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Article

Building Performance Simulations and Architects against Climate Change and Energy Resource Scarcity

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Abstract: In Europe, 40% of the total energy is consumed by buildings; in this sense, building performance simulation tools (BPSTs) play a key role; however, the use of these tools by architects is deficient. Therefore, this study aims to detect the architects' perception on BPSTs. To this end, an online survey was conducted to determine the selection criteria of these BPSTs and non-users, to investigate the reasons for not using the tools. The outcomes showed that there was a wide gap between architects and the management of simulation programs in Spain, mainly due to the lack of training. BPSTs are described as a kind of intellect amplifiers, as they are perceived as powerful allies between professors and students of architecture and between architects and architectural design; therefore, through BPSTs, sustainability is taken very much into consideration to make buildings more energy efficient. Therefore, it is primarily concluded that further and higher education must undergo significant improvement to use simulations as part of the architectural design.

Keywords: building performance simulation tools; architectural design; energy education; BPSTs users; architectural education

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1. Introduction

Climate change and the scarcity of energy resources are two major challenges in the near future (European Renewable Energy Council, 2010). In the U.S.A., 48% of the total energy is consumed by buildings; in Europe, 40%; and in the United Arab Emirates, 70%. Therefore, countries create policies that allow the construction of net-zero energy buildings (NZEB). In this way, only that which complies with the regulation is built; therefore, using energy simulation becomes essential [1–4]. As a results of legislation, architects have a key role in contributing to the success of the NZEB; however, architecture is the only profession that integrates creativity and technology, generating various difficulties to deepen technical development [5].

Simulation is a human, psychological and social discipline since it involves the interaction between the human and the computer [6]. The human dimension is one of the most important performance indicators since a deep understanding of it allows progress in the development of the simulation [7]. This discipline arose in 1960 when the U.S. government carried out projects to evaluate the environment in fallout shelters and, during the 1980s, building performance simulation tools (BPSTs) were developed to assist architects in their analysis [8]; however, it was not until a decade later that they began to use simulations [9,10]. In 2010, the number of tools listed in the U.S. Department of Energy (DOE) Building Energy Software Toolkit (BESTD) reached approximately 400 [11], which means that between 1997 and 2010, the number of tools has quadrupled; however, less than 40 are aimed at architects [12,13].

The growth of the use of energy modeling in architecture is evident at the international level, according to the American Institute of Architects [14], thus showing the commitment of the profession in the U.S.A. to integrate the energy modeling processes within the design practice. However, according to Mahdavi [15], there is a generalized process of disconnection between the design process and the architectural simulation process. In the design process, the goal is to achieve decreasing thermal results, taking the generic choices in the initial stage, but considering that the decisions are already taken because both the owner and the designer have become fond of the design and its modification is not possible. During the simulation process, the thermal models are developed from the detail to the set of elements that determine the simulation, which is the complete opposite of the architectural design [16].

There is a widespread belief that existing energy simulation tools are not suited to architects' needs during the early stages of designing energy-efficient buildings [17–19]; moreover, they are too complex for them [20]. This leads to the fact that architects do not consider energy modeling as their responsibility [21].

Naboni (2013) [22] reflects the need for BPSTs to adapt to new needs in architecture, such as geometric representation and the way of communicating and representing a design. Usually, there is a non-intuitive and impractical user interface [23] so that development is essential in its simplification [24]. BPSTs requite the input of a large amount of data [25,26] being one of the challenges for architects [27–29], thus limiting data entry is crucial. However, many of the input data cannot be available in the early design stages [30], so it is necessary to use default values and templates [31].

There is a simplified method for handling BPSTs, which is used to minimize runtime and does not require a large amount of input data [32]. This approach is often used to cope with the initial design requirements [33–35]. Schlueter and Thesseling [28] call it a statistical model of calculation and it serves to judge the performance of a building. Lam, Huang and Zhai (2004) [36] argue that complicated simulation tools do not provide better support for decision making, so, for architects, simple energy simulation tools always offer more advantages than the complicated ones [37].

In respect of the outcomes obtained from the simulation software, these are excessive and complex, and their output lacks visual quality as architects seek to represent the results achieved within the 3D geometric model [38]. Additionally, the significant information extraction from BPSTs requires expert knowledge, since the information must be processed in order to be applied in the decision making of the building design [39].

Currently, architects are beginning to use new energy modeling tools, but this practice is still deficient [40–42]. To encourage the use of BPSTs, there are consultants who help architects to capture the meaning of the models [43–45]. Attitudes, values and experiences expressed by architects must be understood so that these tools can be adapted to their preferences and can thus they can be incorporated into the architectural design. The building designer should be considered the user of the simulation software, generating practical models and examples of application [46–49]. Additionally, there must also be a change in architectural education [50].

Therefore, it is necessary to go deeper in the calculation methods selection, so that the use of BPSTs is extended among professionals and to make the most of the calculation tools. This study aims to investigate all those needs that architects have with respect to BPSTs, therefore, an online survey, focused on both non-users and users, was conducted. The main objective of the investigation is to detect the reasons why BPSTs are not used.

2. Methodology

In order to ascertain the architects' needs regarding the BPSTs, an online survey was conducted that consisted of two parts. The first one was intended to define the state of knowledge on BPSTs of architects in Spain and to detect the reason why there is a poor use of BPSTs. The second part was only directed to architects who have handled the tools in order to determine the selection criteria chosen according to the five approaches defined by Attia et al. (2012b), which are:

(1) Usability and information management (UIM) of interface;

(2) Integration of intelligent design knowledge base (IIKB);
(3) Accuracy of tools and ability to simulate detailed and complex building components (AADCC);
(4) Interoperability of building modelling (IBM);
(5) Integration with building design process (IBDP).

