Implementation of BIM in the Subject Technical Industrial Projects—Degree in Industrial Technologies Engineering—University of Valladolid

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Abstract This study attempts to illustrate the current situation in the Industrial Engineering School in Valladolid regarding the development and management of engineering projects using the BIM (Building Information Modelling) methodology. It is widely accepted that the evolution of information modelling (BIM) is affecting the role of professionals in projects and in the management of the project life cycle. It is starting to become clear within the university environment, that the information modelling of BIM technology must become part of the education of future engineers. It uses integrated project delivery to respond to the professional demand that requires the development of skills in the educational practices to tackle the problems and limitations arising in the new practices. The BIM methodology covers everything from the project stage to asset management. The proposal of its inclusion in the Industrial Engineering School Degree qualifications came about in order to stagger the introduction of the student into the project process set up through this "new philosophy".

Keywords BIM · Teaching · Implementation · Modelling · Engineering · Projects

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J.L. Ayuso Muñoz et al. (eds.), *Project Management and Engineering Research*,
Lecture Notes in Management and Industrial Engineering,
DOI 10.1007/978-3-319-51859-6_17

1 Introduction

It is starting to become clear within the university environment that the information modelling of BIM technology must become part of the education of future engineers. BIM technology uses integrated project delivery (IPD), such that the professional demand and the approach of including these skills in the educational practices must tackle the problems and limitations arising in these new practices. In Spain, this methodology, both from a constructive and a pedagogical perspective, is not widely employed.

The overall objective of this study is to demonstrate the need for implementing BIM technology into study programmes of industrial engineering schools belonging to public universities in Spain. The BIM has been included for several years in universities elsewhere that are committed to the integration and training of professionals in this subject. To achieve this objective, this study focuses on the procedure and results of having implemented the BIM into the Industrial Engineering School at the University of Valladolid.

Firstly, a relevant literature review will be conducted of the existing research on the subject from different perspectives, obtaining a significant sample which will provide data on research carried out in other countries that support this paradigm shift.

1.1 What is BIM?

Building information modelling (BIM) is the process of creating and managing parametric digital models of a building (or a piece of infrastructure) during the building's life cycle (Mom et al. 2014).

There is no clear holistic approach or methodology to assess the adoption of building information modelling (BIM) technology at corporate level. Approaches are proposed for developing critical success factors that can be further developed for assessment of BIM adoption at an organisational level in the architecture, engineering and construction (AEC) industry (Tsai et al. 2014).

The BIM application not only provides solutions, which can be adopted and developed in other organisations and contexts that share similar challenges, but also provides knowledge on problems and bottlenecks of the application, necessary complementary tools and possible arrangements of the organisation (Miettinen and Paavola 2014).

Work methodologies and tools currently employed in the construction sector do not allow for changes to cope with market requirements. There is also no time for planning in projects that require more detailed specifications and productive efficiency is a struggle.

In the light of this, the development and application of production methods that favour multi-disciplinary and integrative work and collaboration between agents involved in the construction process is vital.

The BIM technology emerges as a response to the necessity to integrate all agents involved in the process during the different project stages (Patiño et al. 2014).

1.2 Uses of BIM

Work fragmentation is one of the key aspects of BIM, as well as the different locations of the participants and the different agents involved. However, with the advance in Information and Communication Technology (ICT), and in particular cloud computing, work fragmentation can potentially be overcome.

Cloud computing has become increasingly popular in recent years given that it continues to demonstrate the substantial advantages that it provides to the different users of this technology. These advantages are being widely discussed by many researchers and academics worldwide.

There are also risks in using cloud computing technology, security being the main concern. (Chong et al. 2014).

1.3 BIM Training Requirements

It is widely accepted that the evolution of BIM in the construction sector is increasingly affecting the role of professionals in architecture, engineering and construction (AEC) management and the industry (Wang and Leite 2014).

