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Conceptual Framework for the Use of Building Information Modeling in Engineering Education*

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The objective of this paper is to present a critical literature review of the Building Information Modelling (BIM) methodology and to analyze whether BIM can be considered a Virtual Learning Environment. A conceptual framework is proposed for using BIM in a university context. A search of documents was carried out in the Core Collection of Web of Science; it was restricted to the last five years (2013–2017). A total of 95 documents were analyzed; all documents were written in English and peer reviewed. BIM meets all the characteristics of Virtual Learning Environments. The proposed framework has three dimensions (competencies, pedagogical approach and level of integration). It allows for the planning and analysis of future experiences of teaching BIM in a university context.

Keywords: BIM; higher education; construction engineering; computer-aided design; virtual learning environment

1. Introduction

The new socio-economic scenario requires increasingly well-trained professionals and citizens. This is a challenge for the Higher Education sector. Graduates and post-graduates must acquire competencies during their studies, specifically those related to their profession (specific competencies), such as others, which can be used in the development of the profession as well as in the exercise of a critical citizenship (cross-cutting competencies) [1–4]. Among the first ones, in the engineering and architectural context, may be included: knowledge of materials, the calculation of structures or the drawing up of a budget, etc. Among the second ones, oral and written expression in mother and foreign language, the use of Information Communication Technologies (*ICTs*), teamwork capacities, moral reasoning, sustainability, and so on are found [3, 5, 6].

Nowadays, there is a growing importance of the use of *ICTs* in all areas of life, including education [7–11]. Thus, devices such as mobile phones, tablets, laptops, etc. are used for handle and share information [12]. Without any doubt, competencies related with the use of *ICT*s are highly required by employers. According to some estimation, 90% of works will require *ICT* skills [13]. For this reason, the education authorities consider it a priority to develop these capacities in their policies [13].

On the other hand, there is a growing interest in the study of new technologies, specifically Building Information Modelling (*BIM*), in the Architecture Engineering Construction and Operations (*AECO*) industry [14]. *BIM* "is a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle" [15, 16].

BIM technology has been proposed as an interesting tool for the design, project, construction and maintenance of new buildings and constructed buildings. Its use allows for optimizing structures [17], controlling costs [18], ensuring safety [19] and minimizing environmental impact [20], rehabilitating heritage [21], among other aspects. Its use as a Virtual Learning Environment has not been realized.

Virtual Learning Environments (*VLEs*) are getting prominence in this new scenario [7]. *VLEs* can be defined such as flexible environment that use computers and Internet in order to facilitate a context conducive to learning and content creation.

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According to Dillenbourg et al., a *VLE* has the following characteristics [22]:

- A *VLE* is a space where information is shared.
- A *VLE* is a social space. Students and teachers can interact in a large variety of ways.
- It is explicitly represented: the information can be represented in various ways, such as text, images, three-dimensional virtual objects, and so on.
- All *VLE* participants are knowledge creators.
- Its use is not restricted to exclusively virtual education; they can be used to enrich face-to-face classes.
- The *VLEs* incorporate diverse technologies and integrate diverse pedagogical approaches.
- They are usually used in conjunction with physical environments.

Examples of *VLE* include: virtual laboratories [23], platforms such as Moodle or WebCT [10], or social networks such as Facebook, LinkedIn or Twitter [24]. The former (virtual laboratories and platforms) were created with specifically educational use, the latter were not. Both types can be a motivating tool for students [25]. In this paper we will try to determine if *BIM* can be considered a *VLE*.

Some authors have classified the construction sector according to the following categories: reluctant to change, conservative and highly fragmented [20, 26, 27]. Without any doubt, this is a barrier for the incorporation of new technologies. In this context, education could be a tool to try to overcome this entry barrier. The use of *BIM* technology in Universities could be a catalyst for its use in industry [28]. Furthermore, there are an increasing number of job offers which requires knowledge of *BIM* [29].

Therefore, all these aspects make the relationship between education and *BIM* technology a key aspect of its implementation in the industry [30, 31]. Nevertheless, the number of published articles about this thematic is still rather scarce.

