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BIM for the Realization of Sustainable Digital Models in a University-Business Collaborative Learning Environment: Assessment of Use and Students' Perception

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Abstract: This paper develops an assessment of an academic implementation of building information modeling (BIM) carried out in an expert project subject of a School of Industrial Engineering. The objectives were for the students discover sustainable industrial during the design process and the students understand and participate in a real process of the implementation of industrial projects through real collaboration between academic and business contexts. The outcomes of this academic initiative were evaluated using academic results as well as students' perceptions. Academic results were analyzed using the FUZZY VIKOR method. An analysis of variance (ANOVA) was performed to determine whether the use of BIM, the proposed university-enterprise environment and the sustainability proposal rate of the students' projects had statistically significant effects on the results. Students´ perception evaluation was based on a Likert survey with five levels, and the results were interpreted using fuzzy k-means clustering and classification tree analysis. The results show that 77.8% of students consider that for learning, it is more effective to carry out a project related to an existing company, with the realization of the project with BIM methodology being of great value. The sustainability aspects were applied more easily thanks to the proposed methodology, and they were positively valued by the company.

Keywords: industrial projects; digital models; sustainability; BIM; university-business collaboration; students' perception

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1. Introduction

The architecture, engineering, and construction (AEC) sector is immersed in a paradigm shift that involves the incorporation of more sustainable models, those of the circular economy and, along this line, the BIM methodology is framed as a powerful tool for the creation of ecological digital models. The AEC sector currently faces numerous challenges, including low productivity, lack of research and development, and insufficient technological advances and its academical implementation [1]. From the point of view of environmental sustainability and once the serious problems caused by the current linear economy have been recognized, designers and researchers from around the world began to analyze more sustainable models of the circular economy. The construction industry is no exception to this change, and BIM, even with its limitations, is recognized as a powerful tool for designing buildings based on the circular economy [2]. The fusion of the principles of this paradigm, the BIM methodology, and lean construction can facilitate the construction of sustainable buildings. Lean construction and BIM are quite different initiatives, but both have profound impacts on the construction industry. A rigorous analysis of the innumerable specific interactions between them indicates that there is a synergy that, if properly understood in theoretical terms, can be exploited to improve construction processes beyond the degree of improvement achieved in the cases of independently applying any of these concepts [3].

Industrial projects need strategies to allow energy efficiency and the reduction of waste and emissions [4]. There are studies that corroborate the enormous advantages of BIM methodology in relation to sustainability [5] and sustainability certification strategies [6,7]. In the study carried out by Huang and other authors [8], a questionnaire was designed that consisted of 27 questions distributed among 300 respondents, including planners, managers of construction companies, and employees of green building certification companies, all of them relevant people in terms of BIM and sustainable buildings. According to the results of the study, BIM has made important contributions to the design, construction, and other aspects of the ecology of buildings.

On the other hand, among the most notable technological advances applied to the construction industry, studies have been carried out with the general objective of analyzing the current state of the applications of digital technologies to this sector. Along these lines, in the work carried out by Opoku and other authors [9], the concept of the "digital twin" and its application in construction is exhaustively reviewed and analyzed using a systematic review methodology and incorporating the scientific mapping method. The research analyzes in detail the state and evolution of the concept, the key technologies, and six areas of application in the phases of the life cycle of a project: construction information modeling, structural system integrity, facilities management, monitoring, logistics processes, and energy simulation. The results show that there is a high potential for digital technology to offer solutions to the numerous challenges in the construction industry. These evolved models were originally designed to improve manufacturing processes through simulations with high precision models of individual components. In the case of cities, using increasingly large and accurate BIM models combined with data generated from the Internet of Things (IoT) sensors, it is possible to create, for example, digital twin smart cities. A 3D model of a city can be published online, and the public can visit it to see the proposed changes in urban planning and policy [10].

From digital BIM models, it is possible to know aspects of the operation of the projects during their useful life and to analyze different options that minimize their environmental impacts. These models allow simulations of electrical energy consumption, the carbon footprint of materials, and the total energy incorporated in the project, with the objective of generating alternative designs and analyzing the results considering the economic viability of the proposed scenarios [11–13]. BIM is being developed in the world of construction as a solution to sustainability problems, playing several roles in sustainable design. Its most significant contributions have been in relation to the development of energy efficiency and natural lighting and ventilation, although there are barriers to its application such as insufficient knowledge of the tools due to lack of training and the high cost of BIM software [14], absence of the correct information at the right time to make critical decisions [8,15] or fields not fully developed [16,17]. In a study carried out by Lim and other authors [18], a systematic review of the recent development of BIM in terms of the sustainability performance of existing buildings was performed. As a result, a framework has been developed to fill the research gaps and future needs in the implementation of BIM for the environment, including data acquisition techniques, integrated processes, unified platforms, interoperability and data management, automation, design alteration, and automatic data feedback. This study provides new knowledge about the theoretical developments and the practical or technical aspects of BIM to promote a complete modernization ecosystem.

Therefore, BIM is part of the implementation of the Industrial Revolution 4.0, in which virtual reality and digital twins are key elements. Currently, buildings are responsible for 40% of the energy consumption in Europe, and therefore, there is a growing interest, framed in the European Green Pact 2050, in reducing their energy consumption. In this context, adequate interoperability between BIM and building energy modeling (BEM) is essential to integrating the digital world in the construction sector and, therefore, to increasing competitiveness through cost savings [19]. New technology tools as BIM produce changes in the curriculum of AEC disciplines and in educational student perceptions [20–23]. The students' perception of BIM implementation in a School of Industrial Engineering at different phases and levels shows the use of BIM as a methodology that eases collaborative work [21,23].

The present study shows an evaluation of a new stage of the implementation of BIM in engineering curriculum in a university-business collaborative learning environment. In this stage, during learning of the design process, the student develops an industrial building with ethical principles, social equity, and environmental awareness as a grounded sustainable fact, applying the principles of ecological quality and energy savings. An important objective of this innovative implementation is that the student understands and participates in a real process of executing sustainable industrial projects in a BIM environment through real collaboration between the academic and business contexts. To achieve this objective, a real company in the sector is included as an agent involved in the academic development of the project, maintaining, at all times, high educational conditions in terms of the acquisition of basic and specific skills and the achievement of learning outcomes. This new stage is a stimulus for industrial engineering students as a true link between university studies and professional practice through participation in a comprehensive, shared technical project in which the interested parties come together contributing knowledge so that they can reach the degree of maturity necessary for their integration into professional life [24]. Along this line, studies have been carried out on the importance of the research component in the training of university students from the connection with the university-company link. This alternative makes it possible to solve the existing problems in the orientation, planning, and development of the research activities of the students, which, as with the entire educational process, are complex, requiring conscious and strategic management and direction. An adequate organization of research, inserted through the collaboration between the two agents, would allow professionals to graduate with a comprehensive vision in their training and with a greater domain in their area of knowledge, which consolidates their commitment and interest in their training [25].

The study presented in this work tries to evaluate the influence of the proposed framework on the academic results, the achievement of skills related to teamwork, defense of results, reasoning and decision making, development of technical documentation, use of ICT and autonomous learning, as well as student's perception. The following sections describe the methodology followed, the results obtained and the conclusions that can be drawn from our work.

