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A Bibliometric Analysis on Costs Estimation of Building Retrofit

F Re Cecconi, N Moretti and M C Dejaco

Department of Architecture, Built Environment and Construction Engineering
Politecnico di Milano, via G. Ponzio 31, 20133 Milan, Italy

Corresponding author: nicola.moretti@polimi.it

Abstract. Buildings are responsible for approximately 40% of energy consumptions and 36% of CO₂ emissions in the EU. In developed countries, any intervention carried out for buildings' sustainability improvement is related to energy retrofit. Energy retrofit can be considered as a subset of sustainability management and is one of the key issues to be taken into account for the setup of an effective asset and portfolio management strategy. Among asset management core functions, sustainability management is one of those which must be encompassed in a strategic framework for effectively reaching the goals of the organisation. Within this context, sustainability of buildings should be evaluated according to the environmental, economic and social point of view. These different issues require specific assessment methodologies and metrics. Therefore, in this article, a bibliometric analysis on costs estimation is presented, focusing on Life Cycle Costing methodology for energy retrofit interventions. Articles have been investigated through bibliometric, trend and cluster analysis on a sample of 167 articles. The research has been carried out on one of the most acknowledged databases as Scopus and allowed to identify main trends and dynamics of the scientific literature.

1. Introduction

The building stock in Italy and Europe is often in critical condition and it performs under acceptable levels. This is one of the reasons why buildings are responsible for approximately 40% of energy consumption and 36% of CO₂ emissions in the EU [1]. Therefore, innovative and effective measures must be adopted in order to improve building stock's performances to foster better environmental conditions. Moreover, the significant improvement of the building stock is one of the key achievements to be reached by the 2050 in the EU member states [1–3]. This is also to be achieved in the perspective of reaching higher energy efficiencies near to the ones offered by the nearly zero-energy buildings [4]. Typically, the sustainability principle is divided in three sub categories: environment, society and economics [5]. In this paper the scope of the work is the economic sustainability of retrofit interventions on physical assets, with no distinction in terms of typology, dimension and destination of use. Economic sustainability concerns long terms objectives to be achieved thanks to a thorough and careful definition of achievements. Within this the economic models for the calculation and planning of available resources and possible expenditure to be born for the achievement of these objectives should be defined properly. Among available economic methodologies, the Life Cycle Costing (LCC) [6] is one of the most adopted and can be considered an effective tool for resource allocation during the life cycle of the physical assets.



Therefore, a wide literature review on most acknowledged database has been carried out and main references have been retrieved and analysed in order to investigate the current trends in the application of the LCC methodology in energy retrofit interventions. Choosing the most suitable approach for cost estimation in retrofit interventions is extremely important even for the definition of the cost parameters to be adopted and respected during tenders [7], despite the cost indexes must not be considered as the only factors and parameters to be taken into account for the evaluation of the offers provided by the suppliers [8]. Moreover, the adoption of a sound cost estimation methodology allows great advantages in the standardisation of the assessment of physical assets [9]. A further proof of the importance of the cost assessment in the lifecycle of the physical asset, can be found in the guidelines and principles provided in the standard UNI EN 15643-4 [10] and ISO 15686-5:2017 [6].

2. The aim of the research

The aim of this paper concerns the development of a bibliometric analysis within the context of a literature review on cost estimation through the Life Cycle Costing (LCC) methodology [6] for retrofit interventions. The energy retrofit keywords have been chosen in order to focus the review of the literature, precisely on operations carried out in order to be compliant with most recent energy and sustainability standards, in order to provide a high-quality built environment. This bibliometric analysis contributes in shading light on the literature production on this topic, through the identification of the main dynamics of the scientific production. Moreover, it allows to identify the gaps in literature and support semantic analysis of the contents related to economic assessment of retrofit interventions.

