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Urban mining of e-waste management globally: Literature review

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ABSTRACT

The global generation of electronic waste (e-waste) has been increasing alarmingly, posing significant environmental and health risks. Urban mining, which involves extracting valuable resources from e-waste, has emerged as a promising solution to address these challenges and promote sustainable resource management. This study explores urban mining as a transformative practice for e-waste management, examining its alignment with sustainable development goals (SDGs) and identifying the associated challenges and opportunities. It underscores the critical importance of comprehensive regulations in effectively managing e-waste. The study aims to achieve the following specific objectives: 1) Scrutinize the state of the art of e-waste and urban mining practices, as documented in the literature; 2) Assess the relation between urban mining and circular economy; 3) Explore what kind of wastes are more explored in urban mining; 4) Examine the different case studies on urban mining; 5) Analyze data from collected documents and 6) propose a research agenda. The review synthesized 124 studies to gain insights into the effectiveness of urban mining and its potential contribution to sustainability. The findings reveal that urban mining is more frequently emphasized in the e-waste sector than in the construction sector, representing this study's essential contribution. Furthermore, the study highlights the technologies and research areas currently capturing the attention of researchers, as well as the gaps that need to be addressed in future studies. However, challenges remain, including adequate regulations, extended producer responsibility, and the inclusive participation of consumers and informal workers in urban mining. While urban mining holds significant potential to revolutionize e-waste management and contribute to sustainable resource management, realizing this potential will require robust regulatory support.

1. Introduction

The global e-waste monitor underscores the pressing need for sustainable practices, revealing an increasing trend of e-waste (Baldé et al., 2024). The waste category stemming from e-waste is not just expanding but doing so at an alarming rate globally. It is estimated to grow annually at 3–5 % (Xavier et al., 2021a), a trend that demands our immediate attention and action. The urgency of this situation cannot be overstated, and we must act now to address this growing issue.

With a staggering 53.6 million metric tonnes generated in 2019 and projections indicating a potential increase to 74 MMT by 2030, the urgency of addressing e-waste becomes even more apparent. Urban mining, therefore, emerges as a promising strategy to address environmental concerns and recover high-value secondary raw materials from both e-waste and buildings (Xavier et al., 2023; Ali and Shirazi, 2023; Erdiaw-Kwasie et al., 2024).

Urban mining is a dynamic and transformative practice that addresses and advances multiple Sustainable Development Goals (SDGs). Its impact is far-reaching, spanning various socio-economic, environmental, and regulatory dimensions. This multifaceted approach contributes to specific SDGs and aligns with broader global sustainability objectives (Ali and Shirazi, 2023; Ottoni et al., 2020; Shittu et al., 2021).

Urban mining's first significant contribution lies in its role as a catalyst for social change. By directly addressing SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 5 (Gender Equality), and SDG 4 (Quality Education), urban mining creates tangible job opportunities. It generates income, particularly for informal waste pickers in developing countries. The second dimension of urban mining's impact is closely tied to SDG 12 (Responsible Consumption and Production). The third layer of impact extends across multiple SDGs, including SDG 6 (Clean Water and Sanitation), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), SDG 17 (Partnerships for the Goals), SDG 16 (Peace, Justice, and Strong Institutions), SDG 13 (Climate Action), and SDG 7 (Affordable and Clean Energy) (Junior et al., 2023; Pennesi et al., 2023; Raghu et al., 2023; Ali and Shirazi,

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2023). It operates as a linchpin in the global effort toward achieving these interconnected goals.

Urban mining, mainly applied to e-waste, transforms cities into resource-rich "urban mines." This process targets extracting precious metals like gold, silver, copper, and palladium from discarded electronic devices, aiming to mitigate the environmental impact of e-waste. An analysis of urban mining drivers reveals comprehensive socio-economic, environmental, and regulatory distinctions between developing and developed countries (Xavier et al., 2021a; Erdiaw-Kwasie et al., 2024).

Urban mining stands at the intersection of socio-economic development, environmental responsibility, and global cooperation. Its role in sustainable development is undeniable, as it pioneers innovative solutions to pressing challenges and provides a blueprint for a more inclusive, responsible, and circular approach to resource management (Ghisellini & Ulgiati, 2020; Wuyts et al., 2020).

In light of the gaps observed in the existing solid electro-electronic waste management, as highlighted by Xavier et al. (2023), Gaur et al. (2023), Erdiaw-Kwasie et al. (2024), the current study sets out to achieve the following specific objectives: 1) Scrutinize the state of the art of e-waste and urban mining practices, as documented in the literature; 2) Assess the relation between urban mining and circular economy; 3) Explore what kind of wastes are more explored in urban mining; 4) Examine the different case studies on urban mining; 5) Analyze data from collected documents and 6) propose a research agenda.

The contribution of this study is that we have shown through the literature review that research on urban mining is more focused on e-waste than building waste and presented case studies. Thus, it is necessary to consolidate studies that show the real positive economic, social, and environmental impact of urban mining both for the e-waste sector and the buildings sector, see the most viable or the most adequate, efficient, and effective for the recovery of materials that have value in its two sectors.

The subsequent sections of the study are structured as follows: Section 2 introduces the theoretical background, following systematic literature to the method explored, and results and discussion in Section 4, which examines case studies, the relationship between urban mining and circular economy strategies, technologies explored, gaps, and perspectives for future studies on urban mining practices and the sustainability of e-waste management in the supply chain. Lastly, Section 5 encompasses the study's conclusions.

2. Theoretical backgrounds

2.1. Overview: understanding E-waste

Electronic waste, commonly known as e-waste, encompasses discarded electronic devices that have reached the end of their operational lifespan. This category includes various items such as computers, smartphones, televisions, refrigerators, and other household appliances. The surge in e-waste presents a significant environmental challenge, impacting the environment and human health when not managed properly (Lucier & Gareau, 2020).

The efficient management of e-waste faces substantial challenges arising from environmental, technical, economic, and health issues during the treatment and recycling processes. Improper e-waste disposal can have severe consequences, as it contains various chemicals, metals, plastics, and substances that may contaminate soil, water, and air. Furthermore, e-waste holds valuable and scarce resources, underscoring the importance of recycling and reusing these materials instead of discarding them (Xavier et al., 2023).

The surge in the consumption of electrical and electronic equipment (EEE) has resulted in a substantial increase in the generation of waste electrical and electronic equipment (WEEE or e-waste). This accumulation of e-waste contains valuable metals like gold, posing environmental and health risks (Forti et al., 2020). WEEE presents a promising opportunity for urban mining, given the significantly higher concentration of precious metals than primary sources (Xavier et al., 2022). Gold, precious in WEEE, has the potential for positive environmental and social impacts, potentially reducing carbon dioxide emissions (Peiró et al., 2020). Recognizing WEEE as a secondary raw material for valuable metal recovery, especially gold, emphasizes the need for sustainable methods to upcycle e-waste into valuable products, as demonstrated by a study on synthesizing gold nanoparticles from e-waste (Oestreicher et al., 2020; Srivastava et al., 2020).

As highlighted by Lopes dos Santos (2023), the past few decades have witnessed a notable escalation in the global generation of electronic waste, reaching an unprecedented 53.6 million tons in 2019. This surge has sparked extensive discussions and debates regarding the associated risks, challenges, and opportunities in e-waste management (Ottoni et al., 2020). The focal point of his investigation is the examination of the management facets of e-waste, with a specific emphasis on considering it as the primary waste material of interest. E-waste involves disposing of electronic products such as computers, televisions, and other electrical and electronic equipment (Bonoli et al., 2021).

E-waste poses a substantial challenge due to its rapid growth and potential environmental and health hazards. However, with appropriate policies and technologies, WEEE can be transformed into a valuable resource, given its content of innovative materials like high-tech plastics, compounds, and rare earths. Unfortunately, these materials are often inadequately managed at end-of-life, leading to disposal in landfills instead of recycling and reintroduction into the economy (Tesfaye et al., 2017; Forti et al., 2020; Ali and Shirazi, 2023).

Profitable recycling opportunities exist for certain types of e-waste, such as personal computers and mobile phones, but older televisions and stereo systems are generally considered unprofitable for recycling. Recognizing these differences is crucial for prioritizing and optimizing recycling efforts effectively. Current recycling processes encounter challenges, including improper disassembly or recovery of electronic parts, like printed circuit boards and hard drives, resulting in premature exit from the recycling process or entry into inappropriate methods. Moreover, waste from manufacturing activities, such as defective products, is not sustainably reused, causing a significant loss of critical materials (Xavier et al., 2022; Kumar et al., 2023; Bründl et al., 2024).

Three primary considerations underscore the urgency of addressing e-waste: the alarming growth in e-waste generation, potential health impacts due to improper handling, and the valuable resources embedded within e-waste. With an estimated global discard of over 50 million metric tons annually, projected to reach 120 million metric tons by 2050, comprehensive regulations and policies are essential (Lucier & Gareau, 2020). Addressing health risks and promoting resource recovery through recycling is imperative for environmental well-being and fostering a circular economy (Zeng et al., 2018; Trivedi et al., 2022; Xavier et al., 2023).

Implementing comprehensive regulations and policies is crucial to effectively managing the escalating challenge of e-waste. Extended producer responsibility laws, requiring manufacturers to handle recycling and disposal of their products responsibly, are critical to these regulations (Ismail & Hanafiah, 2020). Collaborative efforts between government entities, private sector stakeholders, and civil society groups are necessary to create awareness, establish collection infrastructure, and implement effective recycling and disposal systems (Guarnieri et al., 2022).

Improper e-waste management can lead to significant health risks and environmental hazards. Exposure to toxic substances, such as lead, mercury, and cadmium, can result in respiratory problems, hormonal imbalances, neurological disorders, and even cancer. Additionally, e-waste disposal can lead to water pollution, soil contamination, and air pollution, contributing to various environmental issues (Kumar et al., 2023).