The construction industry and engineering programmes need to incorporate BIM courses that prepare their students with relevant BIM skills and knowledge, so that they are aware of the possible applications of BIM in their future careers in the construction industry and improve productivity. Students will also learn the importance of collaborating with interested parties in planning, as well as the inherent problems of BIM and its application (Ahn et al. 2013).

1.4 Inclusion of BIM in the Education System

The construction industry needs qualified engineers with BIM knowledge and skills, as well as the rest of professionals belonging to the AEC field.

A detailed set of 39 necessary topics for BIM competency in construction management, together with specific objectives for competency in each topic was recently compiled based on researching the industry's requirements.

A set of guidelines for integrating BIM topics into study programmes has been developed and tested by the Technion-Israel Institute of Technology.

BIM education interventions were planned in four of the seven courses, implemented and evaluated for three terms. The experiments showed that BIM must be introduced as a stand-alone topic, but most importantly, also as a tool for engineering tasks taught in design, analysis and management courses.

Knowledge of the social skills involved in exchanging information and managing knowledge, the professional roles and commercial context are also as important as the technological aspects (Pikas et al. 2013).

The Building Information Modelling (BIM) is becoming an increasingly common practice in the construction industry. Universities which offer construction engineering and educational management must include BIM concepts and skills in their degree programmes (Sacks and Pikas 2013).

Graduates in construction engineering and management today must have strong communication and teamwork skills, the ability to work efficiently with other teams working alongside them, and lastly, know how, to apply the principles of engineering, management and I.T. skills to their practice.

The introduction of BIM in a virtual collaboration environment allows teachers to design a course which includes the use of more realistic scenarios, better simulating the challenges of the real world.

Such experiences teach students how to undertake construction projects in practice, as well as how the different disciplines are based on other information, the type of information needed from relevant disciplines and when and how this information can be exchanged and shared among tools and processes (Becerik-Gerber et al. 2012).

Academics, through industry demand and participation, are starting to realise that in the education of our future engineers, the construction of BIM, which uses integrated project delivery, as well as collaboration and focus on design, have to be an educational priority.

As a result, the academic world is now burdened with the task of determining how to develop these specialised abilities in engineering students so that the professional demand and the focus on incorporating the appropriate skills in educational practices come together to tackle the problems and constraints that arise in these new practices (Solnosky et al. 2014).

Technological advances in the field of technical coordination and simulation provide new methods in BIM construction, which will improve the safety process, quality and last but not least, efficiency.

The lack of people able to work with comprehensive BIM is now one of the main barriers to using these technologies in architecture and engineering. The importance of improving this situation is not to teach students the BIM subject, but to ‘think BIM’ in all related disciplines (Fridrich and Kubečka 2014).

1.5 Objectives Sought in This Work

It remains to highlight what motivates this work and the specific objectives sought by carrying out the experiment explained below, which can be summarised by the following points:

1. The need to include BIM in the regulated teaching system in degree studies in Spanish public universities.
2. To open the field to studies and work carried out linking the academic environment and the professional practice: final dissertations in degrees, masters, etc.
3. To continue with the educational innovation of the European Higher Education Area, (EHEA): Promote group work, discovery of the autonomous potential of students, promote working in a network and with ICTs, multi-position cooperation, international cooperation, working with specialists, and incorporation into multidisciplinary teams, etc.

2 Background, Boundary Conditions, Context

The BIM implementation experiment has taken place within the University of Valladolid. The University of Valladolid is a public university with an extensive background given that it was founded in the year 1241 and its School of Industrial Engineering in 1913. The first School of Industrial Engineering was founded in Spain in 1850.

The degree in Industrial Technologies Engineering, in which the experiment was carried out, brings together knowledge of different technological areas of engineering (mechanics, electrics, electronics, automatics, chemical and organisation) in the industry. This solid and structured scientific-technical training is essential for modern, innovative, advanced and quality engineering.

