Trends and gaps in global research of greenery systems through a bibliometric analysis

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Abstract

This study presents a critical review analysis of greenery systems research through a bibliometric approach. The purpose of this study is to provide a holistic overview by (i) the development of the field; (ii) the research trends and the main issues; and (iii) the main gaps still observed in the literature. Therefore, this paper provides the past, the present and the potential future of this scientific topic and serves as an orientation and guide for researchers who aim for a better understanding of the main progress and gaps. A detailed analysis of 1918 documents found in the Scopus database for the 1974–2019 period was conducted. Content analysis of titles, keywords and abstracts revealed that most of the research has focused on the study of green roofs. Previously this topic was dominated by water runoff analysis, while recent contributions acknowledge greenery as an effective microclimate mitigation strategy, especially in urban areas. The United States was the most productive country, representing almost 20% of the total documents. Over 86% of the relevant documents were published since 2009. Overall, research on this topic is increasing, with new methods and directions but some gaps remain particularly on the areas of environmental impact, costs, health, outdoor thermal comfort, and vertical greenery systems.

**Keywords:** bibliometric analysis; greenery systems; green roof; green facade; research trends
1. Introduction

Green spaces within cities have been reduced due to the population growth and rapid urban expansion. Concentration of building mass, low sky view factors, and shortage of green spaces in cities are identified to contribute significantly to extended heat stress in the built environment, commonly known as the urban heat island (UHI) effect [1,2]. Urban population is expected to increase by up to 70% globally by 2050 [3]. Moreover, extreme climate events are expected to be more frequent, with heatwaves [4] and heavy rainfall events to pose an even larger challenge to the resilience of cities [5,6]. As a result, cities are confronted with a multitude of challenges stemming from climate change and urbanization. Many studies have shown that some of the negative effects associated with urbanization could be alleviated by Urban Green Infrastructure [7] (UGI), which promotes environmentally sustainable and socially resilient cities [8,9].

Specifically, urban heat islands are the best-documented climate change related phenomenon [10], exacerbating building energy needs for cooling, but also compromising outdoor thermal comfort conditions and air quality standards. This is basically imputable to dense urbanisation which is characterised by impervious and low solar reflectance surfaces covering streets, building envelopes and, in general, urban paving [11]. That is the reason why most of the research for mitigating this effect has been focused on enhancing solar reflectance of the built environment skins [12], by means of durable cool materials [13], but also by remaking the city more permeable and able to take advantage from the evapotranspiration phenomenon [14]. For the latter, green urban parks, roofs, facades and greenery in general, represent the key solutions demonstrated to play a key role in improving outdoor comfort [15,16], urban wellbeing and energy saving [17,18].

While a variety of review papers have provided interesting frameworks and updates about the state of the art concerning the phenomenon itself: greenery [19], cool materials [20], resilient cities [21] and other urban heat island mitigation techniques [22,23], etc. A comprehensive and exhaustive bibliographic analysis still needs to be an approach by evaluating research trends in the last almost 50 years of international scientific investigation. In this view, bibliometric represent the most schematic and communicative way of analysing this research trend. Alan Pritchard [24] defined in 1969 bibliometry as “the application of statistical methods to media of communication” since then, bibliometric analyses have notably increased worldwide. Bibliometrics is considered one of the key research tools widely extended to all scientific areas, particularly applicable to fields with large bodies of literature that are difficult to summarise by traditional review methods. Bibliometrics can provide information that would be difficult to gather or understand by means of individual expertise [25].
Some systematic reviews related to greenery can be found in the literature. However, most of them focus on either a limited aspect of the concept, i.e. green roofs, green facades, [26–28] or the macro-scale research, i.e. green infrastructure, urban greenery, etc. [29–31]. Hence, these literature review remain limited in their capacity to assess large volumes of diverse literature [32]. Indeed, not many studies have outlined the research trends and identify the most important topics, the collaboration network between countries and the gaps in the research topic of this study. Regarding bibliometric analysis, very few studies were found concerning topics related to greenery. For example, regarding the specific topic of greenery was found that Blank et al. [33] studied the directions in green roof research through a bibliometric analysis using the Web of Science database. Xing and Brimblecombe [34] studied the relationship between vegetation and air pollution in urban areas, using the Scopus database and VosViewer software to map the results. Caparros-Martinez et al. [35] analysed the global research trends from 2002-2019 regarding “green infrastructure and water” using both Scopus and WoS database. Finally, there are others bibliometric analysis found in the literature are regarding “green building” concepts; Yin et al. [36] studied the “green innovation” concept using Web of Science database during the period 1981-2016. Albort-Moran et al. [37] also studied the same concept of “green innovation” during the period 1971-2015 using Web of Science database. Finally, Zhao et al. [38] conducted a bibliometric analysis of green building during the period 2000-2016.

