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A Comparative Study of the Use of Building Information Modeling in Teaching Engineering Projects

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ABSTRACT Industrial engineering has incorporated building information modeling (BIM) into its curriculum. This work is a comparative study of the teaching results of engineering projects with and without the use of BIM. This study reports the results of a BIM implementation for a basic engineering project subject in an industrial engineering school. The results were evaluated by surveying the opinions of teachers and students. The teacher evaluations were classified using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) under certain and uncertain conditions. To uncover the possible relationship between students' overall satisfaction, the use of BIM, and criteria used for the teachers' evaluation, a factor analysis and multifactor analysis of variance (Multifactor-ANOVA) were performed. The teacher evaluation showed better results in courses with greater use of BIM. The results indicate that the use of BIM in the engineering project subject could improve the acquisition of the assessed skills and positively influence student satisfaction.

INDEX TERMS BIM, engineering education, learning, project engineering.

I. INTRODUCTION

Building information modeling (BIM) is defined in terms of a 3D intelligent virtual model, collaborative process, or software application [1], [2]. The National Building Information Model Standard (NBIMS) defines BIM as "a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onward", which is similar to the scope of industrial engineering [3]. BIM is a collaborative process and requires a large, multidisciplinary team. Different professionals from the technical project fields are involved in the building life-cycle, which makes BIM highly complex and requires the involvement of multiple disciplines that can interact in a natural way in a BIM environment [4].

VDC (Virtual Design and Construction) of buildings/plants [5] has been used in the United States for several years. VDC includes the design and construction of a virtual building model using computer applications that approximate the finished building so that the processes inherent to the construction, its later use, and its end-of-life can be simulated with the greatest fidelity (for a complete building life-cycle). VDC allows the user to distinguish between two environments, one based on a virtual design and optimization and the other on physical materialization. These environments interact to achieve the project objectives. VDC allows users to find parallels between current product-process concepts and implementation in industrial engineering.

In studies that were conducted to observe BIM implementation in university education and its professional development, the results demonstrate improvements in the application of BIM in educational and professional contexts. These studies also assessed the effectiveness of BIM education in professional colleges and in the industry practices of staff with knowledge of BIM. The results show a growing interest in BIM implementation in university education and suggest that greater and more proactive involvement of all the affected areas could be the solution to advancing

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BIM education [6]. The scientific literature indicates that the academic implementation of BIM focuses on project-based learning [7], problem-solving learning [8] or multidisciplinary approaches [9]. Currently, interest in BIM implementation [10]–[12] and its implementation in education is increasing [13]–[15]. Yalcinkaya and Singh identify twelve trends and future opportunities for BIM, including academic and industry training [16]. Institutions have employed a feedback mechanism to capture student experiences with respect to the use of BIM in their curriculum [17], [18], access to facilities [19], students' proficiency in BIM [20], students' profile [21] and the effectiveness of guided autonomous learning [22].

The implementation of BIM is complex, and there is a lack of awareness and information about BIM [23]. Khosrowshahi and Arayici provide strategies and recommendations that focus on organizational culture, education and training, and information management for BIM implementation in the construction industry [24]. Uhm, Lee, and Jeon describe eight BIM job types, BIM project manager, director, BIM manager, BIM coordinator, BIM designer, senior architect, BIM mechanical, electrical, and plumbing (MEP) coordinator, and BIM technician, and 43 competencies subcategorized into essential, common, and job-specific competencies for the eight BIM jobs. These competencies could allow universities to develop BIM-related courses depending on their educational goals [25]. Problems in the academic implementation of BIM environments arise from poor training and lack of experience in BIM. Although BIM is very useful in practice and its development potential is high, the barriers to its propagation are caused by high cost [26]–[28]. However, the evaluation of BIM implementation using appropriate metrics is a factor to consider in the future success of BIM training [29]. BIM has important implications and advantages for the efficient design of structures and facilities [30]–[33]; thus, its inclusion in industrial engineering training can be of great assistance in the current conception and implementation of technical industrial projects. Despite the advantages of a multidisciplinary approach to BIM training and implementation [9], [34] and the relationship between the product-process concept, development, and implementation of industrial engineering projects and the BIM approach [35]–[47], there are few reports on the introduction of BIM in industrial engineering degrees compared to the experience of BIM implementation in degrees related to architecture or construction engineering. The literature shows a general framework for the academic implementation of BIM in architecture, engineering, and construction [38], [39] or a specific framework in architecture [40], [41]. The implementation of BIM for civil engineers by Barison and Santos introduces principles of BIM first into a basic subject and then between disciplines [42]. D. Ekundayo, Shelbourn, and Babatunde develop a framework to analyze quality, safety, and carbon emissions using BIM in real construction projects [43]. Moon *et al.* use a model based on BIM to visualize risk assessment and workspace conflict optimization

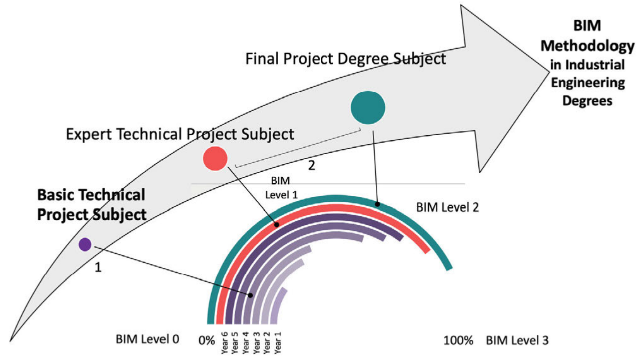

FIGURE 1. BIM implementation in engineering project subjects: Phases, students' BIM knowledge and experience level gain proposal.

in civil engineering projects [44]. Sampaio describes a conflict analysis methodology based on an architectural 3D/BIM model in the academic environment for civil engineers [45]. Nascimento *et al.* proposed a methodology for the interdisciplinary management of construction projects by integrating BIM and lean thinking, which is widely used in industrial engineering projects, to improve the production planning and control of pipe-rack modules in an industrial facility [46]. From the perspective of sustainable development civil engineering projects, there are different approaches to integrating BIM and the LCA methodology used in industrial engineering projects [47]. All of these approaches could be implemented to include BIM in engineering project subjects.