3. Research methodology

The methodology adopted in this article employs the use of the R package Bibliometrix [11]. This specific R tool allows to perform a wide set of bibliometric analyses. Therefore, the investigation of literature in retrofit costs estimation has been significantly speed up. The first step carried out concerns the keyword analysis and selection to be used for retrieving the sample of papers. For this purpose, the Scopus database has been inspected since it can be considered one of the most acknowledged and reliable repository of scientific literature. The first step has been the selection of the keyword to be used in the research. For this paper, the keywords string adopted is the following: (*LCC or "life cycle cost" or "life cycle costing"*) and *retrofit and (building* or construction*)*. This selection is a fundamental stage of the research since it allows to define the boundaries of the disciplinary fields, with a specific focus on some of the thematic areas to be inspected. LCC has been selected since preliminary literature analyses showed that this methodology is the most exploited by academics for calculation of retrofit interventions' costs [12]. This is due to the fact that it is adopted by the EU as standard procedure for energy retrofit costs estimation [1].

The Scopus database has been inspected in fields "*Article title, Abstract, Keywords*". The research has been carried out in early November 2018. A wider set of references would have been retrieved if all fields in the database had been inspected, though the reliability of data collected would have been reduced remarkably. The research gave as results 167 documents. On the selected group of references, a set of bibliometric analyses have been carried out. These analyses are grouped in three sets titled *Historical series analyses*, *Productivity analysis* and *Keywords analyses*, corresponding to the paragraphs 4.1, 4.2 and 4.3 of this article. The first set comprehends a series of operations carried out to analyse the literature production in terms of productivity over the timespan of 40 years: since the first paper related to the selected keyword search has been indexed in Scopus. These analyses help in the description of the overall trend of the selected sample. The second set concerns the analysis of the sample in term of national productivity, according to the provenance of the authors. This operation is useful to understand where are located the most productive authors and which are the most productive countries and the relationships among them. The latter set concerns the investigation of the sample in terms of network and cluster analyses of keyword. Therefore, the identification and interpretation of semantic areas encompassed in the selected sample of references has been possible. This last set of operations

support in the identification of the main connections among semantic areas in the research and provides the basis for identification of gaps in literature.

4. Results and discussion

The results of the research show that the literature since the first article published in 1978, is characterised by a low level of productivity. Nevertheless, it should be considered that the literature research does not consider the grey literature (institutional reports, white papers etc.), which could have increased remarkably the number of references in the sample and the annual production. Table 1 shows a summary of general data on the sample. The history in Scopus of the literature on retrofit cost estimation begins in 1978 and covers 40 years. Despite the long timespan from the first publication the total sample only counts 167 articles written by 396 authors. Even the average citations per documents appear to be low if considered over the entire timespan of 40 years.

4.1. Historical series analyses

The first set of results concerns the historical series. These analyses are useful for the description and representation of main trends of the literature productions. Figure 1 represents the overall scientific production from 1978 until early November 2018. The percentage growth rate equals 4.41 though it is clear that the literature production remarkably increased after 2010. This could be due to the publication in 2010 of the Energy Performance of Buildings Directive (EPBD) [1] which made the scientific literature production remarkably increase.

Table 1. General information on the sample of 167 documents

Documents	167
Sources (Journals, Books, etc.)	113
Keywords Plus (ID)	1385
Author's Keywords (DE)	391
Period	1978–2018
Average citations per documents	9.832
Authors	396
Author Appearances	473
Authors of single authored documents	20
Authors of multi authored documents	376
Documents per Author	0.422
Authors per Document	2.37
Co-Authors per Documents	2.83
Collaboration Index	2.69