Therefore, during the last decade, there has been year-on-year growth in the interest and publication of greenery systems and built environment research [31,39]. Research into this topic is diverse, which highlights the versatility of the concept, which has both supported and hindered its uptake in different locations. To date, to the best of the authors knowledge, there are no studies in the specialised literature that link the concepts of greenery and the built environment from a bibliometric perspective. There has not been a global literature review, and the knowledge generated by these studies is a handy tool for the environmental policy agenda. Thus, the novelty of this study is the capacity to assess a large volume of diverse literature in this topic; identifying temporal and geographic patterns in the literature, who conducted the research, where is the research located, what were the major research topics and themes, where are the gaps, and what are the priorities for future research. Finally, the findings of this study can provide a summary of the status quo of the global greenery research, identify the hot themes in the literature and knowledge gaps, and recommend future research directions, as well as to highlight the existing worldwide relationships between researchers and countries.

2. Methodology

With the rapid increase in the volume and diversity of research and the availability of metadata about research from different literature databases, academics have started examining trends in
academic publications using bibliometric methods [32]. This methodology allows to understand the most important areas of research, as well as the existing worldwide relationships between researchers and countries [40]. Thus, in order to analyse worldwide scientific documents concerning the research topic of greenery, a bibliometric analysis was performed.

Scopus database was selected for this study since it is the largest database of peer-reviewed documents delivering a comprehensive overview of the world’s research output in the engineering areas [41]. No start date was specified for the Scopus search, thereby allowing the search database to identify the earliest papers in the literature.

Figure 1. Overview of the methodology of the bibliometric analysis of the greenery systems topic.

The methodology followed to carry out this study was defined by analysing the amount of publications in Scopus database, using different queries strings until the authors considered having found out the correct and most explanatory query to carry out the study (see Figure 1). This methodology follows the previous study done by Cabeza at al. [40] were deeply explained the query formulation. Since “greenery” is a too generic term, keywords as “building and built environment” were added to link with the greenery and therefore, to obtain the most
consistent results concerning the central topic of this study. Finally, the following search pattern was used in order to avoid distorting the results:

\[
\text{TITLE-ABS-KEY ("Building*" OR "Built environment") AND ("greenery" OR "green roof*" OR "green facade*" OR "green wall*" OR "vertical green system")}
\]

Once the research was done in the Scopus database, it was found that the first publication which appears in the literature was from 1974. Therefore, the topic of the study referred to the time frame from 1974 to 2019 was assessed based on different criteria such as typology of publication (journal papers, conference proceedings and book chapters)), language, scientific product features, distribution of publications by country, categories of distribution topics, analysis of citations as well as the frequency of the keyword appearance. With this query, 1918 documents were found. This search was done in January 2020, and therefore, 34 documents for 2020 were found which were excluded from the analysis as they are not representative for the current year. Thus, 1918 Scopus-indexed documents were analysed for this study in which the “data” consisted of bibliographic information. These ‘data’ included keywords, authors, titles, and affiliations of the documents, as well as citations of its documents. In order to study the trends of this topic, descriptive statistics were used to conduct analyses related to the growth and the increasing interested of the greenery literature, as well as source information.

