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A statistical analysis of life cycle assessment for buildings and buildings' refurbishment research

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A R T I C L E I N F O

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A B S T R A C T

This study aims to examine the literature related to environmental Life Cycle Assessment (LCA) for buildings and buildings' refurbishment from 1994 to 2022 by implementing a statistical analysis based on 'Web of Science' databases. LCA is viewed as a consolidated process that measures the environmental performance of buildings and their services, aiming to address the potential environmental impacts over the life cycle of buildings. A total of 1336 retrieved journal publications for LCA for buildings and 169 journal publications for LCA in building refurbishment. The articles' patterns were investigated in terms of subject categories, journals, countries, and the most highly cited articles. The findings reveal that LCA publications for buildings and building refurbishment have increased over the period 1994–2022, with China being the leading country contributing to the largest number of articles and possessing the most significant influence, followed by the USA for LCA in buildings. While Portugal is the leading country, followed by Italy, for LCA Buildings' Refurbishments. 97.08% of the publications were written in English, 2.04% in German, and 0.68% in Spanish. French and Japanese were the remaining languages, each with one publication, accounting for 0.2% of the 1336 building LCA publications. In contrast to refurbishment, LCA publications were written in only two languages, English (98.7%) and German (1.3%). Results show that the subject area differs depending on the type of LCA publication, with building LCA focusing on construction engineering while refurbishment focused on environmental topics. According to the IF, the most influential journal was renewable & sustainable energy for buildings and refurbishment LCA. However, journal distribution within LCA is still limited, and assessment methods and theme analysis still need to catch up with a clear gap in LCA in environmental impact mitigation and analysis methodologies, which will be a prominent direction of future building LCA research.

1. Introduction

It is a well-known fact that the climate is changing due to numerous causes, including but not limited to building construction, maintenance, and refurbishment. As a result of these changes, most notably the rise in average global temperatures, the world faces many environmental issues, such as rising sea levels and more frequent extreme weather events. These issues can severely impact the natural and built environment and human life in some instances. Therefore, measures must be taken to mitigate the

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adverse effects of climate change. This study will explore the influence of Life Cycle Assessment (LCA) in supporting the building sector's efforts to reduce its environmental impacts and the assets used during the building's life cycle, starting from raw material procurement via construction, use phases to waste management. They measure the carbon footprint, energy consumption or air emission, etc. A considerable body of literature has been published relating to the various subject areas of this study. The reviewed literature aims to briefly consider the global environmental issues facing today before exploring more specifically how the building sector impacts the environment, concluding with a review of the literature relating to building redundancy. Therefore, the main objectives of this study are to:

- Cover the latest publications in the field of LCA for buildings and building refurbishment up to the highest degree of accuracy, utilizing the search of publications quoting the use of LCA in the construction sector from 1994 to 2022 via the use of statistical analysis.
- Provide a comprehensive overview and highlight the recent contributions related to the LCA implementation within buildings and building refurbishment. The review explores alternative strategies and solutions for mitigating the environmental impacts arising from the building sector, ultimately studying the literature relating to building LCA in detail.

These findings provide valuable inputs for selecting subtopics in future research endeavors on building LCA. The advantage of LCA grew promptly throughout the 1990 s when the first research publication appeared by Guinée and Keoleian (A. Keoleian, 1993; [30]. At that time, LCA was deemed with high expectations. However, its result was often critiqued for being inaccurate, which could lead to detrimental environmental decisions. In addition, several types of drawbacks are confronted, including technical, methodological, and communication problems (Lee, 1995, [17]. Since then, robust growth and harmonization have followed, resulting in an international standard accompanied by several rules, guidelines, and textbooks (Lewis, 1996, [25]; Zhang, et al., 2022). This has enhanced the reliability and procedural robustness of LCA. In addition, there are several ongoing international proposals to assist in developing compromises and offer recommendations, including the Life Cycle Initiative of the United Nations Environment Program (UNEP), the Society of Environmental Toxicology and Chemistry (SETAC; UNEP, 2002), the European Platform for LCA of the European Commission, and the emerging International Reference Life Cycle Data System (ILCD) [69,59,32,53].

2. Methods

This research paper reviews the literature on LCA for buildings and refurbishment dating back to 1994 and provides a comprehensive understanding of the field using statistical analyses. By adopting the literature review, the study provides a comprehensive overview of the three-decade research development in the field of LCA for buildings and buildings refurbishment by using statistical analysis techniques; the statistical analysis technique is a well-established and widely recognized research method in information science [24]. It applies quantitative analysis and statistical methods to evaluate the quantitative relation and content information in each research area and further explores the detailed characteristics and patterns of the presented research area. The aims of implementing the statistical study are related to the reflection of the performance and science of the LCA research field. Regarding performance, statistical analyses set out to unpack the valuable research element in the research field of LCA, including authors, institutions, countries, journals, and so forth. In addition, the techniques for statistical analysis are chosen to meet the aim and scope of the study with the large volumes of data collected.

According to several research studies [26,35,33] the authors examine the LCA publication from (2000–2014), (1998 to 2013), and (1999–2018) respectively, the studies focused on the LC cost and social LCA, showing a clear gap in the literature related to the environmental LCA. Therefore, this research study aims to implement a statistical analysis related to the environmental Life Cycle Assessment (LCA) for buildings and refurbishment from 1994 to 2022. As such, a comprehensive analysis of the keywords was concluded with hot topics such as energy, materials, environmental impacts, and sustainable development. This research study will be prominent directions, while life cycle costing and social LC will continue to be the common research methods.

An ordinary form of content analysis, word occurrence analysis, emphasizes the core content of literature as the research object. This can be employed to find the development trends and changes in scientific research in the LCA field. To differentiate the hot-topics within the environmental building LCA field more completely and precisely, synonymous keywords and congenerical words were initially amalgamated and grouped into categories. For example, keywords associated with CO_2, energy, suitability, building materials, HVAC system, building assembly, and climate change were ranked by stated times. Then those keywords with high recurrences are sorted into categories and listed in a table to identify other hot topics in building LCA. While 'Life cycle assessment, building, and refurbishment' were used as the main words. These methods help in identifying hotspots in the building LCA research. Likewise, this study offers useful inputs for the decision-making on the sub-topic selection and publication strategy in building LCA research [1]. (Fig. 1), showing the research methodology overview.

3. Literature review

Of the 1886 building LCA publications retrieved from the Web of Science databases, Journal articles are the most frequently used document type representing 1336 (70 %), followed by 115 review publications (6.09 %), 428 proceeding papers (22.6 %), and 7 editorial material publications (0.3 %) Fig. 2. In contrast, a total of 203 publications were retrieved for building refurbishments from the Web of Science databases, with 169 (83.2 %) articles, followed by 34 review publications (16.7 %), and 3 editorial material publications (1.4 %) Fig. 3.Fig. 4..

The total number of publications gives an overall view of the general trend. However, further distribution related to citation, geographical distributions, languages, and subject categories are required to provide more specific evidence to suggest the status of building LCA within academic literature and therefore influence on society.

3.1. The energy consumption and environmental impact of the construction sector

The construction sector contributes to human life by providing shelter, improving spaces, and facilitating them to adapt to climate change. On the other hand, the sector has a massive environmental impact and waste contribution, with nearly 40 % of raw materials, 36 % of energy consumption, 40 % of waste generation, and 40 % of the greenhouse gas emissions around the globe [2],Hossain, 2019). In addition, to the strong relation between the construction sector and environmental issues such as dust and water pollution [40,14,4]. Therefore, the sector has seriously threatened the sustainable natural environment and human society. Several research studies argued about the correlation between buildings and their

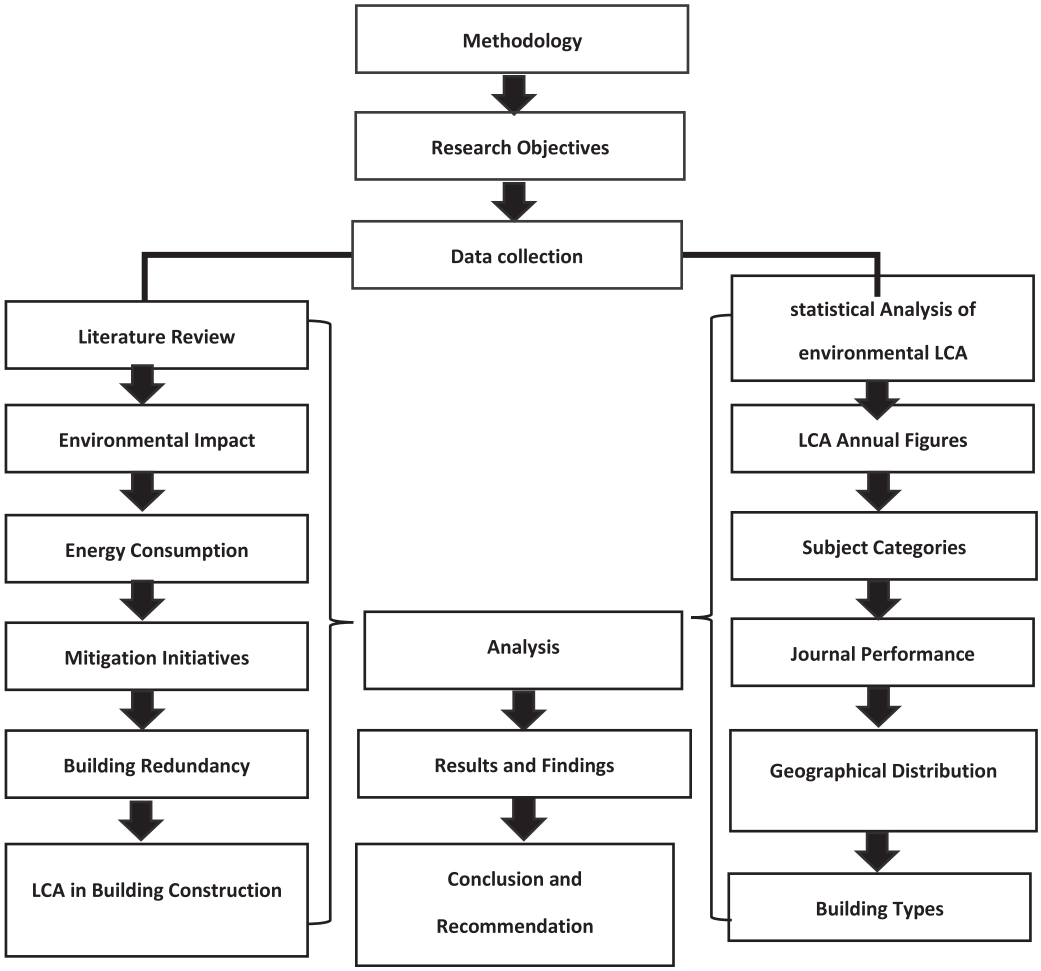

Fig. 1. An overview of the research methodology (Author drawing).

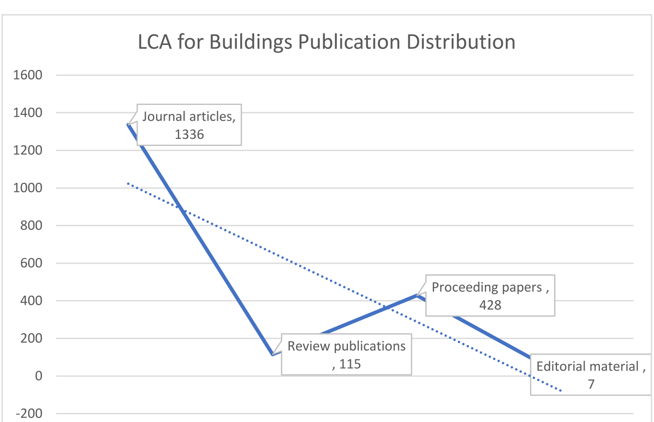

Fig. 2. LCA for Buildings Publication Distribution.