The survey began in early September 2017 until mid-October 2017, obtaining a total of 157 responses, with the resolution time being 15–20 min. The questionnaire was structured in two parts, so the first one consisted of 59 questions that dealt with the definition of simulation; previous knowledge, uses and objectives of the simulation; university teaching; credibility of the simulations; applications of BPSTs; acquisition of tools; collaboration with other disciplines; solutions to produce an approach in the design field; and proposals for improvement.

The second part consisted of 19 questions only thought for users of BPSTs. Several parameters are analyzed, such as the learning source of BPSTs; the frequency of use of the software along with its difficulty; the tools that best fit the architects; the parameters that influence the selection of one software or another; and the barriers that prevent the use of these simulation software. In addition, a synthesis of each of the five criteria [17] listed above ((1) (UIM), (2) (IIKB), (3) (AADCC), (4) (IBM), (5) (IBDP)) was developed and several assessment subtopics were indicated.

For the sample size, the confidence level and the maximum tolerable margin of error were considered [29]. A representative sample was considered using the z-statistic for infinite samples to obtain consistent estimates, and the sample size of 157 respondents corresponds to an error rate of 7.8% with a confidence level of 95%.

3. Results and Discussions

A total of 157 responses were received, of which 61% came from architects, 26% from architecture students and 13% from other disciplines. A total of 54.8% worked in the residential sector and 41.3% in the rehabilitation field. Regarding the usual architectural practice, 46.2% worked developing the design and construction stages. Among all the respondents, 53.7% worked with professionals in multidisciplinary teams and a 43.6% were employed by others. Among them, 29.5% knew the design through computer simulation; this low percentage of users reflects shows that most BPSTs are not compatible with the architects' needs [36,48,50]; similarly, the complexity of these tools for the profession was evident.

A total of 76% of the architects who responded to the survey had a professional experience of less than 5 years, so they were young architects. Figure 1 shows the confidence of this sector of architects in several parameters about the BPSTs, which therefore represent a series of reasons to reduce the gap in the BPSTs use and the architectural design.

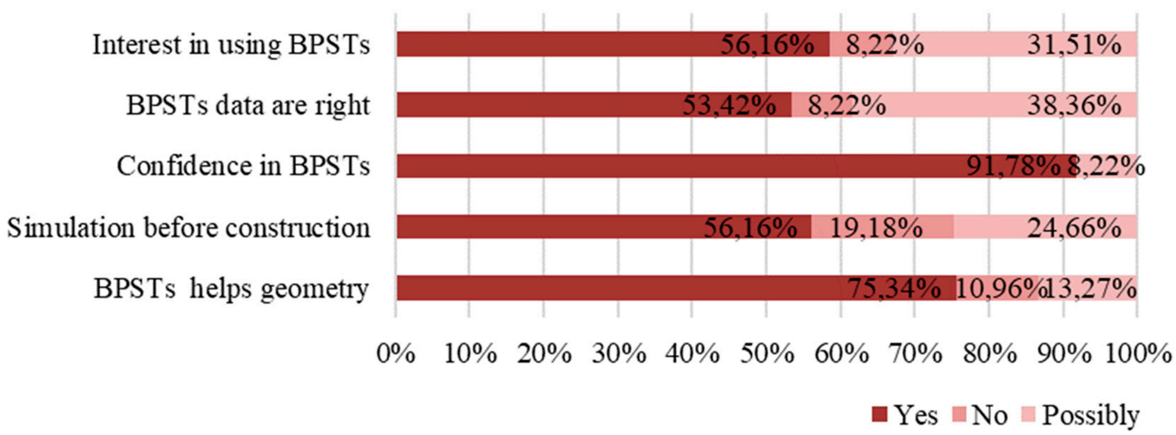
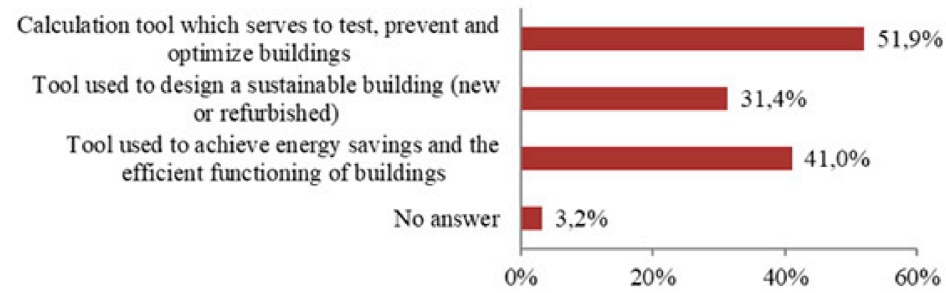


Figure 1. Confidence parameters of architects with professional experience below 5 years.

A total of 45.4% of the respondents were aware of the existence of numerical simulation; some of them define it as "a design tool that allows to improve the behavior of a new or existing building at all levels making it more efficient and more sustainable". According to one of the answers obtained, the objective of simulations was defined as "the control of the costs generated by the activity of construction, from the manufacture of materials to the demolition, with the ultimate aim of avoiding waste of energy and use of resources in the most efficient way while maintaining a standard of comfort". Figure 2 shows the opinions on the definition and objectives of the BPSTs.