With regard to the relationship between *BIM* and Education, some studies have analyzed the implementation of *BIM* in certain areas of the world such as New Zealand [32], Malaysia [33] or the United Kingdom [34]. Some have addressed the problem from a thematic point of view, for example the design of structures [35]. Sacks and Pikas proposed a framework mainly limited to the development of student competencies [36], and, in the same year, Macdonald and Granroth proposed the framework called IMAC (Illustration, Manipulation, Application and Collaboration) [37]. Abdirad and Dossick reviewed the literature between 2007 and 2014 and most of the references in their study were coming from the USA (49/59; 76%) [38].

Thus, the analysis of the most recent experiences in the implementation of *BIM* in the educational field has not been carried out worldwide. On the other hand, there is still a need for a framework to facilitate the use of *BIM* in education, mainly in the university setting. This paper aims to fill this gap by analyzing the experiences published between 2013 and 2017, proposing a new framework that can be used for the design and evaluation of future initiatives.

Hence, the main goals of the current work are:

1. To analyze the scientific production concerning the topic *BIM* and Education published between 2013 and 2017.
2. To assess the use of *BIM* as a Virtual Learning Environment (*VLE*).
3. To propose a framework and practical considerations to the educational community and authorities for the implementation of *BIM* in the education sector.

The remainder of this article is organized as follows. In the next section, methodology is described. Subsequently, a review of previous initiatives is carried out, references are deeply reviewed, the use of *BIM* as *VLE* is analyzed and a framework is proposed. The paper finishes with conclusions.

2. Methodology

The first step in our research process was a bibliographic review of the works published in recent years. To this end, we followed the methodology proposed by Pawson et al. [39]. Figure 1 shows a schematic representation of the process followed for bibliographic review.

The first step in this process is to clarify the purpose of the review. The main goal is to analyze the use of *BIM* in the education sector. The second stage consisted in the search for evidence. In turn, this stage was divided into several sub-stages: literature collection, literature filtration and literature synthetization. In order to do the literature collection, a search of documents was made in the Core collection of Web of Science. The search was restricted to the last 5 years (2013–2017) in line with other recently published articles [14, 41]. On the other hand, the search was restricted to works published in English. All the documents analyzed were peer reviewed to ensure the quality of the review [40].

The next sub-stage consisted in filtering and screening the obtained material, some references only touched in a very tangential way the analyzed topic, others were a false positive (articles that were not about Building Information Modelling). Subsequently, the documents were read, information was synthesized and tabulation, with main aspects dealt with the work, was realized.

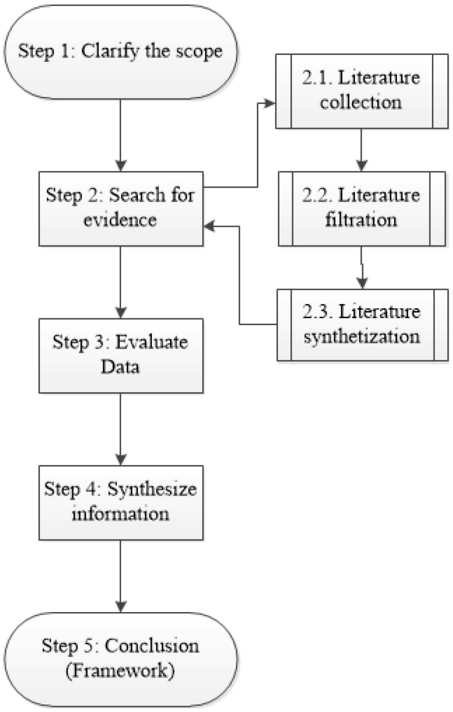


Fig. 1. Illustration of review process based on Pawson et al. [39] and Chong et al. [40].

Subsequently, data were evaluated (step 3) and the information was evaluated (step 4).

Finally, as a result of the bibliographic analysis, it was analyzed whether *BIM* can be considered a *VLE* as well as the framework in which the relationship between *BIM* and the educational space can be understood.

