SENDA MATRIX SOFTWARE AS A CONTROL AND PLANNING TOOL FOR PROJECT DELIVERY IN CIVIL ENGINEERING

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Abstract

This work presents the use of Senda Matrix software as a control and planning tool for project development. Eighth semester civil engineering students in Universidad de los Andes develop a real engineering project through each of its design stages, in a subject called Final Design Project. As a requirement, the project to be delivered has to involve all areas of the Civil Engineering program. As teaching and learning instruments, integrated project delivery (IPD), Lean Construction and project based learning (PBL) are used, through the adoption of some tools as last planner system (LPS), percent plan complete (PCC) and pull management among others. The main objective of these implementation is that students achieve a better control and reduce variability in the development of each phase of the project by applying a cascade planning. This article explains how students use the Senda Matrix software, implemented with Visual Basic for Excel, as a control and planning tool, which assists the construction of the master and phase schedule, the look ahead schedule and the weekly work plans, obtained from different pull sessions. With this software, students manage their work group and the development of the project based on the principles and techniques of Lean Construction.

Keywords: Last Planner System (LPS), Lean Construction, Integrated Project Delivery (IPD), Project Based Learning (PBL).

1 INTRODUCTION

Day after day, complexity and uncertainty increase in construction projects. For this reason, the industry needs to find new methods and management tools to optimize resources and meet the demands under which the project is harmonized. Managers are expected to be able to increase productivity, reduce cost and to ensure quality. The construction industry demands the training of professionals with practical experience in real projects, in such way that experience as a learning process has become one of the most important goals for professors; which directly benefits students' education [1].

Project Based Learning (PBL) is one of the most relevant and commonly used teaching and learning methodology based on the empirical and experimental philosophy. The core idea of PBL is that real-world problems capture students' interest in acquiring and applying new knowledge in a problem-solving context [2]. The principle is that students are responsible for their own learning and the professor plays a facilitator or accompanist role. Consequently, the application of PBL has become an important tool in the introduction to engineering design and professional practice [3] and thanks to its integration with other methodologies, students can be involved in real problems and scenarios.

Specifically, in civil engineering, the PBL has been integrated with both Integrated Project Delivery (IPD) and Building Information Modeling (BIM), aiming to implicate the student in workgroup problems. This integration starts in the initial stages of the project and lasts from the ideas conceptualization to the problem-solving outcome. Students adopt roles from different disciplines, and in that way, they engage in the whole design process and get to materialize their ideas in real models in order to achieve the correct design. Therefore, the IPD application is very useful, because it seeks collaborative decision-making and control by promoting a multiparty agreement among key participants [4]. By encouraging the early involvement of all parties, IPD enables proactive contribution of contractors' knowledge and experience to design development [5].

Parallel with IPD, BIM arose as a technology-supported collaboration that allows professionals to deal with a rapid pace of technological change, a highly interconnected world, and with complex problems that require multidisciplinary solutions [6]. In fact, BIM fosters the real-time information flow between the actors and the different design groups. In addition, it facilitates the decision-making across all the

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stages of the project. Hand in hand with these methodologies Lean Construction appears, to recall the importance of productivity. As in the industry, construction management academic programs have steadily incorporated these key trends within their curriculums [7]. Many techniques of Lean Construction allow the students to understand the Lean principles and how their application can bring enormous benefits to project results by means of reducing waste and increasing value.

With this paradigm change in the teaching and learning process in mind, this study shows the implementation of a free access software Senda Matrix with the aim to facilitate the application of Lean construction, more specifically, Last Planner System (LPS) in the projects delivered in a course based on the PBL and IPD philosophies. This experience took place in a course of the last year civil engineering program at *Universidad de los Andes, Colombia,* considering an average of 60 students per semester. This methodology has been implemented since the first semester of 2015.

Hereunder, a review of the Lean Construction and LPS basic concepts is presented followed by an explanation of the course methodology and a description oft how the Senda Matrix software is implemented. Finally, some obtained results and conclusions are presented as a case that can be applied at academic and industrial levels.

2 LEAN CONSTRUCTION AND LAST PLANNER SYSTEM

Lean Construction can be understood as a new paradigm for project management [8] derived from the application and adaptation of the underlying concepts and principles of the Toyota Production System (TPS) to construction. As in the TPS, the focus in lean construction is on waste reduction, value increase for the customer, and continuous improvement [9]. Many authors have included concepts of the manufacturing industry to the construction industry, for example, Koskela [10] introduced a holistic view of construction as an information and resources flow, with three key goals: cost reduction, time-saving and value added to the client. Similarly, this author challenged the industry to apply the principles behind the revolution in manufacturing and quickly initiated an effort to establish production management on a sound theoretical foundation [11].