This multi-functional and general training is required not only for large industries, but also for SMEs, which occupy a prominent position in the Spanish industry today. These types of technicians have a wide range of functions in specific areas such as research centres, R&D technology projects, in the implementation of emerging industrial technologies, and the development of other new technologies, as well as the participation in multi-disciplinary projects of industrial engineering. This qualification is a great incentive as a solution for the vast diversity and complexity of new problems which arise in modern industry.

Within the competences featured in the teaching programme in the degree qualification report is the competence and ability to design, plan, write, develop, organise, manage and lead projects.

These abilities require the student to be able to analyse the background, set the objectives, plan the work, select appropriate technologies, document and budget the chosen solutions. This competence involves being able to define the scope of the project, specifying the technical characteristics and evaluating the economic-financial aspects and the economic, social and environmental impact of the project, allowing for the effective introduction of technical or environmental improvements in the future.

Currently, none of the industrial engineering schools in any public Spanish university offer BIM as a subject related to projects. At present, a BIM training is relegated to specialised courses, postgraduate programmes, talks, professional association courses, continuous professional development courses, courses in private training centres, etc.

2.1 Academic Context

The degree in Industrial Technologies Engineering taught at the University of Valladolid in the Industrial Engineering School is split across four years, with eight four-month teaching blocks, in which a total of 240 ECTS credits are taught, breaking down into 60 credits per academic year.

The module *'Industrial Technical Projects'* is included within industrial technology and is compulsory. It is worth 6 ECTS credits, 2.4 of which require attendance and the remaining 3.6 do not. It is taught in the fourth year, in the last four-month teaching block.

Prior to this, the student will have completed the *'Projects/Technical Office'* module which follows on from the *'Project Methodology'* module, a core module from the industrial pathway. This module is worth 4.5 credits, of which 1.8 require attendance and 2.7 do not. This module is considered the pre-requisite for the module *'Industrial Technical Projects'*.

The module *'Industrial Technical Projects'* acts as a connecting link and integrates all the knowledge acquired in the previous modules taken by the student in a teaching methodology that includes *Case studies, Exercise and Problem Solving, Project-based Learning* and a *Learning Contract*, combined with *Cooperative Learning,* given that the completion of the project by the student is carried out in groups of two.

2.2 Expected Learning Curve

The student starts off with knowledge which is mainly based on 2D skills, a likely result of their training in previous courses and compulsory disciplines, namely Graphics and Computer Assisted Design.

Therefore, a significant step is taken when faced with *'3D Models'* for the first time.

Once the model was created, the facilities were implemented, depending on the type of industrial facility planned. Subsequently by having models created, these same ones can be used again to detect intersections and geometrical clashes.

However, the real change, subject to the training within the projects/technical office module, is to arrive at an extended notion of what it means to employ *BIM,* and not focus on tools, in our case Revit®.

To implement this learning curve, different types of activities are carried out, depending on the stage at which the group of students find themselves, such as *Classroom lessons, Follow-up work in the Laboratory, Tutorials* and specific *Seminars*, above all in implementing the facilities into the model.

2.3 Expected Results

Once the experience is developed in BIM environments, it is expected that the students assimilate and acquire skills and knowledge on the following aspects:

- Knowledge of the life cycle of the project/construction/asset management/ demolition/end of life.
- Generation of BIM models.
- Incorporation of MEP (Mechanical, Electrical and Plumbing) facilities into the BIM model.
- Use of IFC ('Industry Foundation Classes') standards.

3 BIM Implementation Process

As previously commented, Building Information Modelling is a methodology which is carried out from the planning stage to the asset management, covering the whole life cycle of a building. In this case, its implementation in the planning stage is considered, through the use of certain tools and procedures that will be explained in further detail below.

The idea of establishing this methodology in the degree qualifications of the School of Industrial Engineering came about in order to progressively stagger the way in which it was introduced to the student in the planning process configured through this 'new philosophy'.

3.1 Implementation Stages

To achieve the established objectives, general criteria were provided for the formal elaboration of every technical project, as well as the requirements that had to have been included and the document structure.