A framework consists in a tool that allows us to organize the existing information in domain of knowledge, so that it is easier to interpret and carry out future research [16]. The proposed framework was generated using a mixed method study [16, 42].

In the same way as Succar [16], we consider that the graphical representation of variables and their relationships can help to generate meaning and the construction of the framework.

3. Review results

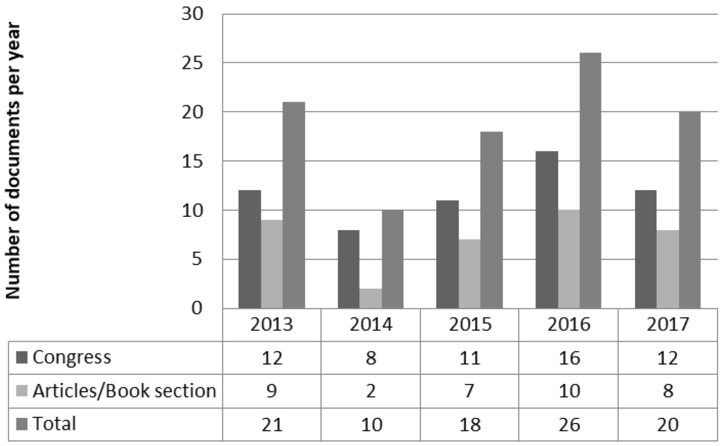
In the search with the terms "*BIM*" and "education" according to the process explained in the previous section, 133 scientific references were obtained. The full texts of 125 references (94% of the search results) were obtained. 7 of these 125 were excluded because they are not written in English, while 23 have been removed because they are outside the scope (false positives). Thus, a total of 95 documents were deeply analyzed. The data obtained from the search, included and excluded references and exclusion causes can be consulted elsewhere [43].

Figure 2 shows the distribution of documents over the time. As can be seen, there was an increasing production of scientific documents between 2014 and 2016; however in 2017 publications have slightly decreased.

Of the 95 documents analyzed, 59 (62%) were from conferences (proceedings or special issues in journals) and 36 (38%) were articles (regular publications) or book chapters. Regarding article sources, Table 1 shows the titles of journals with more than two articles published in the studied sample.

Regarding the corresponding author's affiliation, Table 2 shows the number of documents corresponding to countries with more than one document published in the period analyzed. As can be seen, most of the documents have corresponding authors affiliated with US institutions, followed by Chinese institutions and by Institutions of United Kingdom.

Based on the reading of the abovementioned articles, the following section will analyze whether *BIM* can be considered a *VLE* and a conceptual framework will be proposed.



	2013	2014	2015	2016	2017
■ Congress	12	8	11	16	12
■ Articles/Book section	9	2	7	10	8
■ Total	21	10	18	26	20

Fig. 2. Number of documents per year analyzed.

Table 1. Number of published papers in journals indexed in Web of Science

Journal	Number of articles
Automation in Construction	6
Journal of Professional Issues in Engineering Education and Practice	6
International Journal of Engineering Education	4
Journal of Construction Engineering and Management	3
Eurasia Journal of Mathematics Science and Technology Education	2

Table 2. Number of documents according to the corresponding author's affiliation

Country	Documents	%
USA	28	29%
China	7	7%
United Kingdom	7	7%
Spain	5	5%
Germany	4	4%
Korea	4	4%
Malaysia	4	4%
Australia	3	3%
Czech Republic	3	3%
Portugal	3	3%
Israel	2	2%
New Zeeland	2	2%
Norway	2	2%
Peru	2	2%
Russia	2	2%
Taiwan	2	2%

4. Analysis and discussion

4.1 BIM as a virtual learning environment

To answer the question of whether *BIM* can be used as a *VLE*, the characteristics proposed by Dillenbourg et al. [22] will be analyzed using the evidences found in the bibliography.

Table 3 shows how BIM meets all the requirements of a VLE.