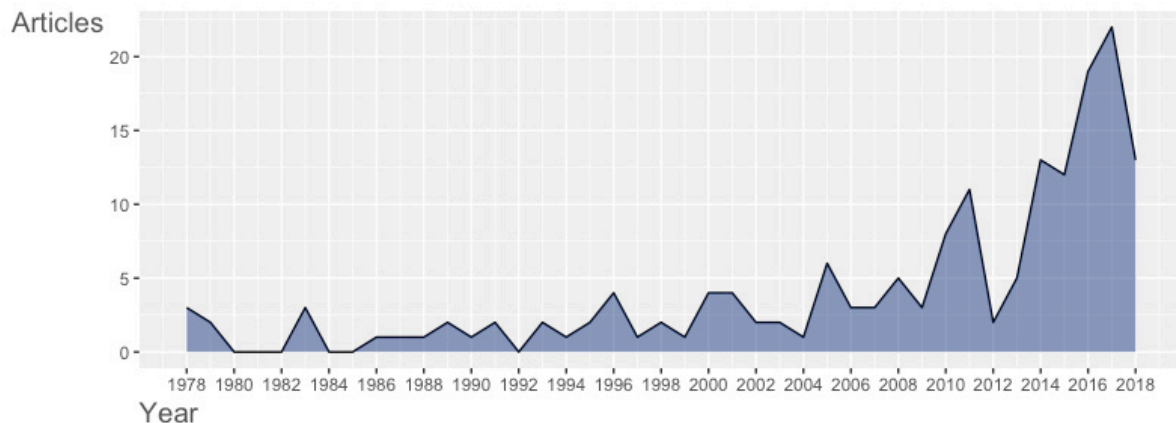


Figure 1. Annual scientific production since 1978.

Even average article citations per year increase in the same years, following a similar trend (Figure 2). Nevertheless, the trend represented in Figure 2 is less homogeneous, though positive since the first publications indexed in Scopus.

4.2. National Productivity analysis

As confirmed by the general data presented in Table 1, among the most productive 10 authors, the most part of them show a literature production of three articles (Figure 3). Moreover, Figure 3 shows that the strongest literature production on LCC and retrofit has to be assigned to USA (more than 40 articles), contributing by more than 25% to the total literature production over 40 years, following USA, Sweden and Italy show equally a literature production of more than 15 articles.

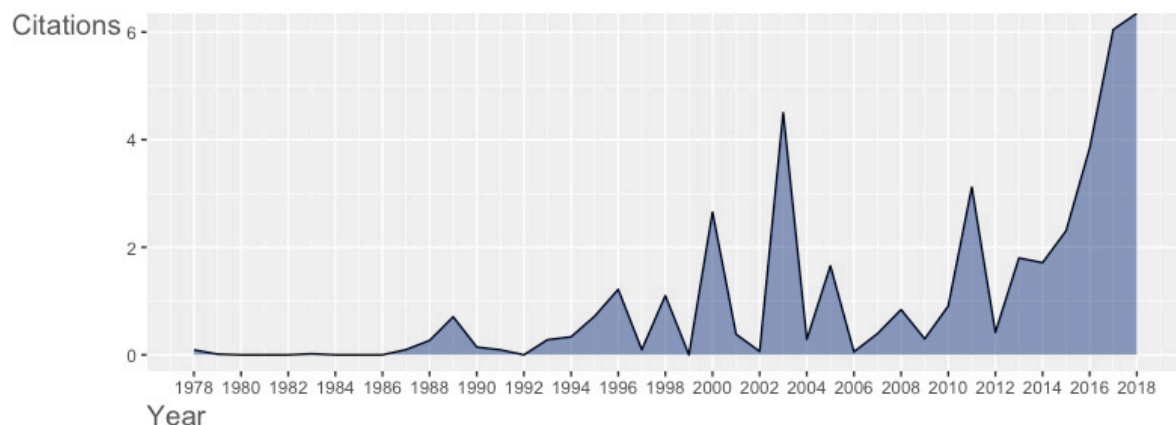


Figure 2. Average article citations per year.

Moreover, USA sits among the first places also for what concerns the total citations (481), followed by Sweden (253) and Spain (139).

This trend is not confirmed if the Average article citations are considered, probably due to the fact that most productive countries' strong literature production lead to a fewer number of average article citation over the years.