Implementation and impact evaluation of BIM into engineering degrees are current topics of interest. Although different applications of BIM show strategies and methodologies close to industrial engineering, few proposals and practical studies of academic implementation of BIM into industrial engineering degrees exist. BIM implementation in an existing curriculum in an industrial engineering school is complex. This work presents a comparative study of BIM implementation in current subjects within a collaborative learning methodology for an engineering project subject in an industrial engineering school without curriculum restructuring. This evaluation considers the evaluation of teachers and students' overall perception of a basic industrial project subject with and without the use of BIM. The research questions of the study are as follows: Is there a difference in the results of the subject for each evaluated course in terms of the use of BIM? Are the rates of students who used BIM and the student satisfaction level significant in the results of assessments of skill and overall learning level?

II. METHOD

BIM was incorporated into engineering project subjects within the mandatory training plan for all degrees in industrial engineering [48]. This implementation was applied in two phases following the approach by Bernstein and Jezyk [49]. The phases are basic project subject (phase 1) and expert

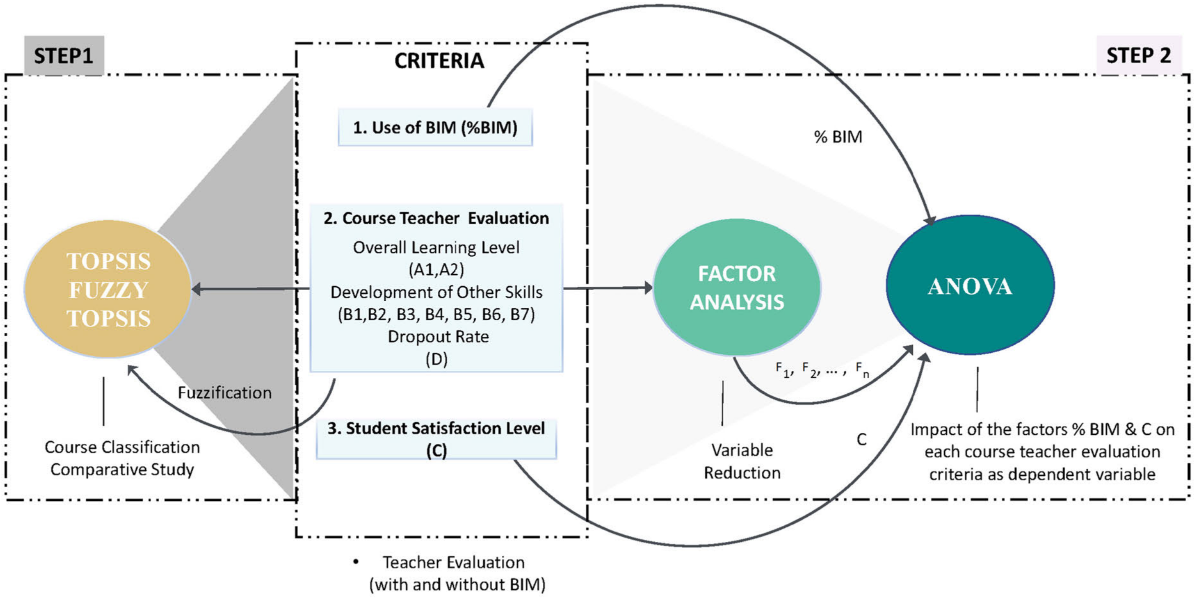

FIGURE 2. **Proposed steps to analyze BIM impact evaluation in basic industrial engineering subject.**

technical project subject – final project degree subject (phase 2) [49], [50]. (Fig. 1).

This study presents the results of the phase 1 evaluation and completes an initial evaluation of BIM implementation in a school of industrial engineering. BIM impact evaluation in basic industrial engineering subjects (phase 1) focused on teacher evaluations and overall student perceptions of the subject. After implementation was defined, its impact was evaluated by teachers regarding the use of BIM. An analysis was thus performed by comparing a basic technical project subject in the different engineering degrees with and without the use of BIM during each year of implementation. The study was developed in two steps (Fig. 2). In the first step, the results of basic technical project subjects for each degree (first three years without BIM methodology and last three years with BIM methodology) were analyzed under certain conditions (using the TOPSIS method) and uncertain conditions (using the FUZZY TOPSIS method), and the results for each evaluated course were classified. In the second step, a possible relationship between students' overall satisfaction, use of BIM, and the results obtained for 10 criteria used for the teachers' evaluation of each evaluated course were studied. In this second step, to reduce the number of variables, exploratory factor analysis and a multifactor analysis of variance (multifactor ANOVA) were performed to determine whether the rates of students who used BIM (%BIM) and the student satisfaction level (C) had statistically significant effects on the results of the course teachers' evaluation criteria.