In this study, VOSviewer was used to develop a visual representation of the most commonly cited keywords in the topic of the study as well as co-authors network and countries. VOSviewer is a freely available computer program that was developed for constructing and viewing bibliometric maps. This program collects the bibliographic data from the Scopus database (in the case of this study). It builds graphical maps by using a bibliographic coupling, co-citation and co-occurrence of keywords [42]. This software is a computer program that plots a relevance distance-based map and clustered keywords from the text in titles, abstracts and keywords. Moreover, it is indeed able to map citation terms, where the overall distance between the same terms provides information on their relatedness based on co-occurrences in the same documents. However, it is important to highlight that the axis (x,y) have no special significance because the maps can be freely rotated. Regarding keywords, it assemblages citation terms and portrays the topic by colour and the size of the circles mapped are the density of the occurrences [43,44].

3. Results and discussion

The following section explicitly describes the results of the bibliometric analysis of the 1918 documents found, published from 1974 through 2019.
3.1. Type and language of publication

The analysis of the type of publication (Figure 2) shows that most of them are articles/papers (1118), which represent 57% of the total documents. Conference papers with 575 documents represent 29%. On the other hand, there is a much lower number of reviews (93 documents) and books (81 documents). Probably because most documents are published in international journals, most documents are published in English, being 96.2% of the total (see Figure 3) within the selected database. Other prominent languages were Portuguese with 43 documents of the total (2.25%) followed by Chinese, Spanish, and Japanese.

![Figure 2. Document type distribution](image1)

![Figure 3. Language used distribution during the period 1974-2019](image2)
3.2. Trends in the number of publications

The trends in the number of publications since the first document found out in the selected database are presented in Figure 4. The first publication found was from 1974, and until 1987 the average is between 1 or 0 publications per year. Since then, the documents slightly increase until the last decade when the number of publications increased considerably. This increase has been significant in the last decade when 86% out of all the publications were published (since 2009). However, during the period 2017-2019, a vast quantity of documents appeared, being from 164 in 2016 to 254 in 2019. Since the first document found in the literature, which was published in 1974, results reveal a year-to-year growth in the number of documents, emphasising the fact of raising awareness among the scientific community.

Figure 4. Trends in the number of publications during the period 1974-2019

3.3. Geographic distribution of the publications
Greenery systems research attracted broad international interest. 75 countries, representing five continents, are represented in Figure 5, which shows the countries that published in the topic of study. With over 334 publications, United States represents by far the country with more publications, representing almost 20% of the whole world publications during the period of the study (1974-2019). The second country with more publications is China with 242 documents, followed by Italy with 167, England 115, and Spain 76. However, when talking about continents, Europe leads in the research of the topic being just Italy, England, and Spain, the most active contributors with 358 documents. However, the articles from the United States are more related to agriculture and bioscience while Europe and Asia the papers are more related to Urban Heat Island and thermal comfort.

Figure 5. World map of the countries distribution.
Figure 6 shows the network of countries in the last decade. The circles represent different countries, and each size of the circles represents the number of publications. When links appear between two circles or countries indicate that they have a cooperative relationship, the thicker the connection, the stronger the cooperation between the two countries in terms of the number of contributions. This figure shows that the newest countries carrying out research on the topic of the study are Poland, the Czech Republic, Indonesia, and Portugal. Regarding the links between countries, it is found a strong relationship between the United States, China and Australia followed by Italy and Spain with the United States as well. United States, Singapore, Canada and Greece also represent the oldest contributors, followed by Hong Kong, China, Spain, Italy, and Australia.

![Figure 6. Countries network in the topic during 2009-2019](image)

On the other hand, Cabeza et al. [45] also compared the per capita number of publications, and they found that the country ranking changed utterly. For that reason, the authors considered it of high interest, and Figure 7 shows the distribution of the total documents per country and the number of publications per million of inhabitants per country for the 18 countries with most of the publications. Data on population per country was from the UN [46]. In this case, big countries like China, India, Brazil, and the USA have a low number of per capita publications (0.17 for China, 1.03 in the USA, and 0.04 for India). Singapore leads this ranking with 12 publications per capita. Other countries with a high number of publications per capita are Greece with 4.62 and Taiwan with 4.58.
Figure 7. Scientific production per country (continuous line) during the period 2013-September 2019 and the number of publications per million inhabitants (single marker).