2. Materials and Methods

In our technical projects subjects, the learning approach and the methodology established by the United Nations Educational, Scientific and Cultural Organization (UNESCO), focused on education on sustainable development (ESD), are taken into consideration. This method provides students with the knowledge, skills, attitudes, and values necessary to overcome global challenges, including climate change, environmental degradation, and loss of biodiversity. The Berlin Declaration on Education for Sustainable Development, adopted at the last UNESCO World Conference, establishes certain commitments to be fulfilled, among which we specifically highlight "harnessing the potential of new digital and green technologies to ensure that access, as well as the development and use of these, is responsible, safe, equitable and inclusive, based on critical thinking and the principles of sustainability, with an adequate evaluation of the risks and benefits and to promote open educational resources, open science, and virtual or distance learning facilities for ESD that are affordable" [26].

The company defined the scope of the practical work and the use of BIM as a requirement for the development of the project. The work to be developed using BIM methodology consisted of a research, development and innovation (R + D + I) center in the automotive sector located in an industrial estate. This development had four premises: Inclusive design, innovation, sustainability and aesthetic. Figure 1 shows these four premises and their impacts. The consideration of these premises in engineering projects in terms of both contribution to the creation of the industrial landscape and the experience of the production spaces are valued. It was mandatory to take into account the current regulations concerning minimum safety and health provisions in the workplace [27], fire safety regulations in industrial establishments [28] and the technical building code (its acronym in Spanish is 'CTE') [29]. The R + D + I center should include at least two engine vehicle benches test areas, a research and development area, an exhibition hall, an administrative and several auxiliary areas. This industrial project was carried out in the mandatory subject of Industrial Technical Projects. This subject has six ECTS (European Credit Transfer and Accumulation System) credits. A total of 35 students took the subject.

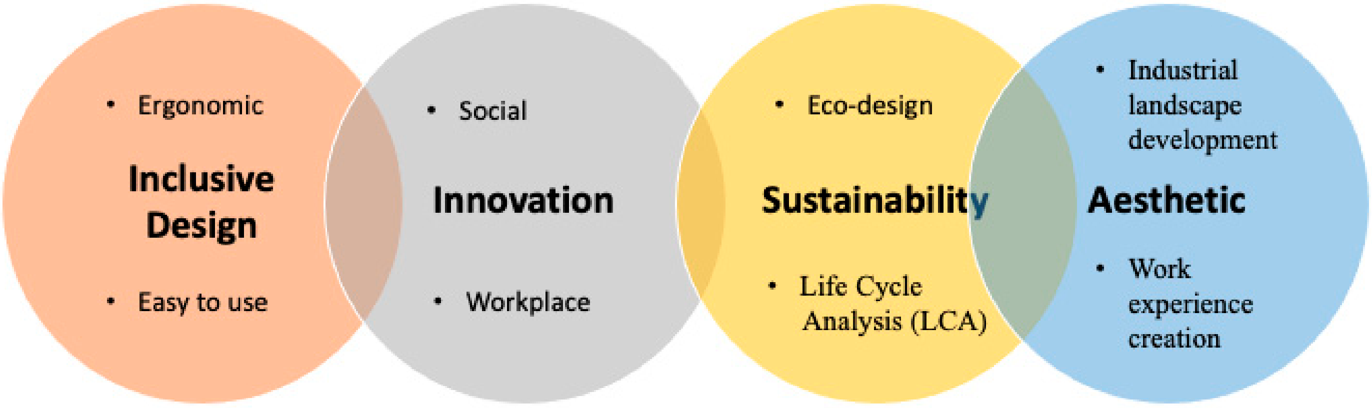


Figure 1. Premises of the practical work of the subject.

The enterprise provided some of the 3D digital models of the production resources and provided training for the development of the industrial process. The work teams used these models and all process data in the development of the workstations. An ergonomic and a study of these workstations were mandatory. The rapid upper limb assessment (RULA) method [30] and the NIOSH equation [31] were chosen as the main tools for ergonomic analysis. Material cycle, energy use and toxic emissions matrix (MET) [32] and life cycle analysis (LCA) under ISO 14040 guidelines [33] were used to study the environmental impact of the proposals. It was a collaborative work through a cloud platform with the organization of a technical office through a central file of the digital model and subprojects, following the active collaborative learning methodology proposed by Blanco et al. [34]. Table 1 shows all software tools and their objectives used in the practical sessions.

Table 1. Practical sessions in laboratory: Tools and objectives.

Software	Objective
REVIT, SketchUp, MagiCAD, Navisworks, Arquimedes Green Building Studio CYPE, Lumion	BIM Methodology Development
DIALux	Lighting Systems Design
SimaPro	Life Cycle Analysis (LCA)
CATIA, DELMIA HUMAN	CAD Design, Ergonomic Analysis
TRELLO	Manage Project

The scientific and technological knowledge that is produced in universities and companies is necessary to be competitive in any economy today. In this complementary process, collaboration between the two is increasingly common. However, this process, which is not without its problems, requires the correct definition of the mechanisms for interaction [35]. Along with the fundamentals of knowledge that have been traditionally taught in engineering schools, there should be the opportunity to practice and acquire a set of skills: creativity, teamwork, problem solving, leadership, and the ability to generate innovative ideas that future employers will demand. To be able to train students with deep technical knowledge and professional skills, universities must carry out their own innovations and find appropriate approaches that serve their students. Previous studies have shown that the university-business collaborative approach is beneficial for both students and the industry. Specifically, the work carried out by Aizpún and other authors [36] presents a novel approach that shows such collaboration. In this experience, teams of students are allowed to work with real industrial projects and apply what they have learned in the classroom. In this line an academic-business team let a collaborative environment between students and professionals to develop student projects. A competition phase was carried out with the presentation of the results by each team. After the decision of the jury (faculty + professionals of the company) the three best projects were awarded.

The methodology applied for the development of the subject has four pashes. Phases, main stages, and actions are shown in Table 2.

Table 2. Project development in technical project subject: phases, stages and activities.

Phases	Actions
Prephase	
Stage 0: Order of magnitude	Meeting of the teaching team and company managers. First approach to the project. Proposal of the type of industrial project to be developed. Conditions of collaboration.
Project phases	
Stage 1: Preliminary	Formation of work teams: assignment of roles. Global vision of requirements and objectives of the project. Concept generation.
Stage 2: Design	Application of sustainability criteria. Exposure sessions and debate between work teams
Stage 3: Development	Generation of digital models. Formalization of the technical project: Project + Process engineering.
Contest phases	
Stage 4: Contest I	Presentation and defense of projects before jury (teaching + company team).
Stage 5: Competition II	Meeting of the teaching team and company managers: Preparation of the training stay.
Stage 6: Competition III	Acquisition by students of specialized training in the company.
Evaluation phases	
Step 7: Evaluation I	Academic evaluation of the projects carried out.
Step 8: Evaluation II	Student survey: analysis of results.

The first two phases constitute the necessary steps for the realization of the technical project. Students were divided into eight work teams of four to five members in Phase 1 stage 1. A work plan suitable for a six ECTS course was established from the beginning of the course. This plan included 4 h per week distributed in two sessions of 2 h. The first session was focused on the presentation of subjects and the fundamentals necessary for the conceptualization and development of the project. During the two hours of the laboratory session (directed sessions) presentations and discussions of the work and partial deliveries are carried out on dates scheduled from the beginning following a process of continuous evaluation. The deliveries are summarized in Table 3.

Table 3. Projects deliveries.

