) to four (4). The second is the “Plus-Delta” approach executed by all the class and conducted for each deliverable in order to get feedback on the methodology of the course and to design changes that increase student satisfaction and quality of the work. In this space, all students expose the positive points of the course that need to be encouraged (+) and the points that can be improved (Δ).

This course is ultimately a research environment as students understand from day one that the knowledge they have until now is only good to get started but that if they want to stand out from the rest of the groups they need to investigate and learn on their own.

5 RESULTS AND CONTINUOUS IMPROVEMENT PROCESS

This course has achieved that the students applied all the knowledge learning across the career in a real problem, which they perceived and propose the design of the solution. The solution involves all the designs of each area of the civil engineering under the three pillars, the above have been accomplished thanks to the implementation of the approach IPD and PBL, where the students are autonomous of itself learning and process. With the aim of managing the knowledge every semester, a review of the opinions and expectations of the students is made that is explained below.

The value engineering (VE) (Matthews & Howell, 2005) of the project developed by the students is that since the beginning they establish the scope and objectives of the project and how each PTM can contribute to achieving it, the VE begin to increase across the phases thanks to the cooperation, innovation and coordination of each area in a BIM Model and using tool as “Scrum” of the agile methodologies.

One of the most important principles of IPD, the continuous improvement, is a key factor to have a positive impact on building a mutual trust and respect for the collaborative mindset and culture inside the group (Pishdad-Bozorgi & Beliveau, 2016) (See Figure 4). With the goal of promoting system-based trust through peer performance feedback in the final design project course undergoes a thorough continuous improvement process that involves the teaching staff and the students. The information gathered corresponds to student performance and level of learning as well as aspects of the course, the methodology, the professor or the student’s that have room for improvement. This process feeds from 3 principal sources of information: (1) final deliverable performance, (2) student satisfaction, the level of learning and competencies development surveys, and (3) plus delta approach after every deliverable.

Figure 4. (Left) Collaborative work for the decision making.
(Right) Responsibilities and Commitments Management.

Final deliverable process is currently graded in four main aspects: (a) technical quality for each civil engineering areas of knowledge, (b) sustainability aspects integrated in the project (environmental, social and economic), (c) overall quality of project graphical and written documentation, and (d) quality of oral presentation.

Before the implementation of this strategy, course projects were presented based on a specific area of knowledge, and each group focused mainly on the technical aspects of their specific designs, leaving behind all other aspects of integration and sustainability. Moreover, lack of BIM tools usage also prevented the students had achieved a thorough understanding of the effect of working in a collaborative and multidisciplinary projects. Additionally, the level of innovation was limited to what the students have learned in previous courses and final documentation was poor due to the lack of proper background on graphical aspects, as well as failure to use advanced software and integrated approaches. Figure 4. (Left) shows an example of a project of the first semester of 2014, where students only focused on the structural design and the best documentation that was produced was a 3d model of the structural analysis software and a very limited 2D CAD plane.

Due to the shortcomings identified, current practices allow students to fully engage closed to real world situations, where multidisciplinary teams have to work together for a unique goal. Projects now involve a great scope in big groups (10+) and, because the use of an integrated approach is enforced, BIM-based projects are generated with the same rigor in the technical aspects of each area and the added value of an integrated parametric model that allows students to present their graphical and written documentation more rigorously (see Figure 5). Furthermore, the competitive aspects of the course encourage students to develop innovative solutions as well as to use state of the art technology and in-house developed software (Ponz-Tienda, et al., 2015) in order to stand out from the rest; this has resulted in advances towards virtual reality, 4D and 5D BIM simulations. The project is shown in Figure 6. (Right) presents an example of such advances that all technical aspects are covered but the deliverable is not limited to specific design but it involves the whole lifecycle of the project prior to the construction phase.

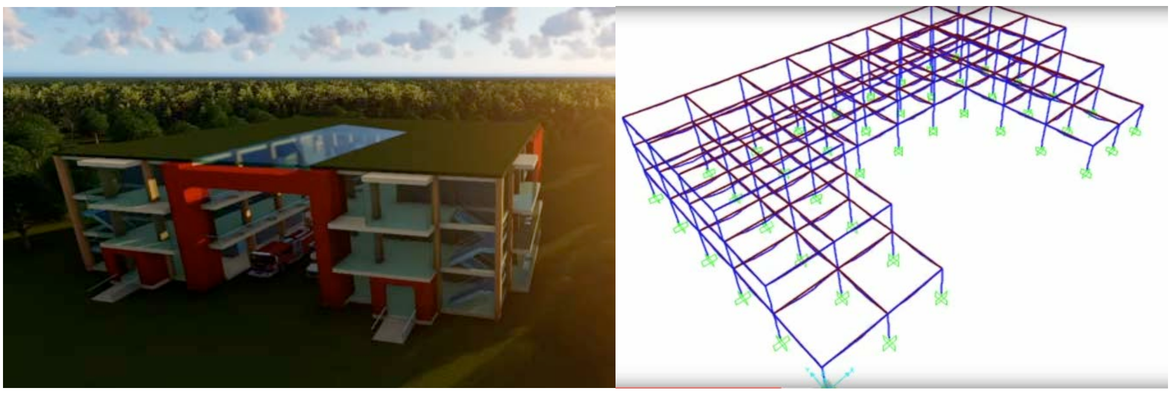

Figure 5. (Left) Fire Station Project. (Right) The analytical model of the Fire Station
for the Structural Analysis.