A. BIM IMPLEMENTATION IN BASIC PROJECT SUBJECT FOR UNIVERSITY DEGREES IN INDUSTRIAL ENGINEERING

Phase 1 of BIM implementation was developed within the mandatory training plan for all degrees in industrial engineering in the basic technical project subject (second year, fourth quarter). All degrees in industrial engineering include this subject within their mandatory training. This basic project subject has 4.5 ECTS credits, and the practical portion of each of these subjects amounts to 50% of the ECTS credits of the total for each subject. The implementation was performed for all degrees: mechanics (Mec), organization (Org), chemistry (Che), electricity (Ele), electronics and automation (Aut), and industrial technologies (Tec). For this class, during the second year of the engineering degrees, the necessary BIM concepts and tools were introduced gradually so that students could perform visualization tasks with sufficient autonomy as well as 3D modeling and simulation in BIM.

For all degrees, the use of BIM was proposed voluntarily, except for the degree in industrial technology. For this degree, the use of BIM was mandatory during the last academic year considered in this study. Parallel to the levels defined in BIM [51]–[54] and upon completing this first phase, students could gain BIM knowledge and experience from level 0 to level 1-2 (Fig. 1).

BIM implementation phase 1 was performed only during the practical portion of the mandatory second-year basic technical project subject for degrees in industrial engineering by adapting the collaborative methodology described by Ghaffarianhoseini *et al.* [23], Moon *et al.* [44], and Blanco *et al.* [55]. The proposed methodology for the subject is based on collaborative learning, implemented project-based learning [56], peer instruction [57] and flipped classroom [58] methodologies. This methodological proposal focuses on an active collaboration learning system [55] and just in time teaching [59], in which the teacher guides the setting of objectives and tasks and shares in the development of the practical classes necessary to carry out the technical project proposal.

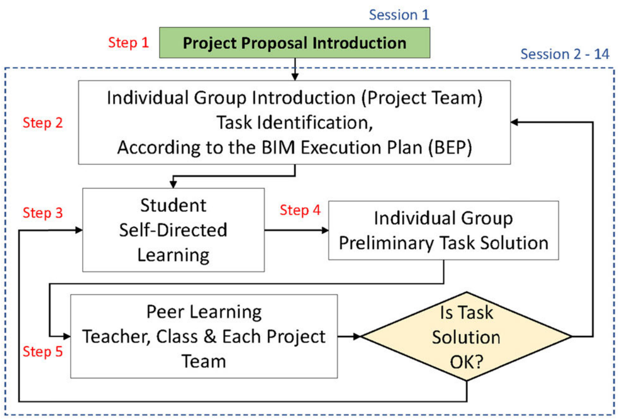

FIGURE 3. **Workflow for each practical work session of technical project proposal into active collaborative methodology using BIM.**

The technical project proposal involves the concept development of an industrial plant. The project is the same for all grades, and only the proposed facilities vary by the disciplines of each grade (mechanics and organization develop water and wastewater systems, chemistry and industrial technologies develop heating, ventilating and air conditioning (HVAC) installations, and electricity and electronics and automation develop electrical systems). Students in each grade are divided into project teams of two students. Each project team develops its own project for the practical portion of the subject.

The workflow of the project proposal is divided into 15 practical work sessions. Each work session, with BIM use, follows the steps shown in Figure 3. All work session activities are conducted in work teams of two students, either in person or remotely. The work teams provide their own solutions for each activity, and their proposals are discussed in a face-to-face session with the entire class. The teacher gives all the specifications of the project proposal in the first session. Each team, following its own BIM execution plan (BEP) [60], creates its project, introduces the project specifications and starts to create the site plan (the context of the industrial plan) in Revit. In the next sessions, each project team defines and builds a model starting with the general building components (preliminary layout, foundations and structures, walls, floors, and roofs) and adding more detailed components (stairs, rooms, furniture, facilities, assembly line). Each project team, according to the disciplines of its grade, designs and builds the facilities (water and wastewater systems, HVAC installations or electricity) required by the teacher. All team members work with the same assumptions of collaborative work in their central model only with their project team. Each project team prepares its project documentation following general criteria for the drawing-up of the documents that constitute a technical project [61], [62] and the final presentation of projects during the last week of class.

Different specific resources were used for BIM implementation and were incorporated into the different years of the classes in this study. Their incorporation considered the tasks and objectives described in each phase. To this end, only Revit Autodesk©, Revit MEP©, RevitStructure©, BIMVision©, and MagiCAD©were used in phase 1. Figure 4 shows an example of a BIM implementation phase 1 academic project developed by students.

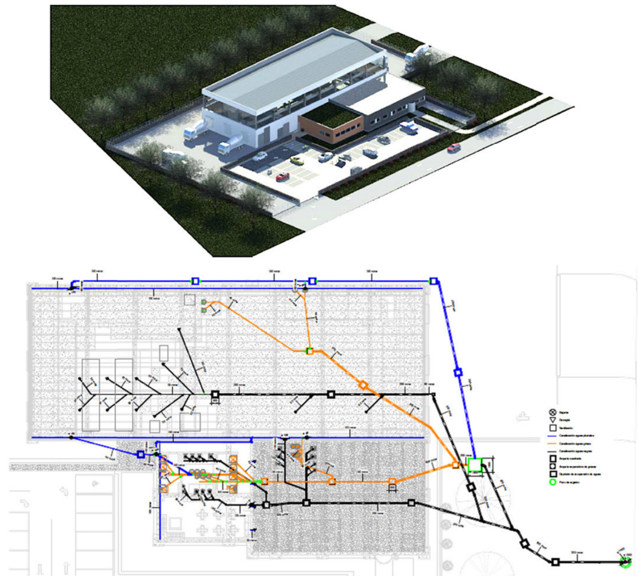

FIGURE 4. **Academic BIM project sample using Revit©: Industrial plant 3D view and water and wastewater systems.**