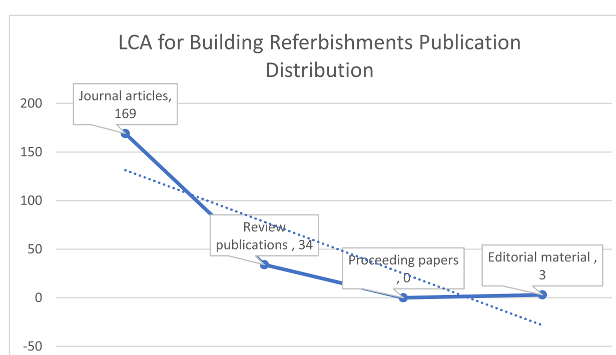

Fig. 3. LCA for Building Refurbishments Publication Distribution.

surrounding environment, which impacted the whole cycle of their existence, including the consumption of raw materials, heat and electricity consumption, water consumption, waste production, and the direct use of land for the construction of the building [42]. Therefore, researchers believe the construction sector can be blamably for its contribution to environmental pollution, the greenhouse effect, and inefficient use of resources [13].The authors in [16] discussed that the sector's carbon emissions, mass growth of waste, and promotion of land-use change had severe effects on the environment, leading to the impact of the rise in global temperatures over the last few decades. It is well known that the construction sector, experiencing a resurgence in growth, significantly impacts the global environment. The authors in [7] argued about the impact of the construction industry and the consumption of around 40 % of the global raw material extraction, which impacts the implementation of the strategic environmental plans in Egypt. The study considers an urgent need to introduce sustainable alternatives for building materials, mainly because these industries emit emissions like Co2. The amount of energy consumed by the

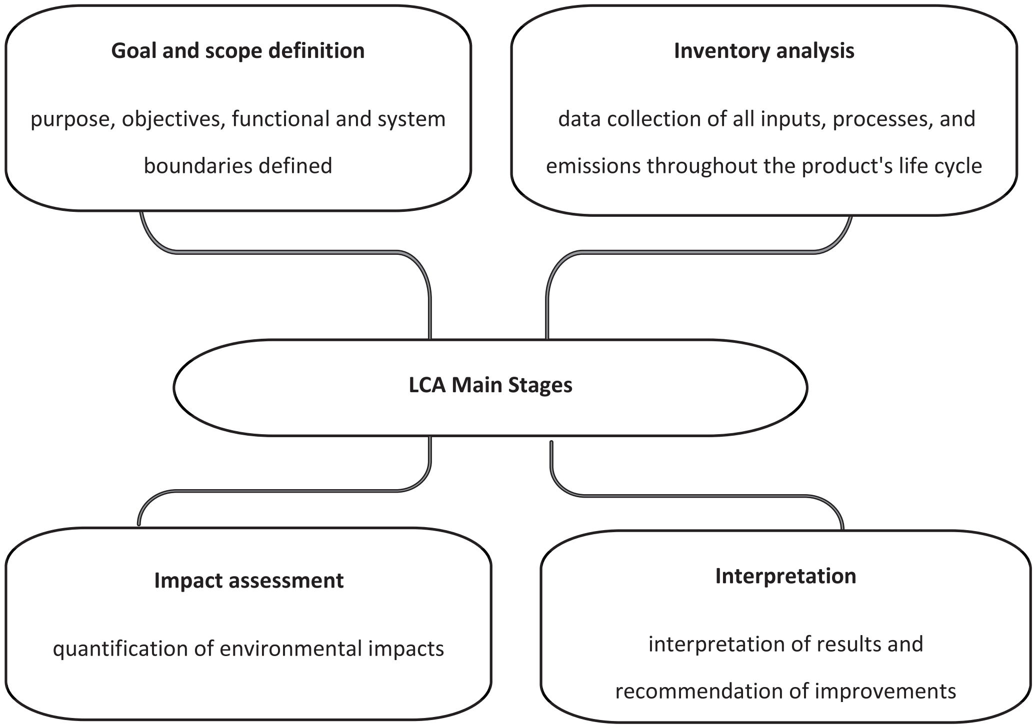

Fig. 4. Life Cycle Assessment Main Stages. (created by Author).

construction industry is explored further in a study by [31] comparing energy consumption by sector, and the results showed that the energy consumed by the building sector is greater than the energy consumed by the transportation and industrial sectors in the United States and Europe. This finding, however, is not entirely unsurprising as there have long been initiatives and policies put in place to decrease the energy consumption of the transportation sector in particular. The United Nations Environment Programme (UNEP) findings on the levels of resource consumption within the construction sector are extended by Ghaffar and Chougan, mentioning that the construction industry accounts for 25 % of water use and 12 % of global land-use change. [27,67]. The Authors in [8] studied the impact of the LCA tool on the environmental impacts of the typical Egyptian residential building following ISO 14040 standards. The results showed that the use stage contributed mainly to all other environmental impacts and specifically related to energy usage in the operational stage, with 71.9 % of the total effects. Examining how the construction sector emits harmful substances into the environment, the researchers in [54,44] focused on the level of greenhouse gas (GHG) emissions attributable to the construction sector, which around one-third of the world's GHG emissions. The recent findings published by UNEP [67] dispute this Figure, suggesting that the amount is somewhat larger, with almost 40 % of global GHG emissions being attributable to the construction sector, suggesting that the construction sector's GHG emissions are increasing.

In Canada, the existing building stock is associated with 50 % of natural resource extraction, 35 % of GHG emissions, 33 % of energy consumption, 25 % of landfill waste, and 10 % of particulate matter (Assefa, 2017). In comparison, the UNEP report [38]) shows that the U.S. building sector accounts for 37 % of the country's total energy consumption, while Hong Kong also accounts for a more significant percentage than Canada, with 40 % being attributed to the building sector. For the E.U., the existing research does not provide a definitive figure on the energy consumption attributable to the building sector [47] stated 37 %, while [73] indicated 40 %, and [61] mentioned as much as 42 % of the E.U.'s total energy consumption. The figures for the U.K. are also inconsistent; the authors [29] showed that the building sector accounts for 39 % of the U.K.'s total energy consumption, while [52] commented that it is 50 %. [43] also suggested that 50 % of the U.K.'s total GHG emissions can be attributed to the building sector, 15 % more than the Canadian building sector. The E.U.'s building sector compares more favorably with the Canadian figures for GHG emissions [18] discussed that 36 % of total EU GHG emissions are attributable to the building sector, a difference of only 1 %. Similarly, the E.U. building sector's figures for natural resource extraction compare favorably with the Canadian building sector, with 50 % for both locations [61].

The rapid increase in world energy use has raised concerns over supply difficulties of energy resources and severe environmental impacts, including but not limited to global warming, climate change, and the reduction in the ozone layer [62]. The global contribution from the buildings sector towards energy consumption, in both residential and commercial, has gradually grown, reaching figures between 20 % and 40 % in developed countries, and has beaten the other major sectors like industrial by 5 %and transportation by 7 % [58,66,65]. Furthermore, the growth in inhabitants, growing demand for building services, and comfort levels, simultaneously with the increased time spent in buildings, confirm that the increasing trend in energy demand will remain. For this reason, energy efficiency in buildings is considered a significant objective for energy policy at local, national, and international levels. The Royal Institution of Chartered Surveyors [60] recognizes that the high level of green GHG emissions resulting from the built environment is not only released during the building's use or operational phase but that a building uses energy and releases GHG emissions throughout its life cycle, both directly and indirectly [3]. The buildings' refurbishment or demolition results in direct energy consumption, while the materials used in a building's construction and technical installations consume indirect energy. This 'indirect energy' can also be described as 'embodied energy, which [71] defined as "the energy necessary to extract the raw materials, process them, assemble them into usable products and transport them to site.Furthermore, according to [5], the heating, ventilation, air conditioning, and lighting systems account for the most significant amount of consumed energy within office buildings in the USA and U.K., with 70 % and 72 % of the total office building energy consumption respectively. The research study by [23] used LCA as an environmental measuring tool in comparing the environmental impacts and energy consumption of office buildings in the hot desert climate zones when new materials are used like; high-performance glazing systems, and conventional clear double-glazing system, followed by the electrochromic glazing system were used. The results showed that the photovoltaic glazing system is the lowest energy consumption and the lowest environmental impacts by achiving, 87 % energy savings. While the authors in [41] argued that one of the main reasons why the construction sector's energy and resource consumption has become so intensive is due to "the introduction of modern building materials that, unlike traditional materials, increase the embodied energy and carbon footprint of the constructions." This is because modern building materials are produced far from their ultimate destination through expensive manufacturing processes. When combined with the increase in construction activity due to increased urbanization, it is widely accepted that the damage exerted on the environment by the construction sector cannot be ignored.

From the above, the authors suggest an area of LCA requiring greater research related to the implementation of LCA within building and buildings refurbishment, and a timely study to quantitatively evaluate the rapidly growing body of literature on building LCA with the performance of statistical techniques, to uncover the characteristics of global building LCA literature from 1994 to 2022, and the worldwide advancement of the building LCA research over the years to be assessed by analyzing the general patterns of publications, language, journals, subject category, country, institution, the most highly cited articles as well as hot topics. These findings will provide valuable inputs for the selection of sub-topics in future research efforts on the building of LCA.

3.2. Mitigation initiatives for the building sector

The environmental impact of the building sector can be classified into an ecosystem, natural resource, and public impact, consuming a significant amount of non-renewable energy, and increasing CO_2 emissions. As such, governments and policymakers have been recommended to mitigate CO_2 emissions [15]. Therefore, several sustainable building standards, codes, policies, and guidelines packages have been established in several countries to enhance building energy performance by reducing CO_2 emissions. In 2015 the Paris Agreement was set up with main long-term goals that each country outline and communicate their post-2020 climate actions, known as their NDC to decarbonize the building sector. A total of 196 Governments have taken proposals for the decarbonization of the building sector by establishing policies and standards. Table 1 summarizes some of the standards and policies committed by different countries under this strategy, including reducing CO_2 emissions in their objectives and setting the minimum requirements for energy performance and building efficiency toward zero or low-carbon buildings.

The research study [49] reveals that implementing Carbon-dioxide mitigation in the residential building sector (CMRBS) in China significantly contributes to the decrease in CO_2 amount. In addition, the CMRBS from 2001 to 2016 was 1816.99 Mt CO_2, and the average mitigation amount during this period was 266.12 kg CO_2, showing a positive impact of the implemented CMRBS. The research further showed that the energy conservation and emission mitigation strategies caused CMRBS to increase effectiveness and are the key to encouraging more significant emission mitigation in the future. In their review paper [61],the authors described a comprehensive list of factors for sustainable building by providing a valuable reference for construction professionals and practitioners attempting to implement Carbon-dioxide mitigation. Sfakianaki's findings further support the statistical analysis published by the European Commission in 2020, comparing the energy consumption between 2017 and 2019, showing a reduced CO2 emissions average among E.U. countries.

While India has always been a strong supporter of a climate policy shaped by the Paris agreement, it still has a long way to go, even with its concern about climate policy growing gradually due to its energy benefits. India is fourth in global greenhouse gas emissions, after China, the United States, and the E.U., and could move up the list further in the coming years. Since the developing countries suffer from poverty and are not responsible for historical GHG emissions, India insisted that; no climate targets should be fixed for

Table 1
Existing standards correlated with reducing CO2 emissions in buildings [3].