Delivery	Description
3D BIM Model	Final Industrial building in 3D (REVIT model): selection of alternative layouts, construction solutions, materials, orientation, solar study and other studies to verify a sustainable project.
Industrial Process	Development of manufacturing process: layout, number of work cells line balancing, cycle time, production, and ergonomics process analysis
Mechanical, Electrical and Plumbing systems (MEP)	Development of at least one complete system
Sustainability	Project life cycle analysis (LCA) study. Basic analysis of the environmental impact of project implementation.
Final Oral Presentation	Oral presentation and defense of the project in class

Each group has a student who carried out coordination tasks. Each work team complete a document with all requirements of the project as a basic BIM Execution Plan (BEP). This document was developed with the support of the teacher and the collaboration of the professional of the enterprise following ISO 29481 [37] and BIM project execution planning guide, version 3.0 of the Pennsylvania State University [38]. This is one of the key points of the collaboration with the company. Specifications, data delivered, tools, and deadlines, are analyzed not only by the teachers, but also by the company's staff.

In the second phase the proposed competition is developed and in the last phase the evaluation of the results is carried out. For this purpose, we have considered the academic results of the students obtained in the Project, as well as the students' perception of the development of this experience.

Figure 2 shows the evaluation phases of the result of the proposal environment learning. The academic evaluation (Evaluation I) was developed in two steps (Figure 2). Three academic courses were evaluated (one year with BIM methodology under the proposed Enterprise-University environment, one year with BIM methodology without Enterprise-University environment, and one year without BIM methodology and without Enterprise-University environment). The samples of each course were relative to the results of students obtained in their technical projects. A total of 24 samples were considerate.

Following other studies [21,34], in this study, the academic assessment uses eight criteria. These criteria are relative to the overall learning level of the student (OLL) and the level of development of other skills by the student. The overall learning level criterion is evaluated using the level of the technical project proposal developed by each work team. The level of development of other skills is evaluated using seven criteria (S_1 to S_7) (Table 4). The relative importance of each criterion was obtained using best-worst method (BWM) [39]. All criteria were evaluated by four teachers. The individual scores for each criterion were synthesized using the geometric mean. The consistency ratio threshold is 0.4108 [39]. The calculated consistency ratio (Ksi = 0.2239) is less than the threshold, so it is acceptable. The weight of each criterion and each sample's evaluation under uncertainty conditions were described in a positive trapezoidal fuzzy number [40]. The 8 criteria under consideration and the value of the relative importance of each criterion under certainly (values form BWM) and uncertainty conditions are shown in Table 3. All criteria were categorized as a benefit to qualify the performance of each sample. In the first step of the academic evaluation (Evaluation I), the academic results were analyzed under uncertain conditions using the FUZZY VIKOR [41–43] method, and the results for each evaluated sample were classified. Each sample under uncertain conditions was evaluated (FUZZY VIKOR method) using a Likert scale with five levels. Table 5 shows the alternative rating scale under uncertainty conditions. In the second step, possible relationships between the use of the University—Enterprise environment, students' sustainability proposal rate, use of BIM, and the results obtained for the 8 proposed criteria used for the teachers' evaluation were studied. In this second step, an analysis of variance (ANOVA) was performed to determine whether the use of BIM (BIM), the proposed University-Enterprise environment (Enterprise) and the sustainability proposal rate of the students' projects (Sustainability) had statistically significant effects on the results of the teachers' evaluation criteria at the 95% level of confidence.

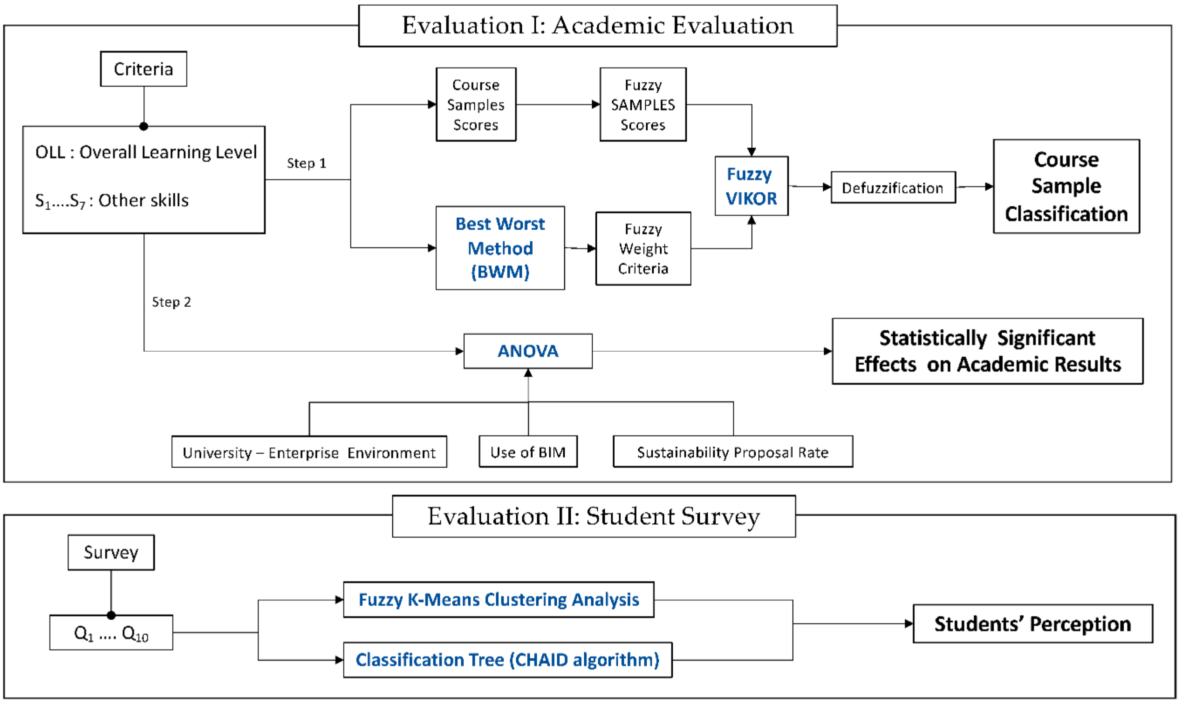


Figure 2. Evaluation phases.

Table 4. Criteria used to academic evaluation: criteria and relative importance of each criterion (weights).

Category	**Criteria**	**Weight**	
		BWM	**Uncertainly**
Overall technical learning	OLL: level of the technical project	0.2239	[0.1221, 0.1628, 0.1832, 0.2239]
Other Skills	S_1: level of use of ICT tools	0.1119	[0.0061, 0.0814, 0.0916, 0.1119]
	S_2: degree of integration and maturity in teamwork	0.1119	[0.0611, 0.0814, 0.0916, 0.1119]
	S_3: level of autonomous learning	0.0896	[0.0489, 0.6512, 0.7327, 0.0896]
	S_4: degree of critical awareness and self-criticism	0.0896	[0.0489, 0.6512, 0.7327, 0.0896]
	S_5: level of reasoning and decision-making	0.1119	[0.0611, 0.0814, 0.0916, 0.1119]
	S_6: level of drafting technical documentation	0.1493	[0.0814, 0.1086, 0.1221, 0.1493]
	S_7: level of presentation and defense of the results	0.1119	[0.0611, 0.0814, 0.0916, 0.1119]

A 5-level liker scale survey was carried out to explore the opinion of the students (Evaluation II). The survey (Table 6) had ten questions with two control questions (questions 6 and 7). The results were analyzed through a fuzzy k-means clustering analysis and a classification tree (CHAID algorithm).

Table 5. Sample Course rating scale.

