Analysis and simulation of energy efficiency on platform BIM: A systematic literature mapping

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ABSTRACT: This paper presents a process of systematic literature review as part of a PhD research focusing on the integration of energy efficiency simulation in the design process using building information modeling (BIM) platform. The main objective is to assess international researches carried out in the last ten years published at major conferences, proceedings and journals approaching the integration of the BIM platform and energy efficiency of buildings. It aims to identify trends and gaps in this area of research. A systematic literature mapping using a Systematic Mapping Study (SMS) tool characterized by the evidence-based paradigm has been carried out. It led to the identification of the main publications and research institutions focusing on the subject during the last ten years. The survey was conducted in the Web of Science, Scopus and Science Direct databases, which resulted in 131 papers adhering to the theme. The survey allowed the identification of the main research focus, as well as knowledge gaps and trends. Results have shown a comprehensive mapping, which defines the current situation of research in the field. They presented an overview of the scientific production, as well as pointed at needed research regarding the integration of BIM and energy issues in buildings.

1. INTRODUCTION

Obtaining adequate levels of energy efficiency in buildings depends largely on the architectural design that, guided by bioclimatic principles, can reduce or dispense the use of artificial lighting and air conditioning. Although the environmental comfort approach should be inherent to every design process, the architectural production seen in most cities shows that many issues related to the energy performance of these buildings have not been addressed, suggesting that many architects have been neglecting these issues (Freire and Amorim, 2011).

In the early stages of the design process, the architect faces a series of conditions that influence the definition of the architectural party and affect the energy performance of the building. In this step, being more than one imaging tool, the BIM technology provides the architect with the possibility to devise a parameterized model. This allows the visualization of building volume, sun incidence, application of materials and finishes and the performance of architectural elements, all expeditiously. This condition favors the design of more efficient buildings in various fields of interest: thermal, energy, urban planning, functional, constructive, etc.

Advances in computational modeling tools in architecture have revolutionized the design process and can contribute to improving the quality of buildings, particularly their energy performance. The modelling of the product, whose main feature is the combination of geometric (such as shape, position and dimensions) with non-geometric information (which include thermal properties of building components), among other approaches, forming what is called the Information Modelling in Construction (Freire and Amorim, 2011).

BIM has established itself as an emerging field of research and application (Succar, 2013). In Brazil, in recent years, research in this area has had a breakthrough that translated into publications, in part due to the support of CNPq and FINEP that, through public notices, encouraged the creation of research networks focused on the "development of innovative solutions in information technology and communication applied to the construction aimed at improving the quality and productivity segment of social housing, especially: Building Information Modeling (BIM) and other solutions to support the project management process; performance simulation; and building operation", directly influencing the production of papers and research development in the country (Kassen and Amorim, 2015).

Despite the subject relevance, it is believed that it has not been properly explored in the energy efficiency field, justifying the realization of a Systematic Mapping Study (SMS) focused on this aspect. This work aims to identify the topics, to characterize the existing publications and presents a research mapping linking the themes mentioned above, and pointing the most investigated topics and those little studied.

2. OBJECTIVE

The main objective of this paper is to map the researches published in the main journals and conference proceedings in the last ten years addressing BIM issues and energy

efficiency in order to identify the main approaches and possible gaps in studies that relate these two themes.

3. METHOD

This research was carried out with the systematic literature mapping, literature search process that uses evidence-based paradigm in a systematic and targeted way, analyzing the information from this search in existing publications. This stage of SMS precedes the Systematic Literature Review - SLR and is important in the early stages of research (Fernandez et al 2009; Granja, 2013; Brereton et al, 2007; Guedes and Bertoli, 2015.). The contribution of this process is the ability to identify gaps in knowledge allowing refining and polishing of the research question investigated (Bailey et al., 2007).

