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The Life Cycle Cost Calculation as an enabler of Product Sustainability

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Abstract

The calculation of the life cycle cost is one of the most complete management techniques to predict an entire product life cycle, as it addresses all phases of a product from its development, its production, use, support and even its ruin. As the cost is a critical factor for the competitiveness and survival of a company in the market, its calculation is one of the main factors that subsidize the decision making about the definition of a product and its constituent raw materials. However, these options are totally linked to the future sustainability of this product throughout its life cycle. Thus, this work sought to identify the state of the art, through a bibliometric analysis, of publications related to the calculation of the product's life cycle cost as a line for planning the sustainability of a product throughout its entire cycle of life. This research identified that there is an exponential growth of research on this topic, there is a lot of potential for further research and that the calculation of the life cycle cost and the sustainability of products are really associated, as currents and relevant themes for contemporary society, focused on solutions for environmental sustainability and preservation issues.

Keywords
Bibliometric Analysis, Product Life Cycle Management, Cost Calculation, Sustainability.

1. Introduction

Everything that is made by man, be it a system, product or service, has a life cycle and is composed of stages (Bey 2017). These stages cover the development, production, use, support and disposal of this product or system. Product Lifecycle Management is a management concept applied in both the industrial and service sectors alike in order to guide new product development efforts (Barbalho and Rozenfeld 2013) as well as to improve product performance, since it guarantees functionality over time, starting from a long-term integrated formulation (Kabiraj 2018).

According to Nakagawa, the life cycle cost consists of the accumulation of costs for activities that occurred during the total product life cycle (NAKAGAWA 1991). More broadly, the Life Cycle Cost calculation involves all costs of development, production, use, support and disposal (Islam et al. 2014).

Although not widely used by companies, Life Cycle Costing or Life Cycle Cost is not a new thing, having actually been originally designed for acquisition purposes in defense related acquisitions, being still commonly used in the Armed Forces around the world (White 1976). Good results coming from these adopting Armed Forces reveal that the results of the Life Cycle Costing contribute, among other things, for allowing managers to make the best decisions about the different acquisition options presented to them (Goldsmith et al. 2017).

With the growth of environmental problems in the world, society's concerns over sustainability issues has increased. Life Cycle assessment, which takes into account the resources used in all phases of the product and its possible associated environmental impacts, throughout its life cycle, has become increasingly necessary as a business practice, competitive advantage and even survival (Bey 2017). Sustainable development presupposes the company's involvement in issues related to the life cycle of its products (Kawauchi, Cooperation, and Rausand 2014), thus being the key to the operationalization of sustainability in organizations (Kabiraj 2018).

Despite ever growing sustainability concerns, in the mainstream companies reasoning, cost is often the first criterion when choosing between different products and their constituent materials. In this way, the Life Cycle Cost Calculation is an excellent master line on which all other decisions that will enable the development of the product and its sustainability are built (Kabiraj 2018). We thus seek to shed light into the following research question: can Life Cycle Cost Calculation be used as an effective tool to make Product Sustainability feasible?

As such, we seek to identify in the current state of art of scientific publications, research that may approach the life cycle costing theme, possibly addressing the aforementioned research question. Our review work is structured as follows: in section 2, we present our methodology, in section 3 we present our research procedures, in section 4 the we present our findings and in section 5, we present our conclusions.

2. Material and methods

In order to identify, compare and map the trends of the main researches that address the development of products associated with sustainability, a systematic bibliometric and mixed methods review was carried out. The systematic literature review synthesizes in a holistic way the reflections on a field of research and has the potential to contribute to researchers in the systematic analysis of the challenges and decisions that occur during the Researches (Pittaway and Cope 2007).

Our work is descriptive in its nature, presenting a quantitative approach and the application of a bibliometric technique, with the objective of systematizing the knowledge about the life cycle costing theme, through the evaluation of the influence of the main authors, countries, journals, articles and keywords. The database used was the Scopus Database. The visualization and analysis of the bibliographic networks were performed using the VOSviewer software, version 1.6.10 (http://www.vosviewer.com/), in addition to an Excel spreadsheet.

This study is the first phase of a research protocol in which a qualitative analysis will follow, similar to Reis et al. (Reis, Barbalho, and Zanette 2017), to define an analytical framework for an empirical analysis of how life cycle cost can impact product effectiveness in a set of defense acquisitions.