The main principle of Lean Construction is that it conceives a construction project as a temporary production system dedicated to the three goals of delivering the product while maximizing value and minimizing waste [10]. However, before moving forward with the research it is important to understand the value concept. Value is understood as a production concept, not an economic concept. Value in this latter sense has no necessary connection to cost [8]. That is to say, the client defines value and the client should be understood not only by the final consumer but also as all the stakeholders involved in the process or workflow.

In the other hand, taking into account the characteristics of the construction projects, lean construction aims to maximize customers' satisfaction through the design of both the constructed facilities and the construction process that delivers these facilities, and through the consequent control of each stage in the construction process [12]. In consequence, construction requires planning by different people, in different work posts of the organization, as well as in various stages of the infrastructure lifecycle [13]. Therefore, planning can be developed in cascade, taking in consideration greater level of detail (zoom in) as long as the project advances and planning can be more specifically described [14]. As a result, a key technique in the lean construction philosophy arose: the Last Planner System (LPS).

The Last Planner System is a planning and control technique in cascade whose main purpose is the reduction of the work variability. In this regard, the construction production control system can be usefully conceived and represented as consisting of three hierarchical levels (1) "Initial Planning" which produces the project budget and schedule, and provides a coordinating map of the deliveries; (2) "Lookahead Planning" which details and adjusts budgets and schedules are made and (3) "Commitment Planning" which is a commitment to what will be done based on actual receipt of resources and completion of prerequisites (Fig. 1) [15].

In addition, LPS needs a coordination of all the stakeholders involved in the process, the commitment of these actors and an important indicator of control that is the Percent Plan Complete (PPC), which indicates the percentage of completed work that was planned.

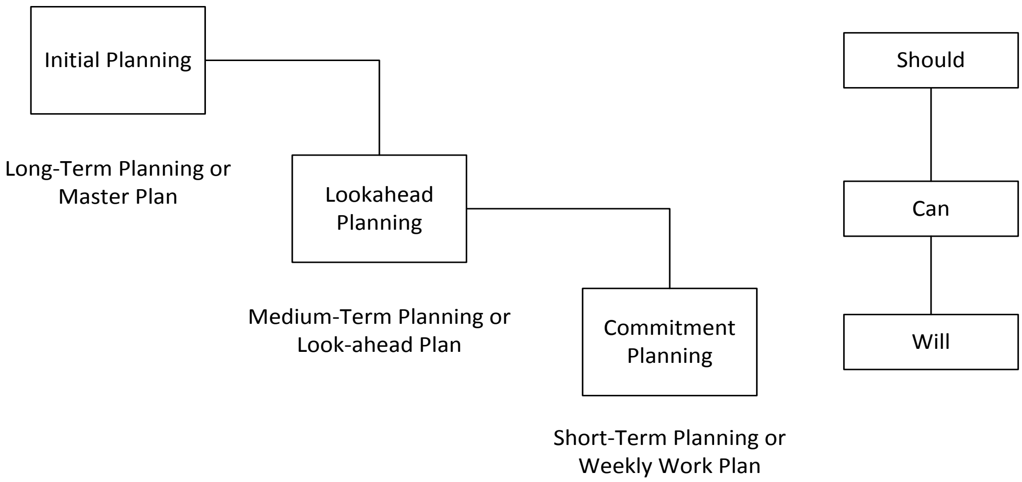
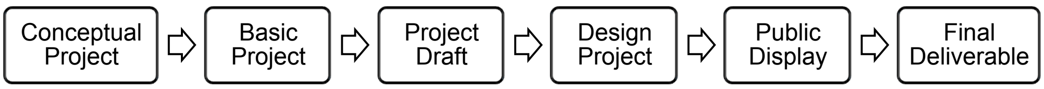


Figure 1. Cascade Planning of LPS.