The stages below were strictly followed:

3.1.1 Study proposal
3.1.2 From CAD to BIM
3.1.3 BIM tools and procedures for the project
3.1.4 Project process sequence and drafting manual.

3.1.1 Study Proposal

Taking into account the limited number of students taking the module (nine in total), it was proposed that a single project be worked on in a group with subgroups of two people working on the shared project. In this way, different users would have the chance to intervene simultaneously on the same advanced virtual construction model, making a base model and certain mini projects on structure and facilities. This way of working fed back the aspects that each student was working on into the overall knowledge of the group.

The scope of the project consisted in the execution of civil works (including heating facilities, electricity installations, sanitation, air conditioning and fire prevention) of a complex made up of office buildings and production premises for the manufacturing of cutting fluid filter machines. The work group decided on their geographical location based on requirements for size, orientation and necessary access to ensure the functionality of the building according to the purpose it would be used for. Likewise, an urban location analysis was carried out on the location selected for the purposes of building conditions. The programme of requirements to carry out in the facility was established jointly between the teaching staff and the work group and concerned both the manufacturing and the administrative area.

3.1.2 From CAD to BIM

The progressive implementation of BIM tools and procedures in the project stage was planned from the outset, starting with an introductory stage in which the student was familiarised with the criteria and way of working of this method, which, as previously commented, encompasses the project's life-cycle. A wide majority of students did not have the slightest notion of BIM until then and were expecting to undertake the work proposed in the module using traditional methodologies, until being introduced to the BIM tools, just recently becoming common in the project field. Therefore, the approach had to be modified by changing the way of thinking about ‘drawing’ to thinking about ‘constructing’ in the use and subsequent management of the buildings, or in other words, from CAD to BIM.

3.1.3 BIM Tools and Procedures for the Project

Given that this teaching innovation undertaken in the 2013/14 academic year was a pilot experiment for the qualification, an accessible modelling program for the student was chosen as a starting point, which had a free educational licence. With this, they were able to design the parametric model of the premises, both geometrically and from the point of view of its facilities and structures. The program REVIT 2013 in Spanish belonging to the BIM Autodesk platform was chosen, which in a single application includes architectural design, construction, MEP engineering and structures.

3.1.4 Project Process Sequence

Once the students were aware that BIM was a fundamental vehicle for the project, the experiment started.

Firstly, the complex was designed and generally modelled with Revit 2013. The building, to be located in the technology park in Valladolid, would comprise two separate areas: rectangular production premises measuring 60 × 20 m, with maximum ridge height of 8 m with a gabled roof; and a square-shaped hub of offices measuring 15 m, two floors and fully glazed curtain walling. Both constructions were connected by a similarly glazed covered walkway.

At the same time, as they were modelling the premises, students wrote a log to clearly remember their own experience, which was finally used to write the manual to help students in subsequent years.

The group worked together on a single project in the design stage resulting in the architectonic BIM of the premises and its building annex, resolving the problems that were arising due to the novelty of applying the new methodology and, as previously explained, the change in the trend that came from having to progressively construct the building rather than draw it. In this way, in CAD systems, two parallel lines take on the meaning that the planner wishes to bestow on them: they can comprise an outside enclosure wall, an inside partition, a roof finish, a window frame or even power lines. On their own and isolated from their context, these lines are flat (2D) and lack any specific meaning. However, in BIM philosophy, each of the elements that is being included in the parametric model (3D) has its own identity. In this way, faced with the empty ‘shell’ of CAD modelling, a paradigm of data which comprises BIM was obtained (Fig. 1).

Once the object has been constructed virtually, the floors, elevations, sections, perspectives and renderings can immediately be viewed in 2D and 3D (Fig. 2).