Recognizing e-waste as a secondary raw material for valuable metal recovery, especially gold, presents urban mining opportunities. When responsibly extracted, the concentration of precious metals in e-waste can contribute to positive environmental and social impacts, potentially mitigating carbon dioxide emissions (Oestreicher et al., 2020).

The exponential production of electronic equipment, driven by rapid urbanization and technological advancements, has made e-waste the fastest-growing waste stream globally. Effective management requires understanding the differences in e-waste generation patterns, including volume, per capita rates, and diversity of e-waste fluxes (Konings et al., 1987).

E-waste management encounters challenges across regulatory, infrastructure, consumer behavior, informal sector integration, community culture, technology, and economic dimensions. Issues include difficulty implementing Extended Producer Responsibility (EPR), insufficient infrastructure like collection centers and transportation, and poor consumer habits such as low environmental awareness and reluctance to recycle. The informal sector faces social challenges and needs integration with formal sectors. Community cultural issues further complicate matters. Technological challenges involve a lack of skilled labor and outdated procedures, while economic obstacles include insufficient funds for technology upgrades and substantial initial capital investment for formal recycling plants. These multifaceted challenges highlight the need for comprehensive strategies in E-waste management (Ali and Shirazi, 2023; Xavier et al., 2023; Gaur et al., 2023).

Addressing the challenges of e-waste necessitates a multifaceted approach. Strategies include promoting recycling and responsible disposal practices, incorporating sustainable design principles in manufacturing, and raising awareness about the environmental and health impacts of e-waste. Extended Producer Responsibility schemes are vital in effective e-waste management (Deng, 2019).

Anthropogenic resources, comprising human-made material stocks and flows, are crucial in advancing sustainable resource management practices. These resources offer substitutes for virgin raw materials, contribute to reducing environmental impact, and facilitate improved communication within the value chain. This systematic approach supports the transition towards a circular economy (Xavier et al., 2023).

The practical understanding and management of e-waste require a comprehensive and collaborative approach involving regulatory frameworks, responsible disposal practices, and the recognition of e-waste as a valuable resource for recovery and reuse. Hence, a conceptual framework is needed to fill these gaps, a framework acknowledging both urban mining practices and the challenges faced during e-waste management.

2.2. Synergies between urban mining and circular economy

The circular economy concept has emerged as a prominent solution in our contemporary world, characterized by dwindling resources and escalating environmental concerns. This innovative approach, distinguished by closed-loop supply chain management, aims to extract valuable materials from discarded products and reintegrate them into the production cycle, promoting efficiency, waste reduction, and sustainable practices (Ottoni et al., 2020; Schroeder et al., 2018; Xavier and Ottoni, 2019).

Urban mining, intricately linked with the circular economy, concentrates on extracting valuable materials from waste streams, particularly emphasizing urban areas. Recognizing the latent value in discarded urban materials, urban mining contributes to circularity in the supply chain. It aligns with principles promoting resource efficiency and waste reduction (Xavier et al., 2021b).

Urban mining assumes a pivotal role by addressing the demand for raw materials, traditionally met through finite resource extraction, which leads to environmental degradation. Adopting urban mining techniques taps into existing resources within cities, lessening the reliance on additional extraction and preventing valuable resources from ending up in landfills. Beyond waste reduction, urban mining creates economic opportunities, fosters job creation, and supports emerging industries focused on recycling and sustainable manufacturing (Burneo et al., 2020; Mollaei et al., 2021; Ottoni et al., 2020; Xavier et al., 2023).

Urban mining aligns with sustainability principles by reducing dependence on primary raw materials and championing material reuse and recycling. Implementing circular economy practices, including urban mining, promises positive impacts such as reduced demand for raw materials, job creation, and enhanced resource efficiency (Ottoni et al., 2020; Sun et al., 2016).

Ensuring the success of circular economy practices, including urban mining, requires technological advancements for efficient material recovery and reprocessing from waste streams. Collaboration between academia and industries is crucial in developing best practices and innovative technologies, driving the circular economy forward (Jk et al., 2017; Silvestri et al., 2021; Xavier et al., 2023).

Urban mining and circular economy principles are pivotal in recovering secondary raw materials, primarily from permanent magnets. Techniques like upcycling transform traditional mining waste into new, higher-value products, contributing to resource conservation and sustainability (Xavier et al., 2021a).

Implementing circular economy practices yields multifaceted positive impacts, including reduced environmental impact, job creation, economic growth, and enhanced resource efficiency. These practices, exemplified by urban mining, create a more sustainable and resource-efficient system (Hao et al., 2020).

While urban mining operates on a small scale without centralized entities, there is a growing recognition of its importance in contributing to the circular economy. Along with circular economy principles, urban mining aims to foster a more sustainable and resource-efficient society (Ghisellini anf Ulgiati, 2020; Aldebei and Dombi, 2021).

Highlighting the recovery of secondary raw materials from permanent magnets, urban mining extracts valuable elements from end-of-life products, reducing the demand for primary resources and promoting resource conservation (Cisternas et al., 2021).

Urban mining plays a crucial role in waste reduction by diverting materials from landfills, reintroducing them into the economy, and reducing the need for new raw material extraction. This practice significantly extends the lifespan of resources and minimizes the environmental impact of traditional waste disposal, making it a practical and beneficial strategy (Sun et al., 2016).

Implementing circular economy and urban mining practices contributes to job creation in various sectors, such as waste management and recycling, and supports economic growth. Furthermore, these practices lead to significant cost savings for cities by reducing waste disposal expenses, underscoring their economic value (Guzmán and Xavier, n.d.).

Furthermore, circular economy and urban mining practices contribute to climate change mitigation by reducing greenhouse gas emissions associated with traditional waste disposal methods. By reusing and reprocessing materials, energy-intensive processes for new resource extraction are curtailed (Manninen et al., 2018).

Due to increasing population and urbanization rates, integrating circular economy principles in urban areas is crucial. Urban mining, within this framework, transforms cities into hubs of resource recovery, material reuse, and recycling, ushering in a more sustainable and inclusive urban landscape (Konings et al., 1987).

Recent studies underscore the interplay between circular economy and urban mining across various contexts, such as rare earth elements, building stocks, and e-plastic recycling. The holistic approach emphasizes the alignment of urban mining with circular economy principles for sustainable resource management (Tsui et al., 2023; Dushyantha et al., 2023; Honic et al., 2023; Agrawal et al., 2023; Qi et al., 2022).

Finally, the symbiotic relationship between urban mining and the circular economy represents a holistic and sustainable framework. This synergy reduces reliance on primary raw materials, creates jobs, minimizes environmental impact, and fosters resource recovery and processing innovation. As global concerns regarding resource scarcity and ecological sustainability intensify, the collaboration between urban mining and the circular economy emerges as a promising solution for sustainable resource management.

3. Material and methods

This study is positioned within the domain of descriptive and qualitative research, focusing on qualitative descriptive studies, which are particularly adept at illuminating poorly understood phenomena (Kim et al., 2017). The choice to employ a Systematic Literature Review is justified, given its ability to meticulously analyze articles within the targeted study area (Cronin et al., 2008).

The methodology provided by Cronin et al. (2008) is a step-by-step guide to assist students and novice researchers in conducting a traditional or narrative literature review. It provides a structured approach to selecting a topic, searching, analyzing, synthesizing literature, and ultimately writing the review. The purpose is to provide a comprehensive and informed overview of a topic different from Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) analysis, presenting a more rigorous framework specifically designed for systematic reviews and meta-analyses (Morris et al., 2021). Nevertheless, in this study, we concentrate more on the systematic review of the literature. In addition, Cronin et al. (2008) offer a practical guide for conducting narrative literature reviews and categorizing and critically assessing the literature.

We systematically scrutinized, categorized, and interpreted the identified articles using the content analysis technique proposed by Bardin (2016). This method involves systematically examining essential elements in each study, facilitating the extraction of common themes, and transforming individual findings into new, nuanced interpretations (Polit and Beck, 2006).

A selection protocol for articles is established to delineate the research scope gap. The methodological procedure outlined by Cronin et al. (2008) consists of five steps: research question formulation, the definition of inclusion and exclusion criteria, database search, initial screening, and detailed analysis and synthesis. This systematic approach ensures a thorough examination of the selected documents (see Table 1).

Table 1 summarizes the systematic review steps as a valuable reference point throughout the research process. Adhering to Bardin's (2016) framework, our analysis follows a structured approach, encompassing three pivotal categories: i) pre-analysis, ii) document exploration, and iii) processing of results, inference, and interpretation. This comprehensive approach ensures a thorough examination of the selected documents.

4. Results and discussion

The findings are categorized into three main themes: literature addressing urban mining in the context of waste, identifying gaps and exploring future research perspectives, and implications for new studies. The analysis is enhanced by a line graph illustrating the number of documents per year, a line graph comparing document counts by source, a horizontal bar chart comparing document counts by author, a horizontal bar chart displaying document counts by affiliation, and a horizontal bar chart presenting document counts by country.

This study provides valuable insights into the "urban mining" domain and highlights critical waste materials, research gaps, and future research directions. The systematic review methodology and comprehensive analysis contribute to a deeper understanding of this field and serve as a foundation for further research and exploration.

Fig. 1 shows "Documents per year" over a specific period from 2013 to 2023. The line on the chart increases from 2013, indicating a growth in the number of documents over the years, reaching a peak in 2021. However, there is a slight decline in 2023 compared to the previous rise. This type of graph is a helpful tool for visualizing trends over time. The upward trend suggests growth, while a downward trend represents a decline. The peak in 2021 may indicate an increase in interest or production in the area or category these documents describe. The decline in 2023 can be interpreted as a decrease in this interest or a reduction in activity. However, it is essential also to consider other contextual factors that may not be represented in this graph alone, such as changes in policies, funding, or global events.