B. USE OF BIM: COMPARATIVE STUDY

Blanco *et al.* [63] used an analytical hierarchical process (AHP) [64] as a tool to compare the adaptation of a collaborative methodology for technical project classes with the use of other methodologies. This process involved the intervention of three expert decision makers with academic and industrial experience in the preparation and implementation of technical projects. During the AHP, they considered 4 criteria and 11 subcriteria to obtain the vector of priorities for the consolidated matrix by means of the row geometric mean method (RGMM). They subsequently produced a classification of each course using a Likert scale to score each criterion. In following up this idea, we used the relative importance of each criterion obtained by Blanco *et al.* [52] together with TOPSIS [65], [66] to classify the results for each evaluated course (step 1). This classification was analyzed under conditions of certainty and uncertainty.

Table 1 shows the 10 criteria under consideration, the value of the relative importance of each criterion under certainty and uncertainty conditions, and its classification as a cost or a benefit to qualify the behavior of each course through TOPSIS and Fuzzy TOPSIS. As Blanco *et al.* [63] note, these criteria are grouped into four categories: overall learning level of the student, level of development of other skills by the student, satisfaction level of the student (C) and student dropout rate for the subject (D). The overall learning level criterion is evaluated using the criteria subject passing rate (the number of students who pass the course compared with the number of students who are tested (A1)) and level of grades (average value of the grades from examinations (A2)). The level of development of other skills is evaluated using the following criteria: level of use of ICT tools (B1), degree of integration and maturity in teamwork (B2), level of autonomous learning (B3), degree of critical awareness and self-criticism (B4), level of reasoning and decision-making (B5), level of drafting technical documentation (B6), and level of presentation and defense of the results (B7).

The values under uncertainty conditions were described in positive triangular fuzzy numbers [77]. To evaluate each course under certain conditions (TOPSIS method), a Likert scale with five levels was applied. Table 2 shows the alternative rating scale under uncertainty conditions (Fuzzy TOPSIS method). When using the Wilcoxon signed rank test [79], [80], the existence of statistically significant differences between the TOPSIS and fuzzy TOPSIS results was evaluated, taking into account the ranking results of the samples for each method.

To reduce the number of variables, an exploratory factor analysis was performed [81]. Through this analysis, the results for each evaluated course were subjected to an analysis of variance (ANOVA) to determine whether there were significant differences at the 95% level of confidence (step 2). This analysis was performed for the results of the A1, A2, B1 to B7 and D criteria to determine which of the factors (use of BIM (%BIM) and student satisfaction level (C)) were significant in the results. The analysis was conducted using Statgraphics©software. The data corresponding to the last 6 years in which the second-year basic technical project subject was taught were considered. During three of these 6 years, the students worked on the practical part of the subject, developing their projects with the concepts of the BIM methodology on a voluntary basis for all degrees and a mandatory basis for only one degree during the last year.

III. RESULTS

BIM for the basic technical project subjects was incorporated only in the last 3 years. The total number of students in the curricula of the second-year subject considered in this study during the last 3 years was 1017, with 32% of the students using BIM during the practical part of the class. The total number of students in the second-year course during the last 3 years has been between 13 and 17% of the total for the degrees in industrial technologies (12%). The degrees in electricity, industrial and mechanical organization show a reduction in the number of students over the last 3 years, especially the last degree. The number of students in the last 3 years increased only for the degree in industrial technologies, and it was stable for the rest of the curricula (12-19% for each degree). The use of BIM has increased during the last 3 years in all curricula for second-year subjects. The degree in chemistry shows more homogeneous behavior over the last 3 years. The highest percentage of students using BIM occurs in the industrial technologies degree (49-100%). It was mandatory to use BIM in this degree during the last year considered in this study. This degree is followed in percentage by the degrees in electricity and electronics and automation (both with similar rates, 24-69%) and by degrees in mechanics (10-44%) and organization (10%). For this last degree, there are only data for one course that incorporated the use of BIM.

The comparison of the results obtained for the basic project classes was performed for each degree in the two calls (ordinary and extraordinary). The data from each course and call were considered, and each variable described in Table 1 was qualified by means of a Likert scale from one to five. Table 3 shows a summary of the results obtained for each comparison variable under certain conditions.

TABLE 1. Criteria used to classify courses: Weights and types.

Criteria	Weight		Type
	Certainty Condition	Triangular Fuzzy Number	
Subject passing rate (**A1**)	0.054	(0.0420, 0.050, 0.0545)	Benefit
Overall learning level of the student (**A2**)	0.055	(0.0420, 0.050, 0.0545)	Benefit
Level of ICT tool use (**B1**)	0.045	(0.0349, 0.042, 0.0453)	Benefit
Degree of integration and maturity in teamwork (**B2**)	0.029	(0.0222, 0.0268, 0.0288)	Benefit
Level of autonomous learning (**B3**)	0.044	(0.0335 0.0405, 0.0436)	Benefit
Degree of critical awareness and self-criticism (**B4**)	0.044	(0.0335, 0.0405, 0.0436)	Benefit
Level of reasoning and decision-making (**B5**)	0.029	(0.0225, 0.0272, 0.0293)	Benefit
Level of drafting technical documentation (**B6**)	0.029	(0.0227, 0.0274, 0.0295)	Benefit
Level of presenting and defending results (**B7**)	0.016	(0.0121, 0.01251, 0.0157)	Benefit
Student satisfaction level (**C**)	0.327	(0.2512, 0.3041, 0.3270)	Benefit
Student dropout rate (**D**)	0.327	(0.2512, 0.3041, 0.3270)	Cost

TABLE 2. Alternatives ratings: Liker scale and triangular fuzzy number.