As can be seen, *BIM* meets all the characteristics that a *VLE* should have. Firstly, by its own definition, *BIM* is a space where information is shared [16]. The creation of the virtual model makes it possible to share information about the geometry, but also about the construction process, the costs that will be incurred, and the safety on site [26, 46]. When a student has access to this methodology, (s)he is exposed to a large amount of information that must be processed and analyzed. Secondly, *BIM* is a social space, the *BIM* methodology responds to an urgent need of the construction sector, coordination. In *AECO* industry, there are numerous involved actors, such as the owner, the builder, the architectural design team, structural engineers. It is not easy to coordinate these actors; *BIM* aims to be a tool to achieve this end. Therefore, *BIM* is usually used in teams. Participatory methodologies are usually used for academics uses; in these methodologies students should develop their teamwork [26, 44]. *BIM* is therefore an environment that encourages social participation and the development of skills such as teamwork [44].

In the *BIM* environment, information is shared in multiple ways. The model itself is a huge source of information.

Another key aspect of using *BIM* in education is that students are active knowledge builders [36]. Students need to move beyond theoretical knowledge and as they progress through their academic degree they need to be more connected to real life and industry [36]. Precisely this methodology allows this connection with the real model; it allows a visualization of the constructive environment and a better incardination of the projects and problems in a real environment.

In general, *VLE* are often associated with distance education. However, this is not an inherent characteristic. In most of the initiatives published in the literature [26, 36, 44, 46], the use of *BIM* is not a substitute tool for face-to-face classes; in other words, *BIM* is a methodology that complements and enriches face-to-face teaching.

Additionally, there are many references that emphasize that *BIM* is more than just a technology [26, 51]; it is a methodology that goes beyond a simple computer program. Consequently, the experiences reported in the scientific literature combine a large number of computer tools [46]. For example, design software such as Revit [26, 31, 36, 47, 52, 53] or Archicad [26, 54], structural calculation software such as Revit Structure or Tekla, budget calculation and scheduling software such as VicoOffice [47]. In some cases, the process of

Table 3. Is BIM a Virtual Learning Environment? VLE's features that BIM meets checklist

Characteristics of *VLEs*	References (among others)
They are a space were information is shared	[16, 26]
They are a social space	[26, 36, 44]
Information can be represented in various ways	[31]
All Participants are knowledge creators	[36, 38, 45]
Their use is not restricted to distance education	[26, 44, 46–48]
Diverse technologies and pedagogical approaches are integrated	[26, 44, 46, 47, 49]
They are usually used in conjunction with physical environments	[30, 48, 50]

interaction between some tools and others has been the subject of research, and students' processes are described in detail [47]. On the other hand, the use of the *BIM* methodology makes it possible to integrate different pedagogical approaches [44]. Although this concept will be developed more deeply in the conceptual framework, it can be said that this methodology allows us to frame the teaching activity in the paradigm of constructivism and collaborative learning [49]. Furthermore, it allows the use of diverse innovative teaching methodologies such as flipped class-room [26], gamification [47], project-based learning (*PBL*) [26, 55], and so on.

Finally, the inclusion of *BIM* methodology does not imply not using other physical environment such as the construction of physical models. There are numerous occasions, for example in the design of deployable structures, in which the behavior of the material and the conditions of the individual joints are crucial to the correct design of the structure [50]. Nowadays, there are certain issues that are not addressed in commercial design software such as material behavior, joint clearances, and so on [50]. In these cases, the construction of mock-ups is justified. These models allow the development of skills that are certainly important in an *AECO* industry professional [50]. The combined use of both types of models (physical and digital) is one of the strong points of the methodology. Firstly, students can study some of their constructions digitally, and once they have chosen the final design they can build the model.

To conclude, *BIM* fulfills all the characteristics proposed by Dillenbourg et al. [22], and it can be considered a Virtual Learning Environment. Apart from being able to explain aspects directly related to the BIM methodology, it can be used to teach other disciplines such as safety and health in construction, budgeting, environmental impact, etc. In the next section, a conceptual framework that allows its application in university classrooms will be developed.