Linguistic Term	Value	Rating Scale (Uncertainty Conditions)
Very Low	$0.0 < S_1 \leq 0.0$	[0.0, 0.0, 0.5, 1.0]
Low	$1.0 < S_2 \leq 1.5$	[0.5, 1.0, 1.0, 1.5]
Medium Low	$1.5 < S_3 \leq 2.5$	[1.0, 1.5, 2.0, 2.5]
Medium	$2.5 < S_4 \leq 3.5$	[2.0, 2.5, 2.5, 3.0]
Medium High	$3.5 < S_5 \leq 4.0$	[2.5, 3.0, 3.5, 4.0]
High	$4.0 < S_6 \leq 4.5$	[3.5, 4.0, 4.0, 4.5]
Very High	$4.5 < S_7 \leq 5.0$	[4.0, 4.5, 5.0, 5.0]

Table 6. Survey conducted with students on the project, BIM, and university-company collaboration.

Field		Question
On the collaboration with the company	Q1	Is it more motivating to orient the projects of the subject toward a real problem raised in collaboration with a company?
	Q2	Do you think that it is more effective for learning to carry out a project related to an existing company than to recreate a fictitious project?
On conducting an internal competition	Q3	Has establishing an internal subject-company competition as a goal for obtaining a reward increased the degree of involvement in the subject?
	Q4	Do you think that presenting and defending the project for evaluation before a jury (faculty + company representatives) can improve the degree of visibility of students before their incorporation into the world of work?
	Q5	Do you consider the award of a training stay in the company interesting?
About the BIM methodology	Q6	The incidence of the BIM methodology in the project was valued
	Q7	Collaborative and coordinated BIM work, with sharing through a central file and subprojects, was valued
On the typology of the project	Q8	The incidence of sustainability aspects in the project was high
	Q9	Do you consider it interesting to have carried out in the course of Industrial Technical Projects an industrial project understood as industrial building + process development?
	Q10	Would you consider it interesting to carry out a project on an industrial product in the course of Industrial Technical Projects?

3. Results and Discussion

All of the work teams developed their own project in fulfillment of the specifications established in the previous section. The results obtained and the evaluation of this academic proposal are presented in this section.

3.1. Project Phases

Academic incorporation of BIM into the project workflow was proposed, and a basis BIM execution plan (BEP) was developed by each work team as the methodology section describes. This document was basic documentation, description, and display of the process development. The academic and professional responsible defined with all teams the project goal along with their potential relationship to the use of BIM. The objectives were the same in all of the groups. Table 7 shows these objectives, their priority (a lower value shows a higher priority), and their relationship to the uses of BIM. In terms of mode of BIM uses, BIM was used for 3D model construction, structural performance, lighting, and sustainability analysis, as well as model revisions and documentation development. All of these uses are identified with the planning and design phases.

Table 7. Projects objectives and potential BIM Uses.

Priority	Project Objetives	Potential BIM Uses
1	Archive a high quality of design and project documentation	Designer, Design Reviews, 3D Coordination
1	Good monitor the process of design to ensure correct deadline of the project	Designer, Design Reviews, 3D Coordination
1	Include all customers targets	Engineering Analysis
2	Include sustainability solutions	Engineering Analysis

The workflow has been organized from the beginning in the cloud, through the creation of a central file in a location shared by the members of each team and the creation of local sub-projects, allowing simultaneous and synchronized work, even from different locations, following a systematic process. Through this process, the digital data flow establishes connections between the tools and all agents (student work team, teachers, and external professionals) through all phases of design, obtaining the best results through collaboration. Table 8 presents models generated, software and types of files used.

Table 8. Models generated according to technical issue and software used.

Technical Issue	Software	File extension	Version
3D Modeling	REVIT	RVT	Educational
Mechanical, Electrical and Plumbing systems (MEP)	REVIT/DDS Cad/MagiCAD/DIALux	RVT	Educational
Render and video	LUMION		Educational
Modeling and structural analysis	REVIT/ROBOT Structural Analysis Professional/CYPE	RVT/RTD/FC	Educational
Clash detection and coordination in BIM	Navisworks	IFC	Educational
Bill of quantities of BIM models	REVIT/Arquímedes/MSProject/Navisworks	RVT/MCSV/MPP/NWF/NWC	Educational
Building Energy Analysis/Sustainability	Green Building Studio/SimaPro	RVT/pdf, gbXM/DOE-2/.EnergyPlus EcoSpold1/CSV, ILCD	Educational
Industrial Process	CATIA V5 DELMIA HUMAN	CATPART/DWG	Educational

The 3D models and documentation generated correspond to the deliverables defined in the methodology section. All teams following the schedule shown in Figure 3.

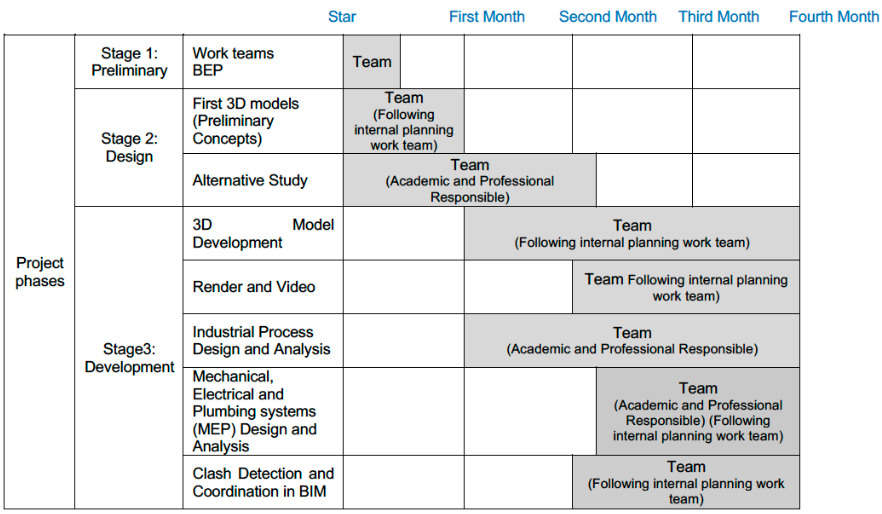
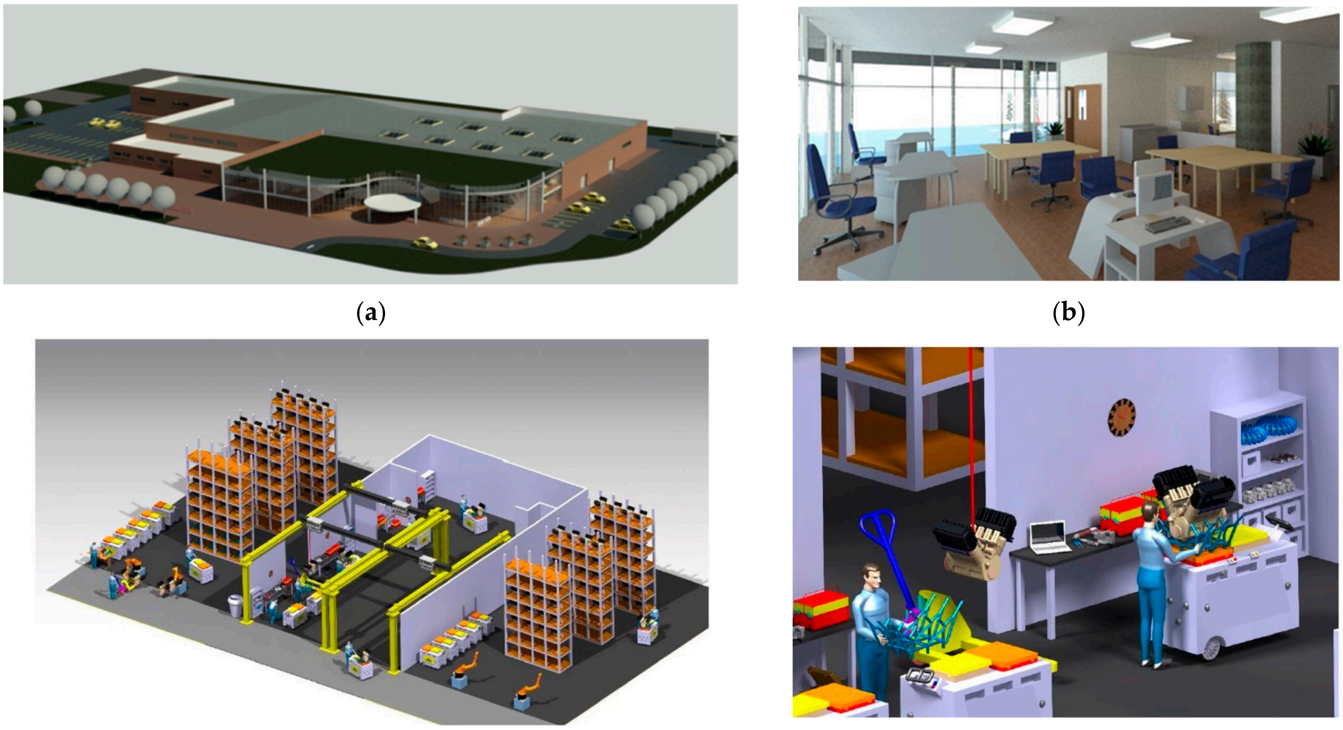