Alternative Rating	Certainly Condition Liker Scale	Uncertainly Condition Triangular Fuzzy Number
Very Low	1	(0, 1.5, 2.5)
Low	2	(1.5, 2.5, 3.5)
Medium	3	(2.5, 3.5, 4,5)
High	4	(3.5, 4.5, 5)
Very High	5	(4.5, 4.5, 5)

TABLE 3. Criteria used to classify courses: Statistical results.

Criteria	Minimum	Maximum	Freq. of minimum	Freq. of maximum	Median	Mean	Standard deviation
A1	1	4	2	18	3	2.986	0.760
A2	1	5	1	2	3	3.194	0.882
B1	3	5	25	2	4	3.681	0.526
B2	3	5	36	4	3.5	3.556	0.603
B3	3	5	36	4	3.5	3.556	0.603
B4	2	4	36	24	2.5	2.833	0.904
B5	2	5	19	2	3	3.014	0.778
B6	2	5	18	3	3	3.042	0.795
B7	3	4	36	36	3.5	3.500	0.504
C	2	5	18	1	3	3.097	0.790
D	1	4	30	6	2	1.833	0.904

The results of a correlation analysis for the comparison variables considered here, together with the level of BIM use (% BIM) for each degree and academic year, can be observed in Figure 5. Variable B3 can be explained using the results of variable B2. With the variables A1, A2, B2, B4, B5, B6, B7, and D, a factor analysis was performed to reduce the number of variables and to identify the relationship between the behavior of the different degrees, the use of BIM, and student satisfaction.

In applying TOPSIS, the best scores were obtained for the degrees in electronics and automation and industrial technology. For each degree, the scores were greater during the extraordinary call, and the score differences between the degrees in the extraordinary call were lower than they were for the ordinary call. The degree with the greatest difference between the scores for the two calls was in mechanics, with the degree in industrial technologies having the lowest differences between the scores for both calls. The academic courses in which BIM was implemented showed better scores, and the score for each degree increased with the increase in the rates of students who used BIM.

Table 5 shows teacher evaluation results under certain (TOPSIS) and uncertain (FUZZY TOPSIS) conditions. The samples are identified by two numbers: the first represents the year, and the second represents the call (ordinary or extraordinary). The values in bold in Table 5 correspond to the samples with the highest and lowest scores. The course ranking is the same for the first five positions and for the last position. The Wilcoxon signed-rank test shows a p-value (.242) greater than the significance level alpha .05, so the TOPSIS and FUZZY TOPSIS samples follow the same distribution. There are no statistically significant differences between teacher evaluations under certain and uncertain conditions.

Taking into account the A1, A2, B1, B2, B4, B5, B6, B7 and D criteria, using certain conditions data and applying factor analysis, three factors (F1, F2, and F3) were extracted, with 75.46% of factors explaining the variance rates. The factors were selected by applying the Guttman-Kaiser rule and Cattell's scree test. The scree plot visualizes the eigenvalues in Figure 6. The extraction method was principal component analysis (PCA). Table 4 shows F1, F2, and F3 factor patterns after the varimax rotation. Each factor column allows for the identification of a few criteria with significant high loadings. From each factor column, the criteria with a factor loading of more than 0.5 were selected. Values in bold in table 4 correspond to each variable for the factor for which the squared cosine is the largest and indicate a good representation of the variable on the factor. Figure 6 shows the association of each criterion to create the construct, taking into account the 3 factors F1, F2, and F3. F1 is labeled "Skills Assessment," F2 "Student Profile," and F3 "Overall Learning Level." The chart in Figure 6 represents the position of the samples on axes F1 and F2 (new rotated factor space). F1 explained 44.36% of the variance, and F1 and F2 maintained 64.0% of the variability of the initial data. High TOPSIS score samples are in green, and low TOPSIS score samples are in red. The

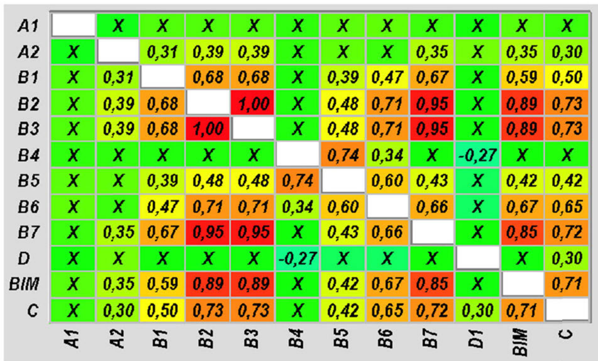

FIGURE 5. Diagram of correlation for the comparison variables: Correlation maps (Kendall rank correlation coefficient). X = p-value no significant difference 5%.