3. Systematic Literature Review

As previously explained, the purpose of this article is to study the Life Cycle Cost Calculation as a tool to make Product Sustainability feasible, As such, we initially sought in the Scopus Base for articles published in English, which simultaneously had the keywords “Calculation”, “Life Cycle Cost ”and“ Sustainability, without time restrictions. At the end of the search, 124 articles were found.

3.1 Topics covered

Publications per year. We try not to adopt any time limitations within the scope of our search, exactly in order to establish the entire trajectory of the theme. Following this strategy, we can identify that the first article dates back to 2005, and the topic remains stable in terms of the number of publication, with few papers published per year until 2013, when a larger publication value starts to be occur until it reaches its peak back in 2019, with no fewer than 48 publications in that year alone.

This analysis shows a very positive trend and a growing interest in the subject. As this research was carried out on February 10, 2020, the number of papers for this particular year cannot be considered final and does not yet reflect the trend of the historical series. This year’s data was then computed with the intents of showcasing that the interest by the research community on the life cycle costing and sustainability themes remains current and unaltered, in this year and that as some works have already been published.

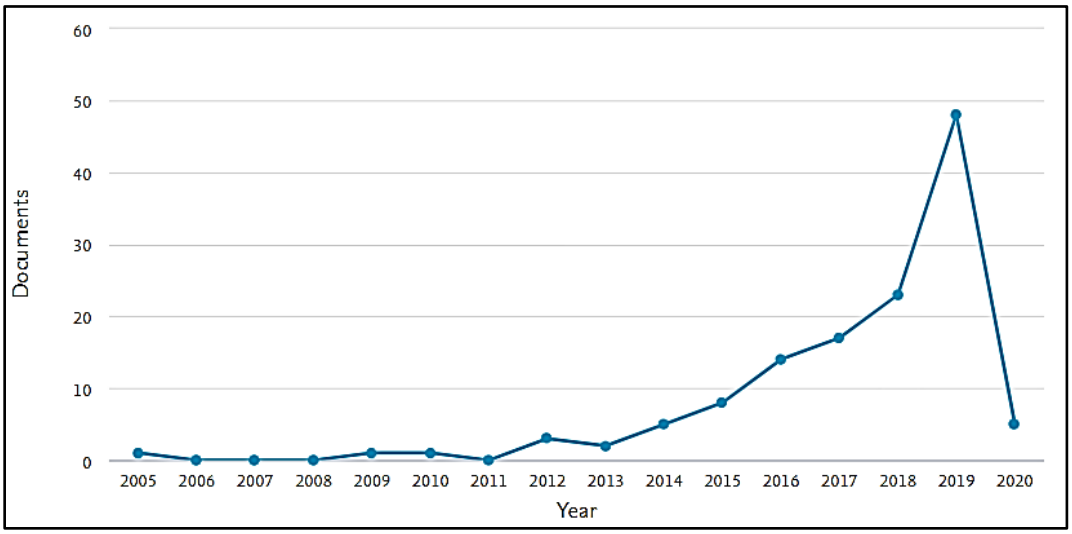

Fig. 1. Number of publications per year

Distribution of articles by periodicals. The 124 articles were published in 62 different journals, of which 46 had only one publication, while eight others only two. We found out that four magazines were responsible for 79 percent of all publications on the topic, leading us to conclude that there is a certain concentration of publications on the topic in a just few venues. The table below shows the top 10 venues with regards to the number of publications.

Table 1. Distribution of articles by periodicals

Periodical	Number of Publications
Journal of Cleaner Production	17
Sustainability Switzerland	16

Energies	8
Energy and Buildings	8
Building and Environment	4
Energy	4
Buildings	3
International Journal of Life Cycle Assessment	3
Stahlbau	3
A Z ITU Journal Of The Faculty Of Architecture	2

Distribution of publications by country. Considering the entire historical series, we can identify that there is no dominant country in terms of publication numbers on the topics of life cycle cost and sustainability, as the difference in the number of publications among the first countries in the ranking is small. We can still identify the top 10 contributors, as together these are responsible for 74% of the publications on the theme.

Brazil in position 20, does not figure in the top ten publishers, having only two publications in total.

