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The Impact of Buildings Throughout Their Life Cycle on the Environment: A Systematic Review

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Abstract. Over their life cycle, buildings consume many resources and energy and occupy much land. This, in turn, harms the environment. This study attempts to provide a thorough understanding of buildings' impact on the environment throughout their life cycle. This research utilizes a systematic literature review (SLR) using PRISMA guidelines. Data collection in this research was carried out using the Scopus database and was complemented by searching on Google Scholar and manual searches. The research stages consisted of several stages: review planning, defining selection criteria, data collection, data selection, quality assessment, data extraction, and data synthesis. After going through all stages of the research, 28 articles were obtained for further review. Based on the analysis conducted on the 28 articles, it was found that buildings throughout their life cycle cause various impacts on the environment, which are classified into three categories based on the recipients, namely impacts on ecosystems, impacts on humans, and impacts on natural resources. Global warming and abiotic (non-fossil) resource depletion are the most common impacts found at every stage of the building's life cycle. This research is expected to encourage researchers and practitioners to continue to develop and apply the concept of sustainable buildings to minimize the impact caused by buildings on the environment.

Keywords: Buildings, environment, systematic review

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INTRODUCTION

During their life cycle, buildings consume many resources and energy [1] and occupy much land [2]. The building life cycle generally consists of six stages, namely extraction of raw material, construction material manufacturing, construction process, operation and maintenance, demolition, disposal, and reuse or recycling [3]. One part of the building life cycle, the manufacture of building materials, contributes considerably to the depletion of natural resources, accounting for 50% of the overall resources extracted from the earth [2]. In addition to natural resource depletion, the building and construction sector is responsible for approximately 38% of global energy-related carbon emissions [4]. In the European Union, buildings account for approximately 35% of total greenhouse gas (GHG) emissions [5]. According to an environmental report by the United Nations, the building sector is responsible for more than 40% of global energy consumption, with the most significant percentage occurring in the building operation phase. Furthermore, in the next 20 years, if policies governing new and existing buildings are not changed, greenhouse gas (GHG) emissions from the building sector are expected to double [6]. Ngwepe dan Aigbavboa [2] in their research, they suggested that the main environmental impacts connected with building life cycle stages are natural resource depletion, waste generation, pollution, and global warming.

As the global environmental crisis escalates and climate change warnings increase, sustainability can be a solution to mitigate these negative impacts. To achieve sustainable construction and building, life cycle thinking is critical for understanding and measuring environmental performance at all phases of the building's life cycle. [7]. Government policies regulating ecological impact assessment, as well as the growing demand for environmentally friendly products and services encourage the creation of a tool to assess buildings' environmental performance. Some countries now require environmental studies as part of building permit applications [4].

Various tools have been developed to assess environmental impacts, such as Environmental Impact Assessment (EIA), Environmental Auditing and Material Flow Analysis (MFA), System of Economic and Environmental Accounting (SEEA), and Life Cycle Assessment (LCA) [8]. There are also several methods specifically developed for the construction sector, which serve to assess and rank measurements for green buildings, such as BREEAM and LEED [9]. Various methods of assessing building performance in the environment have been widely used to evaluate the environmental impact of buildings in recent decades. Alhazmi et al. [10] assessed the environmental consequences of building a villa in Saudi Arabia, from cradle to grave. Life cycle assessment (LCA) was used to evaluate potential environmental impacts. The analysis found that the villa's use phase had the highest global warming and acidification potential with values of 2,61 × 106 kg CO2-eq and 1,75 × 104 kg SO2-eq, respectively. Furthermore, Dong et al. [11] used a systematic review approach to compare the impact assessment results of building case studies. This study reviewed 105 building cases reported within the last decade. The entire building's life cycle was analyzed, from production and usage to the end of life of the building. Statistics for three damage categories and seven impact categories were presented. The research discovered that climate change and energy depletion are not usually the most significant impact categories.

Different countries have developed and adopted different methods for assessing environmental impact to optimize building design and reduce energy consumption and emissions [12]. Haapio and Viitaniemi [13] analyzed and categorized various existing methods of assessing building performance in the environment. They found that the multiple techniques developed aim to evaluate different types of buildings and highlight different stages of the building life cycle. Therefore, several building performance assessment methodologies must be reviewed to obtain assessment results for all stages of the building life cycle.