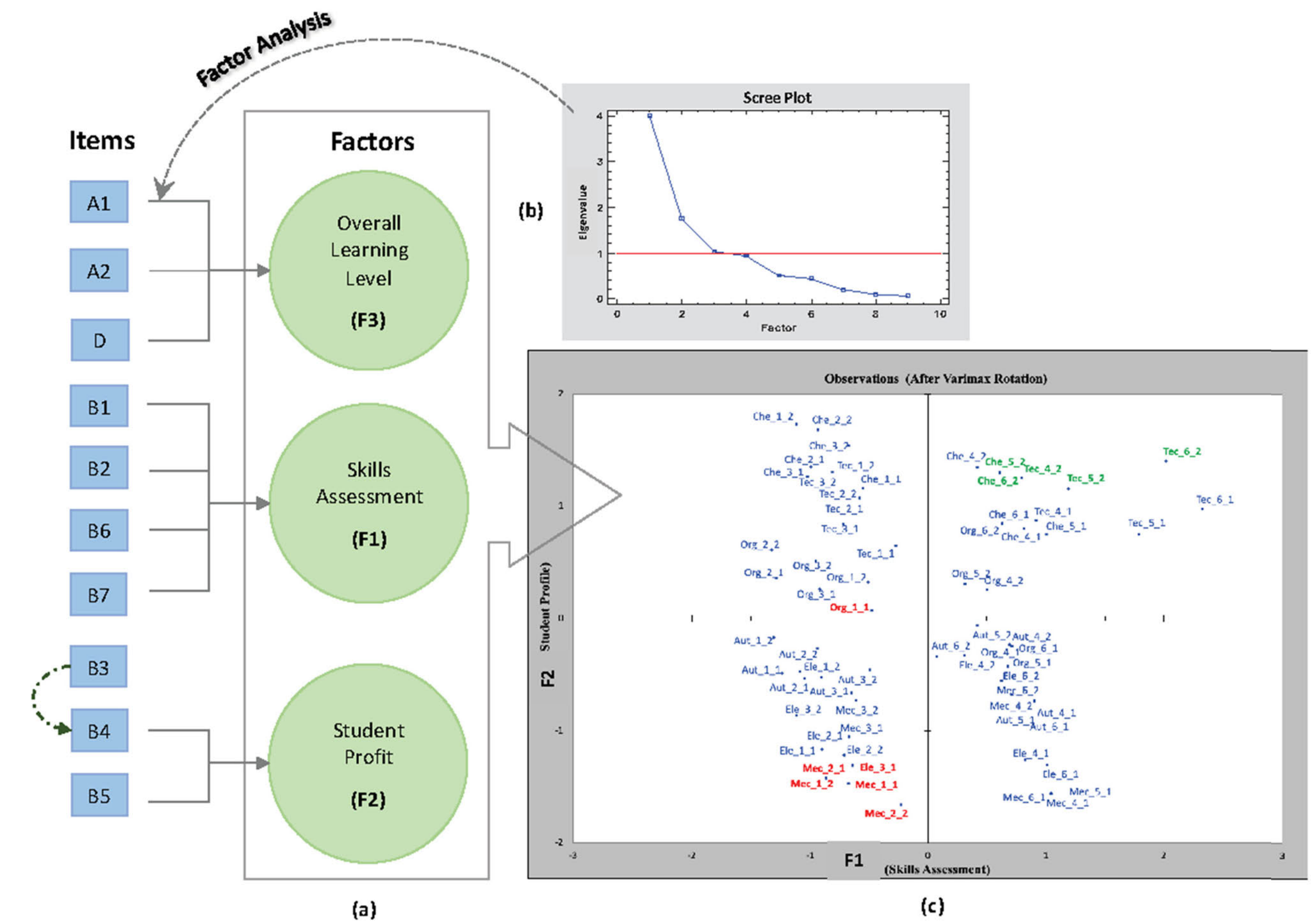

FIGURE 6. Exploratory factor analysis results: (a) initial items and constructs, (b) scree plot to extract factor, (c) samples on new rotated factor space.

TABLE 4. Factor analysis comparison criteria: Factor pattern after varimax rotation.

Criteria	F1	F2	F3
A1	0.276	0.026	**-0.602**
A2	0.451	0.119	**0.714**
B1	**0.813**	0.070	0.024
B2	**0.954**	0.135	0.040
B5	0.483	**0.809**	-0.011
B4	0.010	**0.963**	-0.002
B7	**0.931**	0.010	0.037
B6	**0.747**	0.455	-0.187
D	0.067	-0.485	**0.552**

resulting adequacy of the dispersion matrix using the Kaiser-Meyer-Olkin index (KMO) was 0.722.

The perception of the students following basic project subjects was obtained using the satisfaction comparison variable (C) when they were taking the subject. The academic courses in which BIM was implemented showed better scores for the satisfaction variable (C), and this score increased with the increase in the rates of students who used BIM (% BIM).

By using the student satisfaction level (C) and rates of students who used BIM (% BIM) as independent variables and viewing factors F1, F2, and F3 as obtained in the factor analysis as dependent variables, three analyses of variance (ANOVA) were performed. %BIM has two groups: Used of BIM and Not Used of BIM. C has three groups: Low, Medium, and High. The ANOVA tests were performed to determine whether Used BIM (% BIM) and Student Satisfaction level (C) had significant impacts on the values of the factor scores after the varimax rotation of Skills Assessment (F1), Student Profile (F2), and Overall Learning Level (F3). The results of the ANOVA tests are shown in Table 6, and p-values in bold correspond to significant effects. Effect sizes (Eta squared, η^2) are specified in the last column of table VI.

IV. DISCUSSION

It is not easy to create space for building information modeling (BIM) given an existing curriculum in an industrial engineering school. Our work incorporated BIM in engineering project subjects without curriculum restructuring following

TABLE 5. Teacher evaluation: TOPSIS and fuzzy TOPSIS results and ranking courses.