Figure 3 shows also that the most part of the publications are written by authors belonging the same countries. This could be due to the fact that authors are keener to collaborate within the same research group or with academics with the same national background. Moreover, cost estimation within the LCC methodology could be affected by the national methodologies for price estimation (national pricelists, inflation, currency issues). Therefore, articles seem to be more frequently published by local research groups.

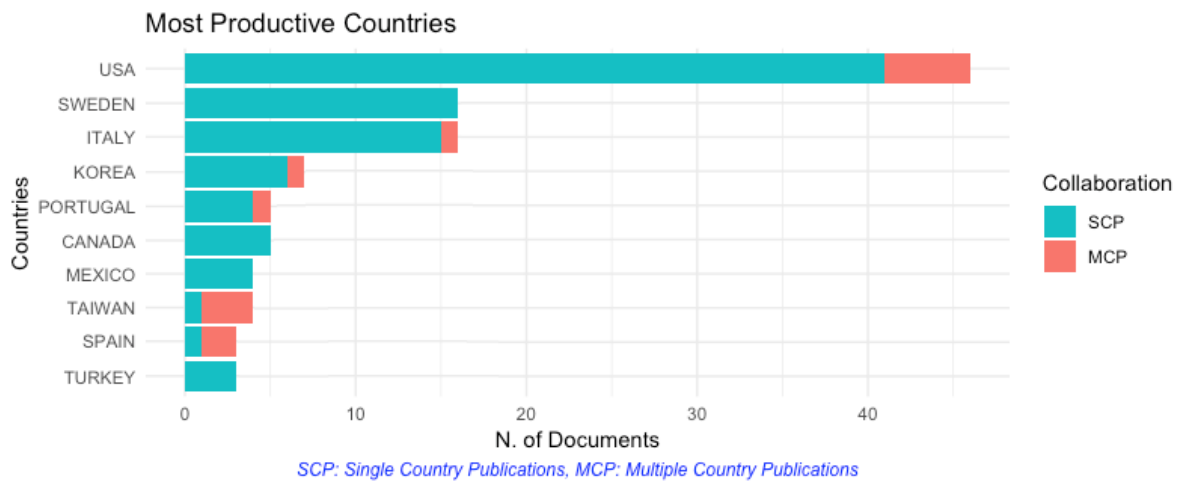


Figure 3. Most productive countries: Single Country Publications (SCP), Multiple Country Publications (MCP).

4.3. Keywords analyses

Network and cluster analyses can be considered among the most effective ways for performing literature analyses and inspections. In this paragraph are presented a set of these analyses concerning the keywords found in the sample of 167 articles. Figure 4 represents a network analysis where the dimension of the circle represents the importance of the keyword in terms of recurrence in the analyses paper, the colour the belonging to a specific cluster of researches and the thickness of the line connecting the circles represents the intensity of the connection among keywords. A co-word network can be created using the formula:

$$B_{coc} = A' \times A \quad (1)$$

Where A is a Document \times Word matrix [11].