Fig. 2 provides the number of documents produced from 2013 to 2023 in different categories or journal titles. These categories are indicated by distinct colors and lines, aiding in the differentiation of corresponding data. We have the document count on the vertical from 0 to 10. On the horizontal, we have the years spanning from 2013 to 2023. The categories include "Sustainability Science," "Journal of Cleaner Production," "Resources Conservation and Recycling," "Waste Management," and "Journal of Environmental Management." It shows different trends for each category over time. For instance, the "Journal of Cleaner Production" category peaked significantly in 2020, indicating a sharp increase in document production that year, followed by a declining trend. It is important to note that the graph does not indicate the exact meaning of these trends or the reasons behind them; it merely presents the document count. To better understand the context and relevance of these variations, it would be necessary to investigate events, policies, or academic changes that may have influenced the production of these documents.

Fig. 3 presents the quantity of documents written by up to 15 authors. On the horizontal, the document count ranges from 0 to approximately 5.5. On the vertical, the authors' names are arranged alphabetically by surname, from "Zeng, X." at the top to "Giese, E.C." at the bottom. By observing Fig. 3, one can quickly deduce which authors have the highest number of publications, with the longest bar indicating the author with the most documents. Zeng, X. is a Chinese author who

Table 1
Systematic Literature Review Steps.

Steps	Description
1. Research Question Formulation	What are the recent trends and advances in the literature on Urban mining?
2. Definition of Inclusion and Exclusion Criteria	Inclusion: Relevant documents on " Urban mining " AND "Circular Economy" <In English>. Exclusion: Documents that do not meet the scope. Next, the publication period was established, covering articles published from 2013 until December 31, 2023.
3. Database Search (Scopus)	Terms: "Urban mining" AND "Circular economy" <In English> Result: 176 documents. The selection of articles for this study involved searching the Scopus database, a globally renowned and extensively utilized platform (Harzing & Alakangas, 2016). Scopus, which indexes approximately 70 % more sources than the Web of Science (Brzezinski, 2015), was chosen for its comprehensiveness. Only AND was employed regarding Boolean operators, with NOT and OR excluded from the search criteria.
4. Initial Screening	Excluded: 0 outside the scope, 42 documents (book chapter, conference paper, conference review, Book, Note, Editorial), and documents in other languages like German (2), Chinese (2), Romanian (1), Portuguese (1), Moldovan (1), Moldavian (1), Italian (1), and French (1).
5. Detailed Analysis; Categorization and Synthesis; Quality Assessment; Report Writing; Discussion and Conclusions	Remaining Documents: 124 articles. Themes: Grouping by relevant themes. Synthesis: Main findings and trends. Assessment of the methodological quality of articles. Clear structure with Introduction, Methods, Results, Discussion, and Conclusions. Implications of the results, recommendations for future research.

Source: the research.

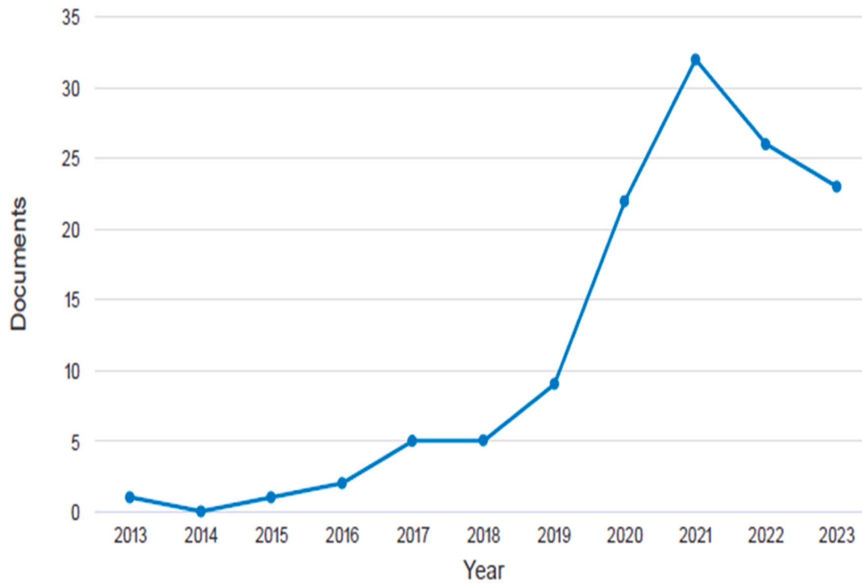

Fig. 1. Documents by year. Compare the document counts for up to 15 authors. Source: Scopus (2023).

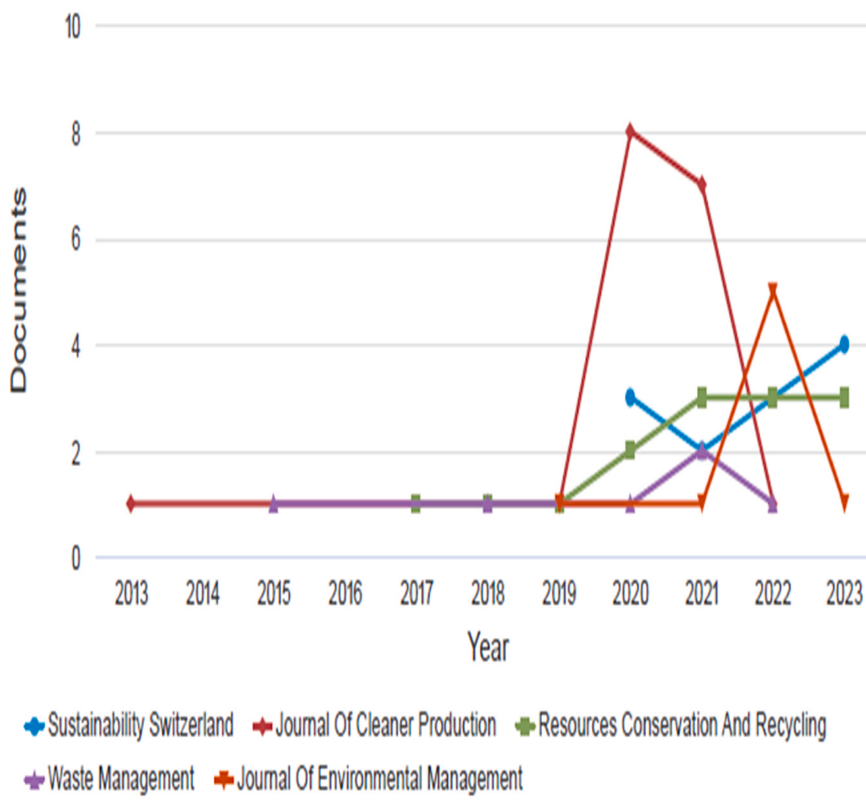

Fig. 2. Documents per year by source. Compare the document counts for up to 15 authors. Source: Scopus (2023).

has published a total of 5 articles, followed by other authors who have contributed four articles each, including Honic, M. (Switzerland), Kovacic, I. (Austria), Ottoni (Brazil), Sprecher, B. (Netherlands), Taskinen, P. (Finland), Williams, I.D. (Hong Kong), and Xavier, L.H. (Brazil). This chart type is commonly used in bibliometric analyses to compare researchers' academic performance or prolificacy.

Fig. 4 presents the documents associated with various universities or institutions. The horizontal axis, labeled as "Documents," represents the count or number of documents, while the bars represent different universities, each identified by name on the vertical axis to the left. The bars extend horizontally in varying lengths, indicating the quantity of documents corresponding to each institution. Each bar displays a number representing the documents affiliated with that institution. For instance, institutions such as "Universität Leipzig," "*Centro de Tecnologia Mineral de Rio de Janeiro*," and "Technische Universität Wien," among others, show numbers ranging from 3 to 6 on the horizontal bar. "Universität Leipzig" and "*Centro de Tecnologia Mineral de Rio de Janeiro*" are associated with six documents, followed by "Technische Universität Wien" and "Tsinghua University," which are linked to 5 papers. On the other hand, institutions like "*Universidade Federal do Rio de Janeiro*," "University of

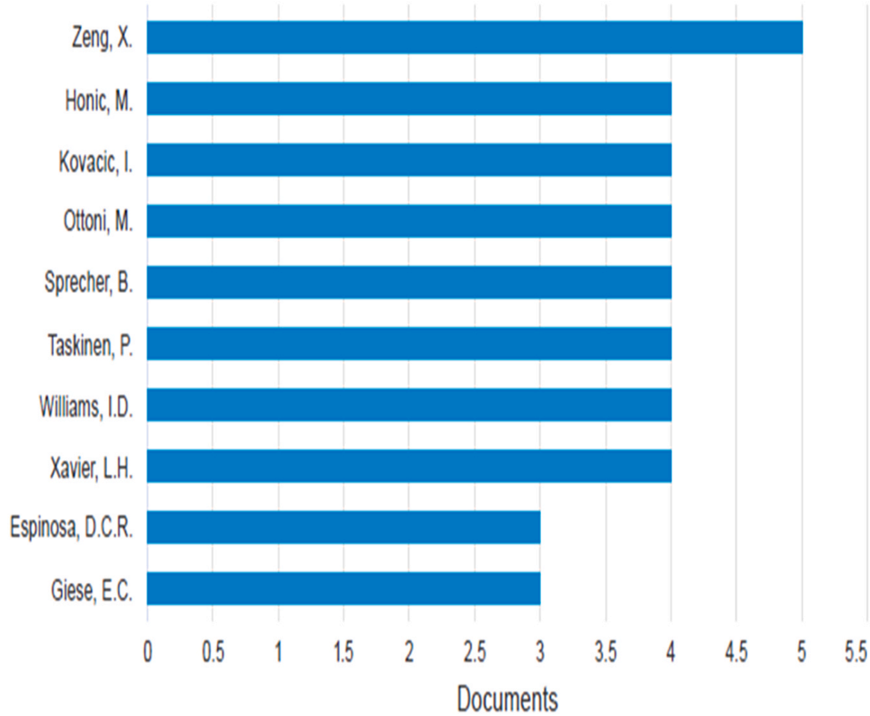

Fig. 3. Documents by author. Compare the document counts for up to 15 authors. Souce: Scopus (2023).