ORDINARY CALL					EXTRAORDINARY CALL				
Course	TOPSIS	Order TOPSIS	FUZZY TOPSIS	Order FUZZY TOPSIS	Course	TOPSIS	Order TOPSIS	FUZZY TOPSIS	Order FUZZY TOPSIS
Tec_6_2	0.837	**1**	0.969	**1**	**Tec_6_1**	0.740	**1**	1.000	**1**
Tec_5_2	0.832	**2**	0.868	**2**	**Tec_5_1**	0.673	**2**	0.904	**2**
Tec_4_2	0.831	**3**	0.813	**3**	**Che_5_1**	0.670	**3**	0.770	**3**
Che_5_2	0.826	**4**	0.781	**4**	**Tec_4_1**	0.668	**4**	0.731	**4**
Che_6_2	0.826	**5**	0.781	**5**	**Che_4_1**	0.666	**5**	0.717	**5**
Che_4_2	0.818	7	0.743	6	Che_6_1	0.662	9	0.654	6
Aut_4_2	0.819	6	0.690	7	Aut_4_1	0.662	6	0.615	7
Ele_5_2	0.702	10	0.650	8	Aut_5_1	0.662	7	0.615	8
Ele_6_2	0.702	11	0.650	9	Aut_6_1	0.662	8	0.615	9
Mec_4_2	0.562	31	0.649	10	Ele_5_1	0.443	25	0.581	10
Org_4_2	0.701	12	0.633	11	Ele_6_1	0.443	26	0.581	11
Aut_5_2	0.807	9	0.628	12	Org_4_1	0.566	10	0.534	12
Org_5_2	0.699	13	0.600	13	Org_5_1	0.566	11	0.534	13
Org_6_2	0.699	14	0.600	14	Org_6_1	0.566	12	0.534	14
Ele_4_2	0.697	15	0.584	15	Ele_4_1	0.440	27	0.532	15
Aut_6_2	0.809	8	0.575	16	Mec_4_1	0.302	31	0.516	16
Mec_5_2	0.559	32	0.559	17	Mec_5_1	0.302	32	0.516	17
Mec_6_2	0.559	33	0.559	18	Mec_6_1	0.302	33	0.516	18
Che_3_2	0.607	23	0.510	19	Tec_3_1	0.566	13	0.429	19
Che_2_2	0.609	19	0.504	20	Tec_1_1	0.565	14	0.377	20
Che_1_2	0.607	26	0.467	21	Tec_2_1	0.565	15	0.377	21
Tec_1_2	0.608	20	0.461	22	Che_2_1	0.563	16	0.377	22
Tec_2_2	0.608	21	0.461	23	Che_3_1	0.560	18	0.368	23
Org_3_2	0.610	16	0.454	24	Che_1_1	0.559	20	0.317	24
Aut_3_2	0.607	24	0.426	25	Org_3_1	0.561	17	0.285	25
Org_2_2	0.609	18	0.411	26	Org_2_1	0.560	19	0.233	26
Ele_3_2	0.608	22	0.398	27	Aut_2_1	0.556	21	0.208	27
Aut_2_2	0.606	27	0.387	28	Ele_1_1	0.341	28	0.207	28
Aut_1_2	0.602	30	0.363	29	Aut_3_1	0.554	23	0.201	29
Ele_1_2	0.607	25	0.359	30	Mec_3_1	0.179	34	0.186	30
Tec_3_2	0.609	17	0.348	31	Ele_2_1	0.336	29	0.161	31
Org_1_2	0.605	28	0.341	32	Aut_1_1	0.553	24	0.154	32
Mec_3_2	0.479	34	0.337	33	Ele_3_1	0.334	30	0.154	33
Ele_2_2	0.605	29	0.324	34	Mec_2_1	0.178	35	0.139	34
Mec_1_2	0.479	**35**	0.297	**35**	Org_1_1	0.554	22	0.124	35
Mec_2_2	0.479	**36**	0.297	**36**	**Mec_1_1**	0.171	**36**	0.093	36

TABLE 6. F1, F2 and F3 analysis of variance.

	SS	DF	RMS	P-Value	Effect Size(η^2)
Skills Assessment (F1)					
C	26.4185	2	13.2092	**0,0042**	0.0697
%BIM	200.993	1	200.993	**<0.0001**	0.5306
Error	151.416	68	2.2267		
Corrected Total	943.170	71			
Student Profile (F2)					
C	19.3431	2	9.67154	0.1163	0.0593
%BIM	10.6306	1	10.6306	0.1228	0.0326
Error	296.05	68	4.35367		
Corrected Total	373.494	71			
Overall Learning Level (F3)					
C	38.6214	2	19.3107	**<0.0001**	0.3507
%BIM	0.0031	1	0.0031	0.9569	<0.0001
Error	71.4971	68	1.0514		
Corrected Total	112.263	71			

Tu *et al.* [81] proposal but focused on the collaborative nature of BIM with active collaborative learning. Our proposal is aligned with several BIM learning trends identified by different authors, including educational innovation in both technical and managerial aspects of BIM, interdisciplinary collaboration [83], collaboration between professionals and teachers in the design of the practical portion of the subject [84], and promoting collaborative work environments and active learning methodologies [85].

The overall evaluation of the results during this Phase 1 BIM, which were performed during the basic technical project courses of all the degrees in industrial engineering through TOPSIS by the teachers, shows better values in the academic courses in which BIM has been implemented. If we compare the values obtained for academic courses in which BIM has been used, this improvement is greater for all the degrees in which the rates of students using BIM increased. For the degree in industrial organization, this increase is lower in relation to other degrees, but it is important to consider that there are very few samples of this degree.