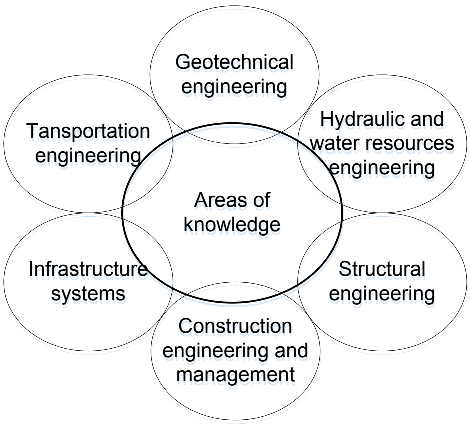
3 COURSE METHODLOGY AND LEAN CONSTRUCTION

The course in which the Senda Matrix software is implemented is called Final Design Project, it is part of the last year civil engineering curriculum at *Universidad de los Andes, Colombia*. 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 distinguishing aspect is the autonomy that students develop, as they become protagonists of their own learning while the teachers have the role of advisors and counsellors of the process throughout the course [6].

The students are organized in groups of 12-15 people. Each group have to design an engineering solution for a tangible real problem that involves all of the civil engineering areas of knowledge such as structural, geotechnical, transportation, water resources, infrastructure systems and construction management engineering. That is to say that the student participates in the first phases of the lifecycle (Fig. 2) of an integrated civil project. From the beginning, students are familiarized with the IPD methodology because they play roles in their area of interest of the civil, so in that way, across all the design stages the groups are responsible for the coordination of the designs of each area and their develop in a 3D model using BIM methodology.



(a)



(b)

Figure 2. (a) Design process deliverables. (b) Civil engineering areas of knowledge to be considered in the project [6].

The implementation of Lean Construction, more specifically of LPS is useful since the conceptualization stage of the project. In the first day of class, the students have the syllabus of the course where they can find the exact delivery dates for each phase (Fig. 2), in other words, the students receive the Master Plan with the program of the course. From that point forward students are responsible for constructing the Lookahead Plan for each deliverable phase and week after week each group organizes a pull session in order to define the Weekly Work Plans (Fig. 3).

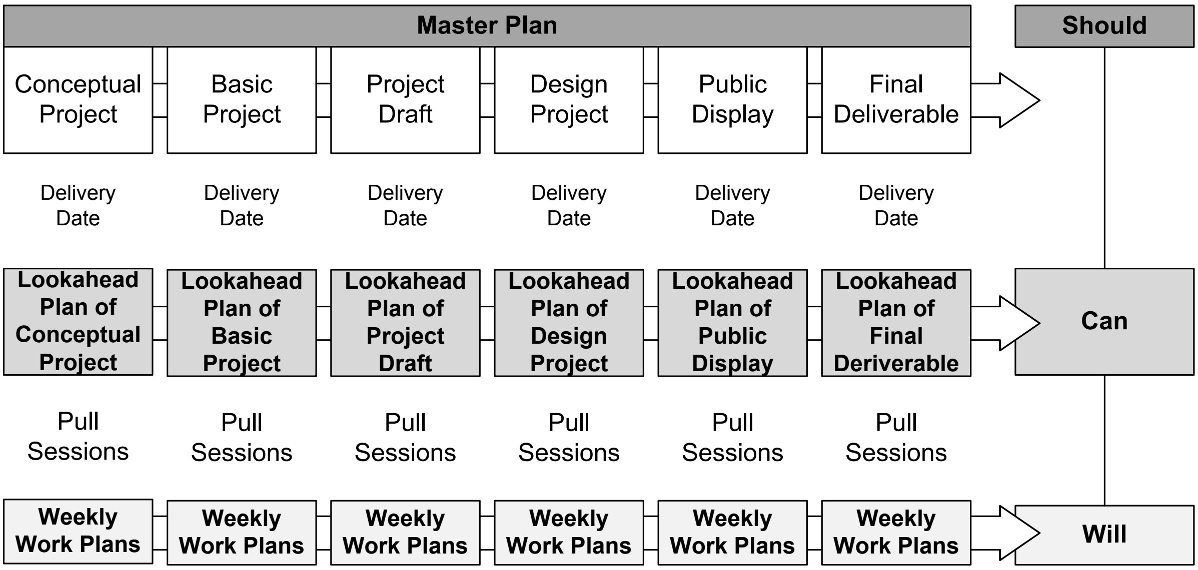


Figure 3. LPS in all phases of the project of the course.