Given the various impacts caused by buildings throughout their lifecycle, with the large number and types of buildings scattered around the world, it is essential to research the impacts of buildings on the environment. This study seeks to provide a thorough understanding of the environmental impacts of buildings throughout their entire life cycle. A systematic literature review is applied to answer this research question. The research question to guide this systematic review is: "What are the impacts of buildings, throughout their life cycle, on the environment?". This research is expected to be a reference for industry, practitioners, and academics in assessing the performance of buildings on the environment and be able to improve building performance, especially in terms of sustainability.

RESEARCH METHOD

Buildings' environmental impact has been studied in several nations using a variety of study methods. Therefore, a systematic literature review (SLR) approach was used to gather and summarize the various existing studies to deliver a thorough understanding of the environmental impact of buildings, which was carried out in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. A systematic literature review seeks to provide a thorough and unbiased synthesis of numerous relevant studies in a single document, employing rigorous and transparent techniques [14]. A systematic literature review consists of several stages. First, it begins with planning the review by defining the scope of the study topic. The PICo framework, which stands for Population, phenomenon of Interest, and Context, is used for qualitative systematic literature reviews [15]. This framework aims to describe in detail the target group of research (population), the aspects under study (phenomenon of interest), and define the research area (context). For this systematic review, the PICo framework used is composed of P (population) = buildings, I (phenomenon of interest) = the impact of buildings, throughout their life cycle, on the environment, Co (context) = all countries that conduct environmental impact assessments on buildings.

Next, the selection criteria are defined. Selection criteria play an essential role in article review, which guides the initial selection of articles. Selection criteria are created to include and exclude articles. Articles will be included if they meet the predetermined criteria. The inclusion criteria in this study include: (1) literature was limited to peer-reviewed journals and conference proceedings, (2) literature was written in English, and (3) literature was published from 2013 to October 2023. After that, data collection began. The search was conducted using keywords related to the research topic. The PICo framework was used to develop the search algorithm [15]. Based on PICo, keywords were identified, and an initial search was conducted to look for studies potentially relevant to the impact of buildings on the environment. The Boolean operator "OR" was used to include synonyms of related keywords, and "AND" was used to combine multiple keywords. The keywords used in this systematic review were: (building* OR "built environment" OR construction*) AND (environment* impact* OR "environment* assessment") AND (challenge* OR factor* OR barrier* OR obstacle*). Data collection was carried out using the Scopus database, as it is an extensive database and provides a collection of peer-reviewed literature and publications [16]. It is complemented by searching on Google Scholar and manually (hand searching) as an additional source of articles. The search results on the Scopus database resulted in 4,294 articles, 27 articles obtained through Google Scholar, and eight articles obtained through manual searches.

The data collected from all sources was imported into EndNote software to aid in the data selection process. Before starting the selection process, duplicates were removed if there were duplicate articles. Next, screening was done based on the title and abstract related to their relevance to the research objectives. The articles that passed the title and abstract screening were next subjected to full-text screening to determine whether they could address the research questions. Finally, to find further publications (by hand), the selected articles' reference lists were reviewed and screened. The number of articles screened at each stage will be entered into the PRISMA diagram, as shown in Figure 1.