An SMS can set a previous step to a SLR, because it makes the survey and selection of texts for review to better answer the research question proposed. This is precisely the difference between these steps: the need for conducting a preliminary mapping for further refinement of the mapped literature. The steps taken in this study are illustrated in Figure 1 (Fernandez et al. 2009). The SMS stages are better detailed in the following topics, showing how research concepts will be applied in each of the mapping step
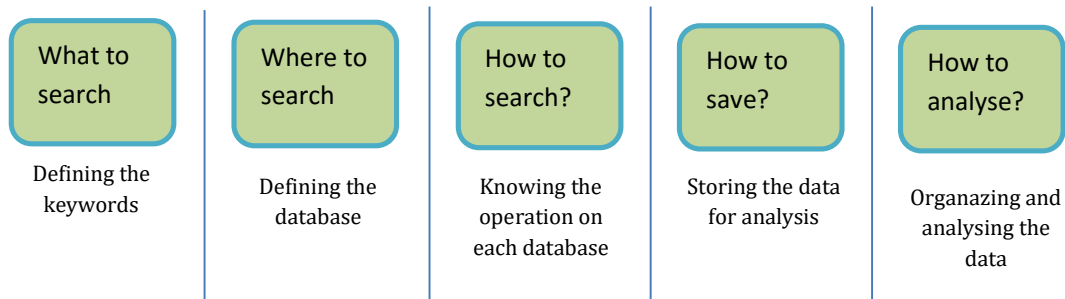
What to search	Where to search	How to search?	How to save?	How to analyse?
Defining the keywords	Defining the database	Knowing the operation on each database	Storing the data for analysis	Organazing and analysing the data

Figure 1: Schematic image of an SMS with the five steps. Source (Fernandez et al. 2009)

3.1   Step 1: What to search

On the first stage, it is important that the subject of the research is already well settled as a consolidated matter, and that the keywords are properly defined. It is where a proper analysis of the used terms is necessary because the result of the search carried out will depend on what fits best the searched theme. In this research, the following terms are used:

1. *Building information modeling* (BIM);
2. *Energy efficiency*;
3. *Design process*.

On the second step, one noted that the term design process was restricting the search. Then, it was decided to work only with the first two main terms: Building Information Modelling and Energy efficiency.

A ten years period was set for the search, corresponding to the years 2006-2015, since the subject is relatively new. On preliminary searches one could prove that the results for previous periods showed a small number of papers.

Only journals and international events proceedings were selected, understanding that these publications show a more scientific profile of literature that addresses these issues.

3.2   Step 2: Where to search

The most relevant databases on research topics were selected, namely: Web of Science (WOS), Scopus (SCO) and Science Direct (SDI).

3.3   Step 3: How to search

At this stage, it is important to know the search engines that each database offers to have confidence that the output data will be consistent with what you are looking for. It is also necessary to define the criteria adopted for inclusion / exclusion, search string, researched period, and which search objects (books, conferences or journals), among other specific aspects.

The adopted sequence was ("bim" OR "building information modeling") AND "energ *" NOT ("medic *" OR "healt *" OR "water *"), in which AND is an operator that brings results that contain, necessarily, the words connected to the same time. OR is an operator that brings results that contain a word or another, and NOT delete the search results that contain these words. The "*" was used to allow to find variations of words such as energy, energetic, as well as to delete from the search terms used by other areas but appear frequently on the preliminary research, such as medicine, medical, health, healthy, among others.

3.4   Step 4: How to save?

The results of the conducted researches need to be "exported" for debugging and analysis of data. However, each database can use a different method to perform this operation, which makes the researcher study in detail these methods for each database, and mount the most convenient and secure exporting strategies.

For the Scopus and Science Direct bases, one chose to export the search results on the Bibtex format, which were interpreted and sent to the worksheet by the JabRef software, which is an open source reference manager that uses BibTeX as its native file format. This software exports data to spreadsheet in Bibtex.xml format that can be imported by Microsoft Excel.

Because each database has resources mechanisms of their own, it was impossible for Web of Science to export the results on this format. For this reason, it was necessary to do it manually. In this case, it was exported in text format (with tab), which will be imported into the spreadsheet, set up to recognize the used tabulators (comma), and then handled, organized and analyzed.