Country	Standards or Policies
European Union	In the EU, a legislative framework has been established, including the Energy Performance of Building Directive (EPBD) and Energy Efficiency Directive (EED). Both Directives' policies aim to achieve buildings with high energy efficiency and a stable built environment by 2050 to enable consumers and businesses to make more informed choices to save energy and cost [21]. In addition, the directive also requires that EU countries set cost-optimal minimum energy performance requirements for new buildings and existing buildings undergoing significant renovation [48].
China	In 2016 the Ministry of Housing and Urban-Rural Development launched the Energy Consumption of Buildings standard, covering the energy usage for various building types. Aiming to limit the energy consumption in the building sector and concurrently limit the total CO2 emissions.
India	In 2016 a policy was introduced as part of the Energy Conservation Act of 2001 for commercial and residential buildings introducing simple enforcement of thermal comfort and passive system improvement.
Australia	In 2017 the National Carbon Offset Standard for Buildings was launched and established in collaboration with the Green Building Council Australia. Aiming at reducing and assessing CO2 emissions from building operations.
Japan	In 2017, the Building Energy Efficiency Act was introduced as part of the Japanese government policy on the zero-energy-building [ZEB]/zero-energy-house [ZEH] system. Aiming to be achieved by 2030 by monitoring measures for mandatory compliance with energy efficiency standards for non-residential buildings.
USA	In 2018, the first code in the USA was introduced (the California 2019 Building Energy Efficiency Standards), to increase buildings' overall efficiency and sustainability.
Singapore	In 2016, the Code on Environmental Sustainability Measures for Existing Buildings was introduced for existing non-residential buildings within Singapore's Building Control Regulations.
Nigeria	In 2017, the building energy code was introduced in collaboration with the German Development Agency (GIZ) and the Nigerian Energy Support Program to set minimum standards for energy-efficient building construction in Nigeria.
Canada	In 2016, stringent energy performance standards for energy-using product categories in buildings were launched. In addition, the Pan-Canadian Framework on Clean Growth and Climate Change committed to a 'Net Zero Energy Ready' (NZER) model in 2030, aiming at increasing energy efficiency in the building sector.

them. Although India increasingly sees itself as a global actor, it insists on its status as a developing country and rejects external interference. Given its growing share of global GHG emissions, it is essential to demand an active role and responsibility in the new climate regime from India. The research study (Harrison, 2014) demonstrates that adopting mitigation strategies is far from simple. It demands sensible balancing of conflicting priorities and intentional strategies; for example, in China and India, the balancing act has been done contrarily as each country has customized its attempt to the specific context of conflicting priorities and inconsistent state capacity. China's approach can be referred to as "state-signaling," while India's approach is a "market-plus." China's approach is more clearly stat than India's, but in both countries, mitigation plays a vital part in building the support base for its policies through processes described as pushing policies and interests.

The Kyoto Protocol is an essential example of limiting and reducing GHG emissions following the agreed individual targets. The Protocol set targets for GHG emissions reduction as an international treaty connected to the United Nations Framework Convention on Climate Change [68]), to reduce 5 % of GHG emissions by 2012 as part of the first commitment and a reduction of 19 % by 2020 as part of the second commitment. As a result of the Kyoto Protocol, the searchers in [16] focused on evaluating GHG emissions directly from buildings, mentioning that governments have developed and implemented policies and legislation to promote sustainable buildings, recognizing the European Commission's target to reduce CO2 emissions by 90 % for the construction sector by 2050 as part of their Roadmap to a Resource Efficient Europe' [68]. Sfakianki [61], explores the opportunities to improve overall resource efficiency. One example selected by Sfakianaki is the target of 70 % recycling by the E.U. Member States by 2020 to reduce waste generation and achieve 'zero waste.' In response to this initiative. In contrast, the study in [22] explored the intent to commit to zero waste by considering how applicable the industry would be within the construction sector and what challenges may be faced. The authors in [63] explore different countries' approaches when developing their regulatory frameworks rather than the specific targets. Their key finding is the discrepancy amongst the approaches, which is an encouraging finding as it suggests that there are alternative strategies and means of achieving best practice should initial attempts not meet expectations. Although on a more local scale, the study in [64] supports this finding [56] by focusing on the various approaches the U.K. government has taken to promote sustainability in the built environment. For example, [70] recognize the implementation of legislation such as landfill tax to deter waste accumulation and policies such as 'Construction 2025′, which draws attention to the operational and embodied carbon emission of buildings, focusing on the operational and embodied carbon emission of building on how much emissions can be reduced. The authors in [64] also explored the effects of energy rating assessments for buildings, such as the Energy Performance Certificate (EPC), Leadership in Energy and Environmental Design (LEED), and the BRE Environmental Assessment Method (BREEAM), which have been introduced globally bring commercial attention to promote sustainability within the built environment. The study in [70] investigates the U.K. government's approach to pursuing alternative strategies to reduce the number of redundant buildings and promote the "optimum use of the existing building stock" by exploring the possibilities of adaptive reuse as an alternative to demolition and rebuilding. It can be argued that alternative strategies, such as adaptive reuse or refurbishment of the existing building stock, have not been more important or necessary than they are today. According to (Zhang, et al., 2022) 80 % of European buildings occupied by 2050 have already been constructed; the study also concluded that "the existing building stock will be responsible for a large portion of the European CO2 emissions in the future if left unaddressed".

The above shows some differences between the approaches to climate change mitigation adopted by different countries and some similarities. These similarities highlight the importance of serious attention to states' challenges in developing the necessary consensus and capacity to implement their climate change mitigation policies. Despite the different approaches of each country and the geographical position, the experiences of each country demonstrate the challenges faced in implementing even relatively modest mitigation strategies. This makes it essential to examine how states develop the capacity to implement mitigation measures, including bringing critical stakeholders on board.

3.3. Life cycle assessment (LCA)

LCA is a comparative analysis process that is used to evaluate environmental hazards and consumption of resources associated with the building, process, or activity over the entire life of the building, following the standardized framework published by the International Organization for Standardization (ISO) in 2006 ISO 14040 and ISO 14044 [39]. As LCA takes a comprehensive, systemic approach to environmental evaluation, increased attention to incorporating LCA methods into building construction decision-making (e.g., new building design or assessment of building refurbishments). Through quantitative assessment, LCA provides a method of analyzing each material and process of a product from 'cradle to grave. From raw materials through manufacturing, transport to site, use on-site, and eventually to its disposal. While the authors [39] widely recognized standards for applying LCAs are included in the 14,000 series of the International Organization for Standardization (ISO) environmental management standards. According to the standards, an LCA is typically structured into four main stages (figure 43), the definition of the objectives and scope, the compilation of an inventory of flows and elements, the impact assessment, and interpretation.

3.4. LCA in the building sector

In response to the increased awareness of the impacts of anthropogenic climate change, and the need for the construction sector to play its part in mitigating these impacts, the concept and methodologies of building LCAs have developed over the years following the International Organization for Standardization (ISO) in 2006 ISO 14040 and ISO 14044 [73]. In (Assefa, 2017), the author discussed the existing research on building LCAs and found that "the last years have witnessed a fast growth of research on the assessment of buildings across the entire life cycle. Furthermore, the author in (Hossain, 2019) evaluated and explored different objectives and elements relating to LCA, summarizing the topics explored within the existing LCA studies vary, from the different types of LCA to performing LCA on specific building components. For example, in their research on the different types of LCA used to evaluate the effects of buildings on the environment, [19] compared the objectives, methodologies, and findings of three different types of LCA: traditional LCA, Life Cycle Carbon Emissions Assessment (LCCO2A), and Life Cycle Energy Assessment (LCEA). The researchers in [20] concluded that while there are differences in the focus of the LCA, all three are suitable to be used as decision-making tools to reduce the environmental impact of buildings. In [57], the authors also explored the use of LCA to aid decision-making through software development that can produce building energy audits and examine energy efficiency. The software enables building owners to obtain specific calculations for their buildings, thus allowing them to make decisions on improving their buildings' energy performance. Other studies [46,6], have focused on assessing how much energy is consumed by running simulation models to help decision-making. While [19] summarized that other LCA studies focus on a single element of a building, building system, or a specific material during the construction stage when using LCA as a decision-making tool. For instance, [34,50] researched buildings' thermal performance and explored heating and energy supply systems. Similarly, LCA is utilized in studies by [37], to analyze the structural elements of a building, while a study by [45] analyses the materials used to insulate the building, ultimately providing information on how a specific element of the assembly of a building can impact upon the environment. Like Llantoy, the researchers in [9] undertook a study focusing on the building envelopes of office buildings by performing an integrated environmental and Energy LCA to assess various scenarios of insulation material combined with different window-to-wall ratios.

Furthermore, according to [72] it is not uncommon among the existing literature for authors to perform LCA on specific materials and components of buildings, such as steel, cement, concrete, and wood. Several authors, such as (Assefa, 2017; [9], recognized LCA's use for assessing the environmental impact throughout a building materials supply chain. For example, plasterboard through LCA identifies GHG emission hotspots within the supply chain and ultimately puts forward considerations and alternative renewable energy sources that have less impact on the environment. It is evident from the existing literature that most LCA studies have focused on new buildings. The prediction of an additional 230 billion m^2 of new building sector floor area to be constructed by 2060 is encouraging as it suggests that the building sector is pursuing strategies to mitigate anthropogenic climate change. However, the existing building stock also has a significant role in mitigation. The authors (Zhang, et al., 2022) recognized that the investment in creating energy-focused retrofit strategies for buildings had progressively increased over the last decade. Several studies support this, such as (Assefa, 2017), which performed an LCA on two scenarios to compare the potential environmental impacts depending on whether the existing building is selectively deconstructed, repurposed, demolished, or rebuilt. When performing a simplified LCA on different environmental categories such as 'Global Warming Potential,' Assefa, found that almost all categories are reduced under the repurposing scenario. Additionally, [71] used LCA to develop a "toolbox" strategy to support how best to refurbish existing residential building stock to ensure maximum energy efficiency. While [57] perform an environmental LCA on different design strategies to sustainably refurbish existing student residence halls. It is also apparent from the existing literature that fewer LCA studies have been conducted on commercial buildings [6]. Furthermore, when there is a study on commercial building LCA, the majority are performed for new buildings, and very few studies have conducted LCA in commercial building refurbishments. For instance, in what is believed to be one of the earliest studies in which a building LCA is performed [32] analyzes the life cycle energy of an office building to present alternative structural systems. Further LCA studies by [11,51,12] have also focused on new buildings in the commercial sector. [50] expand on this further, finding that the published methodologies for building LCA are generally more developed and include more detail for new LCA than refurbished building LCA.

It is clear from the literature reviewed that a substantial amount of research has been conducted under the aegis of global environmental issues and the built environment. The research area concerning anthropogenic climate change is vast, with a wide range of studies investigating the effects of anthropogenic climate change and how the results can be mitigated against. Within this subject area, various studies explore the environmental impact of the built environment, including how the sector consumes energy and how building redundancy can impact the environment. Some studies have examined alternative strategies and solutions to ensure the building sector is best equipped to meet climate change mitigation targets in response to these research areas. An important strategy that has been explored within the existing literature is the application of LCA to understand specific environmental impacts arising from buildings. Research of this type will undoubtedly have a significant impact and influence on society by providing scientifically supported solutions to reduce building GHG emissions, reducing the building sector's effects on the environment, and promoting sustainability. Since this research intends to benefit society, there have been calls for more quantification of the effect of scientific research on society by providing evidence on how much research is being produced and its findings [34]. Several assessment tools were developed for construction disciplines and researchers to analyze the life cycle of buildings, measuring; economic costs, and the environmental performance of building materials and systems, using the LCA process required by the ISO 14040 series of standards. The stages of the LCA for the building sector include raw materials, manufacturing, transportation, use, and end of life, measured by using different tools, including but not limited to The Building for Environmental and Economic Sustainability (BEES) software developed by the U.S. Environmental Protection Agency (EPA) Engineering Laboratory. ATHENA Eco Calculator for assemblies includes a series of spreadsheets created by the Athena Institute in alliance with the University of Minnesota and Morrison Hershfield Consulting Engineers. ATHENA Impact Estimator, also developed by Athena Institute, is the only software mainly designed to evaluate whole buildings based on life-cycle assessment methodology. imaPro is a comprehensive LCA tool developed by PRé Consultants, which includes several impact assessment methods (Hemmati, 2021). SimaPro comes with a huge set of data libraries coving 6,000 processes for all the details of life cycle analysis.