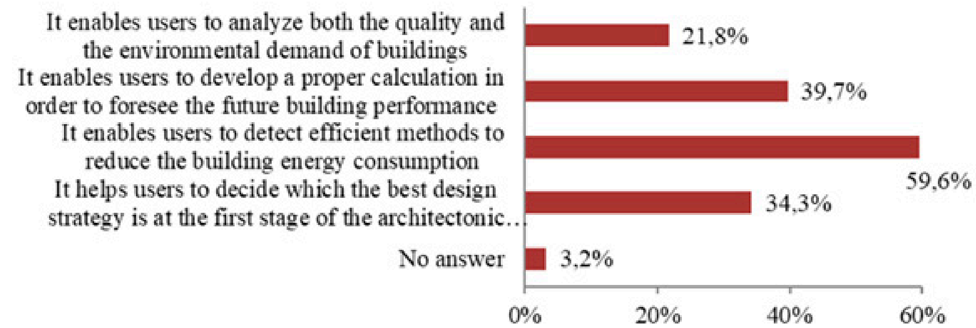
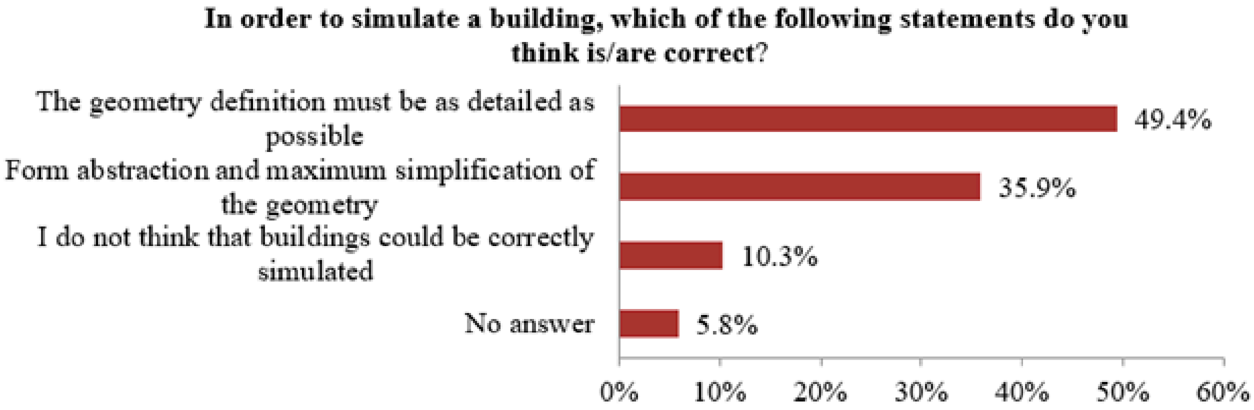


Figure 2. Definition and objectives of the energy simulation.

Figure 3 shows the opinion about how to perform a simulation with a three-dimensional model. One in three respondents thought that geometry should be simplified, the same amount thought otherwise and the remaining third indicated that perhaps this ambiguity is in line with the study developed by Lin and Gerber (2013) [51], which reflects the need to accommodate different degrees of geometry to the optimal solution. With respect to the parameters that are taken into account in a simulation, half did not consider the external shadow or the environment important; however, relevance was given to the climate, the openings in façade, the HVAC systems, the internal gains and the type of construction [34,41,42,52,53].

The suggestions received are the following ones:

- Multidisciplinarity is required during the simulation process;
- Professional assistance is required from the Official Professional Association of Architects;
- A simple and fast workflow should be established in the conceptual development that could be capable of making the most general decisions. Detailed simulations are not practical for the vast majority of projects;
- In order for the initial purposes not to become unrealized goals, a specialist who provides reliability should be consulted.



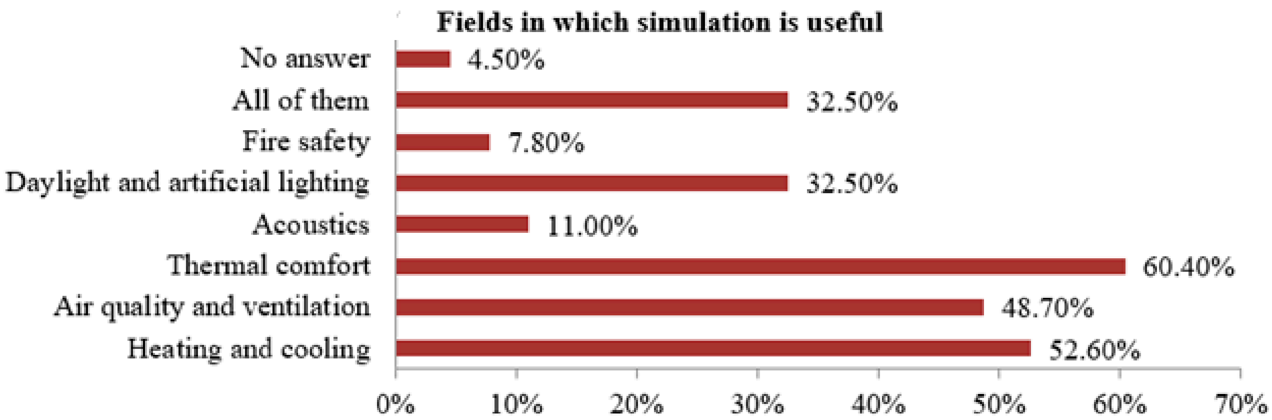


Figure 3. Opinions on how to perform a simulation.

A total of 45.8% of the participants knew a suitable simulation tool for architects; within this percentage, Sketchup (40.9%), Ecotect (16.2%), Design Builder (11.7%), Energy Plus (9.1%) and Open studio (2.6%) stood out. In this context, and as shown in Figure 4, it was considered that the best stage to make use of the energy simulation is during the optimization of the design, according to 60% of the respondents, and the worst one during the construction process, according to 7.20%. The existence of so much difference between phases shows that the BPSTs are not compatible with the working methods of the architects [17]; this fact results in a limited use of energy simulation tools [11].