4.2 A framework for using BIM in education

The proposed framework (*EDU-BIM*), similar to the previous one proposed by Succar for the *BIM* methodology [16], has three dimensions.

The first one is related to competencies. When planning the use of BIM in education, competencies that want to be developed using *BIM* should be described and analyzed. This is a crucial aspect, because this analysis will mark the success or failure of our educational experience. There are many educational innovations that fail because they do not have a clear horizon, in other words, the objectives have not been correctly defined.

The second dimension is to determine the pedagogical paradigm and the methodology to be used in the experience. Indeed, it is a very important aspect to be aware of the psycho-pedagogical assumptions behind the initiative. Sometimes, professors who teach at the university level do not reflect on this aspect. On the other hand, the methodology to be used in the experience must be chosen correctly. A wide variety of innovative methodologies are available to increase student motivation. However, the inclusion of these methodologies in the university curriculum does not guarantee the success of the experience.

Finally, a third aspect must be taken into account: the degree of integration that the *BIM* methodology will have throughout the curriculum. As will be discussed below, there are many possibilities for integrating *BIM* into the university curriculum. Some universities choose to include classes outside the official curriculum, others opt to include complete courses or to introduce transversally the knowledge and skills of *BIM* in subjects such as projects or calculation of structures. In any case, this choice will be fundamental and a degree of the level of integration of *BIM* in the university degree.

Figure 3 shows the three dimensions of the proposed conceptual framework. With a view to its implementation, teachers and academic authorities must ask themselves about each of these three aspects when and how implementing *BIM* in the educational context.

4.2.1 Competencies

The first dimension of the proposed conceptual framework is to identify the competencies to be developed through the use of the *BIM* methodology in the classroom. Competencies are the integration of Knowledge, Skills and Attitudes (*KSA*) that can be used and applied in a particular situation [5, 29, 56].

Nowadays, there is a challenge in the education sector: to determine what competencies should be developed in students for their personal and professional development. Our changing world implies

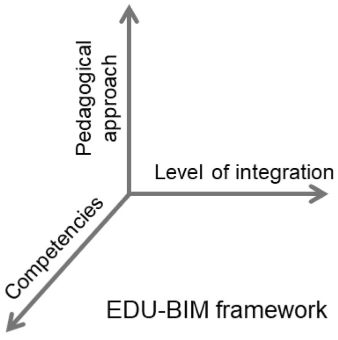


Fig. 3. Representation of the three dimensions of the EDU-BIM framework.

that the competencies required also change very rapidly; therefore it is the mission of academic authorities and educators to analyze and update the competencies required by students and to integrate their development within the corresponding syllabus.

Recent studies have analyzed the professionals' skills required for working in the BIM sector [29, 36, 57]. For example, Uhm et al. examined 242 job offers in the United States, the United Kingdom and China. Using Social Network Analysis, they categorize the jobs into 8 types, and break down 43 key competencies [29]. In their study they classified the 43 competencies into three categories (essential, common and job specific). In any case, they warn against the frequent error of assuming that the teaching of *BIM* should only be focused on the development of competencies related to the computer tools required for the use of the methodology [29]. Similarly, in a previous paper [36], the process for establishing a framework of competencies is described. First, they held a LinkedIn discussion forum, an international workshop to discuss the topic and an in-depth analysis of a set of job offers. As a result, the work includes a set of 39 competencies classified into 3 categories: area and process knowledge, *BIM* technology, *BIM* applications and functionalities [36].

In this way, the first step of any successful implementation of *BIM* in the education sector is to reflect and choose the competencies to be developed.

There is a consensus on the importance of developing both specific and transversal competencies [5, 36, 58–60]. Specific competencies are directly related to the practice of the profession. For example, in *AECO* sector: building modeling, construction planning, budgeting, structural calculations. On the other hand, transversal competencies, being related to the profession, are also related to the exercise of an adult and committed citizenship. For example, the capacity for teamwork, communicative abilities, the capacity to learn by oneself, the knowledge of oneself, interpersonal knowledge, etc. These competencies are becoming increasingly important. In fact, Accreditation Agencies such as European Network for the Accreditation of Engineering Education (*ENAEE*) and the *US* Accreditation Board for Engineering and Technology (*ABET*) require these competencies in the graduated students [59].