3.4. Analysis of authors

It is a commonplace to see collaborations among scholars in academic research. For this co-authorship analysis, the minimum number of articles published by an author set in VOSviewer was three. This means that, every author who appears in Figure 8 published at least three or more articles in this field. In agreement with Wouters et al. [47], who said in the published paper in Nature “The older you are, the higher your h-index, even in the absence of new papers” the authors considered that the minimum number of articles was set in three, in order to allow young researchers appear in this search.

According to Scopus database C.Y. Jim, is the most productive author in the topic of greenery with a total of 31 documents. Other authors with significant contributions to the research community include L.F. Cabeza, with 28 documents, G. Pérez, with 26, both from the University of Lleida, Spain and N.H. Wong with 24 documents from the National University of Singapore. Moreover, Table 1 shows the top ten authors, with a greater amount of publications in the research topic.
Table 1. Leading authors of the topic in query 1.

<table>
<thead>
<tr>
<th>Author</th>
<th>Institution</th>
<th>Country / Territory</th>
<th>#documents search</th>
<th>#doc total</th>
<th>h-index total</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. Y. Jim</td>
<td>University of Hong Kong</td>
<td>Hong Kong</td>
<td>31</td>
<td>228</td>
<td>42</td>
</tr>
<tr>
<td>L.F. Cabeza</td>
<td>University of Lleida</td>
<td>Spain</td>
<td>28</td>
<td>448</td>
<td>63</td>
</tr>
<tr>
<td>G. Pérez</td>
<td>University of Lleida</td>
<td>Spain</td>
<td>26</td>
<td>48</td>
<td>19</td>
</tr>
<tr>
<td>N.H. Wong</td>
<td>National University of Singapore</td>
<td>Singapore</td>
<td>24</td>
<td>160</td>
<td>36</td>
</tr>
<tr>
<td>J. Coma</td>
<td>Polytechnic University of Catalonia</td>
<td>Spain</td>
<td>19</td>
<td>28</td>
<td>12</td>
</tr>
<tr>
<td>K. Perini</td>
<td>University of Genova</td>
<td>Italy</td>
<td>18</td>
<td>32</td>
<td>11</td>
</tr>
<tr>
<td>E. Schettini</td>
<td>University of Bari</td>
<td>Italy</td>
<td>15</td>
<td>74</td>
<td>19</td>
</tr>
<tr>
<td>G. Vox</td>
<td>University of Bari</td>
<td>Italy</td>
<td>15</td>
<td>71</td>
<td>20</td>
</tr>
<tr>
<td>R. Belarbi</td>
<td>University of La Rochelle</td>
<td>France</td>
<td>13</td>
<td>102</td>
<td>22</td>
</tr>
<tr>
<td>M. Santamouris</td>
<td>University of New South Wales</td>
<td>Australia</td>
<td>13</td>
<td>439</td>
<td>72</td>
</tr>
</tbody>
</table>

Figure 8 shows the relationship between authors in this topic. Moreover, as seen in Figure 8, the average of publications per year of the authors provides the information of emerging authors, including among others A. L. Pisello from University of Perugia, C.L. Tan, from the University of Singapore, M. Chàfer from university of Lleida and S. Cascone from University of Catania, whose publications are generally around 2017-20.
3.5. Distribution of the output by subject categories and journals

Regarding the subject areas, the interdisciplinary characteristics of greenery research are highlighted in Figure 9. The highest percentage corresponds to the subject of engineering (46.8%), which means that it is almost half of all the topics that appear. The second one is Environmental Science (37.1%). The sum of the previous two is 84%, meaning that these two topics monopolise most of the study effort.

Moreover, it is interesting to see that social sciences are represented with 19%, followed by Energy 17.7%. The other related topics with less relevance are Agricultural and Biological Sciences, Earth and Planetary Science, Material Science, Computer Science, and Business.