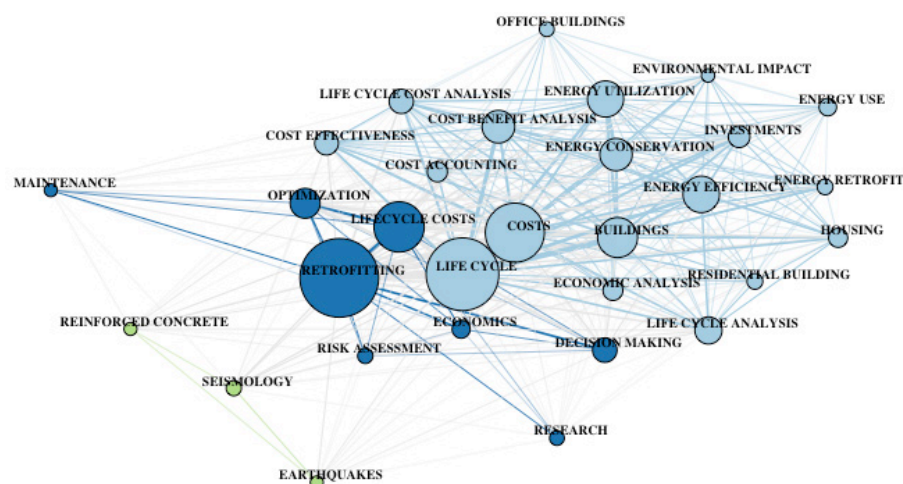


Figure 4. Keywords co-occurrence network among the more frequent 30 associated by Scopus.

Figure 4 shows that the keywords are organised according to three groups collecting articles belonging to homogeneous disciplinary fields. The first group is defined by keywords as “retrofitting”, “optimisation”, “maintenance” and “risk assessment”. This is the field concerning the technical improvement of physical

assets, related to maintenance and risk prevention strategies. A further group of keywords collects words as “life cycle”, “energy efficiency”, “cost effectiveness” and “investments”. This is a group of keywords which define a research field related to energy retrofit policies and efficient investments. Moreover, in this field are also encompassed the keywords “office buildings” and “residential buildings”. This fact suggests that mainly energy retrofit policies are dedicated to this typology of assets. The last group of keywords is connected to seismology and structural engineering, showing a tight connection between energy and seismic retrofit, through the cost optimisation and LCC approach.

Table 2. Most relevant 10 keywords. DE are the Author Keywords and ID are the Keywords associated by Scopus (first 10).

	Author Keywords (DE)	Articles	Articles Keywords-Plus (ID)	Articles
1	retrofit	14	life cycle	67
2	energy efficiency	12	retrofitting	63
3	life cycle cost	12	costs	50
4	life-cycle cost	9	buildings	38
5	life cycle assessment	6	lifecycle costs	36
6	optimization	6	energy efficiency	31
7	retrofitting	6	energy utilization	28
8	sustainability	6	energy conservation	26
9	building retrofits	4	cost benefit analysis	25
10	decision-making	4	optimization	23

Table 2 shows how the first 10 most cited authors' keywords refer to retrofit interventions, sustainability, cost assessment through LCC and energy efficiency. Moreover, the LCC and retrofit, in the analysed sample very often is associated with the topic of decision-making. Row 4 and 5 show a frequent drawback in literature reviews: the keywords are the same, but the spelling is different. This condition brings to the multiplication of keywords associated to the same sub topic of the research. This led to biases and duplications of the same semantic meaning associated to keywords. Other considerations can be done on the difference between the keywords associated by authors (DE) and the Scopus keywords (ID). The Scopus keywords are more comprehensive and wider since they need to contain all authors' keywords which are more specific. Despite the authors' keywords are more useful, they could be misleading or too specific while the Scopus ones are more standardised and help in the research of the references associated to a specific topic.

5. Conclusions

To conclude a semantic analysis of the sample is presented. Figure 5 allows to define the semantic areas of the literature production. It represents the conceptual structure map obtained through a Multiple Correspondence Analysis (MCA) which allows the data interpretation according to the relative positions of the points representing a specific author keyword and their distributions in the graph [13]. As words are more similar in distribution, the closer they are represented in the map.