Therefore, the main aim of the inclusion of *BIM* in university classes should be the development of student competencies [61, 62]. They must be developed in a harmonious and balanced way. There is a debate about whether to train for a job or to educate a future citizen at university [37]. In our opinion, this is a false dichotomy. How to prepare good professionals without considering their citizen dimensions? It is an evident claim that no efficient and productive professionals, of any kind, can arise from an immature citizen. In Howard Gardner's word: A bad person should never be a good professional [63]. Each job will require a specific set of skills, combining specific and transversal skills. But it is very likely that in the not too distant future, new skills or a different combination of skills than those previously required will be asked for. In this context of deep change, it is very important that students have the capacity to face new challenges, to learn by themselves and, if they consider it necessary, to return to formal or informal educational contexts in order to develop the new skills that are required of them.

4.2.2 Pedagogical approach

The second dimension of the proposed conceptual framework is the pedagogical approach. There are many instruments for the development of activities in the teaching-learning process. However, it is crucial to choose, the pedagogical approach from which the development of these activities will be reached. In some situations, the instruments change, the activities change, but they are not approached from a different perspective. The same is still being done with different technological tools; failure is the foreseeable result of these strategies. For example, in many Engineering Schools digital blackboards have recently arrived. However, the use of such devices is almost the same professors did with the classical blackboards. This, obviously, does not represent a relevant innovation on the educational process

As mentioned above, constructivism and collaborative learning can be the paradigms from which to interpret the inclusion of *BIM* [49]. The characteristics of *BIM* make it an instrument that can favor constructivism. Constructivism is a pedagogical theory initially proposed by Piaget [64] and developed afterwards by Ausubel et al. and Bruner [66, 67]. Under this theory, the student must be given the tools to be the real protagonist of his or her learning because the learning process, different from the teaching one, is the result of own-building knowledge. Several studies have shown that *ICTs* favors this type of learning [68, 69]. Another key to constructivism is its social dimension. Students learn by interacting with others students, their teachers, their parents and other people of social community. This is the base of several of the newest active learning methodologies, such as Problem-Based-Learning [70]. Collaborative learning is the situation in which two or more people face the learning process together, the foundations of this system of learning were proposed by Vygotsky [71]. Without doubt, *BIM* encourages this type of learning. One of the objectives of *BIM* is to enable all stakeholders to have access to information simultaneously and up to date. Nowadays, coordination of all actors in *AECO* sector is still a challenge [72]. Therefore, many of the activities proposed for the development with *BIM* are oriented to the development of the competence of teamwork or coordination [44, 72]. Thus, many of the activities that have been described in the bibliography are carried out by teams. For example, an initiative of the California State University, called Green-BIM, describes the work with undergraduate students in the field of sustainability [45, 55]. Many of the initiatives carried out in the Project Based Learning environment, which will be analyzed later, are carried out in teams [60, 73].

Hjelseth proposes to understand the use of *BIM* in education in the context of *TPACK* [51]. The *TPACK* was proposed by Koehler et al. [74, 75], and it states that for the use of a technological tool in education, three dimensions must be taken into account: the Technological Knowledge (*TK*), the Concept Knowledge (*CK*) and Pedagogical Knowledge (*PK*),

Once the pedagogical paradigm has been addressed, it is possible to talk about various instruments that make it possible to introduce *BIM* in the educational context.

Some authors have warned about the difficulty of explaining a tool that has a technological character like *BIM* to students with different technological abilities and skills [76]. In this sense, they have proposed the creation of video tutorials that can explain the more technical aspects and dedicate the time of the classes to the aspects related to the interaction between students and student-teacher [26, 77]. Nowadays, this technique known as *flipped classroom* is trending topic. It consists in providing students with written or audiovisual documentation on the topic to be taught in the next class. The classes begin with a brief assessment of the understanding of the knowledge explained outside the classroom. The rest of the time will be devoted to work that has traditionally been done outside the classroom: time for teamwork, oral presentations, to resolve doubts, etc. [78–80]. Teachers can redo the class schedule in order to adapt it to the students' needs; this technique is known as just-in-time-teaching [81]. Several studies have demonstrated the advantages of this methodology at various educational levels, including the university level [78, 82, 83].