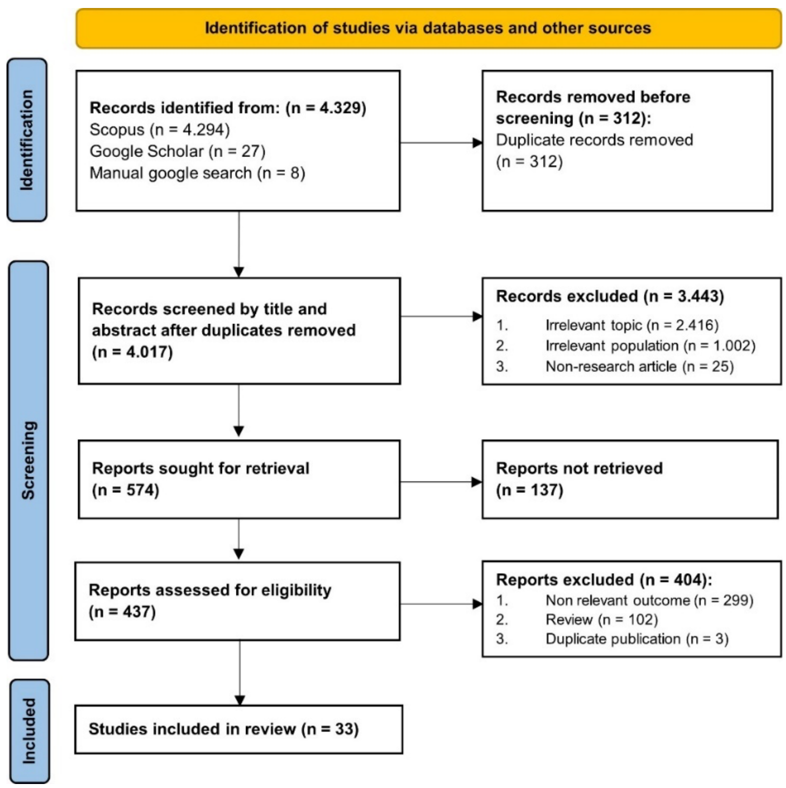

FIGURE 1. Article selection process diagram (PRISMA diagram)

From all articles obtained from Scopus, Google Scholar, and manual search databases, 312 duplicate articles were found and excluded. The remaining 4,017 articles were evaluated based on the title and abstract. 3,443 articles were excluded in this screening stage, leaving 574 articles. A total of 137 articles could not be accessed in full text, so there were only 437 articles to be screened in full text. In the full-text screening, 404 articles were excluded, resulting in 33 articles that passed the data selection.

After the data search, collection, and selection process, the selected articles were evaluated based on quality assessment criteria. Quality appraisal, also known as critical appraisal or risk of bias assessment, aims to analyze the research design, validity of the findings, possible biases, and the overall relevance of the results to other existing studies. In this systematic review, articles that met the selection criteria were assessed using criteria adopted from criteria established by the Critical Appraisal Skills Program (CASP) combined with criteria proposed by Dybå and Dingsøyr [14]. These criteria cover three main issues, namely, the article's validity, credibility, and relevance. These quality assessment criteria consist of 11 questions that aim to assess the literature based on its purpose, methodology, research design, data collection, rigor of data analysis, and statement of findings.

Each article will be assessed based on 11 questions; then each question will be answered with a score between zero (0) and three (3), with a score of zero (0) stating that the answer to the question is not available in the article, a score of one (1) stating that the answer to the question is slightly displayed in the article, a score of two (2) stating that the answer to the question is partially displayed in the article, and a score of three (3) stating that the answer to the

question is displayed in the article. Articles that obtained a score of 20 or more were declared to meet the quality assessment requirements and will proceed to the data extraction stage. Article quality assessment criteria are summarized in Table 1. Based on the quality assessment of 33 articles, 28 articles met the quality assessment requirements.

TABLE 1. Quality assessment criteria [14]

Assessment criteria	
1.	The article is a research paper
2.	There is a clear statement of the research objectives
3.	There is an adequate description of the research context
4.	The research design is appropriate to answer the research objectives
5.	The sample selection strategy is in line with the research objectives
6.	There is a control group that can be used to compare treatments
7.	Data is collected in a manner appropriate to the research problem
8.	Data analysis was done appropriately
9.	The relationship between the researcher and the participant has been adequately considered
10.	There is a clear statement of the findings
11.	Study is helpful for research or practice
Scale	**Description**
0	Not to mention the topic
1	The topic is a slight analysis.
2	The topic was shown partially.
3	The topic is mentioned totally.

Articles that met the quality assessment requirements were extracted to collect relevant information in a structured manner. The data obtained from each article was collected in a data extraction form. The form contained details about the authors, year of publication, research location, objectives, methodology, and conclusions of each article. The main objective was to collate and organize the data required to answer the research questions.

The collected data will then be analyzed, and the research questions will be answered based on the data. Qualitative data analysis, according to Taylor-Powell and Renner [18], consists of three stages: (1) data recognition, namely by reading each article repeatedly to understand the data to be reviewed; (2) code formation and grouping, and (3) identification of themes or patterns, and categorization of data to obtain conclusions. Qualitative data analysis in this systematic review uses NVivo software.