Research on building LCA is proliferating; little study quantifies the amount and type of research conducted on this subject. There is, therefore, a need to quantify and evaluate the existing literature on building LCA. A study by (Zhang, et al., 2022), examined the current literature on building LCA and provided a foundation on which this study can build. The study by [55] focused on global literature on building LCA, published from 2000 to 2014. At the same time, [28] explored the general patterns and main research areas discussed in the published publications. There is not only a need to expand upon their timescale to explore a wider breadth of literature but also a need to pay particular attention to the building LCA literature focusing on the refurbishment of existing buildings due to the impact the current building stock has on the environment and the apparent lack of existing research on this specific topic.

4. Data analysis for LCA in buildings and buildings refurbishments

This section presents the statistical analysis results implemented in this study. Showing the articles' patterns in terms of subject categories, journals, countries, and the most highly cited articles. The findings reveal that LCA publications for buildings and building refurbishment have increased from 1994 to 2022. However, the analysis reveals a remarkable gap between the countries, with China being the leading country contributing to the most significant number of articles with 28.5 % and possessing the most significant influence, followed by the USA with 25.6 % for LCA in buildings. Also, China is the leading country with 19 publications (20.7 %), followed by the USA with 17 publications (18.5 %) for LCA Buildings' Refurbishments. In addition, the results on LCA for building refurbishment reveal three high-level themes, including building types, methodology, and assessment methods. Another gap in the literature found in the most common building type on which LCA research has been undertaken is residential buildings, with 57 %, with comparatively few studies on commercial buildings. In methodology, three themes emerged, including reviews of LCA assessments; development of a framework; and undertaking a building LCA, which accounted for 50 % of the publications. Finally, the assessment method theme analysis found another gap in the literature: the publications only focused on LCA methods. These were very few alternative LCA methods, such as LCEA and LCSA, suggesting that the more environmentally focused LCA methods were not frequently used within the existing research on building refurbishment LCA. These findings help identify the status of the building LCA research, with adequate inputs for the decision-making on the topic selection and publication strategy in the building LCA research. The findings also contribute and provide valuable inputs for selecting subtopics in future research endeavors on building LCA.

4.1. Annual figures for LCA in buildings and Buildings' refurbishments

Noticeably, publication numbers fluctuated for the ten years between 1994 and 2004 (Fig. 5), with two years experiencing no building LCA publications and the remaining years varying from one to five publications. 2005 is the first-year publication numbers reached double figures, which increased in 2006 before a fall in 2007. The results in [36] showed similar trend in the social LCA publication for the period 2003–2018, with rapid growth, with a clear rising trend in related publications (mainly case studies), particularly after UNEP/SETAC Guidelines publication for Social Life Cycle Assessment of Products in 2009.

This decrease is somewhat surprising as the Intergovernmental Panel on Climate Chang (IPCC) released its fourth assessment report in 2007, which one would have thought would increase climate change mitigation initiatives. From 2007, there was an increase in publication numbers year-on-year to 2018, when the total number reached 171. A study by [26] show similar results of an increse in publications and citations steadily from 2000 to 2014. When totla citation reached its peak in 2010 for publication in LCAC and LCIA.

The 2019 shows a decrease in overall numbers, most probably due to only those publications being published to date being counted in the total number. However, when the average number of publications per month is analyzed for each year, 2019 is already witnessing monthly publication figures greater than 2017 and almost surpassing 2018 with a third remaining year. While the total number of publications gives an overall view of the general trend, citation figures provide more specific evidence to suggest the status of building LCA within academic literature and influence society. As can be seen in Fig. 6, the overall trend from 1994 to 2022 increased year-on-year in the total number of citations, except for 2019 and 2020. However, when the average number of citations is analyzed per month, 2018 exceeded the total number of citations per month in 2018.

This trend suggests that the application of LCA is becoming more widely accepted as a tool to assess the environmental impact of buildings, particularly since the introduction of the Kyoto Protocol's second commitment to reduce GHG emissions by an average of 19 % below 1990 levels by 2020, providing the state-of-the-art analysis of different methods of enviromental impact assessment in buildings (Chau et al., 2015).

Between 1994 and 2009, there were only 6 refurbishment publications, with the first publication in 1999, 4 publications in 2005,

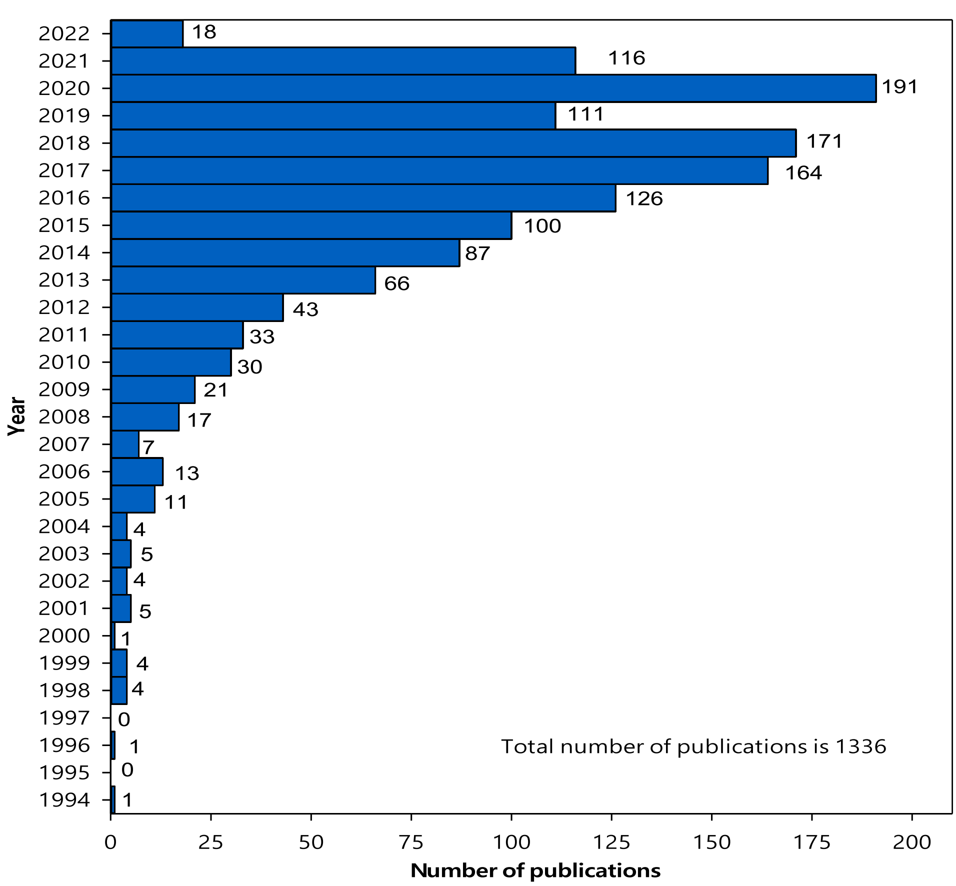

Fig. 5. Total number of buildings LCA publications 1994–2022. (created by Author).

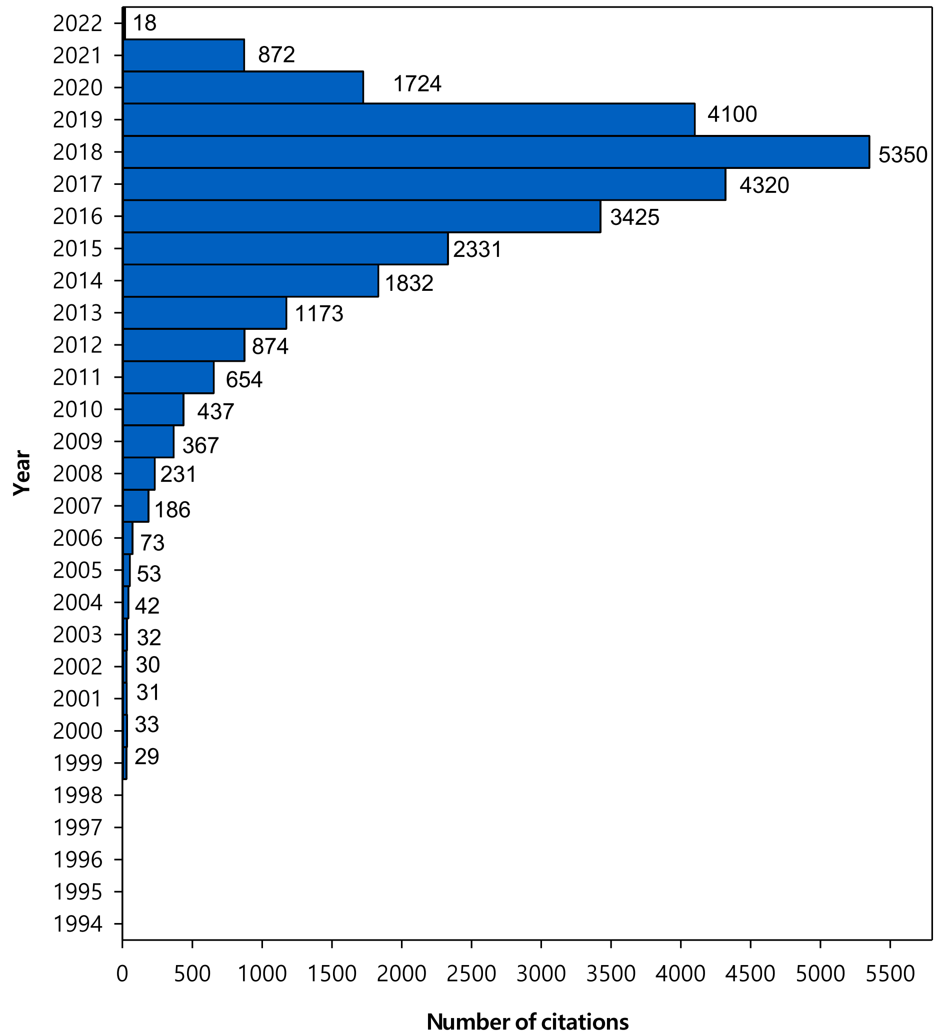

Fig. 6. Total citations of building LCA publications 1994–2022. (created by Author).

and 1 in 2009. In 2014, there was a sharp increase in publication numbers compared to the years on either side. In addition, numbers increased again from 2017 through 2019. An explanation for the rise in 2014 could be in response to the IPCC's Fifth Assessment Report released. Likewise, the general building publications, 2020–2022, show a decrease in overall numbers, most probably due to only those publications being published to date being counted in the total number. However, when the average number of publications per month is analyzed for each year, 2017 and 2018 is already witnessing monthly publication figures greater than any other year. The fewer building refurbishment LCAs found may be related to the poor perception of LCA methodology at the time for building refurbishment, or there were no standard or protocol related to the building refurbishment LCA, and it may also depends on the existing building refurbishment LCA related problems. Fig. 7 shows the total number of publications relating to building refurbishment LCA increased from zero in 1994 to 26–29 publications.