Figure 5 shows the opinion about the training received in the university regarding BPSTs, since it was observed as the most relevant strategy to promote the use of the tools. There was a great interest (70.1%) in the conduct of talks or workshops with experts and in the incorporation in subjects during architecture studies or the Master's thesis project, as indicated by 74% of the respondents. A total of 35.7% specified that there must be Master's or doctorate courses, and 29.9% that there must be courses at the Official Professional Association of Architects. These results are related to the study by Reinhart et al. (2012) [52], which reflects the importance of encouraging "culture" of energy modeling in architecture schools that can lead to improved communication between architects and energy consultants.

Although 43.8% of the respondents considered that improved tools for architectural integration of energy analysis are needed, only 1.3% knew more than 20 people who managed BPSTs, while 53.6% knew less than 4 and 20.3% did not know anyone. Figure 6 shows possible reasons why BPSTs are not used, the predominant one being the lack of knowledge about this type of tools since, as shown by Attia et al. (2009) [17], architects possess different knowledge and working methods than BPSTs developers, who are usually engineers and construction physicists. Other reasons collected from the survey regarding the lack of management of BPSTs are the following:

- Other people in the team (engineers) perform this part;
- Customers do not demand it;
- The licenses of the software are very expensive;
- It is not used at university.

Table 1 shows the opinion of the respondents on a number of relevant ideas related to the use of BPSTs, which are (A) adaptation of the BPSTs to the architects, their previous training and their place of work; (B) advantages and disadvantages of use of BPSTs in the architectural design stages, together with the confidence towards these tools; (C) credibility of the outcomes obtained from a BPSTs; and (D) the importance of BPSTs in the NZEB design and the interest of the architects by the simulation tools in the future [53–55].

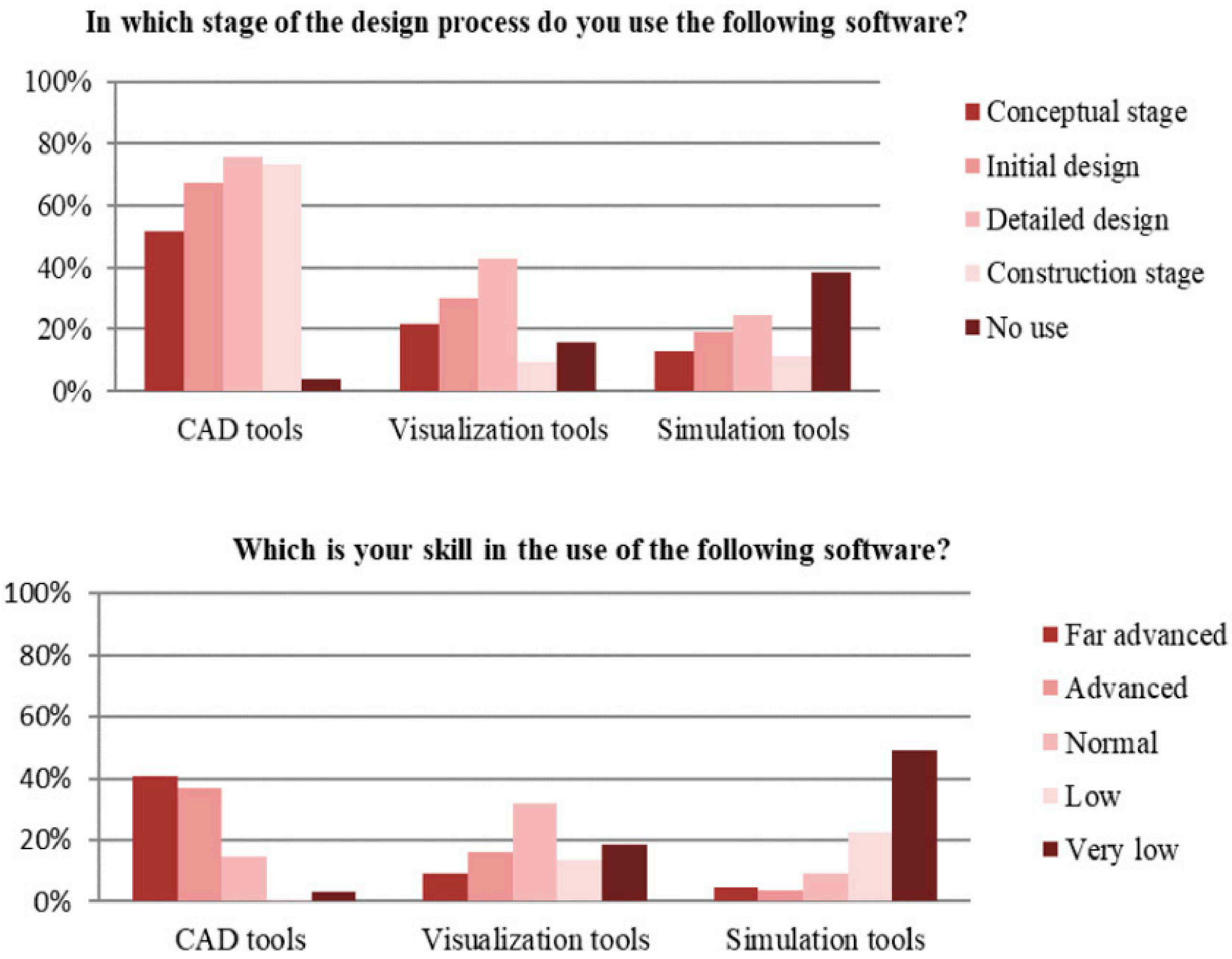
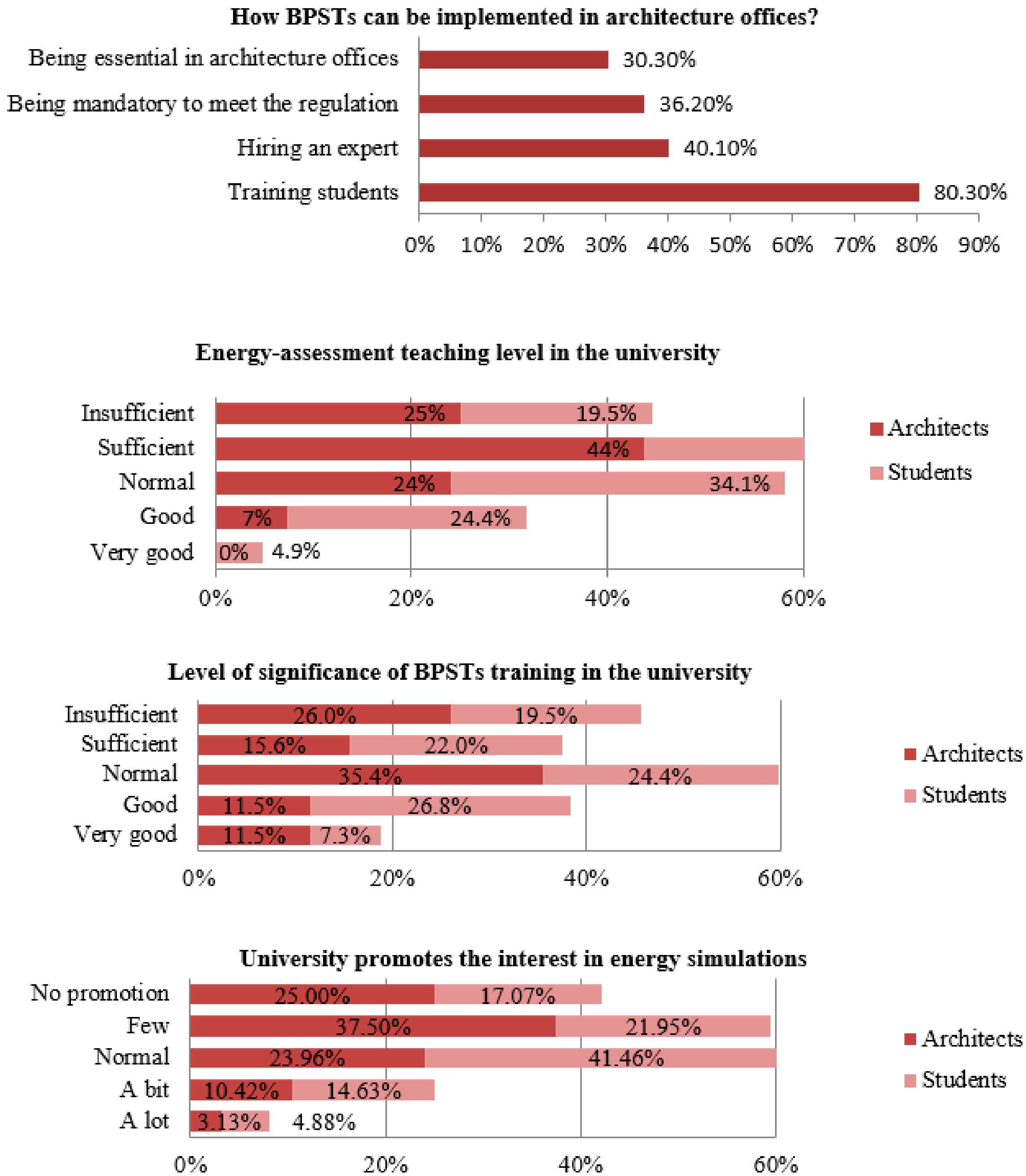