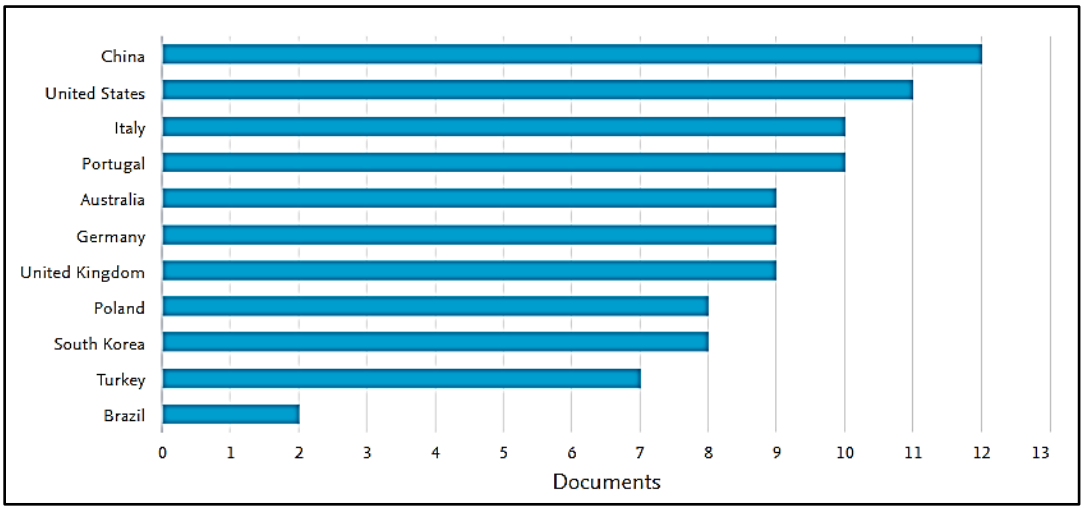

Fig. 2. Distribution of publications by country

Authors with more publications. Of the authors with the largest number of publications, among the 124 published articles, only two have four publications and only seven have three, either as individual author or main author. All other authors have single publications. Therefore, for the remainder of this research, we do not consider any particular author to be an authority on the field, as we believe no one of them is prolific enough.

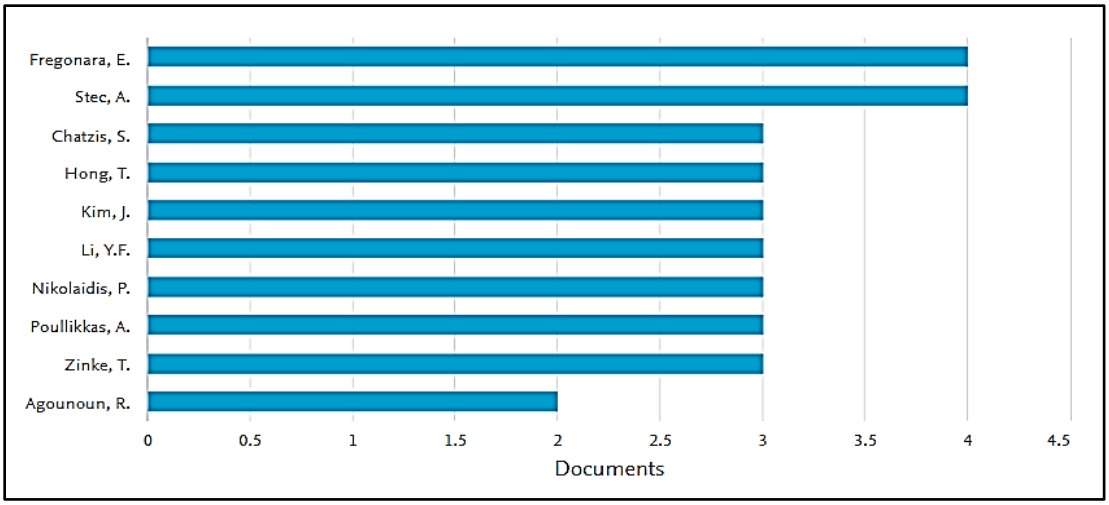

Fig. 3. Authors with more publications

Most cited articles. The 124 articles used in the scope of this research were cited 1299 individual times in the Scopus database, while the 10 topmost cited account for 534 of these citations, thus representing 41% of the total. Among the 10 most cited articles, only the fifth one titled "Economic and environmental evaluation model for selecting the optimum design of green roof systems in elementary schools" belongs to one of the authors who own more than one publication, namely (Kim, Hong, and Koo 2012).