3.5 Step 5: How to analyze

The mapping stage of the process requires more time for the collected data analysis. The data is organized in spreadsheets with the same format, making it possible to import these data into a single worksheet. Initially, one creates a file for each database, to facilitate the import, then attached in the same spreadsheet, separated by different tabs.

Table 1: Fields used for organizing and handling the papers.

Field	Description
Observation*	Notes during the handling process;
Code*	The code o each paper, with reference to the database and a numeric sequence;
Adherence*	Adhering "Y", Non Adhering "N" or Maybe "M";
Title	The title of the paper;
Classification*	Classification according to the main focus of the paper;
Summary	Paper Summary;
ID	Paper identification;
Author	Paper authors;
Journal / Congress	Paper publication vehicle;
Year	Publication date;
Volume	Paper volume;
Page	Paper pages;
URL	Paper website;
DOI	Digital Object Identifier;
Keywords	Paper keywords;
Cited by	Number of paper citations in other published papers

* Items inserted by the researchers to assist the manipulation of data during the process of organizing and extracting information.

In each worksheet the information are detailed in the same format, where four more columns for further information required at the time of analysis were added. They are "Note", "Code", "Compliance" and "Rating".

In the "code" field, a codification was created aiming to identify the item with a unique code, and is composed of a short database (WOS - Web of Science, SCO - Scopus, SDI - Science Direct) and a number of Papers on the worksheet.

In the "Adherence" field "Y", "N" and "M" will be informed, each corresponding respectively to "YES", it is directly connected to the researched theme, "No" if it is not connected, and "Maybe", meaning that it will be examined at a later stage.

The next step is to gather all the worksheets, and after a classification in alphabetical order by title, it is possible to check for item duplication.

Moving forward, a more detailed analysis of each item is made, verifying adherence to the theme, and their classification, which will generate another spreadsheet only with papers adherent to the research. At this point of the SMS, it already has a lot of information to be extracted from the process, and summaries should be read and analyzed to complement the classification and new groups can be created as: more and less researched matter; authors; research centers; countries and continents with the most publications; year and a way of publication; and gaps for new researches.

The "rating" field is used to categorize papers. This is a complex task, where the analysis of the researcher must be very careful to meet the research objectives. The defined criteria and their ratings are shown in Table 2.

Table 2: Fields used for organizing and handling the papers.

Rating	Criteria
Education	Education and teaching about the subject
Analytical study	Discussion of some theory or comparative study;
Case study	Analysis that seeks to assess a matter or a product;
Tool	Investigation on the use of some computational tool;
Interoperability	Communication and transferring information between the different programs;
Method	Analysing methods used to resolve specific issues;
Modelling / Model	Modelling analysis, templates, and its parameters and information;
Operational	About the operation of a product;
Others	Related themes without much relevance to this study;
Project process	Reflections on the design process adopted;
Literature review	Literature review on the subject

4. RESULTS AND DISCUSSIONS

After organizing the spreadsheet of all papers for each database, the process of analysing begins. The results illustrate the scenario of existing publications that relate the concepts of BIM and energy efficiency as shown in item 3.1.

Figure 2 shows the number of papers found in the initial search using the keywords set to meet the purpose of this research on a 10 years period. 1,402 papers were found, most of these in the Science Direct database, with 71% of the total, Scopus and Web of Science 15% and 14% respectively.
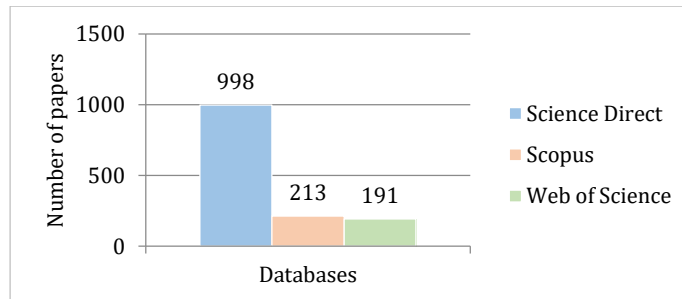