Figure 4. Tools used during the design stage and users' skills.



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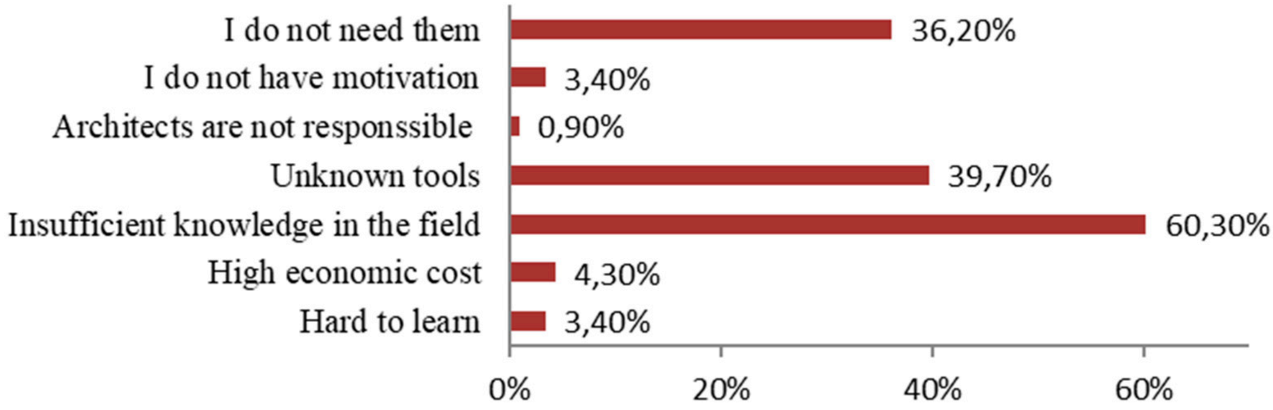

Figure 6. Reasons for not using BPSTs.

Table 1. Confidence parameters in the BPSTs.