In recent years, there is another innovative methodology called *gamification*. *Gamification* could be defined as the use of game design techniques and game elements in non-game contexts, in order to engage people [84–86]. In their beginnings, gamification techniques were born in economic, financial and marketing areas [83]. However, its use has been extended to other areas of knowledge, for example education, engineering or health and care sciences. In many cases, the gamification activities incorporate the use of technology such as video games [87] or badges provided by distance learning platforms such as Moodle [88] or in MOOCs [89]. The gamification activities are an instrument to increase the motivation of the students, as well as to develop transversal skills, such as teamwork or communication skills. All these characteristics make it possible to use gamification in *BIM* contexts; for example, competitions with prize [47, 60], and creating scenarios for avatar simulations [90] or role-plays [54]. Without doubt, this technique can improve the development of the teaching-learning process.

As stated above, in the social constructivism, the creation of knowledge by the students, together with the interaction between them, is fundamental for the success of the teaching process. A good tool for achieving both is *Project-Based Learning* (*PBL*). In this methodology, students learn through the development of a project that is usually carried out collectively. A contextualized project is proposed to the students in a real environment. In this way students develop skills such as critical thinking, the ability to solve problems, improve communication skills, teamwork, etc. [45, 91]. It is a widely used tool in the development of *BIM* training initiatives [26, 54, 55, 73, 76, 92]. For example, Luo and Wu used *PBL* to facilitate Sustainable Design using *BIM* [45]. For that, students of two different subjects carried out a joint project about evaluation and improvement of a Campus building design. Thus, students were divided into different groups with different roles. Students developed specific and transversal skills and showed high satisfaction with the initiative. In another experience, the authors described a *PBL* activity that seeks to integrate design education and cost estimation in a *BIM* environment [60].

A key aspect is the evaluation process. The assessment must have various instruments to determine the degree to which students acquire the skills they need. Hence, the initiatives described in the literature incorporate exams, assignments, oral presentations, team projects, in class activities, and so on [72, 73, 76, 93]. A good practice may be to use rubrics for student assessment [73, 92]. In this way, they can know in advanced how they will be assessed. Obviously, the inclusion of these assessment activities will increase the teacher's workload. To facilitate the evaluation process, some authors have proposed the use of automated correction tools [94].

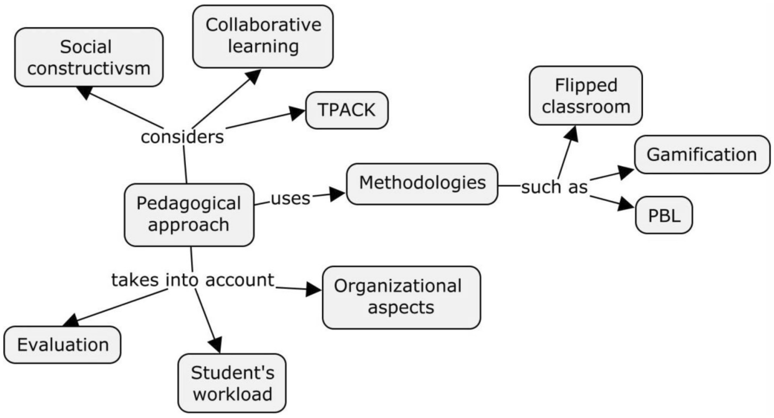


Fig. 4. Conceptual map of pedagogical approach dimension.

Another important aspect, is to evaluate the student workload, in some experiences, students report a high workload [54]. In a current approach to education, the student must be at the center of the educational process. In this sense, it is essential to properly estimate the workload of the tasks [26] and manage organizational aspects such as timetables or infrastructures to enable students to develop their work.