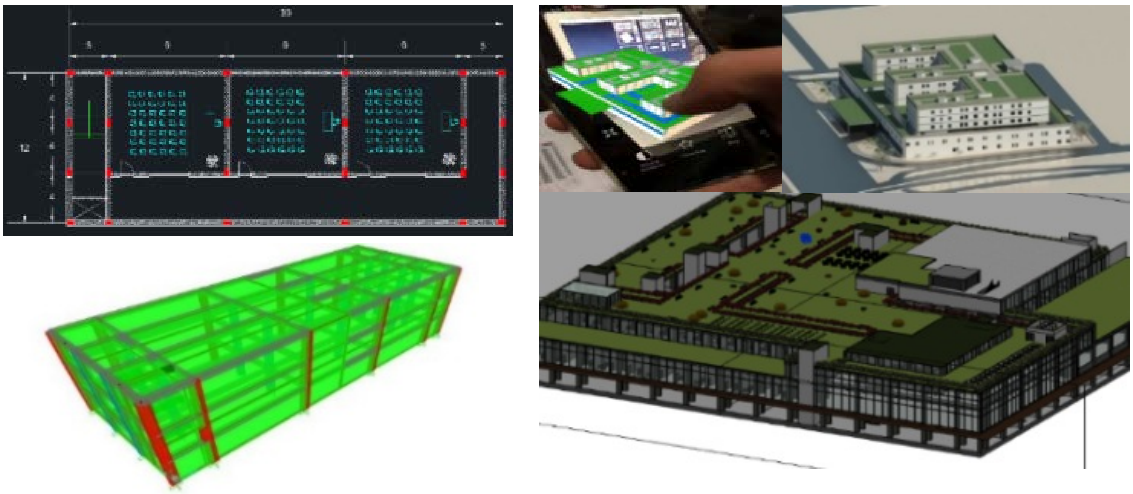

Figure 6. (Left) School project focused only in the structural design. (Right) Hospital fully implemented in Revit and usage of augmented reality tools.

In order to understand the level of learning and development of competencies, a questionnaire consisting of 14 questions is always performed at the end of each semester. The response rate is between 80 and 90% each period. The number of students enrolled in the course ranges from 70 to 90 students. A total of 448 answers are computed over the course of last 7 periods. Questions are intended to understand what sort of skills are developed in students, regardless of the objectives of the course and to what extent they are enforced. As it turns out, from the 11 student outcomes proposed by the ABET accreditation (ABET 2014) students feel that the following skills[1] are developed: (a) apply knowledge mathematics, science, and engineering, (c) design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability, (d) function on multidisciplinary teams, (e) identify, formulate, and solve engineering problems, (f) professional and ethical responsibility, (g) communicate effectively, (h) broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context, (i) recognition of the need for, and an ability to engage in life-long learning, (k) use the techniques, skills, and modern engineering tools necessary for engineering practice. This information is used semester to semester to understand what the course is failing to accomplish and propose new solutions.

The Plus Delta approach is a complimentary tool that allows the teaching staff to gain direct insight into the student feelings towards the course and their proposed improvements. This has been implemented after each deliverable and often result in significant changes for the next periods. For instance, in the first period of 2015, students suggested that large groups could enhance their learning, also, that there should be constant conferences with experts in each area. These changes are now fully implemented. In addition, side provides insight into the strong points of the teaching staff and the methodology and allows the enhancement of some of them. Future changes will be to integrate this class with one of the Architecture programs in order to enhance project initial definition.

6 CONCLUSIONS AND RECOMMENDATIONS

This paper presents a novel university course proposal for enhancing the adoption of Lean construction and integrated project delivery (IPD) principles to university students in their academic and professional development through the project-based learning (PBL) methodology. Thanks to the use of the IPD approach the project objectives can be aligned with the interests of each area of knowledge because since the beginning there is an agreement in the decision making to analyze the different alternatives for the design of the solution. In addition, all the areas are coordinated under the objectives of the three pillars of sustainability due to the commitments and arrangements established in the first phases.

[1] Letters in parenthesis refer to the letter of the ABET proposed student outcomes.

Since this approach was set in motion in the second semester of 2014, an evidenced development of collaboration, teamwork and leadership skills has allowed student groups to reduce variability and waste in their design process as well as to improve their deliverables in terms of customer value added. Moreover, the project is defined and coordinated to a much higher level prior to construction with a differentiator point of continuous improvement through evaluation among students and the constant evaluation of the methodology of work to finally know that you can improve and that plan follow.

The continuous improvement process allows students to develop abilities of collaboration and feedback and allow the course to keep updated and in line with the idiosyncrasy of the university as well as with the teaching objectives. Nevertheless, even when there is a significant improvement over the years, an overall lack of expertise in architectural design and practical engineering as well as in graphical skills, prevent students from achieving a higher level of performance. A similar limiting is that some students are not qualified to perform designs, as they have not yet taken the respective course. This has been corrected by modifying the prerequisites in the student curriculum.

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