		YES	NO	Possibly
A	BPSTs are thought to be used by experts who are NOT architects	33.1%	18.5%	48.3%
	Do you use BPSTs tools at work?	16.8%	65.8%	17.4%
	In your university, in Architecture studies, are BPSTs used?	24.0%	47.4%	28.6%
B	Do BPSTs speed up the design stage?	31.8%	28.6%	39.6%
	Do BPPSTs limit the architect's creativity in the design stage?	15.8%	52.6%	31.6%
	Can simulation software help you to create the geometry?	63.6%	11.9%	24.5%
C	Are the data obtained through simulation software correct?	45.5%	7.1%	47.4%
	Should BPSTs learning be carried out by a trial-and-error process?	29.0%	34.2%	36.8%
	Is building simulation essential before the construction stage?	58.8%	19.0%	22.2%
	Is outcomes validation (comparing with real results) necessary?	87.1%	2.6%	10.3%
D	Are BPSTs thought to be used in the NZEB design?	76.8%	4.0%	19.2%
	Is the architect's necessities identification vital to ease BPSTs use?	62.4%	6.0%	29.8%
	Are you interested in the use of BPSTs in the future?	63.4%	5.9%	30.7%

80–100%, 60–80%, 40–60%, 20–40%, 0–20%.

Figure 7 shows the opinion of architects regarding several parameters that can determine the confidence in the BPSTs. These parameters are (A) the reason for a good architectural design; (B) the replacement of the design by a quantitative simulation software; (C) the utility of the BPSTs to reconsider aspects that have been ignored during the design process; (D) the lack of development of an energy efficient design because of the improvement of a functional one; (E) the study of the optimal form as an effective strategy to avoid the subsequent annex of elements that alter the design; (F) the confidence in the BPSTs to make architectural decisions; (G) the ignorance of the BPSTs as a reason for distrust in them; (H) the possibility of incorporating the decisions of an energy consultant in the design stage; (I) the possible methods of incorporating data into de architectural design; (J) the control of professionals regarding the management of BPSTs; and (K) the importance of working together with the experts in BPSTs.

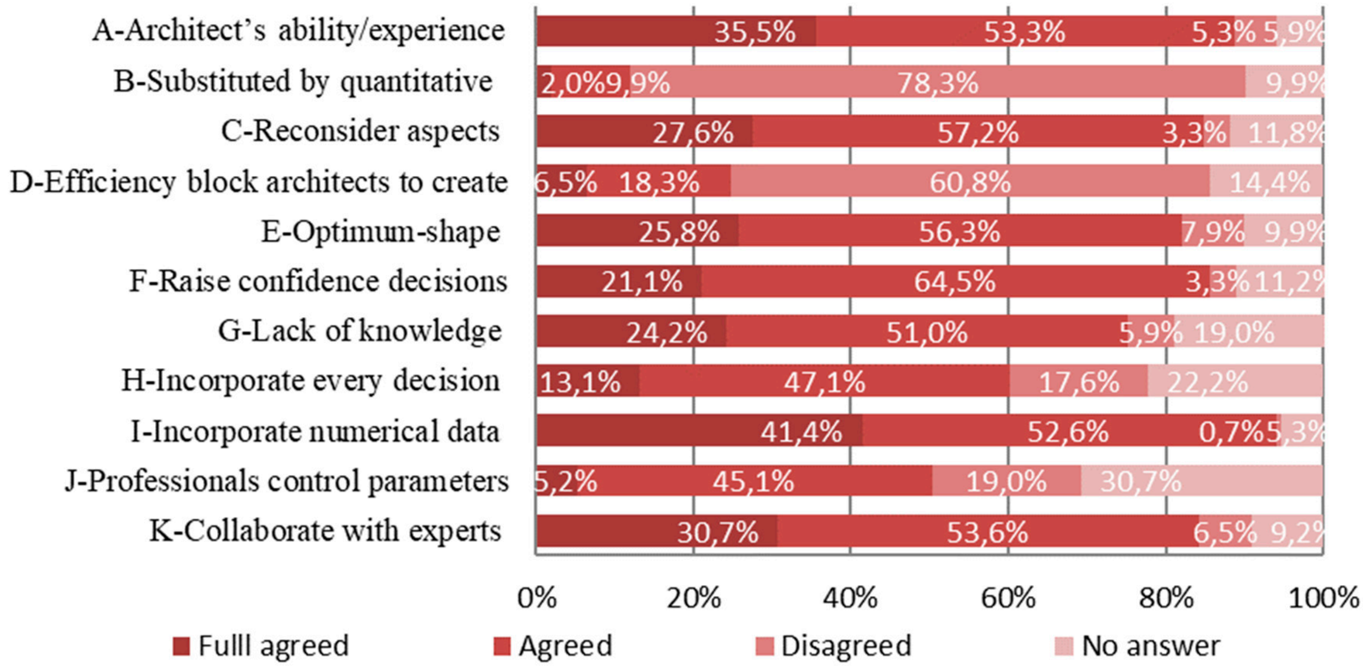

Figure 7. Opinions of architects about the aspects indicating confidence in BPSTs.

Figure 7 shows the general opinions on the use of BPSTs, noting that 28% of respondents used BPSTs, but, to date, 30.9% of that percentage no longer used them; however, 60.8% believed that the use of BPSTs is important. In this context, and among 28% of the participants who had used BPSTs, 14.1% were self-taught and 37.5% took training courses.