In this systematic review, the initial coding stage was done by creating nodes according to the information found in each article. Highlighting the articles that have been done previously will help simplify this process. After doing the initial coding, which resulted in the formation of several nodes, grouping these nodes was then done. Each category or group will contain one or more nodes. Grouping these nodes begins with creating a new node and giving it a name according to the category that will be made. This node will become the parent node, while the nodes in the category will become child nodes. Finally, based on the set of nodes formed, the patterns and relationships in the data are analyzed.

RESULTS

Overview of the Selected Articles

This systematic literature review reviewed 28 research articles sourced from peer-reviewed journals and conference proceedings published between 2013 - 2023, as shown in Figure 2. These articles show that the distribution of articles related to the impact of buildings on the environment was the highest in 2020, totaling seven articles.

Based on the research location, topics related to the impact of buildings on the environment are most researched in China (23.33%), followed by the UK (10%) in second place. Many other developed countries have also researched the impact of buildings on the environment, such as the United States, Czech Republic, and Iran (6.67%, respectively). Research related to this topic is also starting to be investigated in some developing countries, although it is still small, for example, in Malaysia (6.67%), Ghana (3.33%), and South Africa (3.33%).

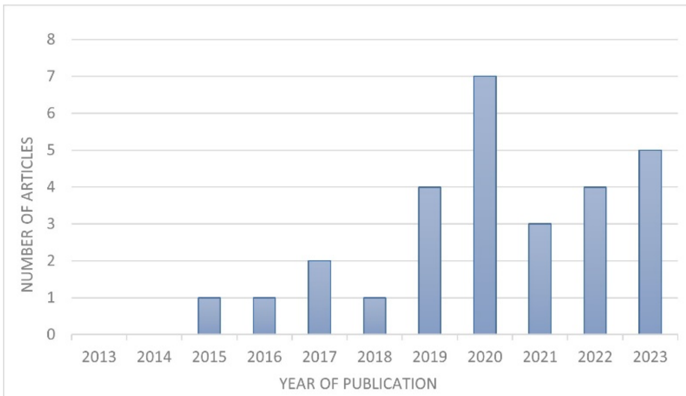

FIGURE 2. Number of articles published annually

Based on the total number of articles selected, eight building types were studied, with residential buildings being the most studied (13.36%), as illustrated in Figure 3.

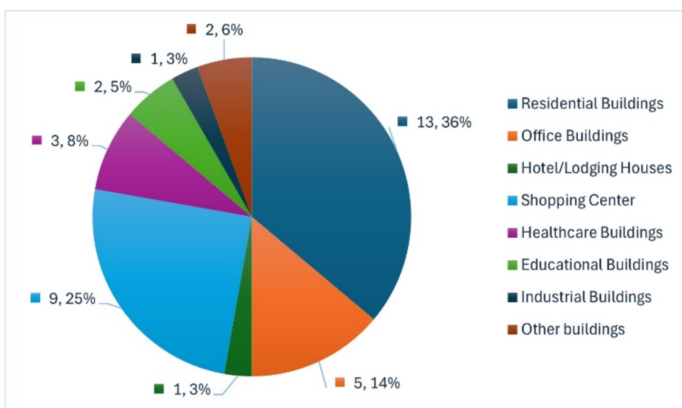

FIGURE 3. Types of buildings

Impact of Buildings on the Environment

Throughout their life cycle, buildings cause various impacts on the surrounding environment, potentially causing harm to both humans and natural resources. According to Mu et al. [19], the main impact categories are broadly classified into three areas based on the affected subjects, namely impacts on ecosystems, humans, and natural resources. In general, environmental impacts can be divided into 15 impact categories [20]. Based on the 28 articles reviewed, 26 nodes were formed, representing the impact of buildings throughout their life cycle on the environment.

These nodes were then grouped into 13 impact categories, including (1) global warming, (2) ecological toxicity, (3) acidification, (4) land use change, (5) waste generation, (6) hazardous chemicals, (7) ozone layer depletion, (8) noise pollution, (9) indoor air pollution, (10) urban air pollution, (11) fossil fuel depletion, (12) abiotic (non-fossil) resource depletion, and (13) biotic resource depletion.