Tabela 2. Most cited articles

1	Life cycle costing and externalities of palm oil biodiesel in Thailand	2012	76
2	Sustainability assessment of energy saving measures: A multi-criteria approach for residential buildings retrofitting - A case study of the Spanish housing stock	2016	73
3	Photovoltaic systems: A cost competitive option to supply energy to off-grid agricultural communities in arid regions	2010	65
4	Life cycle energy and cost analysis of embodied, operational and user-transport energy reduction measures for residential buildings	2016	56
5	Economic and environmental evaluation model for selecting the optimum design of green roof systems in elementary schools	2012	56
6	Electric vehicle cost, emissions, and water footprint in the United States: Development of a regional optimization model	2015	52
7	An optimization framework for building energy retrofits decision-making	2017	47
8	Building life cycle optimization tools for early design phases	2015	40

9	Super-insulate or use renewable technology? Life cycle cost, energy and global warming potential analysis of nearly zero energy buildings (NZEB) in a temperate oceanic climate	2017	36
10	Evaluation of net-zero energy residential buildings in the MENA region	2016	33

Keywords networks. In order to enhance the analysis of the keywords of the articles, an analysis was made using the VOSviwer software for words with 10 or more occurrences, found both in the title and abstract fields. Said software tool identified 35 most relevant ones, clustering them into 3 groups.

According to Van Eck and Waltman, the importance of an item is demonstrated by the size of its representative circle as well as the size of its letters (van Eck and Waltman 2010); the relationship between the words is identified as they are closer to each other.