The suggestions provided by the respondents (Figure 8) are reflected in the following ideas:

- It is important that the simulation tools have an intuitive interface and that there are manuals with practical examples to facilitate understanding;
- Improvement in material libraries and climate data in regions (not just cities) is essential;
- Efforts are being made to force architects to use a foreign, awkward and unintelligible tool instead of giving facilities, even in tools that do not provide detailed results;
- BPSTs should focus on general aspects of easy interaction and understanding. Once the reduction in the price of BPSTs is achieved, more specific tools should be developed;
- There are some doubts about BPSTs ability to make decisions at a volumetric or formal level, as seems to be inferred from some survey questions. In this regard, there are factors of use or other needs that are ahead of energy optimization;
- In the future, several possibilities should be provided in order to adapt BPSTs to researchers (without experience in the design of buildings, but in their improvement);
- More energy efficiency issues need to be taken into account in the design process;
- Raise awareness of the disinformation of the simulations.

According to Attia et al. [12], architects classify intelligence with 33% above usability, with 29%, interoperability with 22% and accuracy with 17%. The term "usability" shows the degree of design of the user interface in a way that facilitates data entry, simple navigation, flexible control and visualization of results [17,56]. A better integration with CAD, data input adapted to the language of the architect [57] and an output of easily interpretable results are needed [10,57]. These investigations are related to the data obtained, as reflected in Figure 9, on the selection criteria of the BPSTs by the architects. The BPSTs users consider that the most important factor is the simple verification (validation) of an energy simulation according to real cases, but they also give relevance to the explanation of the advantages of the software in the practice of the architect and of the configuration of entrance of the data to the software. The interest in simplifying and delimiting the software options in order to facilitate the interpretation of results is not particularly significant.

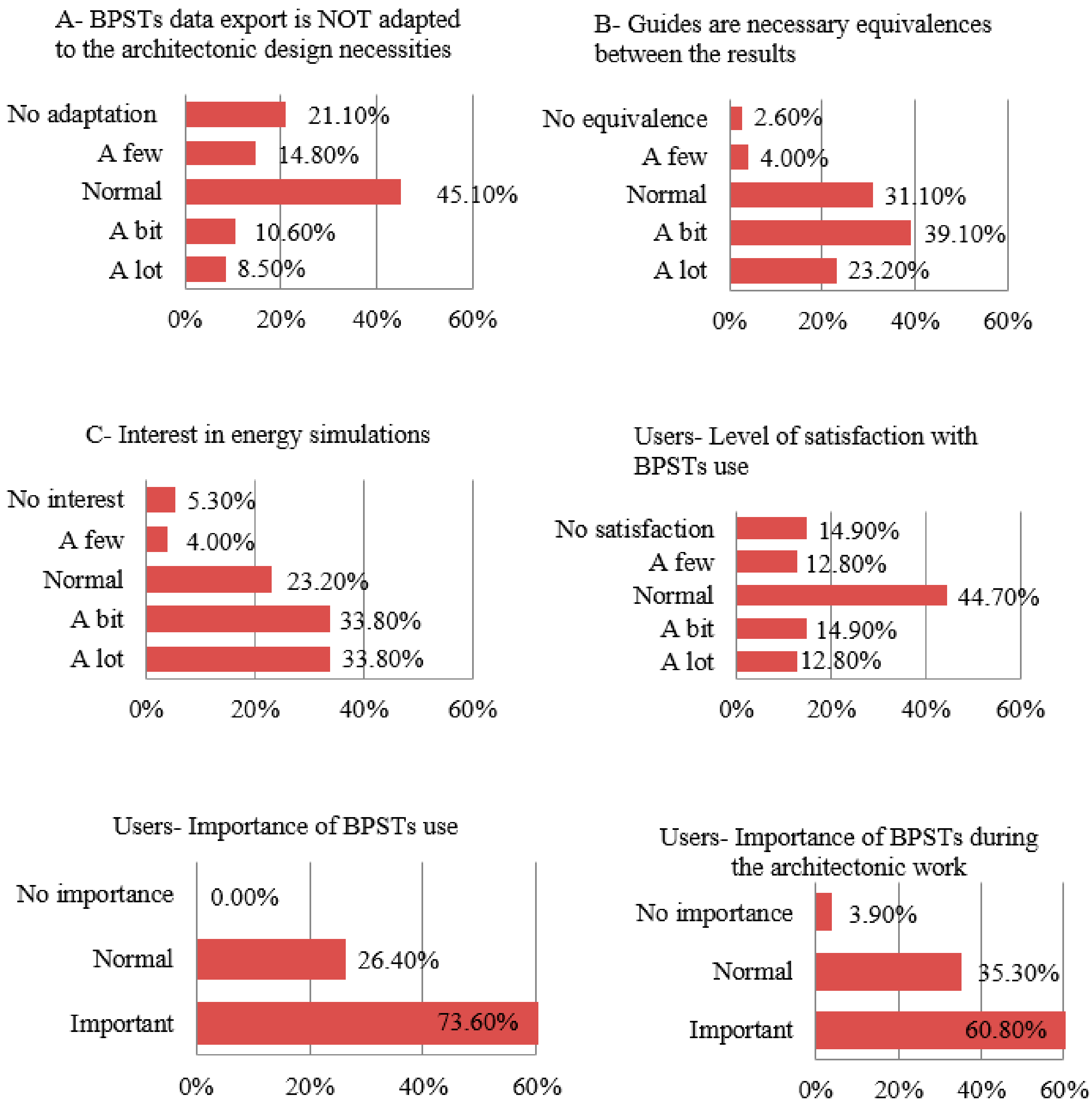

Figure 8. General opinions on the use of BPSTs.