Figure 3. Schedule of project phases.

During the design phases, each team carried out a different project proposal. Figure 4 shows different academic proposals developed by student teams. The contributions in terms of sustainability were outstanding. In general, the projects considered the solar impact in the design phase, trying to take advantage of the solar gain. To show the results of this design, studies of the solar incidence were performed using the software Revit. This allowed the establishment of strategic dispositions of the building with consequent energy savings. Some of the most relevant solutions applied in the projects carried out in relation to sustainability strategies are presented in Table 9 and Figure 5.



(a) (b) (c) (d)

Figure 4. Academic proposal, industrial building, and process: (**a**) Exterior of industrial building (**b**); interior of the administrative area; (**c**) interior of the industrial area; (**d**) work cell.

Table 9. Sustainability strategies: academic proposals.

Field	Action
Orientation	Solar impact Study (Revit Model)
Industrial building envelope	Intensive and extensive green roofs Exhaustive control of the thermal load of the building in vertical enclosures. Photocatalytic pavements in horizontal enclosures
Distribution of spaces	Design of outdoor patios inside the industrial building with trees and benches. Natural ventilation and lighting, with the provision, of darkening devices, transformation of direct radiation into diffuse, uniform distribution of light, conditioning equipment or devices, and penetration of light in places away from light inputs
Facilities	Photovoltaic panels installed on the roof Construction of Canadian wells Low consumption lamps and high efficiency luminaires Separation networks, recovery and reuse of gray water Life-cycle analysis (LCA) of the elements of the production line
Waste management	Installation of a steam boiler and a turbine to energetically take advantage of waste from the exhaust gases from the engines in the bench tests

(**a**)

(**b**)

(**c**)

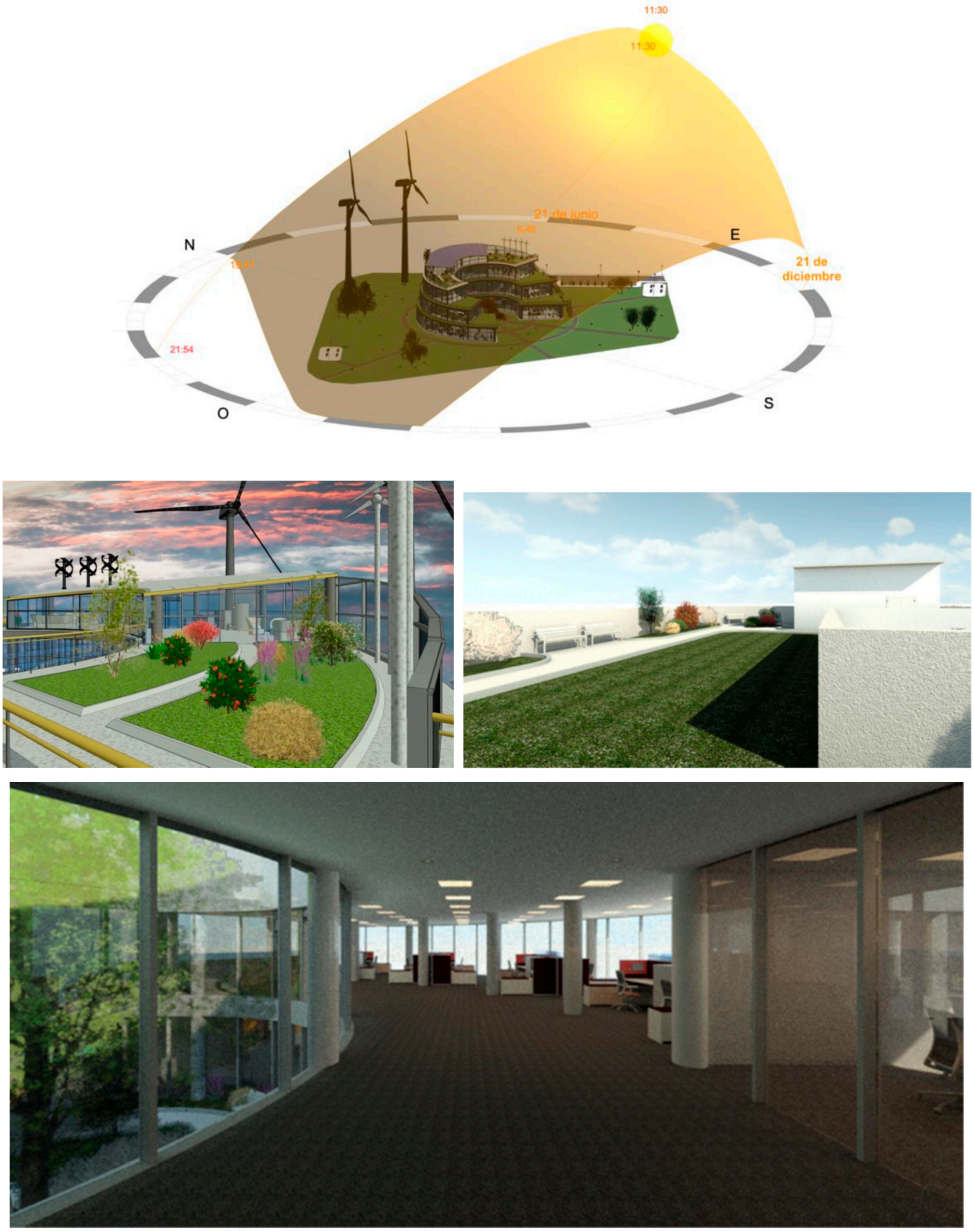


Figure 5. Sustainability strategies: (**a**) Solar study. Revit model (**b**) Examples of vegetation cover. Revit model; (**c**) distribution of spaces, interior administrative area.

3.2. Evaluation Phases

Once the experience carried out on the subject of Industrial Technical Projects was concluded, the following actions were carried out during the evaluation phase to analyze the impact on the results.

3.2.1. Faculty Opinion—Academic Evaluation of Projects

The academic evaluation of the results obtained for each course was performed for three different academic courses (an academic course with BIM and without company collaboration, an academic course with BIM and with company collaboration, and an academic course without BIM and without company collaboration). The data from each course (24 samples) were considered, and each variable described in Table 3 was qualified by means of a Likert scale from one to five. Table 10 shows a summary of the results obtained for each comparison variable.