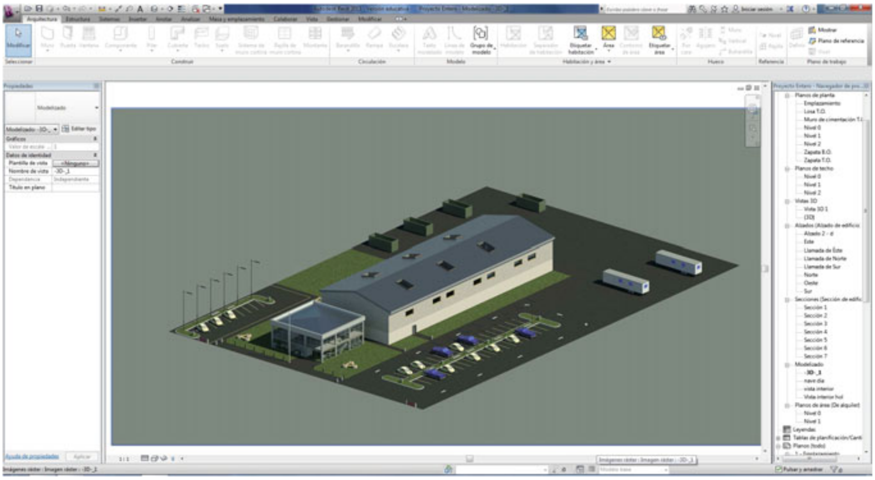

Fig. 1 Isometric perspective. Final result of the complex designed

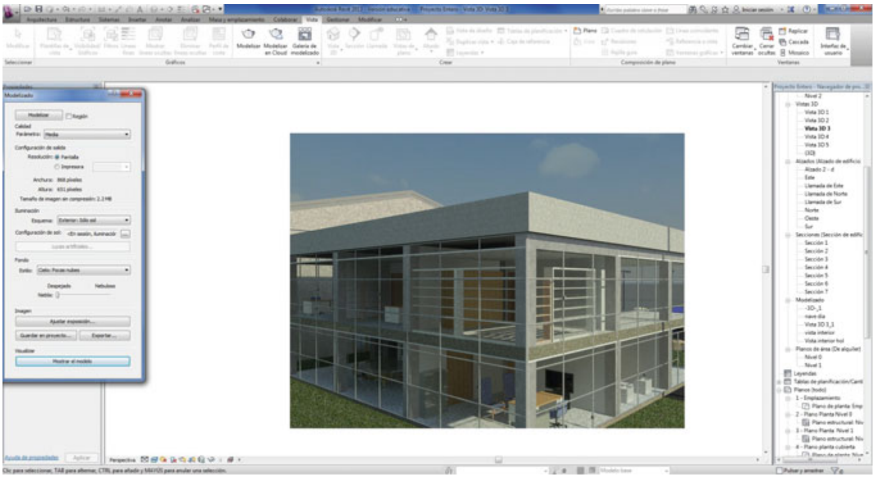

Fig. 2 View of the office building designed by the work group

It is important to note that during the entire planning process the teaching team followed their own educational methodology known as ACLS (Active Collaborative Learning System), which is the result of an exhaustive analysis and design of integrated strategies with additional pedagogical methods for the creation of a valid learning system that could also be applied to practical subjects in other areas. In this system, the student plays an active role in their own learning process, and the knowledge is acquired through group work, collaboratively, acquiring teamwork skills, independent learning, learning from other teams, decision