Figure 2: Results of the initial search separate by database

Figure 3 shows the evolution of the analyses, where 1,402 texts (result of all the added databases) were identified. After closer examination, this number was reduced to 131 texts, considered adherent to the subject, based on the analysis of the titles and abstracts; a decrease of 90.66%.
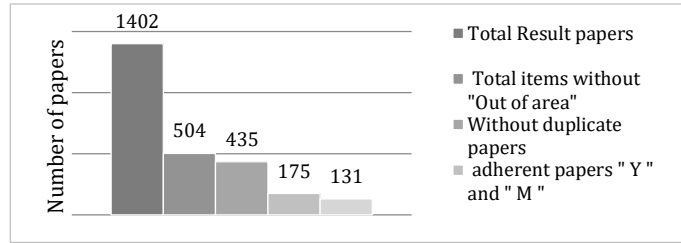
Figure 3: Evolution of the search refinement during the SMS.

Figure 4 shows a clear increase in the number of papers published in more recent years, stressing that in 2015 there was a substantial increase (over 60% from the previous year). From 2010 to 2015, this evolution went from 7 to 36 papers, an increase of 500%. In the last five years 108 papers were published.
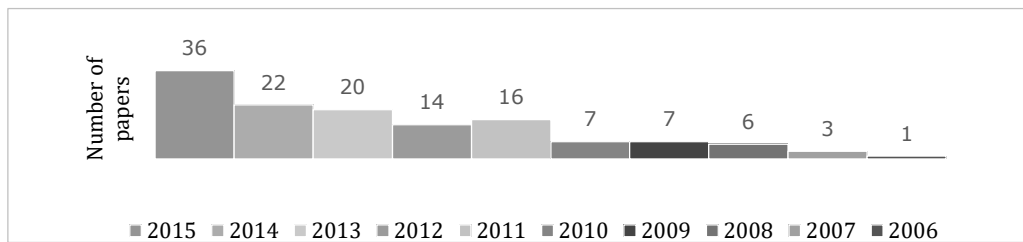

Figure 4: Distribution of adherent papers according to the publication year.

Figures 5 and 6 show a wide dispersion between the events and journals publications as well as the authors of the study as shown in Table 03.
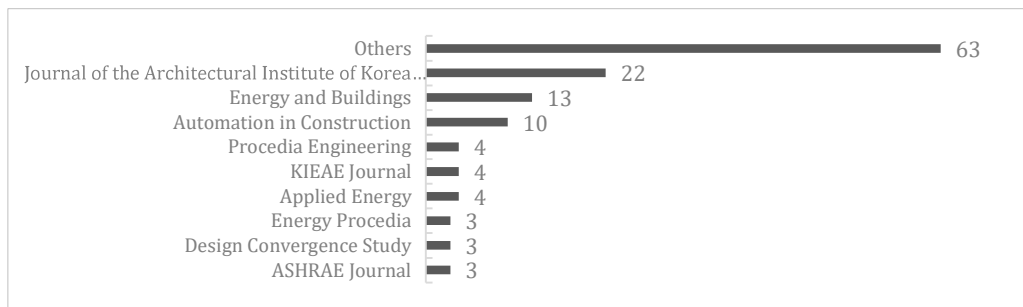