These impacts are spread across each stage of the building life cycle, from the product stage to the end of life, as outlined in Table 2. The product stage begins with the collection of raw materials. The raw materials are transferred/transported to the factory that produces the construction materials, and then the finished products are transported to the construction site. Then, the construction stage includes transporting the essential construction materials from the production plant to the construction site, as well as the installation process until the building is complete. The building use stage consists of the process of utilizing, maintaining, and repairing the building, as well as the utility stage which addresses operational energy and water usage. The end-of-life stage consists of the deconstruction/demolition process, transportation of building waste to disposal facilities, transportation of recyclable materials to recycling facilities, and building waste processing.

TABLE 2. The impact of buildings throughout their life cycle on the environment

Life cycle stages	Impact on the environment	References	Number of articles
Product stage	Global warming	[21]; [22]; [23]; [24]; [25]; [26]; [27]; [28]; [29]; [30]	10
	Acidification	[25]; [28]	2
	Waste generation	[29]	1
	Hazardous chemicals	[21]; [28]; [31]	3
	Ozone layer depletion	[24]; [26]	2
	Fossil fuel depletion	[26]; [29]	2
	Abiotic (non-fossil) resource depletion	[31]; [32]; [24]; [25]; [26]; [27]; [29]	7
Construction stage	Global warming	[33]; [34]; [35]; [36]; [32]; [22]; [23]; [25]; [26]; [27]; [29]; [30]	12
	Acidification	[32]	1
	Land use change	[35]; [36]; [37]; [29]; [38]	5
	Waste generation	[35]; [36]; [38]; [33]; [37]; [27]; [30]	7
	Ecological toxicity	[39]; [35]; [36]; [38]; [37]; [23]; [26]; [27]	8
	Hazardous chemicals	[31]; [35]; [23]; [27]; [28]	5
	Ozone layer depletion	[35]; [36]	2
	Noise pollution	[39]; [35]; [37]; [36]; [38]; [33]	6
	Urban air pollution	[35]; [36]; [38]; [40]; [33]; [41]	6
	Fossil fuel depletion	[35]; [36]; [37]; [26]; [27]; [29]	6
	Abiotic (non-fossil) resource depletion	[33]; [31]; [35]; [36]; [38]; [37]; [26]; [27]; [28]; [29]	10
	Biotic resources depletion	[35]; [38]	2
Use stage (Operational & Maintenance)	Global warming	[33]; [34]; [31]; [40]; [42]; [21]; [22]; [25]; [43]; [29]; [44]	11
	Acidification	[24]; [44]	2
	Waste generation	[33]	1
	Ozone layer depletion	[31]; [40]; [24]; [44]	4
	Noise pollution	[33]; [45]; [46]; [47]; [48]	5
	Indoor air pollution	[31]; [46]; [47]; [48]; [21]; [28]	6
	Urban air pollution	[40]; [42]; [33]	3
	Abiotic (non-fossil) resource depletion	[31]; [33]; [21]; [24]; [25]; [43]; [29]; [44]	8
End-of-life stage	Global warming	[34]; [25]; [28]; [29]; [44]	5
	Ecological toxicity	[28]; [29]	2
	Abiotic (non-fossil) resource depletion	[31]; [21]; [29]	3

Table 2 shows that global warming and abiotic (non-fossil) resource depletion are encountered at every stage of the building's life cycle, with the most reference sources. Global warming refers to the amount of greenhouse gas

(GHG) emissions released during all stages of the building life cycle. The building material production stage, especially the raw material extraction stage, contributes the most to carbon emissions. The transfer of raw materials to the factory where they are produced also generates carbon emissions along the way. Concrete is the building material that makes the most carbon emissions compared to other building materials. GHG emissions during the construction stage are caused by the movement of vehicles and machinery employed in various construction activities, such as material transportation, installation, and so on. At the building use stage, the global warming potential is mainly caused by HVAC systems (heating, air conditioning, and ventilation), lighting, water supply, and building equipment usage. While at the end-of-life stage, GHG emissions are associated with building demolition, including recycling and landfilling, depending on the type of materials used. After the building is dismantled, some materials may be recycled to replace new materials needed for the following building construction. The remaining materials will be landfilled in a waste disposal site, producing carbon emissions.