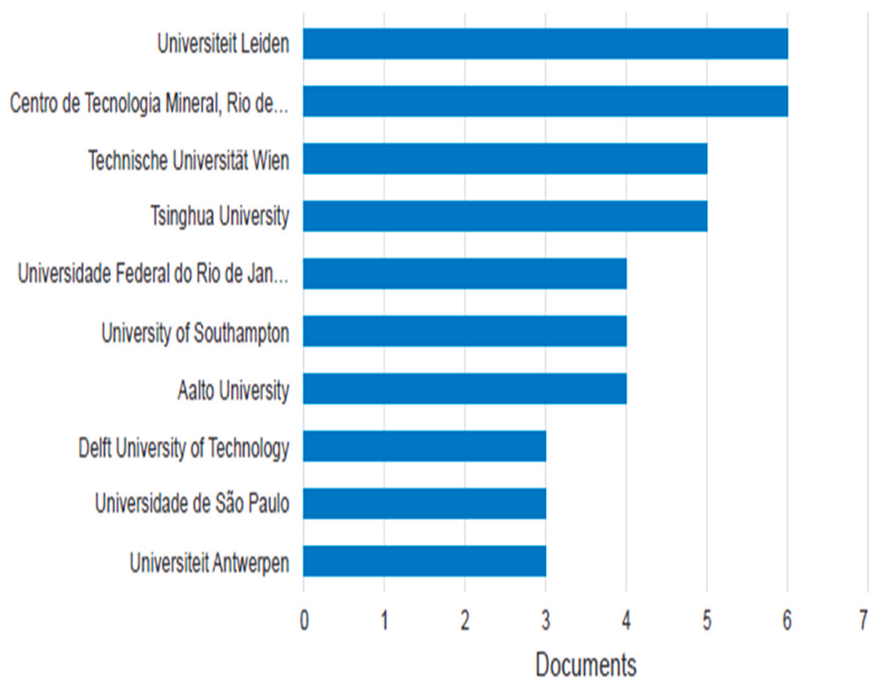

Fig. 4. Documents by affiliation. Compare the document counts for up to 15 affiliations. Source: Scopus (2023).

Southampton," and "Aalto University" are associated with four documents. This list can help refine searches and assist users in finding publications or academic materials specific to a particular institution.

Fig. 5 presents data on "Documents" for different countries. Each bar represents a distinct nation, with the length of the bar proportional to the quantity of documents associated with that country. The longest bar at the top represents China, indicating that it has the highest number of documents among the listed countries. In contrast, the shortest bar at the bottom represents the United States, indicating it has the lowest number of documents among these specific nations. This suggests that China has published the most on the topic over this period, possibly due to its current ability to execute high-quality projects in exceptional construction circumstances and being the first country to possess Rare Earth Elements (REEs). Bar charts are highly versatile and widely used in reports, presentations, and data analysis across various fields, such as business, science, and education.

Fig. 6 is a pie chart that provides a clear and understandable visualization of the distribution of documents by subject area. Each slice of

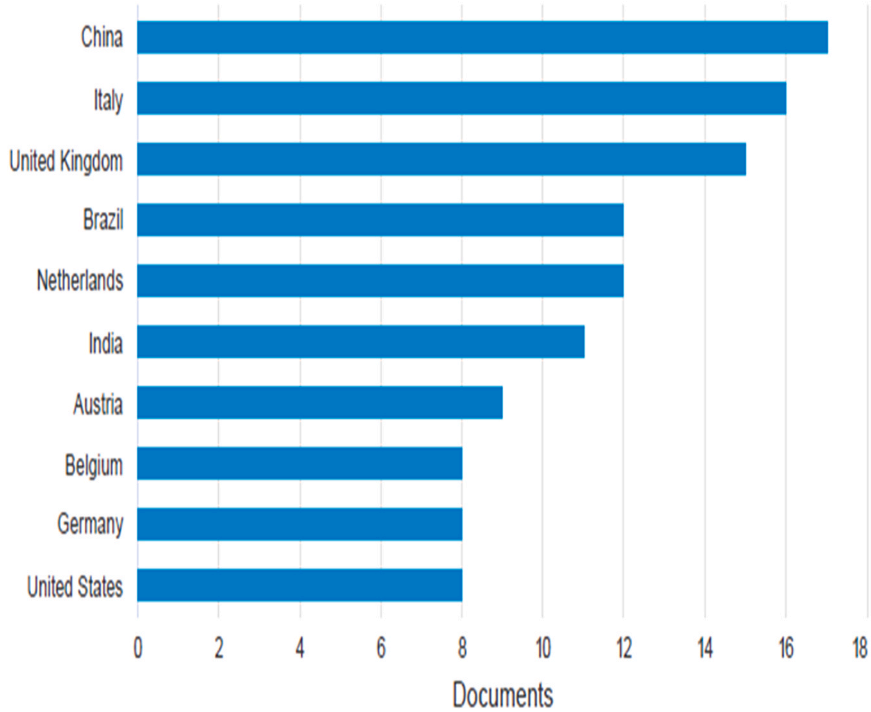

Fig. 5. Documents by country or territory. Compare the record counts for up to 15 countries/territories. Source: Scopus (2023).

the pie represents a specific academic discipline, with the size of the slice proportional to the percentage of documents assigned to that area. For instance, larger slices indicate a more significant quantity of documents associated with them compared to smaller slices. Some featured areas include 'Environmental Science,' which appears to be the largest at 31.1 %, followed by 'Engineering' at 14.6 %, and 'Energy' at 13.0 %. This informs us that these areas have a considerable representation in the total set of documents referenced by the chart. Other areas comprise 'Materials Science,' 'Business, Management,' 'Social Sciences,' and 'Chemistry,' among others. The 'Other' category, represented at 5.7 %, encompasses various fields of study not listed individually or constituting a minor part of the whole. This type of visualization is valuable for quickly understanding how contributions to a specific collection of documents are distributed among different fields of study.

Fig. 7 is a horizontal bar chart that efficiently displays the number of documents per funding sponsor. Each funding sponsor is represented by a horizontal bar, indicating the number of documents associated with it. The bars are organized from top to bottom, with the sponsor having the highest number of related documents at the top and the lowest at the bottom. For instance, the category *'Conselho Nacional de Desenvolvimento Científico e Tecnológico,'* which appears to be the highest on the vertical axis, is linked to 8 documents, as evidenced by the length of the corresponding bar on the chart. This sponsor is from Brazil. Below, we observe the 'Horizon 2020 Framework Programme' and 'European Commission,' each with seven documents. 'European Commission' and 'National Natural Science Foundation of China' with six documents, 'China Scholarship Council' and *'Coordenação de Aperfeiçoamento de Pessoal de Nível Superior'* with four documents also from Brazil. This

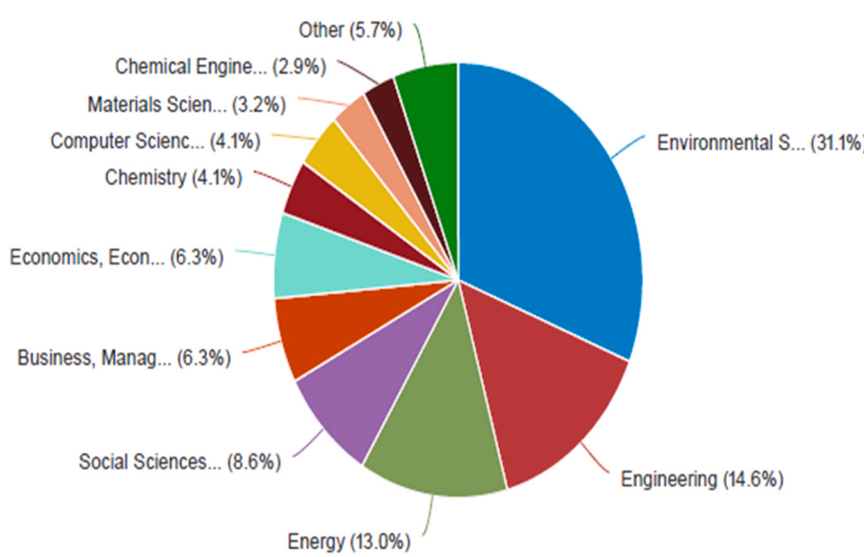

Fig. 6. Documents by subject areas. Source: Scopus (2023).