Applying TOPSIS leads to better results for the extraordinary call than for the ordinary call. This result may be because students need time to complete the tasks and to document and present the project, which is time shared with the rest of the work required for the other subjects and preparation for the theoretical exam for the project course, which leads them to decide to present their project during the extraordinary call instead of the ordinary call. This decision may influence the student dropout rate (D) and overall learning level of the student (A) evaluation criteria. In the case of D, the value decreases (D is a cost criterion) and A increases. If we compare the values between the different degrees, the difference between the two calls is greater for the degree in mechanical engineering and is somewhat more moderate for the rest of the degrees. This degree has the highest number of students, although it is not the degree with the highest level of BIM use compared to other degrees.

The exploratory factor analysis (EFA) reduced the 9 initial items to 3 items. Considering this reduction of variables performed by EFA on the comparison criteria analyses in Table 1. Figure 6 shows the construct with the 3 factors F1, F2, and F3 of Table 4. Factor F1 was shown to be associated with the variables Level of ICT tool use (B1), Degree of integration and maturity in teamwork (B2), Level of drafting technical documentation (B6) and Level of presenting and defending results (B7). All of these criteria are related to skills in the project subject; therefore, this factor can be interpreted as the ''skills assessment'' performed by teachers. Factor F2 was associated with the variables Degree of critical awareness and self-criticism (B4) and Level of reasoning and decision making (B5). These criteria could be related to the personal profile. Then, this factor can be interpreted as the ''student profile'' in the sense that it includes the teacher's evaluation of the decision and criticism-self-criticism level. Factor F3 was associated with the variables Subject passing rate (A1), Overall learning level of the student (A2), and Student dropout rate (D). Table 4 shows that the criteria Subject passing rate (A1) and Overall learning level of the student (A2) had the highest factor loadings. Then, factor F3 can be interpreted as the ''Overall learning level'' in relation to the student dropout rate.

The p-value for the analysis of the variance F-test ($p < .005$, 95% confidence level) suggests that the rates of students who used BIM (%BIM) and the student satisfaction level (C) are significant in the results of factor F1 (''Skills assessment''). However, the degree of influence is higher for %BIM (percentage of variance associated with 53.06%), which together accounted for 60.03%. The effect sizes values of %BIM and C would be considered by Cohen's guidelines as a large and medium effect size, respectively [86], [87]. Student satisfaction level (C) is significant in the results of factor F3 (''Overall learning level''), with a percentage of variance associated with 35.07%. Here, the effect size value of C is considered a large effect size. Student satisfaction level (C) and rates of students who used BIM (% BIM) have a negligible influence on factor F2 (''Student profile''). It is interesting to note that the use of BIM facilitates the generation of technical documentation and helps to better integrate visualizations and data into architectural, engineering, and construction projects [86], [87]. These results were also found in studies of the implementation of BIM in project subjects of the industrial engineering degree [22], [50], civil engineering with the implementation of BIM learning in an integrated project design [89], a project-based online course [90], collaborative multidisciplinary learning [43] and the implementation of BIM in a course in highway engineering [92].

Skills assessments generate better results for the degrees in electrical, electronics and automation and industrial technologies engineering. The skills assessment results have lower average values in courses in which BIM was not used. Regarding the degree of critical awareness and self-criticism (B4) and the level of reasoning and decision-making (B5), there is no significant direct relationship to the use of BIM. This result is aligned with the research of Rahman [93].

If we compare the results of the evaluation by teachers' and students' perceptions, it could be interpreted as indicating that the use of BIM improves the acquisition of the assessed skills, positively influencing student satisfaction. These results are in agreement with other studies in industrial engineering degrees [22], [50], architecture degrees [94] and civil engineering degrees with a collaborative multidisciplinary learning approach [43], in a mandatory freshman-year course titled ''Communicating Engineering Information,'' in a civil engineering degree [95] and in the implementation of a BIM focus on a more practical project-based class in civil engineering curricula [96].

The limitations of this study are directly related to the sample size and the limitations introduced by the fuzzy model [97]. It is necessary to continue to perform this evaluation in the future academic courses to confirm the results obtained here and to test the validity of the proposed models. In considering this conclusion, different authors [98] raise possible reversibility problems in the application of multicriteria decision methods, which should be taken into account when using the data obtained here for comparison with data from new academic courses.

V. CONCLUSION

Considering the positive results obtained, BIM as a mandatory subject for basic project subjects could be successful. Our findings suggest the following:

- BIM implementation in engineering project subjects with an active collaborative learning methodology and without curriculum restructuring into current subjects of the curriculum could be easier and faster.
- The skills assessment results have higher average values in courses in which BIM was used. If we compare the values obtained for academic courses in which BIM has been used, this result is better for all degrees in which the rates of students using BIM increased. The rates of students who used BIM are significant in the skills assessment results of the level of ICT tool use (B1), degree of integration and maturity in teamwork (B2), level of drafting technical documentation (B6) and level of presenting and defending results (B7).
- Regarding the degree of critical awareness and self-criticism (B4) and the level of reasoning and decision-making

(B5), there is no significant direct relationship to the use of BIM.

• Student satisfaction could be positively influenced by the use of BIM, but this result needs further study.

It would be interesting to continue this study with BIM as a mandatory subject for basic project subjects to validate the results presented in this work.

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