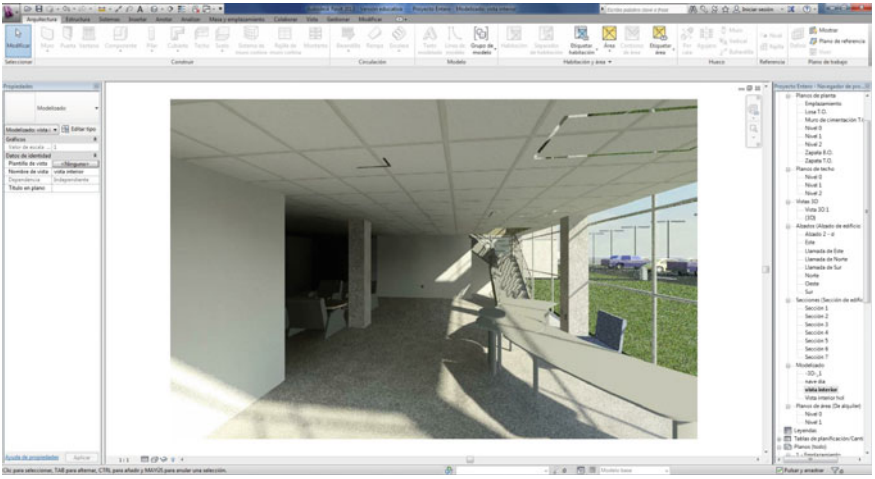

Fig. 3 Inside the office buildings designed by the work group

making, etc. The system also comprises analysing and discussing the work produced by different teams, offering these groups any relevant technical suggestions or constructive criticism. This methodology makes students feel that they are working to increase their general knowledge and improve their interpersonal relations, understanding that teamwork provides a series of advantages which would otherwise take more time and greater efforts to achieve. It is essential to also point out that this work methodology uses ICTs (such as the moodle platform or the cloud) to support the teaching activities, improving the quality of the educational process and facilitating the introduction into the classroom of procedures recognised by the European Higher Education Area (Fig. 3).

Continuing with the BIM implementation process and after obtaining the virtual architectural model of the premises, the following step was to divide the work group into two-person teams who would take on a sub-project linked to the base model, comprising the design and modelling of its supporting structure as well as the complex’s facilities. The same program Revit 2013 would be used for this, but in its Revit Structure and Revit MEP applications. Starting with the initial architectural model, this work came up against considerably more problems than the previous stage and will be commented below.

The design and modelling stage was based on the following cases: the production premises would have a metallic structure based on HEB columns and metal trusses while the office building would be supported by a structure of beams and concrete columns ‘in-situ’, with the latter laid out in a 5 m × 5 m grid. In turn, the foundations would be carried out with isolated concrete footings under the column, linked by bracing beams.

While the modelling of the metallic structure of the manufacturing area was carried out quite effectively even with the setbacks of the analysis of the new Revit Structure module, the inclusion of the concrete structure was no easy task, producing some unexpected results. Once the structural elements, columns and beams had been modelled, it was followed by almost manual placing of the drawbars, compression bars and abutments. Prior to this step, the family of reinforcements had to be loaded, given that certain elements were not initially available in the program. The families used in the project will be those present by default in Revit, other external ones or families created by the planners, in this case by the students.

After the complete structure, the geometric elements and its corresponding reinforcements had been modelled, the need for specific software to calculate the structure was clear, and the entire geometric modelling framework was exported from Revit. Once the results of this calculation were obtained, it could be implemented once again in the original model. This similarly occurred with the reinforcement of the footings and foundation beams.

In terms of the facilities' design, problems arose mainly from the fact that Revit MEP is not adapted to Spanish regulations. In the specific case of electricity, the instalment had to be reconfigured, redefining the voltages given by the American program and adding the necessary 230 and 400 V to the new configuration. A distribution appropriate for this use was also created, as well as another type of configuration from other parameters such as: cable sections, types of insulation, etc. Subsequently these elements, devices and planned electric equipment were positioned, adapting them to the new distribution system created previously (Fig. 4).

As with the modelling of the premises, the students recorded their experiences and subsequently included them in a new manual, in this case about electrical systems.