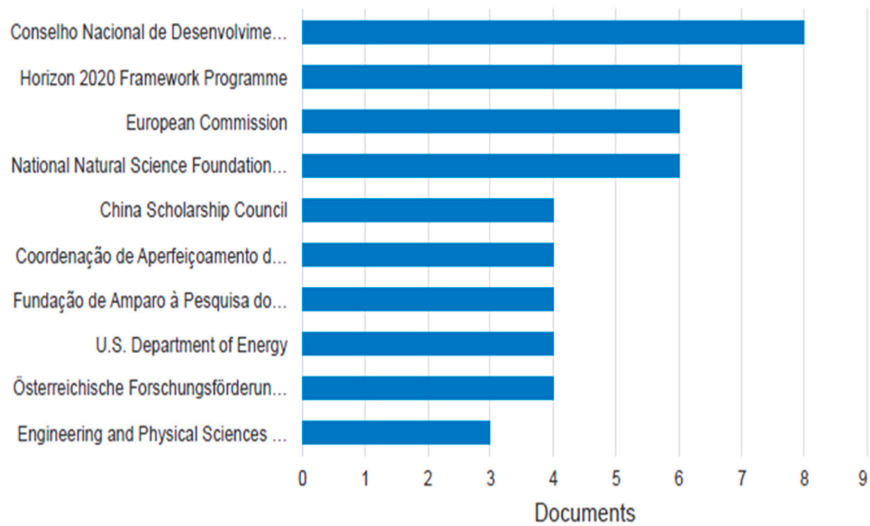

Fig. 7. Documents by funding sponsor. Compare the document counts for up to 15 funding sponsors. Source: Scopus (2023).

suggests that researchers from countries such as Brazil, the European Union, and China receive more funding from funding agencies to support research in circular economy and urban mining. Bar charts are valuable tools for quick comparisons between categories; in this case, they enable a swift comparison to identify which sponsor funded more works based on the number of documents produced.

Through the analysis of documents (see Table 2), we have examined 43 case studies on "urban mining" of various residues in different countries. Among these, we identified 7 case studies in China, 7 in the Netherlands, 4 in Italy, 3 in Germany, 3 in the United Kingdom (UK), and one per country for the others. These case studies explored various types of residues based on the specific needs of each country.

Notably, China stands out among other developing countries in transforming residues into added value, especially concerning electronic waste, followed by urban and construction debris. In Europe, the Netherlands stands out with 7 case studies, primarily focused on construction and demolition waste, with only one study exclusively concentrating on electronic residues compared to other types of garbage. Italy focuses more on different types of urban waste, such as food and municipal solid waste, than electronic waste. As for Germany, it presents 3 case studies focused on construction residues.

Overall, we observed that most case studies conducted in other countries emphasized electronic residues more. However, it is essential to note that the focus of these case studies varies based on the reality of waste management specific to each country.

The analyzed documents encompass various types of waste (see Fig. 8), including Nickel-contained waste, Lithium-ion batteries (LIBs), Municipal Solid Waste (MSW), Industrial Waste (IW), E-waste, Construction and Demolition Waste (C&DW) comprising gypsum, concrete, wood, metals, glass, plastics, windows, doors, tiles, light fixtures, toilet and kitchen fittings, and other building materials. Additionally, the documents cover Waste materials such as iron and steel, waste non-ferrous metals, waste rare metals, waste plastic, waste rubber, glass, rubber tires, and timber stock. Metals like silver, gold, copper, lead, and tin are also considered. Furthermore, the documents address eggshells, apple scraps (cores and peels), Barbera wine grapes, Bergamot juice, Bran waste, Citrus waste, Grapes pomace, Coffee waste, and Food waste (including surplus salt, liquid, and jam process by-products, substandard pressed almond). The analysis extends to End-of-life vehicles (ELV) waste, Waste cooking oil (WCO), Neodymium-iron-boron (NdFeB) magnets, Waste LCD, Municipal Solid Waste Incineration (including Bottom Ash, Flue Gas Desulphurization residue, Coal Fly Ash), Rare Earth Elements (REEs) from end-of-life fluorescent lamps, Food waste, Waste Wiring and Cables (WWC), Seawater waste, Waste printed circuit boards (PCBs), and Wastewater.

4.1. Urban mining and circular economy strategies

Avarmaa et al. (2019) assert that the circular economy and urban mining contribute to the circular economy by reducing waste and optimizing resources, mainly by recycling precious metals from end-of-life electronics. Urban mining is highlighted as a pivotal strategy for achieving circularity in resource use, aligning with the circular economy's goal of maximizing resource efficiency and reducing waste production, as proposed by Habib (2019). Akcil et al. (2019) explore circular economy strategies such as reuse, refurbishment, remanufacturing, and recycling for critical resources like neodymium and dysprosium in NdFeB magnets, emphasizing the significance of urban mining in enhancing resource efficiency and reducing dependence on primary mining.

According to Cheng et al. (2019), the study posits that the circular economy is essential for societal recycling through urban mining, serving as a critical mechanism for realizing circular economy principles and minimizing environmental impacts. Heisel and Rau-Oberhuber (2020) align the circular economy, following Ellen MacArthur Foundation principles, with urban mining within the construction industry, emphasizing resource efficiency, waste reduction, and a regenerative economic system.

Ghisellini and Ulgiati (2020) underscore urban mining as contributing to the dissemination of circular economy culture, presenting urban mining projects as practical applications of circular economy principles. Assi et al. (2020) highlight the crucial role of urban mining in municipal solid waste incineration (MSWI) management, promoting a zero-waste approach by reusing all waste materials, especially from MSWI fly ash and bottom ash.

The potential of urban mining initiatives to enhance circular economy goals is emphasized, transforming small e-waste anthropogenic stocks into valuable resource flows, according to Pierron et al. (2021). In summary, the authors consistently underscore the interplay between circular economy and urban mining, with urban mining emerging as a crucial strategy within the circular economy paradigm, contributing to resource efficiency, waste reduction, and sustainable material management.

In the context of circular construction hubs, Tsui et al. (2023) assert that urban mining assumes a crucial role, focusing on recovering materials from the built environment for subsequent reuse or recycling.

Table 2
Case study on Circular economy and Urban mining.

Case studies		Topics	Features	References
Germany	1	Building	The study underscores the significance of optimizing the utilization of current buildings, emphasizing that this goes beyond merely managing waste and extracting secondary materials.	Ortlepp et al. (2018)
	2	Building	The study highlights the importance of prioritizing resource efficiency, protecting raw materials, and advancing the circular economy in the context of material stocks and flows within the built environment.	Ortlepp et al. (2016)
	3	Building	The study uses dynamic modeling and simulation to forecast future building material flows in Germany's residential building sector and explore the medium—and long-term potential for recycled concrete.	Mostert et al. (2022)
European Union	1	Building	The study stresses the significance of shifting to a circular economy to manage gypsum waste. It underscores the necessity of adopting sustainable practices and ensuring efficient resource utilization in this context.	Jiménez-Rivero & García-Navarro (2017)
	1	REEs	The study underscores urban mining as an opportunity for a thriving European rare earth elements (REEs) market. It emphasizes the significance of actively monitoring and extracting value from materials within urban areas.	Bonoli et al. (2021)
China	1	E-waste	The study emphasizes the importance of recycling and recovering nickel-contained waste to minimize waste flow and slow down the depletion of nickel resources.	Zeng et al. (2018)
	2	C&DW, WEEE & MSW	This study explores the recycling of various waste materials in the context of China's Urban Mining Demonstration Base Construction Program.	
	3	Urban environments	This study's primary focus is exploring and analyzing steel stocks as a critical waste material in urban environments in mainland China.	Song et al. (2021)
	44	Building	The study primarily focuses on the material intensity coefficient (MIC) of buildings in China, which provides insights into the amount of various materials used in building construction.	Zhang et al. (2022a,b)
	5	Urban environments	The study delves into recycling diverse waste materials through urban mining, explicitly focusing on steel, non-ferrous metals, rare metals, and other resources found in urban areas.	Shen et al. (2022)
	6	Urban environments	The study investigates the extensive recovery and utilization potential of different waste types, encompassing municipal waste, urban construction waste, general industrial solid waste, and hazardous solid waste.	Shen & Liu (2022)
	7	E-waste	The study highlights the significance of urban mining in tackling e-waste management and resource extraction challenges.	
Italy	1	Mix-wastes	The study explores repurposing a range of waste materials and by-products from various sectors in the circular economy.	Ghisellini &Ulgiati (2020)
	2	Urban environment	This study explores waste materials, including residual waste bales produced from municipal solid waste (MSW) mechanical selection in the Campania Region, Italy, between 2000 and 2009.	Cesaro & Belgiorno (2020)
	3	Food waste	This study explores fish waste generated in the retail trade and restaurant sector in Emilia-Romagna, Italy. The waste materials include fish scraps, heads, and by-products generated during the processing and preparation of fish for consumption.	Greggio et al. (2021)
	4	E-waste	The study explores the management and potential valorization of disused informatics electrical and electronic equipment (EEE) at the University of Bologna. Specifically, it focuses on obsolete components and materials from end-of-service electronic equipment.	Bonoli et al. (2018)
Switzerland	1	Urban environments	The study investigates two types of waste materials—polycyclic aromatic hydrocarbons (PAHs) in spent asphalt pavements and copper in diverse waste flows. It analyzes the material flows and stocks of these waste materials in the Canton of Zurich, Switzerland, and identifies effective measures for circulating safe and high-quality materials within defined limits.	Kral et al. (2019)
	2	Building	The study explores the potential for recovering and reusing waste materials from buildings in Switzerland. Specifically, it focuses on recovering and reusing concrete, steel, and wood from residential buildings constructed between 2012 and 2016.	Kakkos et al. (2020)
Hong Kong	1	E-waste & ELV	This study explores the potential for urban mining of two waste streams: waste electrical and electronic equipment (WEEE) and end-of-life vehicles (ELV). The study covers 14 types of e-waste and eight types of ELV and estimates the potential output weight of the urban mine in Hong Kong for various materials, including metals, plastic, glass, and rubber tires.	Kuong et al. (2019)
Taiwan	1	Food waste	The study focuses on waste cooking oil (WCO) as the critical waste material explored. It discusses the generation sources of WCO in urban environments, including the residential and commercial sectors.	Tsai (2019)
UK	1	EEE	This study focuses on exploring and prospecting reusable small electrical and electronic equipment (EEE) within distinct urban mines (DUMs), particularly in the context of universities in the United Kingdom. The study specifically addresses the magnitude of the reusable stock of small EEE, including devices such as mobile phones, computers, and other consumer electronics commonly found in urban environments.	Shittu et al. (2022)
	2	Building	The study primarily explores the quantification of timber stock in residential buildings constructed in the London Borough of Tower Hamlets before 1992. Its focus is estimating the timber accumulation in these buildings, including timber distribution across different building types and ages. The study provides insights into the material intensity of timber in the built environment, specifically focusing on terraced houses, flats, and maisonettes.	de Tudela et al. (2020).
Denmark	1	Household wastes	The study investigates waste materials in two landfill sites in Denmark, namely Hvalsø and Avedøre. The Hvalsø landfill contains various household waste, including metallic objects, and has undergone remediation, covered with approximately 2 m of soil. In contrast, the Avedøre landfill has heterogeneous wood, plastic, metal, and rubber surface waste.	Sandrin et al. (2020)
	2	Building	The study explores the stock of construction materials in Odense, Denmark's urban built environment. Specifically, it quantifies the total amount and spatial distribution of 46 construction materials stocked in buildings (residential and nonresidential), roads, and pipe networks (wastewater, water supply, and natural gas).	Lanau and Liu (2020)
Netherlands	1	Building	This study explores the potential for recycling and repurposing various waste materials generated from the built environment, particularly demolition waste. It focuses on 12 materials: concrete, brick, wood, glass, ceramic, gypsum, bitumen, cast iron, aluminum, steel, plastic, and insulation.	Verhagen et al. (2021)