Students use the LPS as a planning and control technique. In this course, they use the Senda Matrix software that is a Free and Open-Source Software (FOSS) under License Creative Commons-CY (Attribution). This software allows students to implement the cascade planning proposed by LPS (Fig. 4). In the Master Plan students schedule the delivery dates for each phase and create the calendars used in all the course, on these terms, the students establish the strategic planning (phase planning), showing the main activities [16]. In the Lookahead plan, the students develop actions in the present to produce the desired future for each deliverable, preparing, analysing, and solving the conflicts and restrictions in a lower and more detailed level [16] depending on the phases analyzed. Finally, the Weekly Work Plans (WWP) helps to study the evolution of the project and to the production with the application of Plan Percent Complete charts [7] that allow a more detailed level of analysis to be performed.

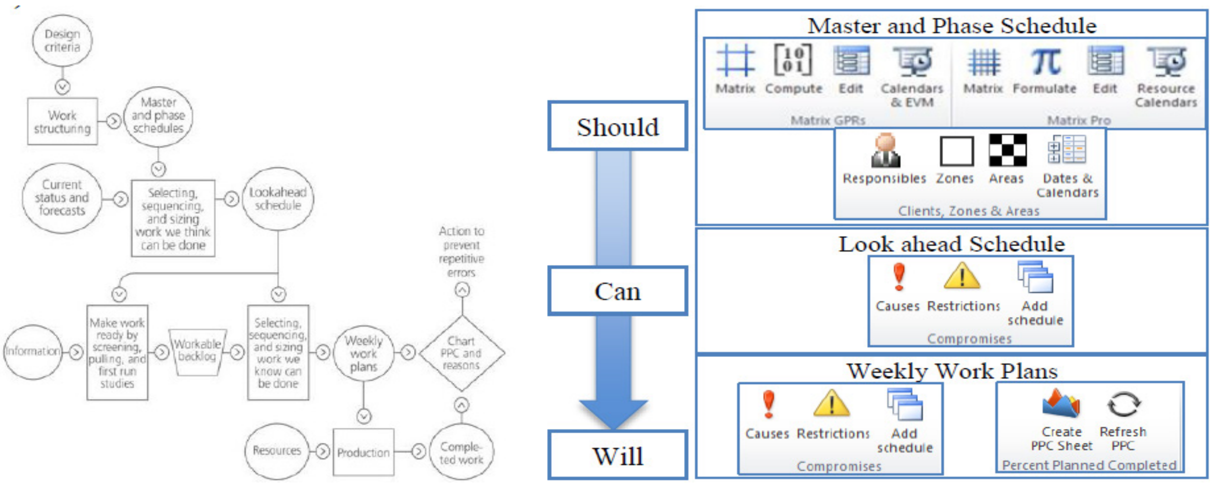


Figure 4. LPS [17]. Pull System with Senda Matrix [16].

4 RESULTS OF SENDA MATRIX SOFTWARE

The principal input of the Lookahead plans and WPPs are the coordination meetings and pull sessions organized by each group. In the pull sessions, the students use post-it notes in order to boost the meeting, foster participation, and to establish activities or tasks and their respective responsibles, causes and restrictions (Fig. 5). Then the information obtained can be transferred to Senda Matrix, which works as a plug-in for excel. This plug-in works as a new tab (Fig. 6) in the ordinary Excel menu, which makes it a very intuitive easy to use tool for both students and professionals. It also allows students to work on both large and small-scale projects and to handle as many tasks, responsibles, causes and restrictions as they want.