Figure 4 shows a concept map of the second dimension of the proposed framework for *BIM* education.

4.2.3 *Level of integration*

The third dimension of the proposed conceptual framework is devoted to the level of integration of the methodology into the curriculum. There is no consensus on how *BIM* can be taught at the university level [36, 95]. Therefore, there are several strategies to integrate *BIM* into the curriculum [36, 46, 53, 57, 58, 92, 95, 96]. Solnosky et al. described six different strategies in order to teach BIM at University level [53]. In our approach, we have grouped them into three groups, in a similar way to that proposed by other authors [36, 38, 46].

Firstly, and the most common one [58, 95] is to teach *BIM* in an individual course or workshop. In this strategy, competencies are developed in a compulsory or elective course. It is usually used in the first initiatives that appear in each of the universities. Generally, Computer Aided Design *(CAD)* or design subjects include contents related to the *BIM* methodology. This approach has some limitations. Usually, an introductory course is limited in time and contents; furthermore, students do not acquire a vision that incorporates all the possibilities offered by *BIM*.

For these reasons, and probably in a complementary way [32], the teaching of *BIM* can be approached transversally throughout the existing curriculum [95]. Through this strategy, the various subjects address the inclusion of *BIM* from their own perspective. For example, University of Penn has deployed an initiative, with 20 courses involved (5 of them incorporate *BIM* in depth) [95]. In this way, students can be aware of all the possibilities of the *BIM*, integrating each of the fields of knowledge with the tools and functionalities of the *BIM*. This approach is more effective than the previous one and can certainly complement it [97]. Furthermore, this procedure allows the adaptation of the techniques and processes taught to the maturity of the students [98, 99]. Thus, contents are incorporated at the appropriate time in the curriculum. For example, basic skills can be explained in the first courses and more specialized aspects in further courses.

There is an even higher level of integration. As we have defended in previous sections, it is necessary to *learn by doing* [26]. This can be applied to *BIM* learning. In addition, learning is most effective when it takes place in a contextualized environment similar than future professional one [32]. Probably, future problems will be essentially multidisciplinary, and therefore need to be solved through the use of various fields of knowledge. This recommends avoiding fragmented knowledge, opting for a holistic approach to knowledge. In this sense, there are several initiatives that choose this line of work. For example, multidisciplinary projects involving various courses, degrees and so on. For example, Nakapan describes a 4+1 project where freshmen collaborate with students in the final year [100]; Wei Wu and Hyatt organize a competition which consists in the design of a tiny house that takes place over several subjects combining gamification and *PBL* [60].

These levels are not selective, but often complement each other. They represent the natural evolution of *BIM*'s integration into the university environment. Firstly, a subject is introduced in the curriculum either in compulsory or optional format (1st level), secondly, *BIM* knowledge is introduced in other subjects (2nd level). Finally, the subjects address joint problems to increase the efficiency of the teaching and learning process (3rd level).

5. Conclusions

In this work the bibliographical references, indexed in the Core collection of Web of Science and published between 2013 and 2017, have been analyzed. Without any doubt, the first decades of the 21st century are being characterized by the emergence of information and communication technologies; also in the *AECO* sector. The emergence of the *BIM* methodology is revolutionizing the sector and is a source of improved competitiveness.

Although there is widespread agreement on the importance of addressing *BIM* in education, there is no agreement on how to carry out this task. For this reason, it is still interesting to analyze the experiences made while proposing new frameworks that will allow us to re-interpret future experiences.

Throughout the work, we have shown how *BIM* meets all the characteristics of Virtual Learning Environments. This fact makes *BIM* a tool that allows learning about other disciplines such as health and safety, construction planning, environmental impact, cost management, etc. A conceptual framework based on three dimensions has been proposed. The first dimension of the conceptual framework corresponds to the competencies that are intended to be developed, the second dimension corresponds to the pedagogical foundations; and finally, the third dimension reflects the degree of integration that *BIM* has throughout the curriculum. This conceptual framework will make possible to design, program and analyze future actions in order to incorporate *BIM* in the university context.

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