(*continued on next page*)

Table 2 (*continued*)

Case studies		Topics	Features	References
	2	Building	This study explores the waste materials from demolishing buildings in the Dutch building stock. The authors compiled material intensity (MI) data for structural and component building materials, covering various building types, sizes, and construction years. The waste materials explored in this study include concrete, brick, wood, metal, glass, insulation materials, and plastics, among others.	Sprecher et al. (2022)
	3	EEE	This study explores the potential for urban mining of metals in the Dutch electricity system by 2050. The waste materials investigated include bulk and critical minor metals in electricity generation, storage, and transmission technologies.	Sprecher et al. (2022)
	4	Building	The study explores various waste materials in the context of circular demolition and the circular economy in the construction sector. Some waste materials highlighted in the survey include concrete and stone debris.	Jonker-Hoffrén (2023)
	5	Building	The study investigates the recovery of waste materials from Parkstad, a region in the Netherlands, specifically focusing on the southeast of Limburg. The area is undergoing extensive demolitions, leading to considerable waste materials. The study examines wood as a critical material, emphasizing its large quantity (14,000 tons) and its potential for reuse in various building applications, including insulation and construction structures.	Bitar et al. (2022)
	6	Building	The study explores the concept of circular construction hubs within the construction industry context. As such, the waste materials investigated in this study are primarily related to construction and demolition waste. This includes concrete, wood, metals, plastics, glass, and other building materials generated from construction, renovation, and demolition activities.	Tsui et al. (2023)
	7	Building	The waste materials explored in this study primarily focused on construction and demolition waste (CDW), with a specific emphasis on end-of-life (EOL) concrete. The study investigates the potential for upgrading the management of EoL concrete within the context of the circular economy and sustainable waste management practices.	Zhang et al. (2020)
Ecuador	1	Urban environments	The study explores various waste materials collected in Ecuador's urban areas, particularly in Cuenca, Quito, and Guayaquil. The central residues collected include White paper, economical paper, Cardboard, Soft plastic (LDPE), Hard plastic (HDPE), Polyethylene terephthalate (PET), Glass, Metals, and Electronic waste.	Burneo et al. (2020)
Japan	1	Building	The study explores the potential for recovering materials from vacant houses through urban mining. While the specific waste materials are not explicitly mentioned, urban mining implies recovering various materials in vacant homes, such as wood, reinforced concrete, steel, and other building materials.	Wuyts et al. (2020)
Brazil	1	E-waste	This study focuses on electronic waste (e-waste) generated in the Metropolitan Region of Rio de Janeiro (MRRJ). E-waste refers to end-of-life, meaning post-consumed, post-industrialized, or post-sold electrical and electronic products. The study explores the potential for urban mining of e-waste in the MRRJ, with a focus on the recovery of secondary raw materials (SRM) such as precious metals (e.g., gold, silver, platinum), rare earth elements (REE) and other valuable materials (e.g., Nb, Sb, In) that can be extracted from e-waste.	Ottoni et al. (2020)
NAFTA & MERCOSUR	1	E-waste	This study focuses on e-waste management in the Americas, specifically in NAFTA and MERCOSUR countries. E-waste refers to discarded electronic products, including computers, mobile phones, televisions, and other devices. The paper discusses the potential risks associated with e-waste, including hazardous substances such as heavy metals and persistent organic pollutants. The article also explores the potential for material recovery from e-waste through circular economy principles, including pyrolysis, leaching, and bioleaching techniques.	Xavier et al. (2021a,b,c)
Canada	1	Building	The study explores construction and demolition waste materials in the context of urban development and material stock accounting. Specifically, it investigates the quantity of construction materials embedded in Kitchener and Waterloo, Canada's building, road, and sidewalk stocks. It also examines the implications of building demolitions on material waste Generation.	Mollaei et al. (2021).
France	1	Building	The study employs GIS modeling to examine the spatial distribution of human-made stocks, identifying patterns and characteristics of building and network material stocks in the Paris region.	Augiseau & Kim (2021).
India	1	E-waste	The study explores electronic waste (e-waste) as the primary focus of its investigation. Electronic waste, also known as waste electrical and electronic equipment (WEEE), encompasses a broad range of discarded electronic products such as mobile phones, computers, laptops, printers, CDs, and other accessories.	Sharma et al. (2021)
Romania	1	E-waste	The study explores two key waste streams: e-waste and end-of-life vehicles (ELVs) 1. E-waste refers to discarded electronic devices, such as computers, mobile phones, and televisions, that have reached the end of their useful life.	Modoi & Mihai (2022)
Greece	1	E-waste	This study examines obsolete features and smartphones produced in Greece from 1995 to 2035, focusing on estimating the quantities of these mobile phones and the critical raw materials (CRMs) and precious metals (PMs) they contain. Employing dynamic material flow analysis, the study assesses the lifespan of these devices, predicts future sales, and estimates the resulting waste flows.	Kastanaki & Giannis (2022)
United States	1	Building	The study underscores the significance of estimating the types and quantities of materials stored in buildings to evaluate the feasibility of circular economies at the Building stock level through urban mining. It acknowledges that while urban mining can be a potential strategy to support circular economies by reusing materials, there may be Other solutions for achieving complete circularity in the building stock. The research concentrates on the building stock and specific structural systems in the United States, potentially limiting the applicability of the findings to other regions or building types.	Arehart et al. (2022)
Spain	1	E-waste	The study investigates extracting critical raw materials from waste electric and electronic equipment (WEEE) in Spain. It analyzes 43 categories of electronic and electrical equipment (EEE) introduced in the Spanish market from 2016 to 2021, considering the composition of up to 57 elements, with 34 being critical. The focus is on the potential recovery of metals from WEEE, encompassing base, precious, and critical metals. Metals evaluated include aluminum, copper, gold, silver, palladium, platinum, cobalt, lithium, nickel, and rare earth elements (REEs).	Torrubia et al. (2023)
Portugal	1	E-waste	The study explores the management of small electronic devices, called small IT, including smartphones, laptops, tablets, e-readers, digital cameras, gaming consoles, and media players. It focuses on these small IT devices to assess the potential for urban mining and identify citizens' behaviors and motivations related to recycling, reuse, and repair.	Espino Penilla et al. (2023)

Source: The research.

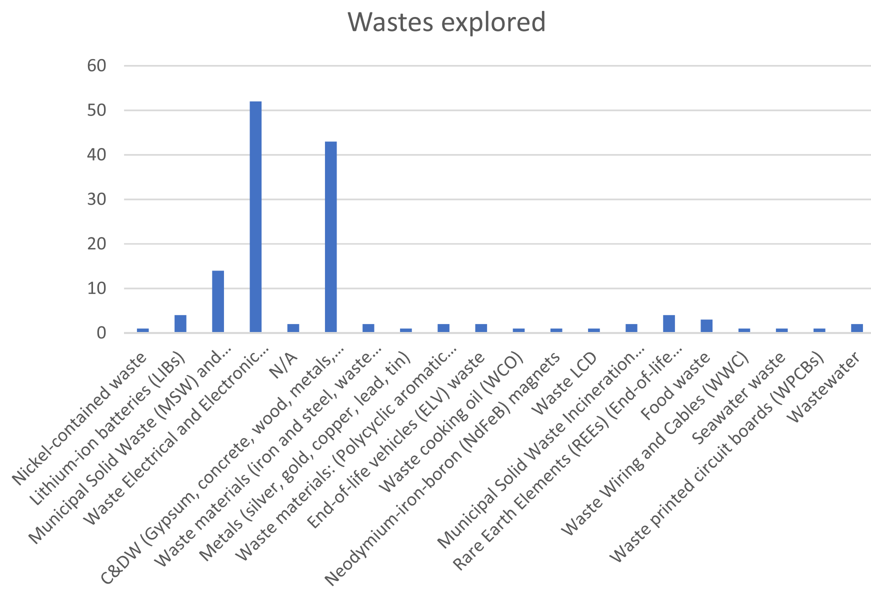

Fig. 8. Types of waste Source: Scopus (2023).

This urban mining perspective, estimating secondary resource availability through mapping material stocks and flows, aligns with circular construction hubs' principles. The relationship between urban mining and the circular economy is further highlighted, recognizing urban mining hubs as a specific type of circular construction hub essential for facilitating material reuse and recycling in the construction industry, contributing to circularity.