Fig. 8 shows the total number of citations per year. However, when the average number of citations is analyzed monthly, 2018 exceeded the total number of citations. This trend suggests that LCA is becoming more widely accepted as a tool to assess the environmental impact of buildings' refurbishments. Fig. 7 shows the average percentage of building refurbishment LCA publications relative to the total number of buildings LCA publication is 8.7, showing a clear gap in the publication related to LCA for buildings refurbishment.

4.2. Subject categories for LCA for building and Buildings' refurbishments

The 'Construction building technology' was the most common subject, with 17.7 % (427) of the publications falling within this category, followed closely by 'Engineering civil,' which accounted for 16.5 % (399). The following four most common subject categories are found in 11.8 % (285) to 14.3 % (344) of the publications, ahead of the less common categories such as 'Environmental studies,' which accounted for 3.4 % (82). Therefore, the allocation of subject categories suggests that while the environment is considered among the existing literature on building LCA, it is not the most dominant subject. Instead, the literature is dominated by the subjects of construction and engineering. The top 15 categories are shown in Fig. 9.

Comparing the 169 buildings' refurbishment LCA publications were divided into 23 subject categories. Fig. 10 shows the top 15 categories. Similarly, to the general building LCA publications, 'Construction building technology' was the most common subject with 19.4 % (73) of the publications within this category, followed closely by 'Energy fuels,' which accounted for 18.3 % (70).

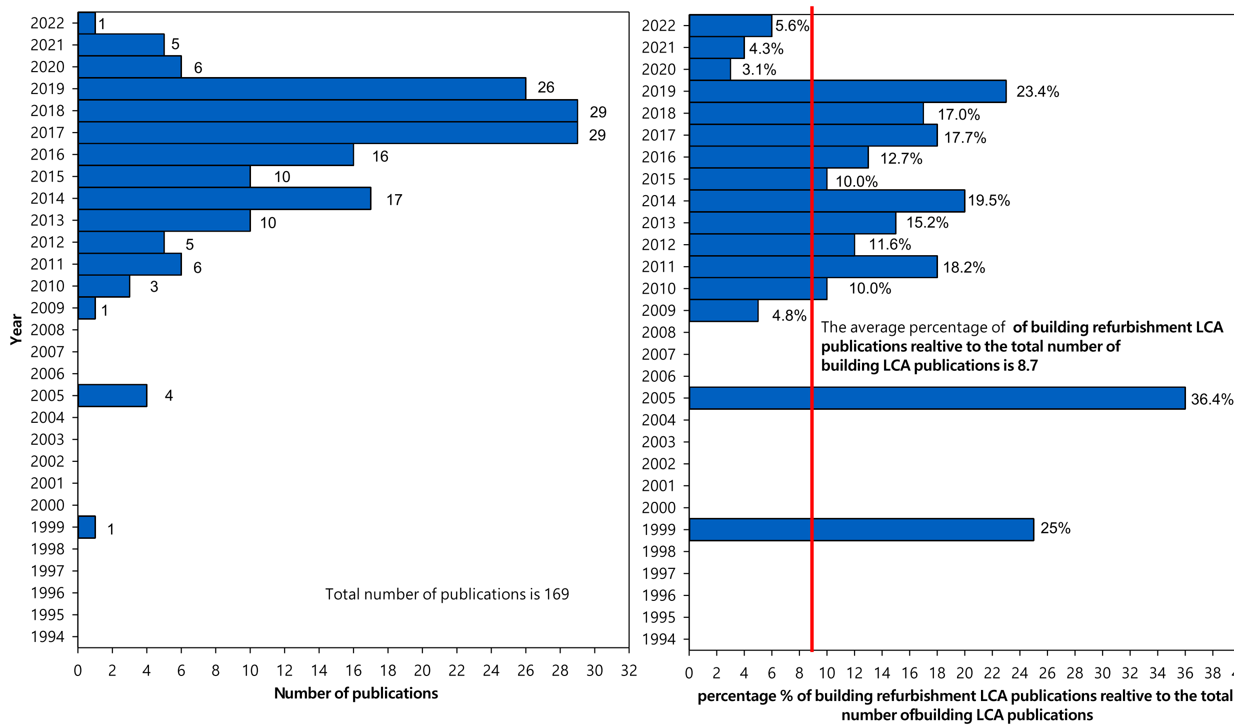

Fig. 7. The total number of building refurbishment LCA publications 1994–2022 (created by Author).

In contrast to the general LCA publications, a higher proportion of environmentally focused subjects were present among the refurbishment publications, with categories such as 'Green sustainable science technology,' 'Engineering environmental,' and 'Environmental sciences' forming a part of the subject of at least 80 % of the publications. This suggests that the research on refurbishment LCAs has been more specifically focused on the environmental impact of existing buildings than the general LCA publications. Also, the increasing trend in adopting LCA studies is associated with escalating waste-management policies (in Europe) and implementing the ISO 14044: 2006 standards for LCA methodology (worldwide).

4.3 Journal performance for LCA for Building and Buildings' Refurbishments There are 524 journals that have published articles on the building LCA by 2022. Table 2 shows the top 10 in terms of the total publication numbers of these journals. The top 10 journals accounted for 62.1 % of the building LCA publications in the period 1994–2022. The number of publications indicates that energy and buildings appeared to be the most influential journal, with 155 building LCA publications (15.1 %). Building and environment was the next most influential journal with 118 publications (11.5 %), closely followed by the journal of cleaner production with 117 publications (11.4 %). Overall, these three journals accounted for approximately-one-third of the total building LCA publications, with the remaining top 10 journals accounting for 24.2 %, suggesting that the distribution of existing building LCA literature is limited.

To explore the exact influence of each journal, however, it was necessary to consider the most recent Impact Factor (IF) for the top 10 journals, as shown in Table 2. By comparing the IF and the ranking of the journals by publication number, it can be inferred that the highest-ranked journal by publication number did not necessarily have the most significant impact factor. For example, among the top 10 journals, renewable & sustainable energy reviews were ranked fourth by publication number but had the highest IF at 14.98, while Energy and Buildings is the first in a number of publications with IF of 5.879 showing a significant influence on the building LCA research.

Fig. 11 shows the distribution of the building LCA publications within the top 10 journals over the last 25 years. Overall, the number of buildings' LCA publications in the top 10 journals has increased from 0 in 1994 to 64 in 2022.

With a clear peak of 191 in 2017. In contrast to the annual figures for total publications and citations, there was an increase from 2008 to 2020. Moreover, there was a decrease in the total number of publications from the top 10 journals in 2018 and 2022. While the latter could be due to the year being incomplete, the former could be due to a wider variety of journals available in recent years for academics to publish their research. Looking more specifically at the distribution of publications within each journal, the number of publications in Energy and Buildings fluctuated throughout the period despite it being the highest-ranked journal suggesting again that the highest-ranked journal by publication number does not necessarily have the most significant influence.

In contrast, the 2012–2018 Journal of Cleaner Production comprised a progressively larger portion of the field, demonstrating its increasing impact on building LCA research despite being ranked third by the total number of publications. There isn't any specific reason for the fluctuations in the publication of the studies. It depends on the existing LCA related problems.

While, the 169 buildings' refurbishment LCA publications were distributed among 46 journals. Table 3 shows the top 10 journals in terms of publication numbers, where 71 % of the total number of publications were published. While the top five journals are the same as the top five general building LCA publications, the refurbishment LCA publications witness the addition of Energies and Energy, which were not present in the available top 5 journals. This suggests that the existing research on building refurbishments is more aware of the need for buildings to reduce their energy consumption to help mitigate anthropogenic climate change. To fur-

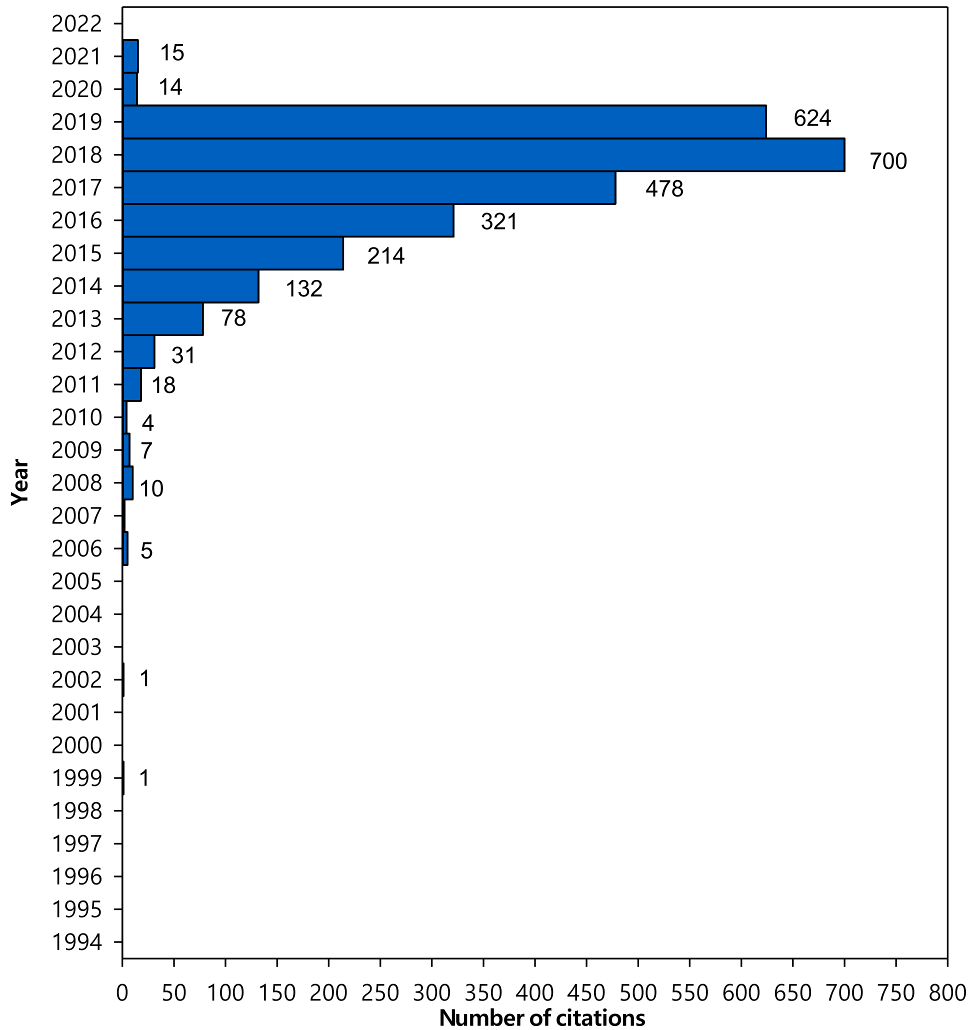

Fig. 8. LCA total number of Refurbishment Citation. (created by Author).