Table 10. Teacher evaluation of criteria: statistical results.

	OLL	S_1	S_2	S_3	S_4	S_5	S_6	S_7
Minimum	2.00	1.000	1.000	1.000	2.000	2.000	3.000	3.000
Maximum	5.000	5.000	5.000	5.000	4.000	5.000	5.000	5.000
Freq. of Minimum	4	3	3	3	4	2	7	7
Freq. del Maximum	5	4	5	4	7	3	4	6
Mean	3.625	3.583	3.750	3.500	3.125	3.500	3.875	3.958
Std. deviation ($n-1$)	1.013	1.176	1.189	1.180	0.680	0.834	0.680	0.751

Alluvial Diagram (Figure 6) shows a graphical representation of possible correlations between the use of BIM (BIM), university-enterprise collaborative learning environment (Enterprise), sustainability student proposal rate (Sustainability), and overall learning level (OLL) results representing them as flows. Each height rectangle is proportional to its number of samples (e.g., there are 16 samples with the use of BIM, of these samples, 8 samples are with the use of University-Enterprises environment, all of them with a high rate of sustainability proposal and of these samples, 5 samples with very high overall level and 3 samples with medium overall level). These possible correlations are represented with curved lines whose width is proportional to their values [44].

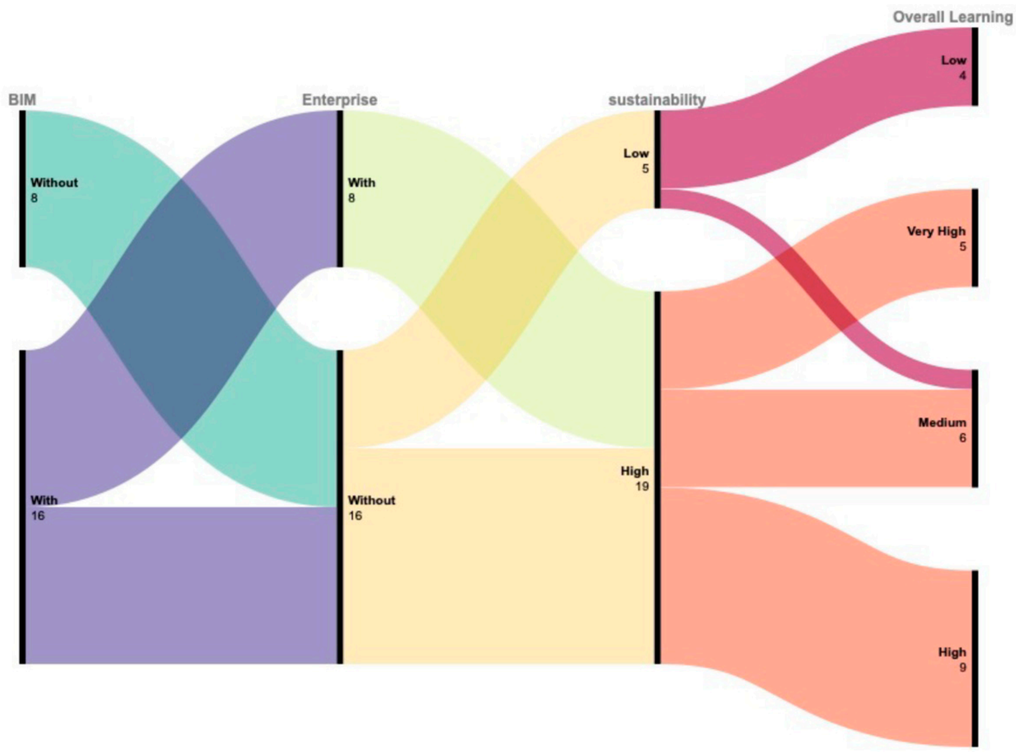


Figure 6. Academic Evaluation: Alluvial Diagram (score < 2: low, scores 2 to 3: medium, scores 3 to 4: high, scores ≥ 4: very high. Data displayed graphically using RAWGraphs [45]).

The academic results were rated using the FUZZY VIKOR method, considering the criteria and their relative importance shown in Table 2. The values obtained for the three academic courses are shown in Table 11. The samples are identified by four numbers: the first represents the use of BIM (1: Used of BIM, 0: Not used BIM), the second represents the use of the university-company environment (1: Used, 0: Not Used), the third represents the rate of sustainability proposal (1: High, 0: Low), and the fourth is related to the project of each work team developments in each academic course.

Table 11. Teacher evaluation: Fuzzy VIKOR results and ranking courses by S, R and Q (v = 0.5).

Course	S_i		R_i		Q_i	
	Value	Order	Value	Order	Value	Order
C_1_1_1_3	0.12697	**1**	0.32353	**1**	0.00390	**1**
C_1_1_1_6	0.12699	**2**	0.32354	**2**	0.00394	**2**
C_1_1_1_1	0.14751	4	0.33298	3	0.01569	**3**
C_1_1_1_5	0.12904	3	0.37680	5	0.01603	**4**
C_1_0_1_6	0.16212	5	0.37604	4	0.03177	**5**
C_1_0_1_3	0.20804	6	0.38615	7	0.07390	**6**
C_1_1_1_4	0.21603	7	0.38407	6	0.07751	7
C_1_1_1_2	0.21720	8	0.39066	9	0.07853	8
C_1_1_1_7	0.21721	9	0.39167	10	0.07953	9
C_0_0_1_4	0.22576	10	0.38948	8	0.08082	10
C_1_1_1_8	0.22822	11	0.39168	11	0.08396	11
C_1_0_1_2	0.23608	12	0.40870	13	0.09110	12
C_1_0_1_7	0.24630	13	0.40871	14	0.09523	13
C_0_0_0_2	0.25016	14	0.40490	12	0.10846	14
C_1_0_1_1	0.25490	15	0.41735	16	0.11481	15
C_0_0_1_1	0.27651	17	0.41548	15	0.12252	16
C_0_0_1_3	0.31046	19	0.42909	17	0.14073	17
C_1_0_1_4	0.32346	24	0.47424	24	0.14282	18
C_1_0_1_5	0.31074	20	0.46720	22	0.15160	19
C_1_0_0_1	0.31079	21	0.46728	23	0.15166	20
C_0_0_0_1	0.25962	16	0.44249	19	0.15460	21
C_0_0_0_3	0.27656	18	0.44776	20	0.16321	22
C_0_0_1_2	0.31083	22	0.44249	19	0.17472	23
C_0_0_0_4	0.31517	23	0.45317	21	0.18080	24

By using BIM, enterprise, and sustainability as independent variables and overall learning level (OLL) and skills S_1 to S_7 as dependent variables, eight analyses of variance (ANOVA) were performed. BIM has two groups: Use of BIM and Not use of BIM. Enterprise has two groups: Use of university-enterprise collaborative environment or not use of this environment. Sustainability has two groups: High rate of sustainability proposal or low rate. The ANOVA tests were performed to determine whether the use of BIM, use of University-Enterprise environment, and Rate of sustainability proposal had significant impacts on the values of the level of overall learning level (OLL) use of ICT tools (S_1), degree of integration and maturity in teamwork (S_2), level of autonomous learning (S_3), degree of critical awareness and self-criticism (S_4), Level of reasoning and decision-making (S_5), level of drafting technical documentation (S_6) and level of presentation and defense of the results (S_7) The results of the ANOVA tests where independent variables have got significant effects, are shown in Table 12 (p-values in bold correspond to significant effects).