Brglez et al. (2023) define the circular economy as an economic system that eliminates waste, emphasizes product and material regenerative design, and aligns with circular city concepts to address Sustainable Development Goals. Urban mining in this context involves extracting valuable resources from existing urban stocks, supporting material circulation, and contributing to resource regeneration and waste reduction in cities.

Dushyantha et al. (2023) focus on rare earth elements (REEs) within the circular economy, aiming to repurpose products containing REEs and transform them into new sources. Urban mining is pivotal in transforming e-waste into a valuable resource for REE recovery. Honic et al. (2023) propose a framework for assessing building stocks, advocating for integrating urban mining into the construction sector to minimize waste and promote the reuse and recycling of materials using technologies like BIM and GIS.

Agrawal et al. (2023) describe the broader sense of the circular economy model, involving closing the loop of resource usage and promoting the recycling and reutilization of waste materials. Urban mining plays a crucial role in this scenario by extracting valuable minerals and materials from various secondary waste resources, contributing to the transition from a linear to a circular economy.

In the study on e-plastic recycling, Qi et al. (2022) highlight the circular economy's focus on treating waste plastics as resources for reuse or recycling, with urban mining, particularly the recycling of e-plastics, supporting circular economy principles by improving resource utilization efficiency and promoting sustainable practices in electronic waste management. Li et al. (2022) discuss the circular economy's goal of promoting the sustainable use of resources in the case of spent Copper indium gallium diselenide (CIGS), with urban mining aligning with circular economy principles through the efficient separation and purification of indium and gallium, minimizing waste and reducing the environmental impact of electronic waste disposal.

Kastanaki and Giannis (2022) emphasize the circular economy's goal to minimize waste and make the most of resources in the study on forecasting critical raw materials in obsolete features and smartphones in Greece. Urban mining, through recovering valuable materials from electronic waste within metropolitan areas, supports circular economy principles by contributing to the sustainable management of resources and reducing waste generation.

The circular economy is an economic system that minimizes waste and maximizes resource use efficiency, providing an alternative to the traditional linear "take-make-waste" model. Urban mining, as defined in this study, refers to recovering valuable resources and materials from waste streams and the built environment in urban areas, focusing on extracting resources from demolition waste, electronic waste, and other anthropogenic stocks for reuse.

Finally, this systematic literature review reveals that the examined documents have extensively explored the exploration of e-waste alongside other categories like construction and demolition residues, metals, and municipal solid wastes within "Urban Mining." Therefore, it becomes imperative to broaden the application of this concept to encompass additional sectors of residue recycling activities. By doing so, we can actively contribute to sustainable development on a global scale. (Table 3)

4.2. Technologies explored in the main studies

The explored technologies facilitate material stock characterization, experimental investigations, and the development of recovery processes in urban mining applications, including enhanced landfill mining, building and e-waste mining, and battery recycling. Advances in geophysical techniques, digital tools, and metallurgical processes contribute to closing resource loops through urban mining.

In Enhanced Landfill Mining (ELFM), researchers explore using thermal plasma processing to derive value-added products from municipal solid waste. They underscore the integral role of waste-to-energy technologies in ELFM, emphasizing their significance in resource extraction from landfill sites and aligning them with broader sustainability goals.

A novel Geographic Information System (GIS) based method for material composition estimation in non-domestic buildings has been introduced in Germany. The focus is on acquiring reliable data for strategic planning by governmental authorities, aiming to enhance the monitoring and deployment of resource flows and ensure effective resource utilization for a more circular economy.

Innovative technologies are imperative across diverse domains, from lithium recovery and e-waste recycling to nickel challenges and geophysical investigations. These studies highlight the pivotal contribution of advancements in shaping sustainable waste management practices and driving strategies for efficient resource recovery. The integration of technologies emerges as a critical driver in advancing responsible and resource-efficient practices across various sectors, from urban mining to circular economy principles.

Exploring new urban mining technologies and strategies centers on recovering materials from the built environment for reuse and recycling. This includes innovative methods for processing recycled concrete, insulation, gypsum, steel, and wood. Adopting modular construction systems, prefabricated components, and non-toxic materials aligns with circular economy principles, aiming to establish a circular and regenerative economic system within the built environment.

It also introduced a novel technology to treat and reuse waste materials, emphasizing stabilization mechanisms using bottom ash and other components. This zero-waste model promotes circular economy principles and sustainability, marking a significant advancement in waste management and resource recovery, contributing to circular economy goals.

Other studies investigate advanced techniques for reclaiming clay bricks, large-scale implementation of technologies for recycling end-of-life concrete, microbial activities in recycling critical metals from waste printed circuit boards, and technologies for reclaiming and reusing structural building products. These technologies address technical challenges and barriers associated with recycling and reusing materials, with a shared focus on achieving efficiency, cost-effectiveness, and sustainability.

The documents also cover the development and proposed use of technologies for deconstructing buildings, extracting and synthesizing gold nanoparticles from electronic waste, estimating material quantities using various technologies (BIM, GIS, AI, LiDAR, etc.), managing e-waste with advanced metallurgical technology, the Internet of Things (IoT), and space debris recovery.

Furthermore, the study explores the application of bioprocesses like bioleaching in extracting metallic elements from waste electrical and electronic equipment, providing a cost-effective and sustainable approach aligned with circular bioeconomy principles. Incorporating innovative technologies in mapping steel resources, recovering valuable metals from complex feedstocks using electrochemical methods, and a hybrid leaching process for lithium-ion batteries demonstrates ongoing efforts to advance sustainable urban mining and circular economy practices.

These studies highlight innovative technologies (see Table 4) that promote sustainable waste management, resource recovery, and the transition towards circular economy practices across various sectors. The technologies discussed encompass a wide range, from physical processes and pyrolysis to hydrometallurgical processing and bioleaching, emphasizing their importance in efficiently handling electronic waste and advancing circular economy principles.

4.3. *Main gaps in documents analyzed*

Table 5 outlines that the examination recognizes gaps and limitations in analyzing material stocks in residential buildings, municipal solid wastes, e-waste, and other areas.

The systematic literature review identifies significant barriers to the progress of urban mining for various wastes globally. Firstly, the need for efficient takeback logistics networks and consumer incentives hampers material collection and management. At the same time, the absence of policies and frameworks addressing end-of-life and end-of-use considerations adds complexity to sustainable management. Secondly, the prevalence of informal players using outdated techniques poses health and environmental risks, emphasizing the need for modernized urban mining practices. Thirdly, reliable data and efficient audit procedures help ensure accurate assessments of waste challenges and the implementation of effective urban mining strategies. The lack of GIS complicates the identification of urban mines. Additionally, the high costs associated with adopting sustainable technologies act as a financial barrier, discouraging waste investors and impeding the adoption of environmentally friendly practices. Moreover, the absence of comprehensive legislative bases in developed and developing countries covering functionality testing, waste treatment conditions, and permits for collection, transportation, storage, and treatment obstructs the establishment of effective urban mining practices.

4.4. *Perspectives for future studies*

Table 6 highlights the critical perspectives presented in the documents for advancing future studies in sustainable resource management and urban mining through improved data-driven analyses, innovative technologies, robust economic and environmental assessments, integration with circular economy principles, engaged stakeholder collaboration, and application-focused case studies and demonstrations.

Filling these gaps would contribute to a more robust and comprehensive understanding of all materials waste associated with urban mining and the circular economy. Addressing these gaps through standardized approaches, complete data collection, improved occupational safety, validated industrial technologies, and cleaner processing methods could significantly enhance progress in various waste management and resource recovery initiatives. Overcoming these regulatory review limitations through detailed jurisdictional analyses, policy benchmarking, and the identification of supportive policy mechanisms could strengthen the implementation of resource recovery projects and promote circular economy goals. Harmonized yet adaptive regulations often serve as a foundation for sector-wide transitions toward sustainability. To address these limitations of behavioral understanding, engaging in education, incentives, and collaborative behavior change programs involving all stakeholders could enhance participation in the circular economy at the consumer level.

This systematic literature review has illuminated the " urban mining" domain by comprehensively analyzing residues and waste materials. Through the systematic examination of relevant articles, several key findings have emerged.

Firstly, it has been determined that certain waste materials are predominantly targeted in "urban mining." These include electronic waste, construction and demolition waste, and mining waste. Understanding the specific materials of interest is crucial for effective resource recovery and sustainable urban development.

Secondly, this review has identified research gaps within " urban mining." Despite the growing interest in this field, some areas still require further investigation. These gaps include the need for more comprehensive studies on the environmental impacts of urban mining practices, the development of effective recycling technologies, and the exploration of circular economy strategies.

Lastly, this review has highlighted promising avenues for future studies in "urban mining." These include integrating advanced technologies such as artificial intelligence and robotics in waste sorting and processing, exploring innovative business models for urban mining enterprises, and collaborating with stakeholders from academia, industry, and government to facilitate knowledge exchange and implement sustainable practices.

This study comprehensively explains "urban mining" and its implications. The findings contribute to the existing body of knowledge and serve as a foundation for further research and exploration in this field. We can enhance resource recovery, reduce waste generation, and promote sustainable urban development by addressing the identified research gaps and pursuing promising avenues. The potential impact of this research is significant, inspiring further research and action in "urban mining" to create a more sustainable and resource-efficient future.

Table 3
Relationship between the Urban mining and Circular economy concepts.