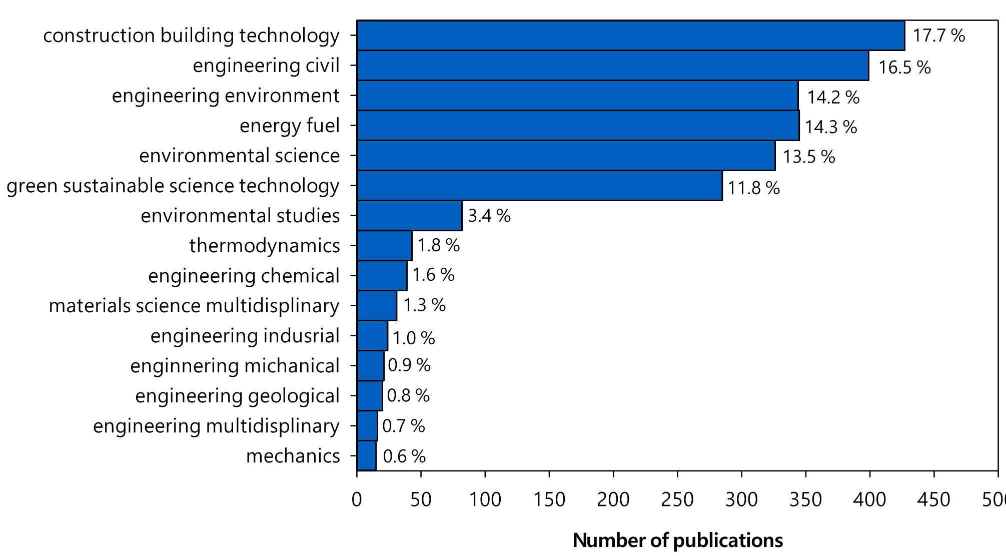

Fig. 9. Top 15 Subject Categories of Building LCA (Created by Author).

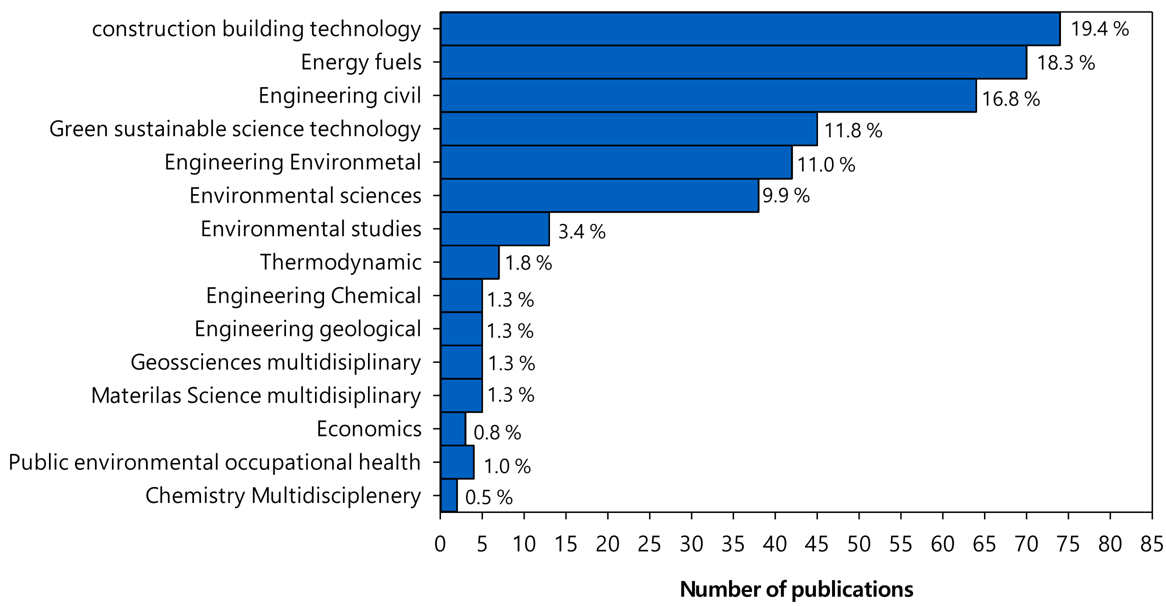

Fig. 10. Top 15 subject categories of building refurbishment LCA publications 1994–2022 (Created by Author).

Table 2
The Top 10 journals containing building LCA publications.

	Journal name	Total Publications	% of total publications	IF/2020
1	Energy and Buildings	155	15.1	5.879
2	Building and environment	118	11.5	6.456
3	Journal of cleaner Production	117	11.4	9.297
4	Renewable & sustainable energy review	53	5.2	14.98
5	Sustainability	48	4.7	3.251
6	International journal of life cycle assessment	46	4.5	4.141
7	Building research and information	29	2.8	5.11
8	Applied energy	28	2.7	9.746
9	Sustainable cities and society	23	2.2	7.587
10	Journal of building engineering	22	2.1	5.318

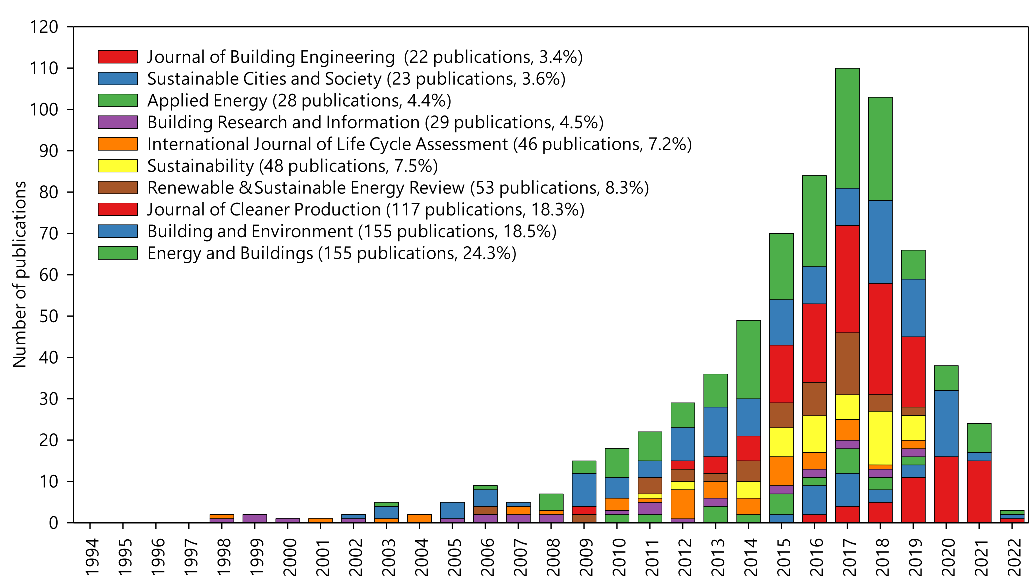

Fig. 11. Distribution of building LCA publications within top 10 journals 1994–2019. (Created by Author).

Table 3
Top 10 journals containing building refurbishment LCA publications.

	Journal name	Total Publications	% of total publications	IF 2020
1	Energy and Buildings	37	21.3	5.879
2	Building and environment	15	9.7	6.456
3	Journal of Cleaner Production	14	9.0	9.297
4	Renewable & sustainable energy review	11	7.1	14.98
5	Sustainability	8	5.2	3.251
6	energies	7	4.5	3.004
7	International journal of life cycle assessment	7	4.5	4.141
8	Sustainable cities and society	6	3.9	7.587
9	Journal of building engineering	5	3.2	5.318
10	Energy	4	2.6	7.147

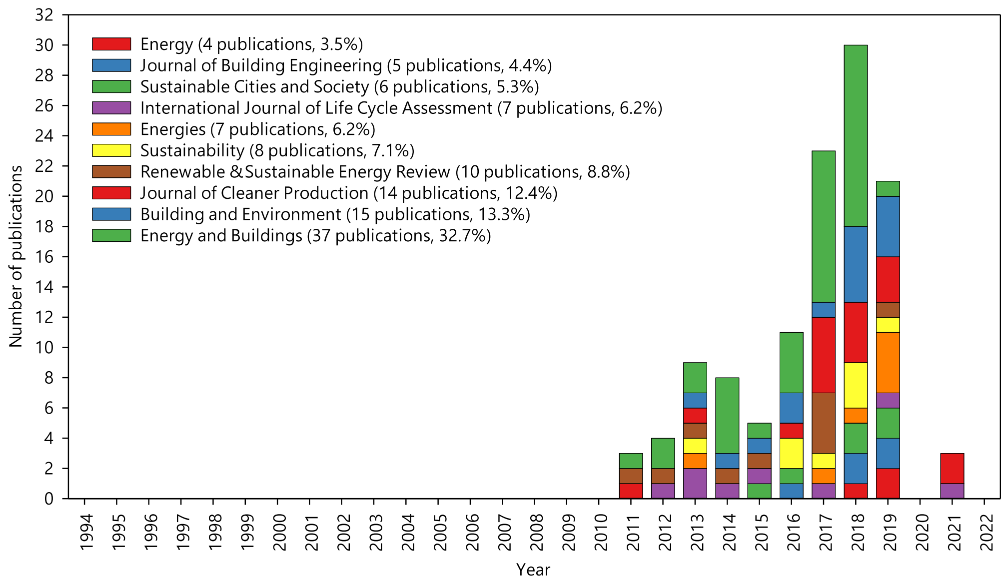

Fig. 12. Distribution of building refurbishment LCA publications within top 10 journals 1994–2022.. (created by Author).

ther explore the current literature's influence on building refurbishment LCAs, Table 3 shows the IF of the top 10 journals. Like building LCA publications, the highest-ranked journal by publication number did not necessarily have the greatest IF and influence the research field and broader society. For example, the highest-ranked journal by publication had the seventh-ranked IF at 4.141, suggesting that most of the top 10 journals had a more significant influence.

Fig. 12 shows the distribution of the refurbishment LCA publications within the top 10 journals over the last 25 years. In a similar trend to the general LCA publications, the number of refurbishments LCA publications found in the top 10 journals increased from zero in 1994 to 3 in 2019, with a peak of 29 in 2017. the top 10 journals.

The reduction in 2019 could be in response to the dramatic increase in 2018, resulting in a shortage of research in this field in 2019 and beyond. While at first, the decrease in 2015 appeared surprising in comparison to the general trend, on further analysis, the publications from the top 10 journals in 2015 accounted for over half of all the journals in which refurbishment LCA publications were published in that year, demonstrating that most publications were from Looking more specifically at the distribution of publications within each journal, While Energy and Buildings were the most common of the top 10 journals, the publication numbers fluctuated throughout the period, suggesting again that the highest-ranked journal by publication number does not necessarily have the greatest influence. In contrast, the 2016–2019 Journal of Cleaner Production and Building and Environment comprised progressively larger portions in the field, demonstrating their increasing effect on building LCA research despite being ranked third and second respectively for a total number of publications.

4.3. Geographical distribution for LCA for building and buildings' refurbishments

A total of 68 countries contributed to the 1,336 building LCA publications retrieved from the Web of Science databases. As can be seen in Fig. 13, China and the USA contributed to the most building LCA publications, with 167 and 153 publications, respectively, over the past 25 years. Italy led the contribution of E.U. member countries with 100 publications in total, followed by Spain (84 publications), England (60 publications), Germany (59 publications), and Sweden (52 publications). However, considering the E.U. collectively, its member countries contributed to the most building LCA publications, with 635 accounting for over half the total publications. These results are due to the EPBD, mandating that by 2020 all new buildings or those receiving significant retrofit must show a very high energy performance. Leading; the E.U. has increased interest in and impacts LCA's use to assess the built environment's environmental impact. Of those countries that contributed to building LCA publications, the fewest contributions were from South America, Africa, the Middle East, and Asia (Fig. 13). The fewer LCAs found are because some geographical areas may be related to the region's poor perception of LCA methodology and may also depend on the existing LCA-related problems.