However, the most critical situation arose when undertaking the plumbing work. After unsuccessfully attempting to model in Revit, the team in charge of this area

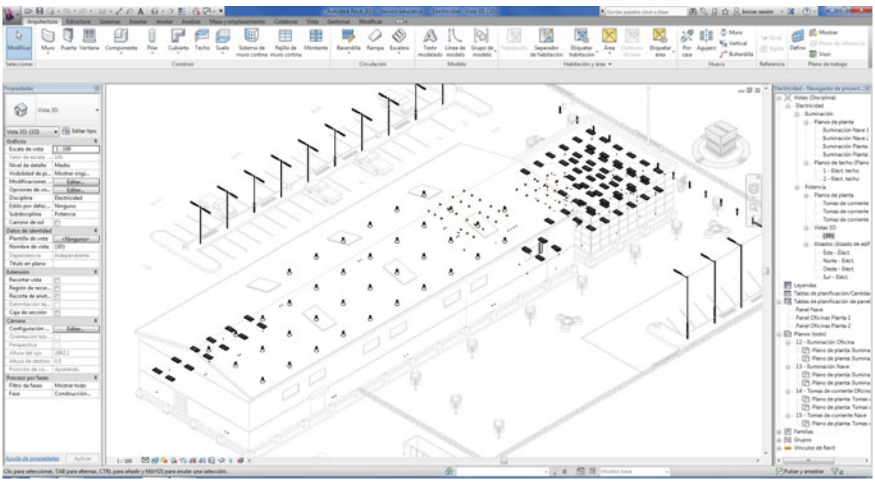

Fig. 4 3D view of the electrical facilities designed by a work team

decided to export the data to a 2D CAD program and continue the design of these facilities this way. This was due, in part, to the need to find solutions to be able to complete the project together and go on to present and deliver within the scheduled dates for the academic year. By doing so, the process initiated in BIM had 'fractured' somewhat, straying from the desired methodology. Seemingly a step backwards had been taken by returning to 2D, so distant from the BIM concept. Nevertheless, that was not perceived as a failure but as a new starting point in the staggered process underway. It also generated awareness of the BIM implementation strategy which should be considered as a way for new solutions to coexist in their early stages with 2D design applications. The stance of massively abandoning these applications was considered due to this fact, arriving to the conclusion that in the initial stages (or the PRE_BIM stages) it would perhaps be more practical to consider the possibility of importing/exporting to and from CAD. In that case, it is evident that while the implementation is underway, old systems should be withdrawn as they are clearly antagonistic.

Once the manufacturing premises and offices of the project and their facilities and structure had been modelled, the technical documentation was produced: report and appendices, plans, specifications, measurements and budget. For the measurements, Revit's planning tables were used through the management of data introduced in the project process. Lastly, the program Presto was used in the budget stage, which although is not BIM, can operate together with BIM applications allowing it to obtain the necessary information from the models to create the budget.

4 Results and Conclusions

The conclusions drawn from this study are, firstly, that there is a strong belief in the need to implement the BIM in university training for engineers in Spain. The educational community should move forward and put itself at the forefront where new methodologies are concerned, advertising and adapting itself to new technologies to train students on tools which they will be required to use in the professional world as is the case of the BIM.

Although the authors have been in very direct contact with the students, many problems were detected when understanding and handling the programs which, contrary to what was first expected, have substantially delayed the process.

Overall, the experience has been satisfactory and the authors are encouraged to continue its development. In this way, it is evident that the following stage of the BIM implementation process should comprise the calculation of all that was pre-designed in the modelling stage, using specific programs both for installations and structures.

Although the students have demonstrated their involvement from the start, the authors have detected that greater awareness of BIM is needed on all levels in the project field in Spain.

Once the study was concluded, all participants in the experiment were fully aware of the need to implement BIM within the study programmes of engineering in the public university, which is currently more in demand in Spain.

The students' teamwork has proved the need for the awareness of working together and to develop skills in coordination, leadership, negotiation, motivation and communication, all required by the current labour market.

Resources and support are needed within the university system for BIM to be implemented. Universities should promote this implementation, training staff and students, attending training courses, creating BIM knowledge training days, etc. A BIM culture within the education system must be created.

The students have gained awareness of the immediate importance of the use of BIM for the future development of their careers. This is an unstoppable phenomenon, so it is important to adapt to it sooner, to avoid suffering the consequences of compulsory implementation on an international scale.

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