With these results, the interaction between the topics can be confirmed, such as the multidisciplinary research carried out within the greenery framework. When talking about greenery systems and/or built environment, the synergy between different fields of study can be seen: from engineering to arts and humanities through business and management.
On the other hand, Figure 10 presents the top 12 sources of greenery research in accordance with the Scopus database. Energy and Buildings had published 191 articles and was ranked top, followed by Building and environment (185) and IoP Conference Series (168). Out of the top 12 journals, seven are published in the Netherlands.
3.6. Analysis of keywords

Keywords represent the main contents of existing research and depict the areas studied within the boundaries of a given domain. The co-occurrence of keywords enables to highlight the main areas of research and highlights. As mentioned before, the size of the nodes is proportional to the frequency of occurrence or citations. At the same time, adjoining lines represent bibliographic links with the thickness proportional to the strength of co-occurrence or co-citation. Moreover, to reduce ambiguity, synonymous keywords were clustered (i.e. UHI, urban heat island effect and urban heat island to be “urban heat island”. The main topics depicted within the selected field are represented in ¡Error! No se encuentra el origen de la referencia.. In this study, “green roof” has by far the highest values of total link strength and occurrence what means that this keyword is the most inter-related and has the highest degree of frequency within all the literature analysed. However, it is important to highlight that there is probably more mention of green roofs as most governments around the world have initiated legislation for having green roofs on buildings in the last decade.

¡Error! No se encuentra el origen de la referencia.. Co-occurrence map and link of the most frequent keywords of the query.

More broadly, four overarching themes became apparent when dominant research themes were mapped. The different colours show a grouping of the words and the size of the circle of each word is related to the frequency it appears in the publications. The lines between words show the links between them. Results are clearly separated into four different topics: the red cluster (cluster #1) includes terms such as climate change, sustainable development, and urban planning. In the second cluster (green cluster #2) terms such as buildings, urban heat island, and energy efficiency. The blue cluster (cluster #3) is related to green roofs, water quality, runoff, etc. The yellow cluster (cluster #4), which is very difficult to appreciate, includes terms related to environmental impact and carbon dioxide, showing a significant research gap in this area of study.

Moreover, when studying the keywords, it is very important to see the trends of the years in publications. Figure 12 shows the colours within the year of publication. As it can be seen, the topics that were found in the blue cluster are the ones which were first studied. On the other hand,
we can see the emerging topics which are mark in yellow, which are climate change, greenspace, environmental impact and thermal insulation (always regarding greenery systems).

![Figure 12. Detail of the co-occurrence keywords.](image)

3.7. Most influential publications

This section presents the 20 most cited studies found in the Scopus database (Table 2). The most cited paper is “Green roofs as urban ecosystems: Ecological structures, functions, and services” by Oberndorfer et al. (2007) [48] from the journal BioScience, with 584 citations. This paper offers a review, which describes the history and components of green roofs and the evidence of the benefits that contribute to overall ecosystem services. The second most cited paper is “Green roofs as a tool for solving the rainwater runoff problem in the urbanised 21st century?” written by Mentens et al. [49] from the journal Landscape and Urban Planning and, again, it offers a review of the available European literature about the potential of green roofs in reducing the surface water runoff. The thirst paper is “Passive building energy savings: A review of building envelope components” by Sadineni et al. [50] from the journal Renewable and Sustainable Energy Reviews. This paper mainly reviews the components of the building envelope and the respective improvements from an energy efficiency point of view, regarding greenery systems, this papers focus in a section about green roofs, but is not the main aim of the paper. Notice that 10 out of the ten most cited papers worldwide are related to cluster number #3, more specifically to green roofs. Only in position 115 appears the first article that is not related to green roofs; Jacson [51]
studied the relationship between urban design and human health and the greenery effects to human health.

Table 2. Most influential papers in the topic of “greenery systems”