The publications from each country increased from the beginning to the end of the period from 1994 to 2022.. The USA was

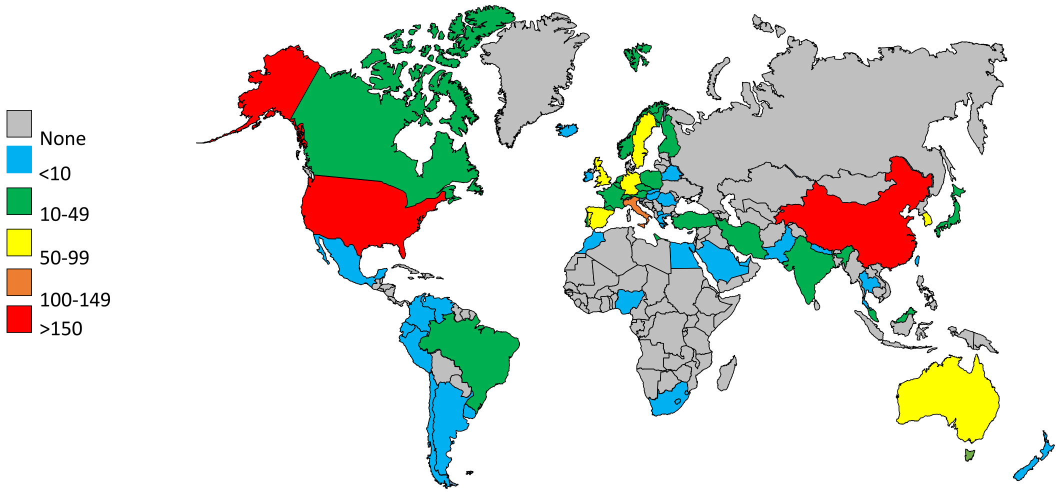

Fig. 13. Geographical distribution of building LCA publications 1994–2019 (created by Author).

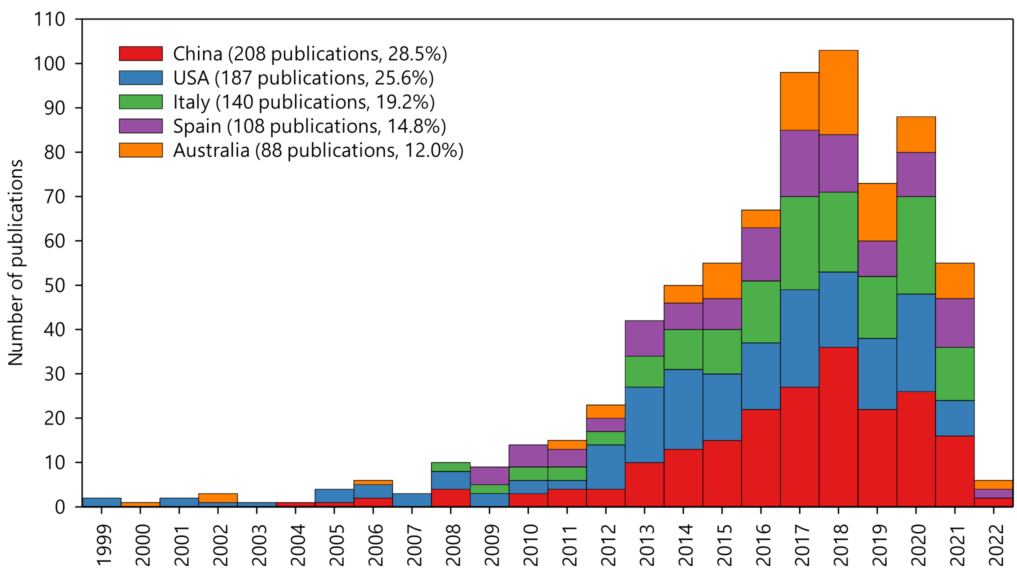

Fig. 14. Top 5 productive countries contributing to building LCA publications 1994–2022. (created by Author).

the most productive for ten out of the twenty years that building LCA publications were produced before China surpassed it, experienced a dramatic increase from 2013 to 2020, and ultimately contributed to the most building LCA publications over the period. Further, 97.08 % of the publications were written in English, followed by 2.04 % in German and 0.68 % in Spanish. French and Japanese were the two remaining languages, each with one publication, accounting for 0.2 % of the 1336 building LCA publications. This indicates that English is the predominant language in the field of building refurbishment LCA research, even in those non-English speaking countries like China, Spain, and Italy. Language restrictions do not change the impact of publications. Fig. 14 shows the number of buildings LCA publications by year for the top five producing countries from 1994 to 2022.

While A total of 39 countries have contributed to the 169 building refurbishment LCA publications. Italy contributed towards the most building refurbishment LCA publications, with 24 publications from 1994 to 2022. The USA and China contributed to 17 publications each, resulting in the top 3 countries contributing to 37.4 % of the total refurbishment of LCA publications. In total, the E.U. member countries contributed to 84.5 % of the 169 building refurbishment LCA publications, demonstrating that not only does the E.U. have an interest in and impact on the use of LCA for assessing the environmental impact of the built environment in general, but that it has a specific interest on the environmental impacts of building refurbishments. Like the general building publications of those countries that contributed to building refurbishment LCA publications, the fewest contributions were from South America, Africa, and the Middle East, demonstrating that the distribution of refurbishment LCA research is limited among these countries (Fig. 15). Fewer LCAs found that some geographical areas may be related to the poor perception of building refurbishment LCA methodology in the region, and it may also depend on the existing LCA-related problems. Also, there were no standards or protocols for building refurbishment LCA.

As shown in Fig. 16, publications from each country increased overall from the beginning to the end of the period. However, despite this general trend, each country's productivity fluctuated. For example, Sweden's contribution decreased between 2013 and 2014 but remained steady until 2017, While Portugal's contribution spiked dramatically in 2017.

Furthermore, the USA witnessed a dramatic decrease from 2014 to 2015 before rising again to 2014 levels in 2019. In contrast to the general building LCA publications, there was no dominant country

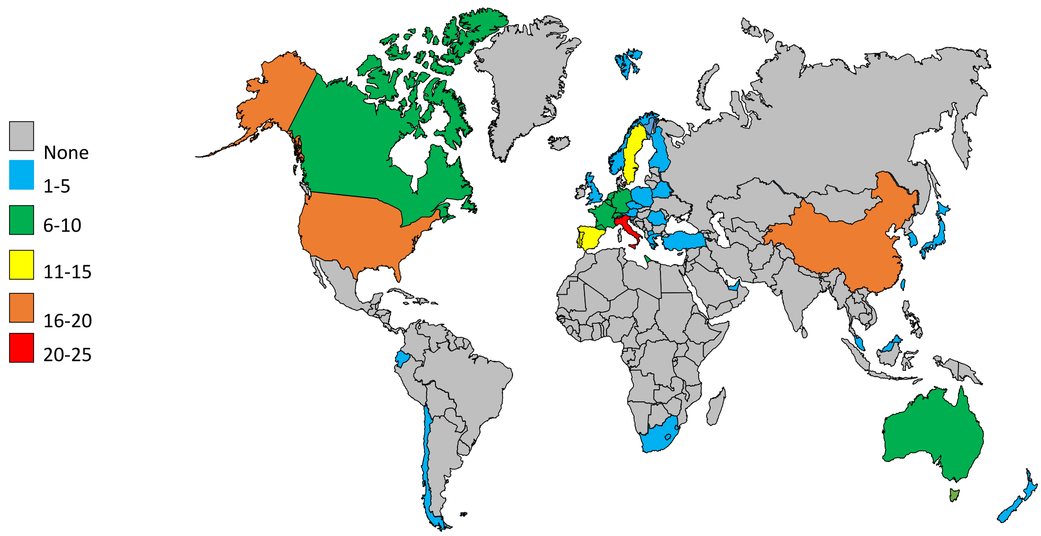

Fig. 15. Geographical distribution of building refurbishment LCA publication 1994–2020. (created by Author).

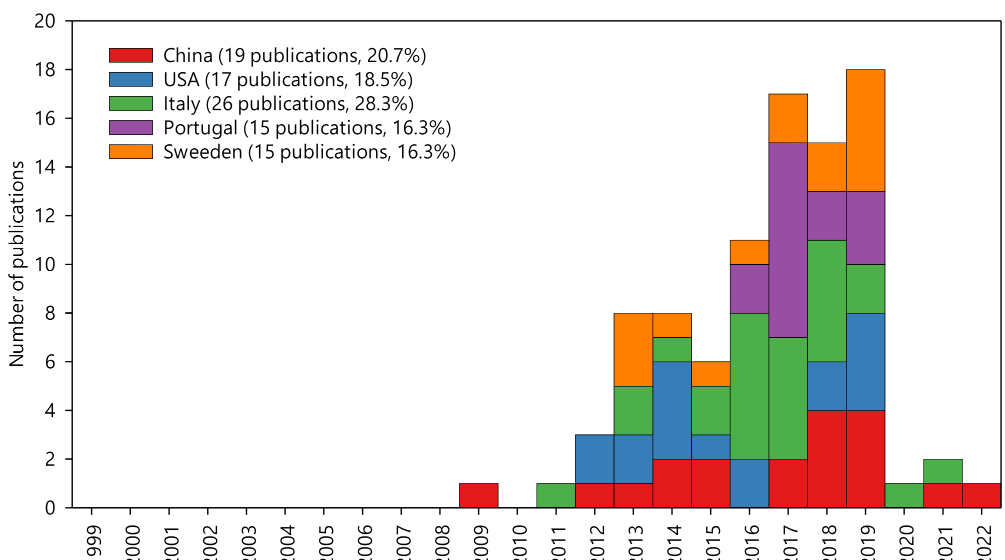

Fig. 16. Top 5 productive countries contributing to building refurbishment LCA publications 1994–2022. (created by Author).

throughout the period, suggesting that existing refurbishment LCA research is relatively well distributed among the top ten productive countries. Additionally, building refurbishment LCA publications were written in only two languages, English (98.7 %) and German (1.3 %). This indicates that English is the predominant language in the field of building refurbishment LCA research, even in those non-English speaking countries like China. Language restrictions do not change the impact of publications.

4.4. Common themes of buildings' refurbishment LCA publications

A content analysis of the 169-building refurbishment LCA publications retrieved from the databases led to two main themes that were then explored further. Fig. 17 shows a thematic diagram of these high-level and mid-level themes.

5.6.1 Research subject.

Three mid-level themes were featured within the high-level theme of the research subject, which emerged from the content analysis of the building refurbishment LCA publications:

- Review of LCA assessments,
- Development of a methodology or framework, and
- Undertaking a building LCA.