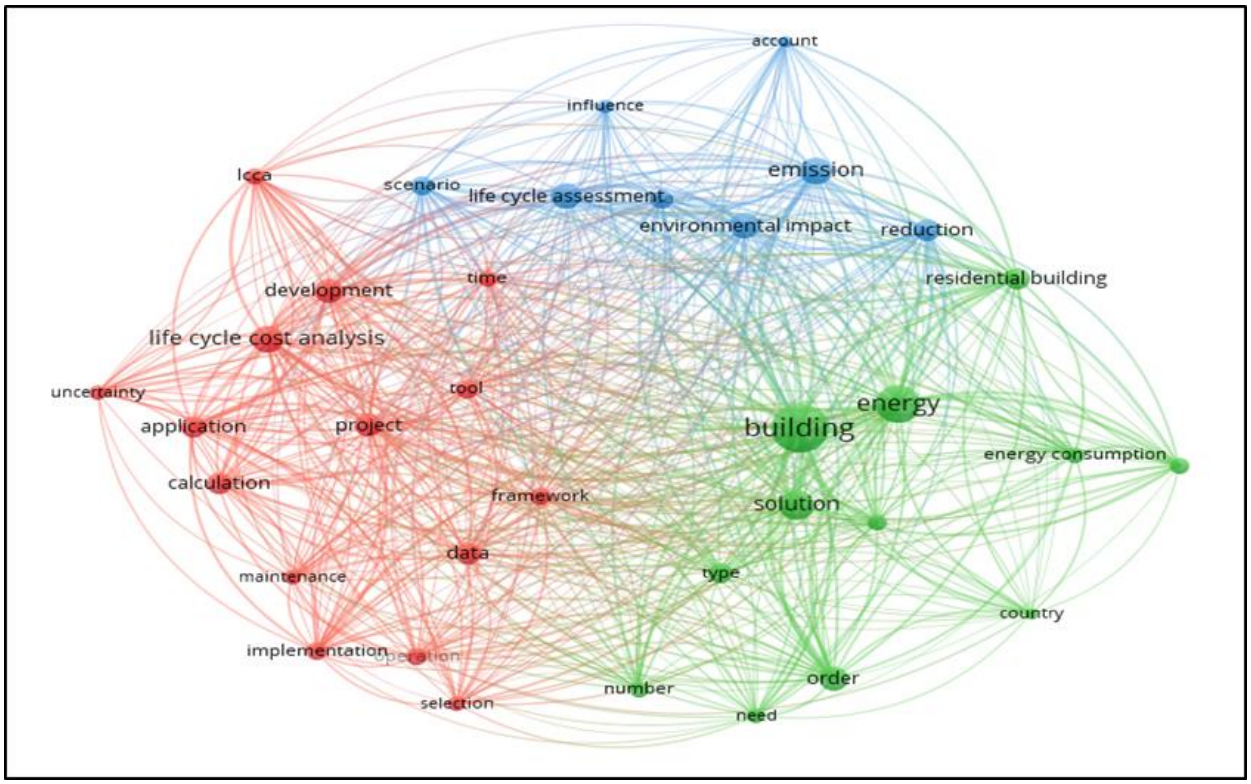

Fig. 4. Keyword networks

Analyzing Fig. 4, we can identify three large groups of words, which, led by their most cited key words, suggest the following main thematic areas: Energy and construction industry (building, energy, residential building, energy consumption), Product development (life cycle cost analysis, development, Project, calculation) and environment (environmental impact, life cycle assessment, emission, reduction).

4. Discussions

The analysis of the number of publications per year shows that interest on the subject is increasing with a strong growth trend. This trend is consistent with the increase in environmental problems that are plaguing the world as well as with global actions aimed at seeking solutions to reduce such problems. Further, the spread of publications

throughout magazines of different areas of focus showcases the relevance of the topic across different domains of interest.

The distribution of publications by countries coincides with the main economic and knowledge generation axes today: China, the United States and Western Europe. This fact could point towards the perception by such countries that the researched theme is a potential generator of technological advantage for the production of wealth. This is a hypothesis, and despite it, some other leads, also point towards the lack of research maturity on the topic, as we could not identify any large school of thought or any countries in particular that largely dominate knowledge on the subject.

Finally, the analysis of keywords with its three groups revealed the thematic areas involved. The strong relationship between product development, power generation and construction with impacts on the environment was clear. Seeking to synthesize the connections of the areas formed by the key words, despite being more used in product development, we will identify the calculation of the life cycle cost during development / construction, subsidizing decisions that will impact sustainability.

5. Conclusion

Our Bibliometric analysis regarding relation between the calculation of the cost of the life cycle and the sustainability of a product, showed that: there is an exponential growth of interest on the subject, as we can see by the increasing amount of publications over the years; we can also conclude that there is a lot of potential for additional research, given the current low overall production of articles.

The analysis of the keywords in these few works shows that the life cycle cost and the sustainability of the products are, in fact, associated themes, being also current and relevant for contemporary society, focused on the solution of sustainability and environmental preservation issues. It also showed that the calculation of the cost of the life cycle is still more common in product development, perhaps because this is the area most linked to the defense industry, which due to its great technological complexity gave rise to this technique. What it demonstrates, the great potential of application of the calculation of the cost of the cycle of life in the other areas for reduction of the environmental problems and of sustainability.

As limitations, this research was carried out on top of a single database, namely Scopus, which limits its scope. Thus, it is suggested that future studies adopt more bases and that articles related to the theme receive a more detailed analysis. This research will continue in a qualitative phase for in-depth comprehension of the theoretical and empirical relation on this theme.

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Antonio Henrique Duarte has a degree in Business Administration from the Federal University of Minas Gerais, an MBA in Project Management from the Getúlio Vargas Foundation, a Postgraduate Degree in Complementary Applications to Military Sciences at the Brazilian Army School of Administration and is currently a Master's student in Mechatronics Engineering at the University from Brasilia. He has the American certification in project management "Project Management Professional (PMP)" from the Project Management Institute (PMI); and the English certifications in project management "PRIN-CE2® Foundation" and "PRINCE2® Practitioner"; the English certification in an agile project "PRINCE2 Agile Foundation"; and the English certifications in program management "MSP® Foundation" and "MSP® Practitioner", the English certification in portfolio management "MoP® Foundation Certificate in Portfolio Management". He is an adjunct in the Governance Advisory of the Brazilian Army's Strategic portfolio - Brazilian Army Project Office. He has experience in the area of defense project, programs and portfolio management, working in the last ten years mainly in the themes: methodology, strategic portfolio, project management, program management, risk management, quality, indicators, knowledge management and planning strategic. He is a collaborator researcher at the Research Group on Innovation, Projects and Processes and PMO Global Alliance.

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Rodrigo Augusto Dos Santos has a PhD in Computer Science at the University of Texas at Arlington, master's in computer science at PUCRS, he is currently an Adjunct Professor at the University of Texas at Arlington and a tutor

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