<table>
<thead>
<tr>
<th>Rank</th>
<th>TC</th>
<th>Title</th>
<th>Year</th>
<th>Author</th>
<th>Journal</th>
<th>Cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>584</td>
<td>Green roofs as urban ecosystems: Ecological structures, functions, and services</td>
<td>2007</td>
<td>Oberndorfer et al. [48]</td>
<td>BioScience</td>
<td>#3</td>
</tr>
<tr>
<td>2</td>
<td>475</td>
<td>Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century?</td>
<td>2006</td>
<td>Mentens et al. [49]</td>
<td>Landscape and Urban Planning</td>
<td>#3</td>
</tr>
<tr>
<td>4</td>
<td>439</td>
<td>Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates</td>
<td>2008</td>
<td>Alexandri and Jones [52]</td>
<td>Building and Environment</td>
<td>#1 #3</td>
</tr>
<tr>
<td>5</td>
<td>422</td>
<td>Green roofs; Building energy savings and the potential for retrofit</td>
<td>2010</td>
<td>Castleton et al. [53]</td>
<td>Energy and Buildings</td>
<td>#3</td>
</tr>
<tr>
<td>6</td>
<td>406</td>
<td>Analysis of the green roof thermal properties and investigation of its energy performance</td>
<td>2001</td>
<td>Niachou et al. [54]</td>
<td>Energy and Buildings</td>
<td>#3</td>
</tr>
<tr>
<td>7</td>
<td>363</td>
<td>The role of extensive green roofs in sustainable development</td>
<td>2006</td>
<td>Getter and Rowe [55]</td>
<td>HortScience</td>
<td>#3</td>
</tr>
<tr>
<td>8</td>
<td>344</td>
<td>A green roof model for building energy simulation programs</td>
<td>2008</td>
<td>Sailor [56]</td>
<td>Energy and Buildings</td>
<td>#3</td>
</tr>
<tr>
<td>9</td>
<td>328</td>
<td>Investigation of thermal benefits of rooftop garden in the tropical environment</td>
<td>2003</td>
<td>Wong et al. [57]</td>
<td>Building and Environment</td>
<td>#3</td>
</tr>
<tr>
<td>10</td>
<td>304</td>
<td>Quantifying air pollution removal by green roofs in Chicago</td>
<td>2008</td>
<td>Yang et al. [58]</td>
<td>Atmospheric Environment</td>
<td>#3</td>
</tr>
<tr>
<td>11</td>
<td>291</td>
<td>Positive effects of vegetation: Urban heat island and green roofs</td>
<td>2011</td>
<td>Susca et al. [59]</td>
<td>Environmental Pollution</td>
<td>#2 #3</td>
</tr>
<tr>
<td>12</td>
<td>278</td>
<td>Analysis of the green roofs cooling potential in buildings</td>
<td>1998</td>
<td>Barrio [60]</td>
<td>Energy and Buildings</td>
<td>#3</td>
</tr>
<tr>
<td>13</td>
<td>272</td>
<td>Green roofs as a means of pollution abatement</td>
<td>2011</td>
<td>Rowe [61]</td>
<td>Environmental Pollution</td>
<td>#3</td>
</tr>
<tr>
<td>14</td>
<td>249</td>
<td>The relationship of urban design to human health and condition</td>
<td>2003</td>
<td>Jackson [51]</td>
<td>Landscape and Urban Planning</td>
<td>#1</td>
</tr>
</tbody>
</table>
3.8. Knowledge gaps and future research

Reviewing the papers related to the greenery topic in the period 1974-2019, it provided on an in-depth discussion to summarise the contemporary mainstream research topics, identified research limitations and proposed the framework for future research directions. The findings are reported below.

- The first knowledge gap is related to the environmental impact of those systems. Although most studies advocated the benefits of green roofs, green facades and greenery systems, very few studies can be found in the literature regarding its environmental impact, life cycle analysis, etc. Life cycle assessment (LCA) is a methodology to assess the environmental impacts associated with a product, process, or service by considering the balance between the environmental load and possible benefits, but also from the point of view of material optimisation. As suggested by Henry and Frascaria-Lacoste (2012) [68], the adoption of LCA analysis for the labelling of green products could increase their use, since green labels have the potential to boost the confidence of consumers.
- The second knowledge gap is related to the real performance and benefits of green facade and green walls. Many studies still advocate the benefits of green roofs, but very few studies are found regarding the green facades, moreover, depending on the climate vertical greenery systems have results still controversial [17]. As Rilley (2017) [69] concluded in his study about lessons learnt of green walls, some of the latest research is less positive than living wall proponents may wish. For that reason, rather than hiding or ignoring unfavourable results, new data is absolutely necessary to provide an opportunity for the emerging living wall industry.

- The third knowledge gap found is related to the cost. Cost is the most significant factor hindering greenery systems proliferation [70]. The initial capital investment of greenery systems in buildings is commonly higher than other exterior cladding systems, as well as long-term maintenance costs and watering costs are also problematic, and very much affected by the specific implementation boundary conditions.