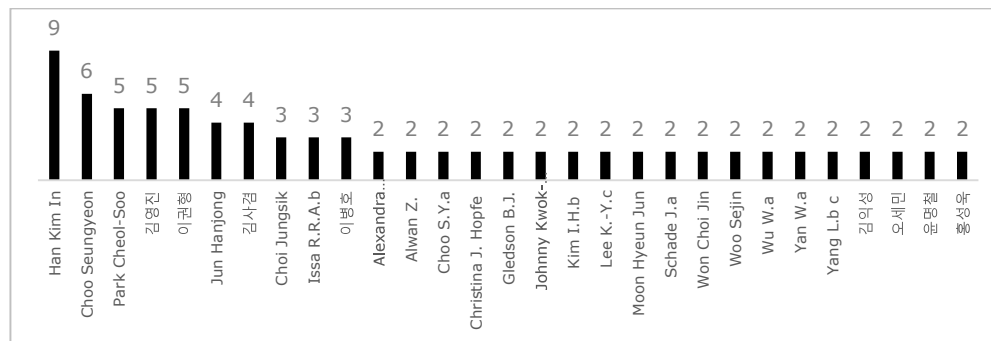Figure 5: Main journals and international events on the subject.

Figure 6: Main authors of publication on the subject.

Table three shows the dispersion among the authors who have published results of their scientific researches and, most of these (91% of total), published only one scientific paper. With up to two published papers, the number of researchers working on the subject number goes to 5.6%. On the other hand, only 11 of the theme researchers have more than 02 publications, a percentage of slightly more than 3%.

Table 3: Scientific Production by researcher.

Scientific Production	Number or researchers	Per cent
09 papers	1	0,30%
06 papers	3	0,89%
05 papers	2	0,59%
04 papers	2	0,65%
03 papers	3	0,89%
02 papers	19	5,62%
01 paper	308	91,12%

Figure 7 shows the classification of items according to the main focus of research among those listed in Table 2. More than half (55%) of researches are concentrated in three specific areas that are: Analytical Study, Tool and Method. The areas of Education and Building Management have few publications, suggesting the need for research in these areas.
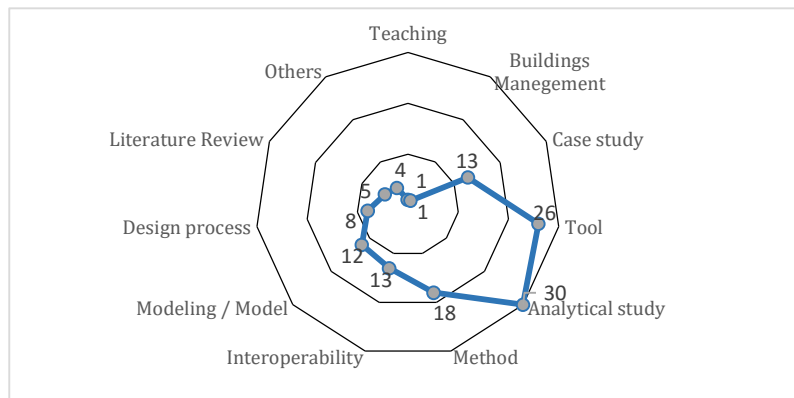

Figure 7: Main focus of published papers.

Figure 8 shows the growing number of publications for the previously classified subjects, emphasising tools, which presented a stronger growth between 2013 and 2015.
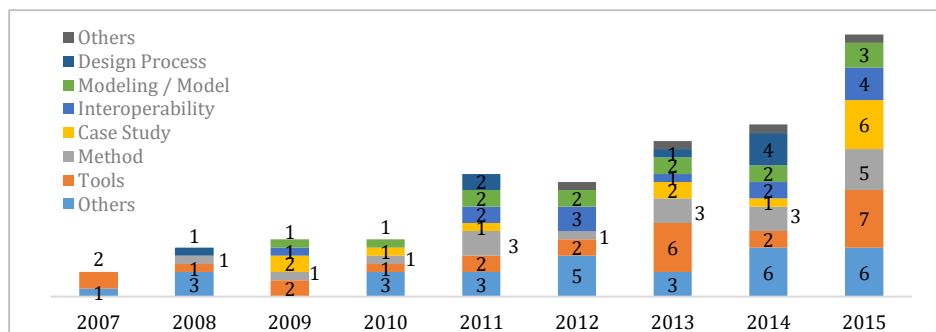

Figure 8: Distribution of the papers' main focus by year.