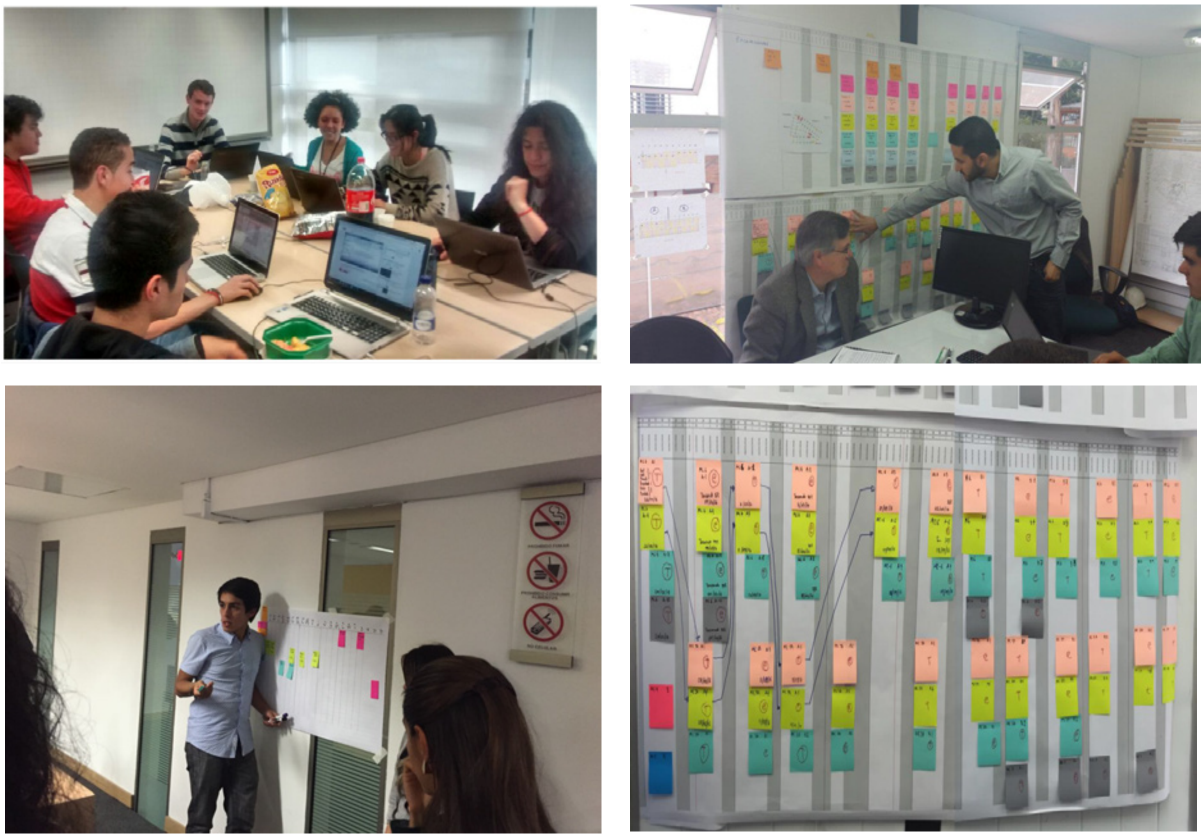


Figure 5. Coordination Meetings and Pull Sessions.

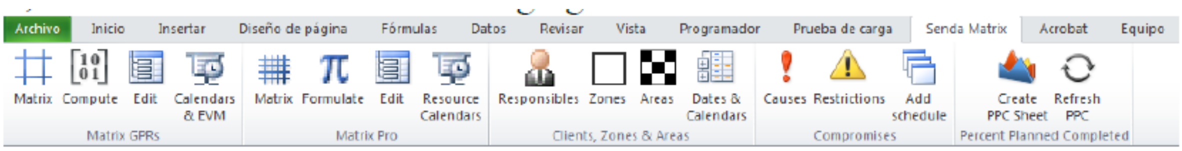


Figure 6. Senda Matrix Ribbon for Excel [16].

Senda Matrix enables a different kind of analysis for a project and allows the students to make a cascade planning as posed by LPS. As can be seen in the Fig. 7 the students create the tasks are with their start and finish dates and consequently, generate a project schedule for each Lookahead. The schedule contains the relations between the tasks, the durations and priority. Similarly, the calendars for the projects are created.

Following the characteristics of the Lookahead Plan, the students using Senda Matrix can establish the present restrictions to complete the initial plan or Master Plan (Fig. 8). This is so important and useful for the development of their project because they can anticipate milestones that are necessary for complete their commitments and delivery times. In addition, the responsibles for each restriction are determined and documented for their control and monitoring. One point so important for Lean Construction and LPS is the identification of the client due to in this way it can be defined value for the project. The above is made in Senda Matrix with the corresponding commitment date set by each responsible.