- The fourth knowledge gap is related to the outdoor thermal comfort and air quality improvement associated with greenery systems. Urban greening can mitigate urban heat island (UHI) effect, improve thermal comfort by improving micro-climate conditions, and provide shading [71]. Moreover, greenery can bring other benefits, including the ability to attenuate noise levels, improve air quality and reduce urban stormwater runoff. However, more research is needed since a few recent and well-updated studies are related to this topic [72].

- The fifth and the last gap is related to the benefits to human health. Many studies associate the positive impacts of green spaces which have a lasting positive effect on wellbeing [73]. Moreover, a report by the World Health Organization (2016) [74] advocated the implementation and evaluation of targeted, evidence-based green space interventions to promote the health of urban residents. Those health benefits were among others; enhanced immune functioning and reducing chronic diseases and mental health disorders. Regarding urban scale, using green infrastructure to improve urban air quality is currently on the rise. However, these need to be matched by scientific evidence and appropriate guidelines. Kumar et al. [73] stated that urban greenery could promote health benefits, but there is still scarce empirical evidence linking these benefits to air pollution reduction by urban vegetation. This means that considerable efforts are needed to establish the underlying policies, design and engineering guidelines governing its deployment.

4. Summary and conclusions
This bibliometric analysis aimed to detect the status quo and trends of global greenery research. The final query was analysed, TITLE-ABS-KEY ("Building*" OR "Built environment") AND ("greenery" OR "green roof*" OR "green facade*" OR "green wall*" OR "vertical green system"). With this query, 1918 bibliographic documents were found in the Scopus database, which allowed to examine and visualise the current state and trends of the topic. The first document was found in 1974, however, over 86% of the relevant documents were published since 2009. This trend illustrates the establishment of this novel research area. Besides, this topic is indeed multidisciplinary and includes both engineering and environmental sciences. Our study suggests that until recently, most research emphasis has been related to green roofs. As Blanked et al. [33] stated in their study, this growth is probably the result of increased awareness of environmental issues. Furthermore, the desire to harness green roofs to mitigate environmental impacts such as managing stormwater runoff and urban heat islands, as well as new policies implemented by governments in some countries.

In terms of the subject categories of greenery systems research, engineering and environmental sciences obtained most of the bibliographic records. Regarding the keywords, ‘green roof’, had so far the most frequent citation, which can also clearly seen in the most influential paper which is related to green roofs. This topic is the most studied in the last decade. Several influential journals have published significant greenery research findings, including Energy and Buildings, Building and Environment, and Acta Horticulture. Regarding the countries, the United States in the country with almost 20% of the total publications in this topic followed by China and Italy. However, emerging countries appeared as Poland, Portugal, and the Czech Republic. When it is seen the scientific production per country and the number of publications per million inhabitants, Singapore is the most productive country. According to the Scopus database, C.Y. Jim is the most productive author in this domain.

Finally, based on the results of the study, there are five important topics for future research that are related to the gaps mentioned before: (1) performing LCA studies, specially about vertical greenery systems. The LCA can be an approach to assess the impact of these solutions by focusing on the construction phase and its contribution to both the energy balance and the entire life cycle. (2) VGS in winter are still controversial depending on the study and the climate. Then, more research is needed in this field to overcome since some of the issues presented in the research, specially, research into technical aspects of living walls can begin to provide answers to questions about their advantages and challenges. (3) Cost. While numerous studies about greenery have been conducted on its potential benefits, there has been little focus on its cost, which is still one of the main issues for implementing these solutions. (4) Environmental and health benefits. Greenery offers the opportunity to lessen the adverse effects of climate change and urban heat
island effect and, thus, generate important benefits from the perspective of human health and wellbeing. In the current context of the global health crisis, an important recommendation for future research is to continue advancing precisely the analysis of the role of these systems from the perspective of public health.

This study, presented an in-depth understanding of the status quo, with highlighting gaps and proposals for a future agenda of greenery systems research for both researchers, policymakers, and practitioners. Researchers may be, therefore, interested in following the recommended directions and fill the existing knowledge gaps, thus extending the body of greenery systems knowledge and practice.

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References