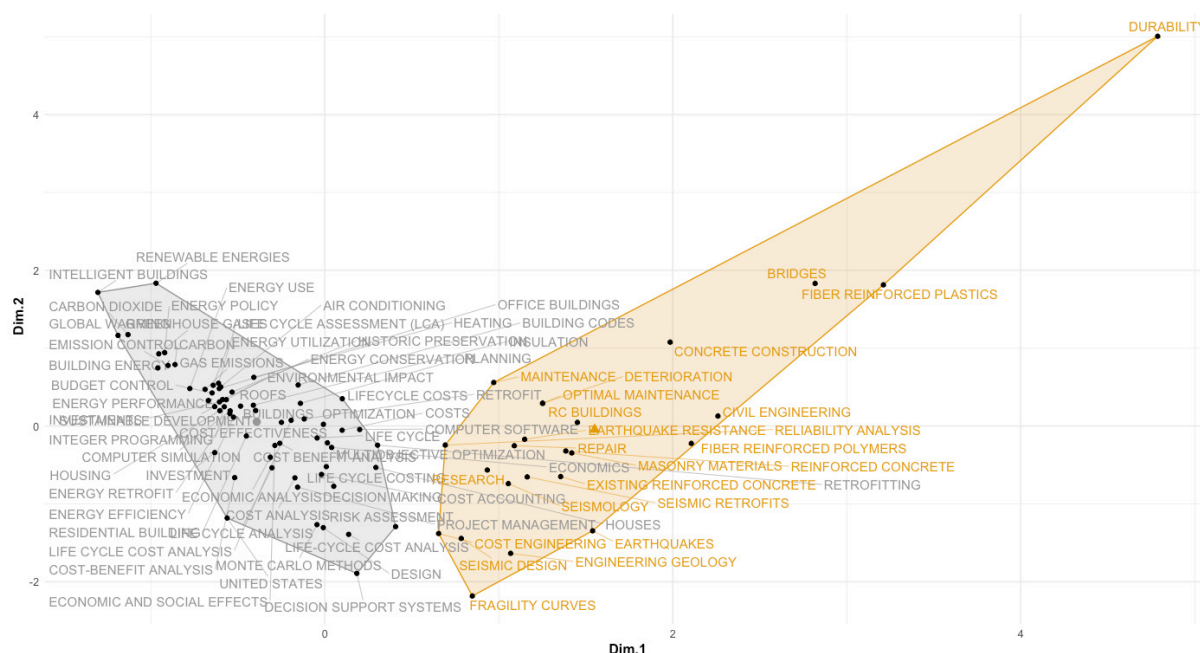


Figure 5. Conceptual structure map obtained through the analysis of the whole sample.

The most external keywords on the representation defines the boundaries of the semantic area to which they are associated. The analysed sample processed accordingly shows two main semantic areas. The grey area is related to the development of decision-making approaches within the context of the renewable energies policies and towards the perspective of the intelligent buildings. This first set suggests the possibility to tie the LCC for retrofit to the contemporary and highly relevant topics of the smart buildings [14]. The use of advanced control and management systems in physical assets is gaining momentum since it allows to effectively provide a qualitative built environment for assets' owners and users. Nevertheless, the economic appraisal of installation and maintenance of the installed systems still needs to be investigated. The second set, the orange one, concerns keywords mainly belonging to structural engineering, durability and maintenance and seismology. These topics are clearly strictly related to the previous ones, since they provide the computational and operational basis for the definition of effective energy retrofit strategies. Within this context, an emergent research field concerns the use of the Artificial Neural Networks (ANN) for the sustainability performance prediction of retrofitted buildings [15,16]. Again, in this research field cost estimation appear to be a key issue to be considered. The topics mentioned above, related to the two sets identified are only some of the literature gaps to be filled. To conclude it can be stated that through the bibliometric analysis on Scopus, the main trends related to the literature production in energy retrofit and cost estimation have been presented and discussed. Nevertheless, the grey literature has not been taken into account. This could have extended remarkably the analysis, considering also the approaches (through white papers, reports etc.) of non-academic institutions. Being the LCC the most exploited methodology in energy retrofit, suggested by the EU it would have been interesting to analyse how national agencies are addressing the implementation of the EPBD. Nevertheless, the Scopus database has been chosen as source of articles therefore it usually collects and share high quality academic literature: the scope of the bibliometric analysis for this article. This article sits in the wider research framework of the definition of an energy retrofit policy for school buildings in Italy [15]. Within this context, the definition of a sound methodology for energy retrofit cost assessment is crucial and can be intended as a next development of the research work.

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