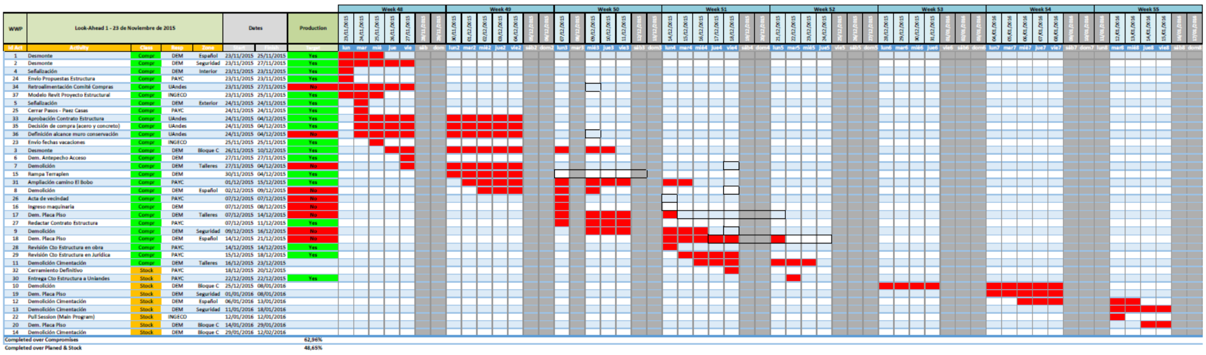


Figure 7. Lookahead activities and schedule.

Restr. Id	Restr. Text	Client	Needed at Date	Respons	Compromis at Date
Grua		OJCTM	30/08/2016	OJCTM	30/08/2016
Plan izaje		HSQE	27/08/2016	OJCTM	26/08/2016
Procedimiento instalación torre grua		HSQE	11/09/2016	OJCTM	04/09/2016
Formaleta Columnas	Se habló de 6 juegos de columnas más pantallas	OJCTM	19/09/2016	OJCTM	12/09/2016
Procedimiento columnas y placas		HSQE	26/09/2016	OJCTM	19/09/2016
Andamios y equipos contra caidas	Equipo certificado	HSQE	26/09/2016	OJCTM	19/09/2016
Punto de anclajes fijos y moviles	Equipo certificado	HSQE	10/10/2016	OJCTM	03/10/2016
Red seguridad	Equipo certificado	HSQE	10/10/2016	OJCTM	03/10/2016
Color Concreto	Definido por el Arquitecto Daniel Bermudez	OJCTM	26/09/2016	PAYC	12/09/2016
Formaleta vigas cimentación	Metalica ≥70 metros lineales	OJCTM	11/09/2016	OJCTM	05/09/2016
Arboles	Esta proxima a salir la licencia	OJCTM	04/09/2016	PAYC	05/09/2016
Detalle Estructural Vigas Puente	VA-24 entre ejes 3C y 3E. VA-12. VA-6	OJCTM	12/09/2016	PAYC	05/09/2016
Diseño redes		OJCTM	17/10/2016	PAYC	10/10/2016

Figure 8. Restrictions, responsibles and dates of Lookahead Plan.

Continuing with the cascade planning, these is the technique of the Weekly Work Plan whose benefits are tangible in the productivity and control of the day-to-day. The main information that is established at this point is the fulfilment of commitments knowing which tasks are commitments or stocks according to their priority (Fig. 9). The percentage of fulfilment will determine if the task is completed or not and what were their dates of execution. Taking the above data, the students can generate PPC charts and analyze their evolution week after week (Fig. 10). The main objective is to determine why the commitments could not be fulfilled (causes) and what is causing the interruption of workflow. In this way, lessons learned are identified and the continuous improvement, exposed by Lean, is guaranteed.

Week_36_2016						Dates		Production		Week 36						
										29/08/2016	30/08/2016	31/08/2016	01/09/2016	02/09/2016	03/09/2016	04/09/2016
Elemento	Id_Elem	Modulo	Class	Cause	Observaciones	Start	Finish	Pct (%)	Target	lun	mar	mié	jue	vie	sáb	dom
Caisson	1	14	Compr			29/08/2016	30/08/2016	100,00%	Yes							
Caisson	1	15	Compr	wea	Piedra y nivel freatico alto	31/08/2016	01/09/2016	25,00%	No							
Caisson	1	16	Compr	Oth	Precedencia no completa	02/09/2016	03/09/2016	0,00%	No							
Caisson	9	13	Compr			29/08/2016	31/08/2016	100,00%	Yes							
Caisson	9	14	Compr	Sub	Tarea incompleta	01/09/2016	03/09/2016	25,00%	No							
Caisson	10	16	Compr			29/08/2016	31/08/2016	100,00%	Yes							
Caisson	10	17	Compr	Sub	Actividad incompleta, para fundir	01/09/2016	03/09/2016	75,00%	No							
Caisson	16	7	Compr			29/08/2016	31/08/2016	100,00%	Yes							
Caisson	16	8	Compr	Sub	Tarea incompleta	01/09/2016	03/09/2016	25,00%	No							
Caisson	17	14	Compr			29/08/2016	31/08/2016	100,00%	Yes							
Caisson	17	15	Compr	Sub	Tarea incompleta	01/09/2016	03/09/2016	25,00%	No							
Caisson	18	10	Compr	Sub	Actividad incompleta, para fundir	29/08/2016	31/08/2016	75,00%	No							
Caisson	18	11	Compr	Oth	Precedencia no completa	01/09/2016	03/09/2016	0,00%	No							
Caisson	19	8	Compr			29/08/2016	31/08/2016	100,00%	Yes							
Caisson	19	9	Compr	Sub	Actividad incompleta, para fundir	01/09/2016	03/09/2016	75,00%	No							
Caisson	21	3	Compr			29/08/2016	31/08/2016	100,00%	Yes							