Meanwhile, abiotic (non-fossil) resource depletion refers to the reduction or use of non-renewable, non-fossil-derived natural raw materials, such as metals (e.g., iron, aluminum, copper), minerals (e.g., sand, limestone), and water. This depletion occurs due to these materials' extraction, processing, and use during the various stages of a

building's life cycle. In the concrete production process at the factory, electricity is used to drive machinery such as electric cars, conveyor belts, and concrete mixers, and water is added in accordance with the concrete's water-cement ratio. Electricity is also required to process reinforcement bars in prefabricated plants, steel cutting, and bending machines. In the steel production process, metal is the primary raw material, and electricity is used as the energy source for the equipment. Various abiotic resources are used during the construction process, such as water in the concrete casting process, electricity for cutting machines, and so on. During the building's operational period, multiple resources, particularly water, are used to support the residents' various activities. The water is then used to clean and reduce dust during the building's destruction at the end of its life. At the same time, electrical energy is used to operate equipment and machinery used in the demolition process.

DISCUSSION

According to the findings of the literature search, papers about the environmental impact of buildings throughout their life cycle were most frequently published in 2020, decreased in 2021, but increased again in the following years, with the majority of study taking place in China. This shows that public awareness, especially among researchers and practitioners in construction and the environment, is increasing and becoming a significant concern.

A query in Nvivo based on all 28 articles reviewed in this systematic review was created to see some of the words that often appear in the collected data. The percentage of each word indicates the intensity of the word's occurrence; the greater the percentage value, the more often the word appears. The most frequently occurring words related to the life cycle impacts of buildings on the environment are shown in Table 3.

TABLE 3. Ten keywords with the highest frequency of occurrence

Word	Count	Percentage (%)
Emissions	438	1,76
Concrete	376	1,51
Energy	351	1,41
Consumption	255	1,02
High	224	0,90
Carbon	211	0,85
Steel	207	0,83
Electricity	177	0,71
Production	168	0,67
Transportation	167	0,67

Based on Table 3, the five (5) most frequently occurring words are emission, concrete, energy, consumption, and high. In addition, some related words, such as transportation, carbon, steel, electricity, and production, also appear frequently. These words are interrelated in that concrete building construction was most studied in the set of articles reviewed in this review. Most studies indicated that concrete contributes the most to emissions throughout its life cycle when compared to other materials. This finding goes along with research conducted by Thiel et al. [49], which stated that concrete contributes 73% of the environmental impact of buildings. In addition, the production and transportation processes are among the stages that generate many carbon emissions and consume resources and energy.

The review of all articles shows that various assessments of building performance on the environment have been conducted on numerous types of buildings in developed and developing countries. Based on these results, it was found that buildings cause many impacts on the environment. The application of the concept of sustainable buildings has been carried out in several developed countries. It can reduce the environmental impact caused, although the difference is still slight. The research results in developed countries are expected to be a reference and encourage developing countries to raise awareness of the importance of environmental issues, especially in the construction industry, and increase the application of sustainable building concepts.

CONCLUSION

Research related to the impact of buildings on the environment has been conducted in many countries using various research approaches. Therefore, a systematic literature review approach was employed to gather and summarize the various existing studies to deliver a thorough understanding of the environmental impact of building existence. After going through all stages of the systematic review, 28 articles were obtained for further review. Through a systematic review of 28 selected articles, the study found that buildings have noteworthy environmental impacts throughout their life cycle, from the construction to the operation, and finally the demolition stage. This systematic review examined different building types in various countries, of which residential buildings made up the largest proportion. Based on the review of all articles, the impact of the existence of buildings on the environment can be categorized into three main groups based on who they affect, namely impacts on the ecosystem, impacts on humans, and impacts on natural resources. Global warming and abiotic (non-fossil) resource depletion occur at all stages of the building life cycle, according to the majority of reference sources. High energy consumption in buildings will increase the potential for global warming. The use of environmentally friendly building materials and the application of construction technology and sustainable building concepts can reduce the environmental impact caused. The results of this study are expected to encourage researchers and practitioners to continue to develop construction technology and environmentally friendly building concepts and apply the concept of sustainable buildings in a broader scope to minimize the impact caused by buildings on the environment.

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