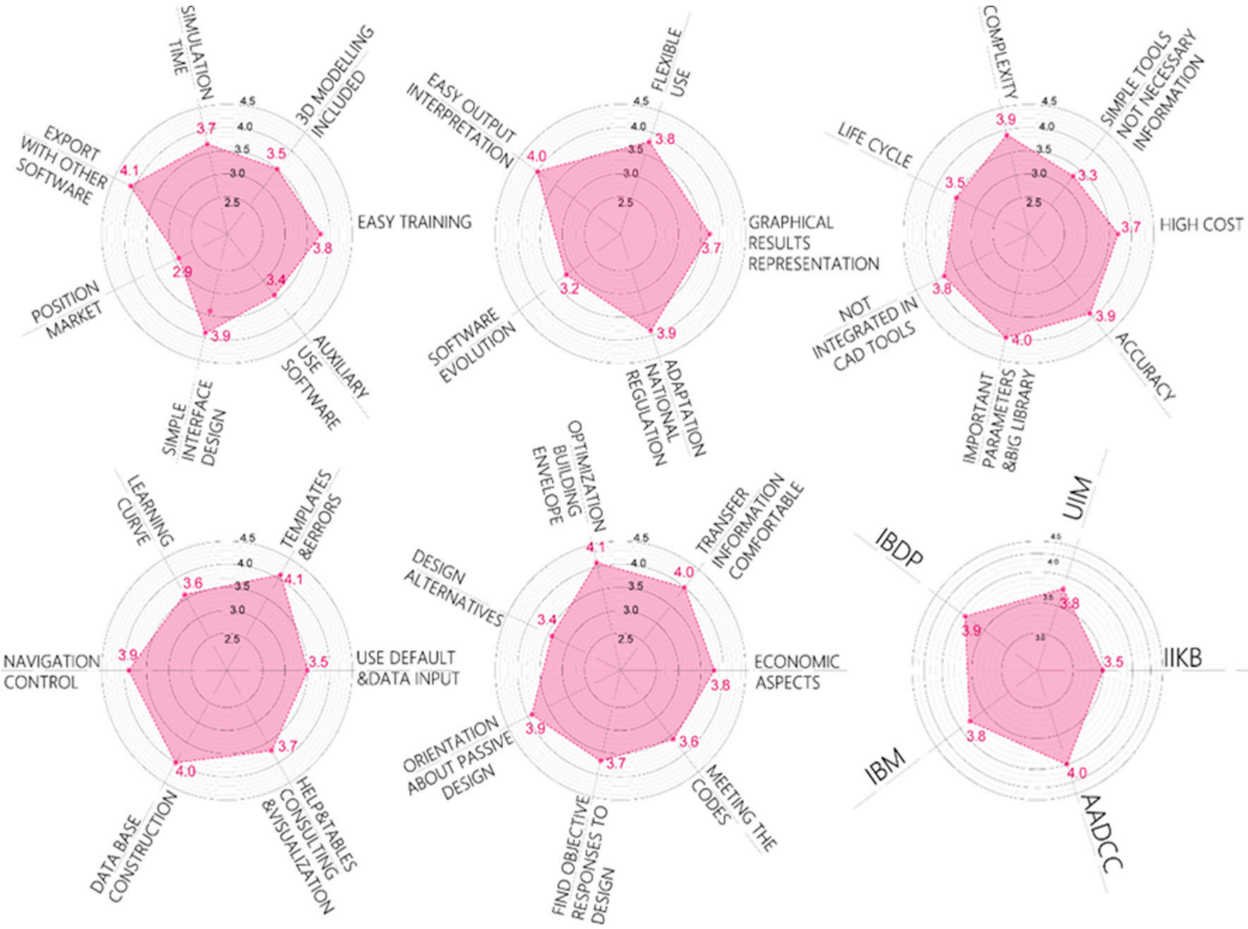

Figure 9. BPSTs selection criteria.

4. Conclusions

This study identifies the current situation of architects and architecture students in Spain regarding BPSTs. Two topics are discussed, the general knowledge and the use of the simulation in its architectural practice and the tools selection criteria from the point of view of the architects. Both topics help to evolve in both the academic and professional field. Additionally, the outcomes obtained from the survey provide an overview of the BPSTs characteristics that should be improved in order to achieve a greater acceptance between architects. Therefore, the following conclusions are reached:

- There is no familiarization with the BPSTs, since no training is carried out or a change in the teaching structure of university courses. However, the new generation of architects is receptive to the use of BPSTs, since their attitude is not vitiated by the traditional practice of an architect, although this interest is not being used, so the situation persists;
- Many respondents have never heard of the BPSTs concept ever, and 72% did not even use it. In order to improve the practice on simulation by the architects, criteria and specifications of general use of the programs must be established, adapted to the way they work;
- Today, there is still a wide gap between architectural design and simulation tools.

For decades, energy efficiency must be developed in all possible areas, and regulations include energy requirements that must be met. Therefore, this study is of particular interest to teachers to achieve improvement measures regarding energy simulation in the realm of architecture, giving rise to a necessary innovation. In this way, professionals will be prepared to design buildings by using the advantages of simulation tools, during all stages of design, to construct sustainable buildings.

As future research lines, it is intended to develop a guide that shows the comparative between a real case and a simulated one, showing the different architectural design options with its advantages and disadvantages. Specifically, it is proposed to develop a design guide for a simulation program (Design Builder-Energy Plus) with general guidelines adapted to the exclusive use of architects. After the analysis of knowledge and having detected where the weaknesses of the architects are, it will be a simple guide, with limited data entry and with special emphasis on the parameters that can modify the design, shape, orientation or other design alternatives. All this allows the development of research projects that link architects with other stakeholders to adapt BPSTs to the way they work.

The analyses of the results shown in this article make it clear that newly licensed architects lack knowledge of BPST. The authors propose to solve this deficiency by incorporating building energy simulation in two different areas of architectural curricula: there should be a coordination between the areas of construction; and facilities and architectural projects. Design courses should encourage the use of BPST through assignments on the influence of passive strategies in architectural design. Simulation results should justify design decisions in the conceptual phase of the design process.

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