Table 12. Teacher evaluation of criteria: ANOVA results.

	Source	DF	SS	RMS	F	*p*-Value	Effect Size (η^2)
OLL	BIM	1	1.644	1.644	5.769	**0.026**	0.0651
	Enterprise	1	1.451	1.451	5.089	**0.035**	0.0578
	Sustainability	1	3.674	3.674	12.888	**0.002**	0.1346
	Error	20	5.701	0.285			
	Corrected Total	23	23.625				
	Source	**DF**	**SS**	**RMS**	**F**	***p*-Value**	**Effect Size (η^2)**
S_1	BIM	1	4.568	4.568	4.687	**0.043**	0.1255
	Enterprise	1	9.131	9.131	9.370	**0.006**	0.2229
	Sustainability	1	1.761	1.761	1.807	0.194	0.0524
	Error	20	19.489				
	Corrected Total	23	31.833				
	Source	**DF**	**SS**	**RMS**	**F**	***p*-Value**	**Effect Size (η^2)**
S_2	BIM	1	6.835	6.835	6.051	**0.023**	0.1738
	Enterprise	1	6.772	6.772	5.995	**0.024**	0.1724
	Sustainability	1	0.658	0.658	0.582	0.454	0.0198
	Error	20	22.594				
	Corrected Total	23	32.500				
	Source	**DF**	**SS**	**RMS**	**F**	***p*-Value**	**Effect Size (η^2)**
S_3	BIM	1	5.739	5.739	4.539	**0.046**	0.1521
	Enterprise	1	2.332	2.332	1.844	0.190	0.0679
	Sustainability	1	1.962	1.962	1.552	0.227	0.0578
	Error	20	25.288	1.264			
	Corrected Total	23	32.500				
	Source	**DF**	**SS**	**RMS**	**F**	***p*-Value**	**Effect Size (η^2)**
S_4	BIM	1	2.283	2.283	7.837	**0.011**	0.1769
	Enterprise	1	0.046	0.046	0.159	0.695	0.0043
	Sustainability	1	0.049	0.049	0.168	0.686	0.0046
	Error	20	5.826	0.291			
	Corrected Total	23	32.500				
	Source	**DF**	**SS**	**RMS**	**F**	***p*-Value**	**Effect Size (η^2)**
S_6	BIM	1	2.889	2.889	8.294	**0.009**	0.2138
	Enterprise	1	0.014	0.014	0.040	0.843	0.0013
	Sustainability	1	0.658	0.658	1.888	0.185	0.0583
	Error	20	6.968	0.348			
	Corrected Total	23	10.625				

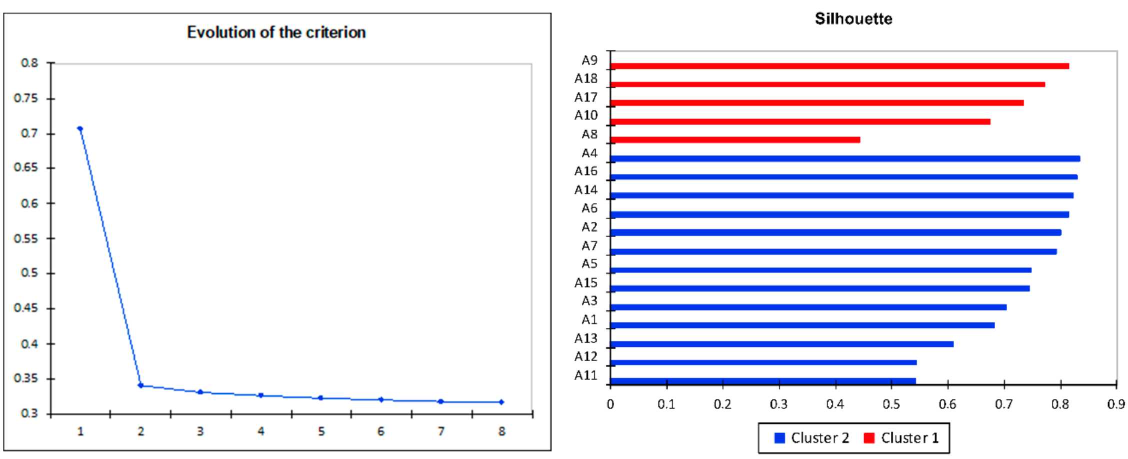
3.2.2. Students' Perception

The second action carried out in the evaluation phase consisted of a study of the opinions of the participating students through a survey of 10 questions, grouped into 4 fields. The assessment of the survey was performed using a Likert scale from 1 to 5, with 1 not agreeing and 5 totally agreeing (Table 13). Questions 6 and 7 were used as control questions. A contradictory answer between these 2 questions would invalidate the answers provided by the student. The survey was answered by 18 students (51.14%). Taking into account the control questions, none of the samples received were rejected. Table 4 shows the results obtained for each of the questions. A total of 83.33% of the students absolutely agree that it is more motivating to guide the projects of the subject toward a real problem raised in collaboration with a company and that learning is more effective in this way. The rest (16.67%) consider this strategy adequate. A total of 77.22% of the students positively value the implementation of the project with BIM methodology; of these, 33.33% completely agree with this assessment. A total of 77.8% of the students think that a contest increases involvement in the subject. In the opinion of the students, the training stay at the company and presenting and defending the project for evaluation before a jury (faculty + company representatives) does not improve the degree of visibility of the students before their next incorporation into the world. labor. A total of 98.99% of the students agree that the incidence of sustainability aspects in the project was high (50% of them totally agreed). A total of 83% of the students considered it interesting to have carried out an industrial project understood as industrial building + process development. More than 20% of the students agree that it would be interesting to carry out a project of an industrial product in the subject of Industrial Technical Projects.

Table 13. Survey conducted with students on the project, BIM, and university-company collaboration: Statistical Results.

Variable	Minimum	Maximum	Mean	Std. Deviation
Q1	4	5	4.83	0.38
Q2	3	5	4.39	0.85
Q3	1	5	2.61	1.24
Q4	1	5	3.28	1.27
Q5	1	5	2.67	1.57
Q6	1	5	3.56	1.38
Q7	1	5	3.22	1.70
Q8	1	4	3.00	0.84
Q9	1	4	3.67	1.49
Q10	2	4	3.22	0.73

Through a fuzzy k-means clustering analysis (coefficient of fuzziness 1.05) [46], the samples obtained were classified into two clusters. The index of dissimilarity used was the Jaccard index. The optimal cluster number was chosen with the elbow curve method using the evolution curve of the clustering criterion (Figure 5) [21,47]. With 2 clusters, the minimum value is the within-cluster sum of squares, and the maximum value is the between-class sum of squares. Cluster 1 contains 5 samples and corresponds to the samples in which the answers to questions Q3 to Q9 obtained a lower score and that to question Q10 a higher score. This group could be identified as having less interest in BIM, the type of projects that can be developed with BIM, and the approach of the competition within the subject, as well as a greater interest in guiding the subject in a product development project. Cluster 2 contains most of the samples, presenting samples with high interest in BIM and the projects that can be developed with BIM. The average silhouette [48] mean width was 0.72. The graph silhouette shows an acceptable grouping of the samples in their respective clusters (Figure 7).



(**a**) (**b**)

Figure 7. (**a**) Evolution of the clustering criterion. (**b**) Silhouettes of clusters.