Publications that reviewed LCA assessments accounted for the least common research subject, with only 8.4 % of publications discussing this topic. Publications that developed a methodology or framework accounted for 24.5 %. The most common building type within these publications was residential, which supports the finding of residential as the most common building type within refurbishment LCA research Publications that undertook a building LCA accounted for the most common research subject, with 50 % of the total refurbishment LCA publications discussing this topic. This is an encouraging finding as it suggests that LCAs are being undertaken to assess the environmental impacts of refurbished buildings and existing ones being considered for refurbishment. Additional content analysis was conducted to explore this mid-level theme further to decipher more themes within the research subject. The findings in [10] demonstrated the same trend in terms of the build-

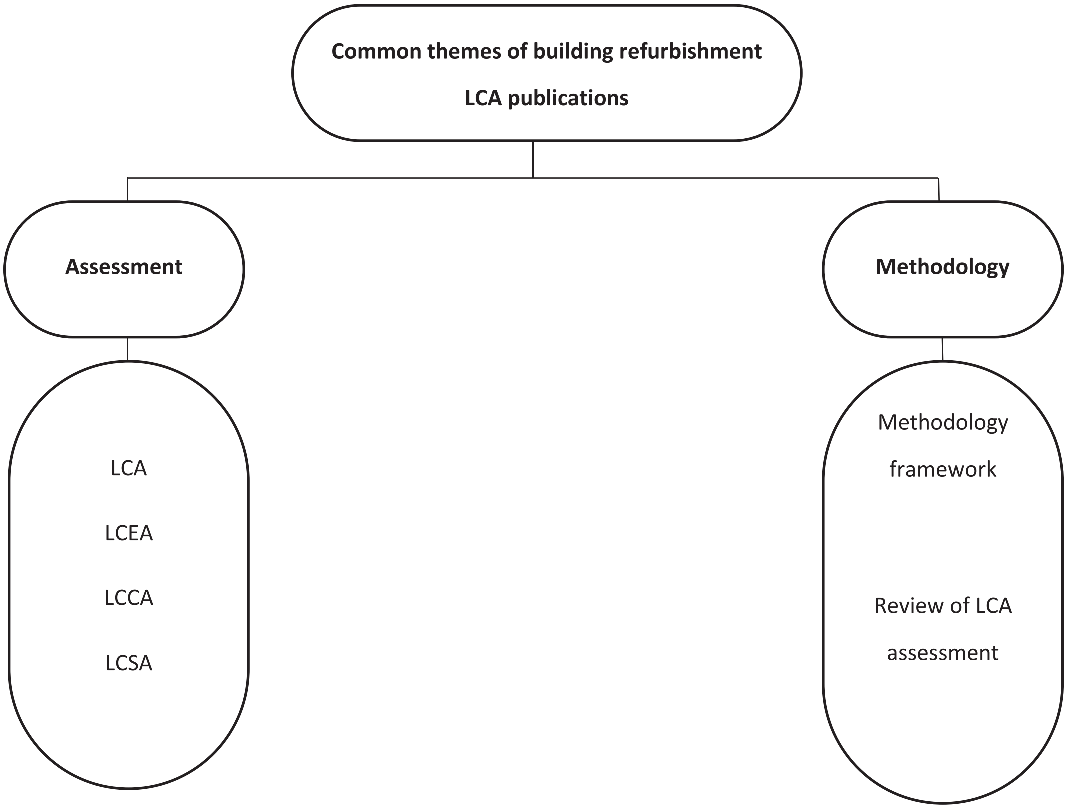

Fig. 17. Thematic diagram of themes within building refurbishment LCA publications 1994–2022. (Created by Author).

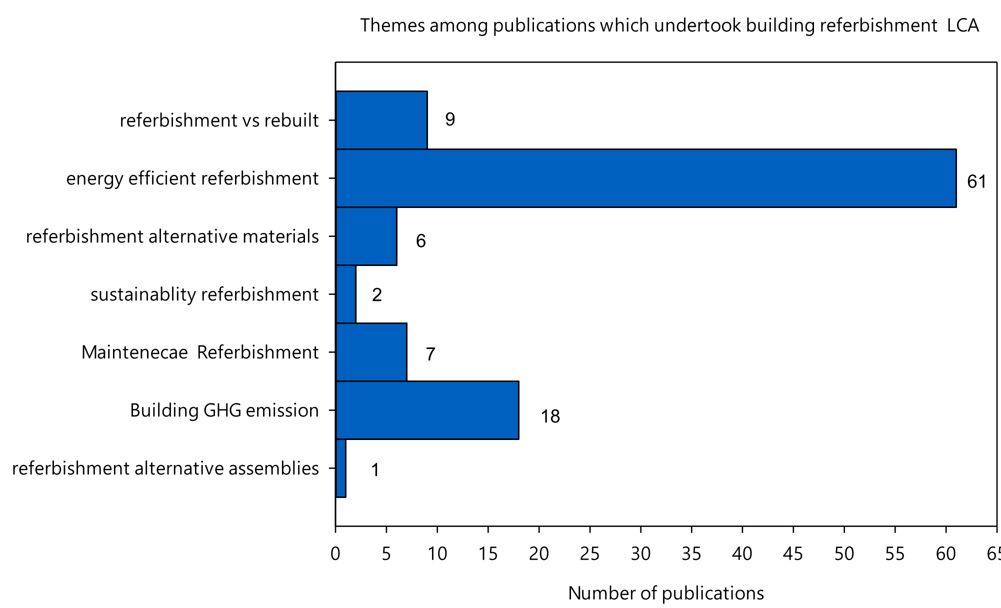

Fig. 18. Themes among publications that undertook building refurbishment LCAs. (Created by Author).

ings typology effect significantly on energy demands and global warming potentials of buildings.

Fig. 18 shows the results of this additional content analysis. LCAs on energy-efficient focused building refurbishments were the most common LCA undertaken within the publications. Within these publications, three types of energy dominated: electrical (accounting for 10.3 %), solar (11.8 %), and thermal energy (77.9 %). Various refurbishment techniques were discussed within these publications to improve the efficiency of the buildings. Those publications focusing on improving the electrical systems to reduce GHG emissions mainly discussed energy-efficient lighting systems, while solar energy-focused publications discussed the opportunities of installing rooftop photovoltaic (P.V.) systems to provide a renewable energy source to the building. Thermal-focused publications discussed improving the efficiency of HVAC systems and facade shading but mainly focused on improving the external envelope of the building, with the majority (81.4 %) of these publications focusing on retrofitting the insulation to the exterior walls. The high number of publications focusing on thermal energy and building envelope is unsurprising as improving building performance by controlling the amount of heat loss or gain from a building has been the subject of broader building research in recent years due in part to heating energies being among the largest contributors to GHG emissions from buildings [9].

Following the theme of energy efficiency focused LCAs, the second most common theme among publications that undertook a building LCA was LCAs on existing buildings to determine their GHG emission impact. As shown in Fig. 18, this was followed by publications that compared the effects of scenarios to refurbishing an existing building or demolishing and rebuilding. LCA publications that investigated alternative building assemblies and materials as part of their refurbishment also featured within the central theme of the research subject.

4.4.1. Specific assessment method

Four mid-level themes emerged from the high-level theme of specific assessment methods:

1. Life Cycle Assessment
2. LCA and Life Cycle Cost Assessment
3. LCA and life cycle cost analysis
4. LCA and social life cycle assessment

Over three-quarters of the 169 buildings' refurbishments, LCA publications, discussed LCA methods only. The majority of these were focused on residential buildings (57 %), followed by commercial (14 %) and institutional (12 %). Of the commercial LCA publications, the majority focused on office buildings. LCA and LCCA methods were discussed in 19 % of the publications. Again, residential buildings were discussed most frequently; however, in this instance, institutional buildings were more frequently considered than commercial buildings, a finding that supports [71], the comment that While "many studies have addressed energy renovation of buildings, they rarely combine economic and environmental life cycle analyses, particularly for office buildings." LCA and LCEA methods were discussed in 3.5 % of the assessment-focused publications, While LCA and LCSA methods were discussed in 1.4 % of the publications. Furthermore, neither of these method combinations was discussed for any commercial building. These findings suggest that the more environmentally focused LCA methods are not used within the existing research on building refurbishment LCA.

5. Contributions

These findings contribute and provide valuable inputs for selecting subtopics in future research endeavors on building LCA. The contribution of this paper can be summarized as follows:

- The paper clearly shows the gap in the literature related to LCA publication in both building and building refurbishment in relation to the geographical distribution with China with 28.5 % for LCA Buildings, 20.7 % for LCA building refurbishments, and the USA with 25.6 % for LCA buildings, and 18.5 % for LCA building refurbishment.
- The research study clearly showed the gap in the literature related to the LCA publication for building refurbishment in comparison to LCA for building with 8.7 %
- Another gap in the literature found in the most common building type on which LCA research has been undertaken are residential buildings with 57 %, with comparatively few studies on commercial buildings.
- The allocation of subject categories suggests that while the environment is considered among the existing literature on building LCA, it is not the most dominant subject. Instead, the literature is dominated by the subjects of construction and engineering

6. Conclusion

The literature review identified several critical environmental issues facing the world today and how the building sector explicitly impacts the environment. A key finding from the literature review was that it could not be disputed that the global climate is changing, and according to the consensus, there is strong evidence to suggest that issues such as global warming are occurring at an unprecedented rate because of human activities. Another key finding was that extensive research had been undertaken on how the building sector impacts the environment. For example, it was found that the sector is responsible for over a third of the global energy and resource consumption, resulting in almost 40 % of global GHG emissions attributable to the industry. Furthermore, it was found that the majority of buildings that will be occupied by 2050 already exist, and these existing buildings will be responsible for a large proportion of future GHG emissions if mitigation strategies are not implemented.

The literature review identified several mitigation initiatives that have been developed specifically for the building sector in an attempt to reduce its impacts upon the environment. Developing from international treaties such as the Kyoto Protocol, government policies have introduced initiatives such as 'Resource Efficiency Opportunities in the Building Sector, which explores opportunities to improve resource efficiency (European Commission, 2014). Furthermore, policies such as 'Construction 2025′ have been introduced to focus on energy consumption and GHG emissions from the built environment. It was also found that alternative strategies and solutions such as refurbishment and reuse as an alternative to demolition and investment in sustainable construction techniques can support the sector's mitigation effort. Moreover, it was apparent from the literature that a critical strategy in supporting this effort was the use of LCA as an analysis tool to evaluate the environmental impacts of new and existing buildings.

The statistical analysis of building LCA and building refurbishment LCA publications retrieved from the Web of Science databases identified several significant findings. Firstly, the overall trend showed an increase in the number of both types of LCA publications over the past 25 years and an increase in citation numbers suggesting that the influence and status of this research have increased overall. The analysis also found that the subject areas differ depending on the type of LCA publication, with general building LCAs focusing on construction and engineering while refurbishment LCAs focused on environmental topics. Although differences were found depending on the precise analysis conducted, according to the IF of each journal, the most influential journal was renewable & sustainable energy reviews for both general building and refurbishment LCA publications. However, the overall distribution of journals within this research field is limited. For example, the top 10 journals accounted for 71 % of LCA publications' total refurbishment, suggesting that the research is not massively far-reaching. Furthermore, the geographical distribution of building LCA publications did show research being undertaken globally. However, the USA, China, and the E.U. were heavily dominated collectively for general and refurbishment LCAs.

The content analysis of the building refurbishment LCA publications retrieved from the databases found three high-level themes: building type, research subject, and assessment method. Of the building types discussed within the refurbishment publications, the majority (57 %) focused on residential buildings in comparison to 12 % discussing commercial buildings. Therefore, it is apparent that there is a need for more LCAs to be conducted on commercial buildings, in particular offices, as it was highlighted in the literature review that offices "have one of the highest levels of energy consumption compared with other building types. Three themes emerged from the theme of the research subject: reviews of LCA assessments; development of a methodology or framework; and undertaking a building LCA, which accounted for 50 % of the publications. A further content analysis focusing on those publications that launched LCA found the most common energy efficiency-focused LCAs. Finally, the assessment method theme analysis found that the publications only focused on LCA methods. Where alternative LCA methods were used, such as LCEA and LCSA, these were not on commercial buildings and were few, suggesting that the more environmentally focused LCA methods were not frequently used within the existing research on building refurbishment LCA. The findings offer a status-quo overview and critiques of research developments in LCA as well as the future research direction on the performance of LCA for commercial building that future studies should investigate.

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CRediT authorship contribution statement

Aseel Hussien: Methodology, Investigation, Writing – review & editing. **Ahmed Abdeen:** Writing – review & editing. **Emad Mushtaha:** Writing – review & editing. **Nusrat Jannat:** Investigation. **Ahmed Al-Shammaa:** Methodology, Writing – review & editing. **Shafayat Bin Ali:** . **Sulaf Assi:** Methodology. **Dhiya Al-Jumeily:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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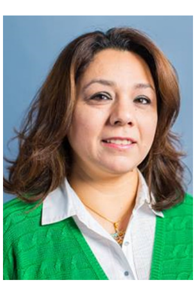

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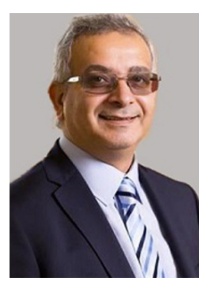

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