576

Table 4 highlights the most cited papers by other researches while table 5 shows the most used references by papers on the previous table.

Table 4: Most cited papers

AUTHOR	TITLE	YEAR	CITED BY
Schlueter, A.; Thesseling, F.	Building information model based energy/exergy performance assessment in early design stages	2009	143
Azhar, Salman; Carlton, Wade A.; Olsen, Darren; Ahmad, Irtishad	Building information modeling for sustainable design and LEED (R) rating analysis	2011	73
Costa, A.; Keane, M.M.; Torrens, J.I.; Corry, E.	Building operation and energy performance: Monitoring, analysis and optimisation toolkit	2013	35
Welle, B.; Haymaker, J.; Rogers, Z.	ThermalOpt: A methodology for automated BIM-based multidisciplinary thermal simulation for use in optimization environments	2011	26
Wang, Y.a; Wang, X.a; Wang, J.b; Yung, P.a; Jun, G.c	Engagement of facilities management in design stage through BIM: Framework and a case study	2013	22
van Treeck, C.; Rank, E.	Dimensional reduction of 3D building models using graph theory and its application in building energy simulation	2007	17
Stadel, A.; Eboli, J.; Ryberg, A.; Mitchell, J.; Spatari, S.	Intelligent sustainable design: Integration of carbon accounting and building information modeling	2011	16
Nguyen, T.H.a; Shehab, T.a; Gao, Z.b	Evaluating sustainability of architectural designs using building information modeling	2010	15
Sanguinetti, P.; Abdelmohsen, S.; Lee, J.; Lee, J.; Sheward, H.; Eastman, C.	General system architecture for BIM: An integrated approach for design and analysis	2012	14
Schade, J.; Olofsson, T.; Schreyer, M.	Decision-making in a model-based design process	2011	11
Díaz-Vilariño, L.; Lagüela, S.; Armest, J.; Arias, P.	Semantic as-built 3d models including shades for the evaluation of solar influence on buildings	2013	10

Table 5: Most cited references in table 4 papers

Author	Year	Títle	Citations
Eastman C.M., Tiecholz P. , Sacks R., Liston K.	2008	BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors	03
B. Dong, K.P. Lam, Y.C. Huang, G.M. Dobbs	2007	A comparative study of the IFC and gbXML informational infrastructures for data exchange in computational design support environments	02
Bazjanec V.	2004	Building energy performance simulation as part of interoperable software environments	02
Eastman C.M.	1999	Building Product Models: Computer Environments Supporting Design and Construction	02
Gallaher M.P., O'Conner A.C., Dettbarn J.L. Jr., Gilday L.T.	2004	Cost analysis of inadequate interoperability in the U.S. capital facilities industry	02
DOE	2011	EnergyPlus Energy Simulation Software	02
U.S. Green Building Council	2009	Green Building Facts	02
Bazjanac V.	2008	IFC BIM-based methodology for semi-automated building energy performance simulation	02
	2007	International Alliance for Interoperability (IAI)	02
Young N.W. Jr., Jones S.A., Bernstein H.M.	2007	Interoperability in the construction industry	02

With the results obtained through SMS, the grouping of texts by knowledge in particular (see figure 8), it is possible to know what has been produced on the subject and the most important authors.

5. CONCLUSIONS

This paper conducted a systematic literature review (Systematic Mapping Study SMS), aiming to identify the bibliographic production of papers in scientific journals and proceedings of international scientific events, published between 2006 and 2015.

The results show a trend of exponential growth of the works that address the need to integrate to the design process of architects who use BIM platform as a design tool, with online information on the energy performance of the building that is being designed.

The discussions presented in this paper are part of a PhD research in its initial stage. One sought, from the analyses made, to identify topics needing further research, from the results of a systematic review of the literature addressing the integration of the energy performance of buildings to the architectural design process.

Results also suggest the growth on the number of researches with the "Analytical studies" approach in the "Tools" and "methods" aiming at an integrated analysis of energy efficiency simulations in BIM in the development of architectural design.

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