Figure 9. Information of the WWP.

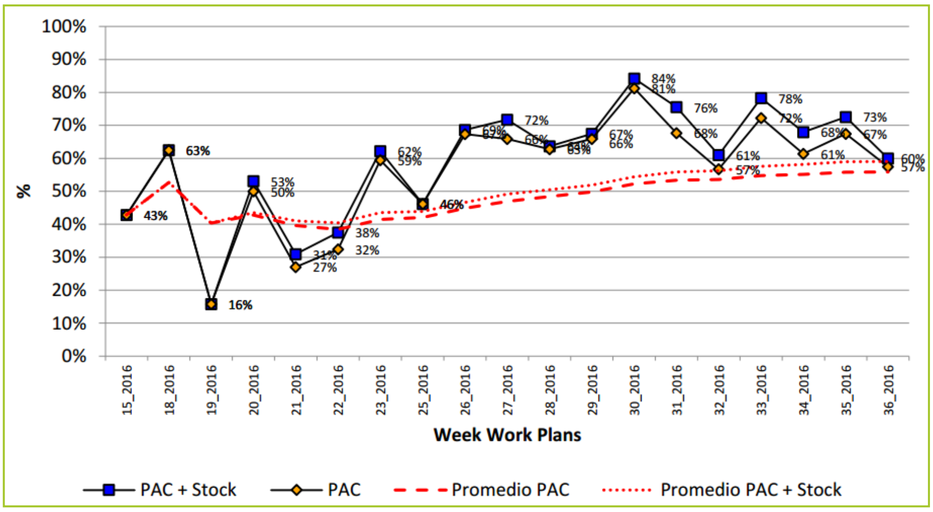


Figure 10. PPC Graphic of the WWP.

5 CONCLUSIONS

The globalization and the complexity of the projects have generated that the construction industry seeks young professionals who are familiar with daily problems that demand criteria in decision-making, the creation of innovative solutions and teamwork with different disciplines. For this reason, many methodologies have surged in the learning and teaching process at the universities. PBL integrated with IPB and BIM are applied in bachelor programs with the aim of involving the students in real scenarios, in this way, they strengthen their teamwork skills, autonomy and responsibility where the student is the protagonist in their learning.

The experience of the application of these methodologies is presented is this research through a real case in a course of last semester of the undergraduate program of civil engineering at *Universidad de los Andes*. The integration with Lean construction, and more specifically LPS, has guaranteed that the students could plan and control their projects fulfilling the deliverables throughout the whole lifecycle.

LPS is a key technique of Lean Construction which is a planning and control technique in cascade whose main purpose is the reduction of the work variability. This research presents the objectives that students are looking when they implement each step of cascade planning, in addition, the benefits of each step are shown with the aim to establish the value for each of the clients and control the fulfilment of the commitments to ensure a flow of continuous production. On the other hand, LPS is an excellent tool for the integrated planning and control of a project, especially when the team is made up by different design work groups since it eases coordination and decision making. Lastly, the integration of IPD and PBL into a civil engineering course has enabled the flourishing of collaboration, leadership and empowerment skills among students.

Senda Matrix software has been proven to be a helpful and usable tool for the implementation of LPS, it guarantees that the LPS application is easy for students, firstly, after its free access, and secondly because it has all the components required in order to deliver a cascade planning. Summary, among the great benefits of Senda Matrix, is that it is a software of free access for any user, presents all the necessary components to carry out a planning through LPS, features an easy-to-use interface and allows the students to perform evolution analysis.

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