Question Q6 (Evaluates the implementation of the project with the BIM methodology) was classified into 3 levels (Low, scores 1 and 2; Medium, score 3; High, scores 4–5). Taking this question as a dependent variable and the rest of the questions as explanatory variables, the classification tree shown in Figure 8 was developed using the chi-squared automatic interaction detector (CHAID) algorithm [49]. The significance level used was 5%. The tree shows 5 nodes selecting questions Q2, Q6, and Q10. From the analysis of the classification tree, it can be deduced that 77.8% of students consider that for learning, it is more effective to carry out a project related to an existing company (Q2), with the realization of the project with BIM methodology being of great value (Q6). Of these samples, 55.6% also show no interest in carrying out a project related to an industrial product (question Q10).

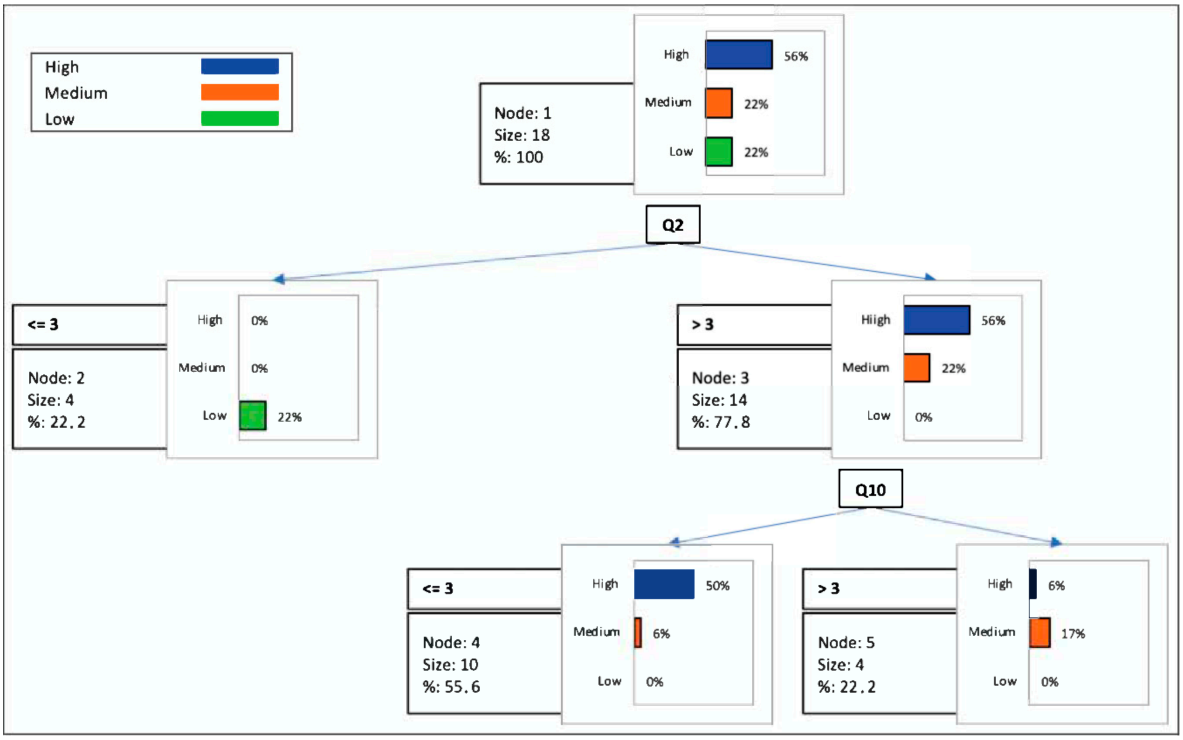


Figure 8. Classification tree of the samples.

4. Discussion

The academic results of all teams were very satisfactory. A comparison with the results of previous courses showed improvement in the quality of the work and therefore in the academic results. The use of BIM, the use of the University-Enterprise environment and the sustainability proposal rate have statistically significant effects on the values of the level of overall learning level (OLL). The ranking course (VIKOR method) shows better results for samples with the University-Enterprise environment (top four positions). The top nine positions correspond to samples with the use of BIM. The first sample without the use of BIM was ranked 10th. The *p*-value for the analysis of the variance F-test ($p < 0.005$, 95% confidence level) suggests that the use of BIM (BIM) is significant in the results of the use of ICT tools (S_1), degree of integration and maturity in teamwork (S_2), level of autonomous learning (S_3), degree of critical awareness and self-criticism (S_4), and level of drafting technical documentation (S_6). These results show that the BIM methodology provides an exceptional opportunity to carry out a collaborative team project, with coordination and leadership tasks being essential in the professional practice of an engineer. This result is in agreement with other academic BIM proposals [22,50–53]. The use of the University-Enterprise environment is only significant in the results of the degree of integration and maturity in teamwork (S_2). There are no statistically significant differences in the results of the level of reasoning and decision-making (S_5) and the level of presentation and defense of the results (S_7). These results need further research.

High levels of motivation were observed in the students in the face of a specific goal linked to the academic purpose of the subject. The university-business collaborative learning environment proposed has motivating factors common to other studies [54–60]. As other studies denote [61,62], the inclusion of a real and competitive challenge, posed in collaboration with a business environment, was more effective than working on a fictitious case, and it is an important component of engineering education. The students found that presenting their projects to the rest of the teams, teachers, and professionals of the participating company was satisfying and that their personal relationships increased with your curricular activities. Koola and Subramanian report these results in their collaborative real competition challenge but with extracurricular activities [60].

Although uncertainty was incorporated through fuzzy logic in the grouping of the different samples obtained in the survey, the study was limited by the sample size, the use of the fuzzy clustering model itself, and the chi-squared automatic interaction detector (CHAID) algorithm used in the development of classification tree. Also, the results were limited by the VIKOR FUZZY method. This needs further investigation by comparing the results obtained with those obtained by other methods, as suggested by other studies [63,64].

5. Conclusions

From the results of this study, the following conclusions can be drawn:

- The use of BIM and the use of the collaborative business academic learning environment implementation in the engineering project subject is significant in the overall learning level (OOL) assessment results, and they could be an excellent approach for developing the practice of the course (particularly the use of the collaborative business academic learning environment presented).
- The skills assessment results have higher average values in courses in which BIM with or without the proposed collaborative business academic learning environment was used. The use of BIM is significant in the skills assessment results. Only regarding the level of presenting and defending results (S_7) and the level of reasoning and decision-making (S_5), there is no significant relationship to the use of BIM.
- The use of the collaborative business academic learning environment is significant in the skills assessment results of the level of ICT tool use (S_1) and degree of integration and maturity in teamwork (S_2)
- Student perception shows a positively influenced by the use of BIM and the collaborative business academic environment learning presented in this study. In addition, another important issue derived from the incorporation of the company into the development of the subject was that competitiveness and motivation could be an important role.
- Considering the sustainability proposal rate, the sustainability aspects were applied more easily thanks to the proposed methodology. BIM methodology can be of great help in the development of industrial projects due to the interoperability existing between different programs to carry out not only the design of the project but also certain studies and analyses necessary for the achievement of a digital model based on sustainability criteria.

This work contributes to increasing the scope of the collaborative business-academic learning environment and, in particular, aims to support the learning on BIM projects. The collaborative business-academic environment is an interesting topic of research and a useful application in technical project learning. The approach developed in this work could be used in other subjects (e.g., final degree project, basic project subject) or professional courses in BIM, adapting the specifications to the specific requirements of these subjects or courses. The results need further studies (an in-depth study of the fuzzy model, a comparative study of the results using different Multiple-criteria decision-making (MCDM) Methodologies), and to continue with the collaborative university-business learning environment approach to validate the results presented in this work.

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