Characteristics	Key Points from Specific Studies	References
• Urban mining contributes to the circular economy by recovering resources from waste streams, reducing dependency on primary extraction. • It allows materials to be used through reuse, refurbishment, and recycling. • By providing secondary materials, urban mining facilitates material circulation and resource efficiency goals of the circular economy. • Several studies emphasize urban mining as a critical strategy to achieve circularity, particularly in construction, waste management, and urban development contexts.	• Relationship is explored in the context of rare earth element recovery from e-waste. • Urban mining potential is assessed for housing and construction sectors. • Studies evaluate using BIM and GIS to map material stocks to support urban mining and circular construction hubs. • Behavioral factors influencing e-waste management are examined to promote more sustainable practices aligned with circular economy principles. • Technologies are proposed to recover materials from municipal solid waste incineration residues through urban mining and bioleaching. • Critical material flows within cities are assessed to understand circular systems at the urban scale.	Jones et al. (2013); Ongondo et al. (2015); Jiménez-Rivero & Navarro (2016); Swain (2017); Jiménez-Rivero & Navarro (2017); Ottoni et al. (2020); Xavier et al. (2021a); Xavier et al. (2021b); Xavier et al. (2023); Avarmaa et al. (2019); Mollaei et al. (2021); Akcil et al. (2019); Heisel & Rau-Oberhuber (2020); Augiseau & Kim (2021); Murthy & Ramakrishna (2022); Bitar et al. (2022); Sprecher et al. (2022); Modoi and Mihai (2022); Scialpi & Perrotti (2022); Zeng et al. (2022); Sprecher et al. (2022); Funari et al. (2023); Zandonella Callegher et al. (2023).

Source: The research.

4.5. Theory and practical implications

Islam et al. (2021) found that more than half of consumers keep electronic equipment out of use, and small electronic equipment is stored more than large electronic equipment as limited space is required. On the other hand, they found that "mobile phone chargers" and "digital cameras" are widely stored electronic products. They mentioned that high-income groups dispose of e-waste properly through appropriate channels, unlike the low-income class. These challenges persist throughout supply chains (Neves et al., 2024).

According to Erdiaw-Kwasie et al. (2024), urban mining is viable for addressing environmental concerns and recovering valuable secondary raw materials from electronic waste. Xavier et al. (2021a,b,c) describe urban mining as comprising three key stages: upstream, midstream, and downstream. Integrating these stages with reverse logistics systems is essential for practical urban mining. Urban mining is a circular economy concept applied to managing electrical and electronic equipment waste, underscoring the importance of closing the life cycle of electronic products—from raw material extraction to the recycling and reuse of materials. This approach promotes sustainability and environmental responsibility throughout the entire value chain, demonstrating a novel method of value recovery based on circular economy principles and emphasizing the responsibility of all stakeholders involved in this new value chain.

Urban mining also illustrates how electronic products can be reintegrated into the production cycle by recovering secondary materials and implementing reverse logistics systems. The upstream stage involves extracting raw materials and producing electronic components, engaging various industries, including chemical, metallurgical, and technological sectors, startups, and producers of oxides, alloys, and sheets.

In the midstream stage, processed raw materials are manufactured, and electronic parts and components are assembled into final products ready for consumer use. A management entity oversees and coordinates production cycle operations at this stage, making midstream a critical juncture for maintaining product circularity between the upstream and downstream stages. This phase offers significant economic, social, and environmental growth opportunities for all e-waste management participants.

Various entities, including recyclers, operators, secondary material companies, management entities, and exporters, play pivotal roles downstream. This stage involves pre-processing, processing, and disposal activities, such as concentrating anthropogenic stocks and segregating and recovering products, components, and materials based on their intended destination. In value chains, consumers are often overlooked in e-waste management, yet they are crucial as the initiators of material circularity through e-waste generation. Therefore, stakeholders must implement door-to-door collection campaigns, drop-off points, and recycling centers.

Enhancing the effectiveness of urban mining in e-waste supply chains requires fostering collaboration among stakeholders in the formal and informal sectors, spanning from upstream to downstream, through an integrated reverse logistics system. This collaboration should be supported by oversight and enforcement from regulatory bodies. Additionally, it is crucial to establish public environmental education policies, develop clear guidelines for sustainable practices, and ensure ongoing monitoring of companies' adherence to environmental laws and regulations.

4.6. Limitations and challenges

This study reviews the current state of e-waste and urban mining as discussed in the literature. We systematically searched scientific articles published in English using the Scopus database. The methodology, including the research process, filtering criteria, and inclusion and exclusion parameters, is thoroughly detailed, analyzing 124 articles on the subject (Table 1). It is important to note that this review is not exhaustive, as it excludes book chapters, opinion pieces, conference papers, conference reviews, dissertations, theses, and other databases such as Science Direct, Web of Science, Sage, Taylor & Francis, and Emerald. For a more comprehensive analysis, future studies should consider other databases, employing the PRISMA technique to conduct a meta-analysis alongside the literature review, providing a more structured and rigorous approach essential for systematic reviews and quantitative studies. Additionally, challenges remain regarding adequate regulation, extended producer responsibility, and the inclusive participation of consumers and informal workers in urban mining. Urban mining holds significant potential to revolutionize e-waste management practices and contribute to sustainable resource management.

5. Conclusion

This study provided valuable insights into the relationship between urban mining and the circular economy. We identified that scientists predominantly focus on global case studies and the impact of research in these areas. The results revealed that urban mining is more heavily emphasized in the electrical waste sector than the construction sector, highlighting this study's contribution. Additionally, we identified the various technologies and research topics that currently capture researchers' interest and the gaps that future studies should address. This study can guide decision-makers in this sector, encouraging researchers to address the gaps in achieving the SDGs advocated by the United Nations. Overall, this research represents a valuable contribution to the field and is a helpful guide for researchers, policymakers, and

Table 4
Technologies suggested by studies.

Qt	Technologies	Characteristics	References
1	Advanced Experimental Techniques	• Equilibration-quenching technique to investigate the behavior of materials at high temperatures • Laser Ablation Inductively Coupled Plasma Mass Spectrometer (LA-ICP-MS) for trace element analysis • Scanning Electron Microscopy-Energy Dispersive X-ray Spectrometry (SEM-EDS) for micro-structure and composition analysis	Avarmaa et al. (2019); Wan et al. (2021); Zhou et al. (2020); Kovacic & Honic (2021); Kumari and Samadder (2023); Shittu et al. (2022).
2	Geophysical Technologies	• Magnetic and seismic surveys to characterize landfill materials • Differential GPS for accurate magnetic data mapping • ReflexW® software for seismic data processing	Sandrin et al. (2020); Habib (2019); Oezdemir et al. (2017); Song et al. (2021); Greggio et al. (2021).
3	Digital Technologies	• Building Information Modeling (BIM) for material assessments and waste prediction • Material Passports to describe product and building material characteristics • Scanning technologies to support integrated resource assessments	Kovacic et al. (2020); Heisel & Rau-Oberhuber (2020); Lanau & Liu (2020); Kovacic & Honic (2021).
4	Recovery Technologies	• Hydrometallurgical, pyrometallurgical, and other processes for lithium recovery from batteries • Hydrometallurgical treatment for gold extraction and nanoparticle synthesis from e-waste • Acid leaching using orthogonal array design of experiments for metal recovery from batteries • bioleaching and electrochemical methods; • New technologies for sorting and separating e-waste materials, such as automated sorting systems, robotics, and artificial intelligence.	Martins et al. (2021); Barrueto et al. (2022); Xavier et al. (2023); Agrawal et al. (2023); Kumar et al. (2023).
5	Characterization Technologies	• Geographic Information Systems (GIS) for spatial analysis of material stocks • Remote sensing data and high-resolution mapping for national-scale stock estimates	Oezdemir et al. (2017); Mollaei et al. (2021); Song et al. (2021).

Source: The research.

Table 5
Gaps encountered in studies analyzed.

Qt	Gaps	Characteristics	References
1	Limited scope	The study's narrow geographical and temporal scope restricts the findings' applicability.	Oezdemir et al. (2017); Mollaei et al. (2021); Kakkos et al. (2020).
2	Lack of Geographic Information Systems (GIS)	Unreliable data on e-waste, inefficient audit procedures, and the absence of GIS to locate urban mines.	Wuyts et al. (2020); Aldebei & Dombi (2021); Mollaei et al. (2021); Song et al. (2021); Erdiaw-Kwasie et al. (2024).
3	Reliance on secondary data	Estimating material stocks relies on secondary data sources like census data, which may need to be completed or updated. This could introduce errors in the quantification of stock amounts.	Swain (2017); Junior et al. (2023); Camargo et al. (2023).
4	Lack of economic analysis	The study highlights potential resource efficiency and material reuse benefits but needs to discuss the economic viability of urban mining and circular economy approaches in construction. It is still being determined if the extraction and processing costs outweigh the resource recovery benefits.	Pierron et al. (2021); Lopes dos Santos, (2023).
5	Lack of standardized recycling processes	Standardization across e-waste recycling technologies and processes must be standardized, making comparing performance and optimizing operations difficult.	Jones et al. (2013); Avarmaa et al. (2019); Aldebei & Dombi (2021).
6	Lack of directives legislation	Comprehensive and transparent legislative bases are needed, including specifications for functionality testing, WEEE treatment conditions, packaging used for EEE, and permits (collection, sorting, and treatment, among others).	Shittu et al. (2021), Xavier et al. (2023), Shen & Liu (2022), and Bonoli et al. (2018).
7	Limited composition data	Limited data exist on the materials and chemicals present in different types of e-waste, challenging efforts to develop targeted recycling approaches.	Kovacic & Honic (2021).
8	Focus on large appliances.	Most research focuses on large appliances like TVs and computers, but more needs to be done to understand how to recover critical materials from smaller consumer devices like phones.	Xavier et al. (2021a); Qi et al. (2022); Ghisellini et al. (2022a, b).
9	Low recycling rates	E-waste recycling rates fail to keep up with rising end-of-life generation, indicating the need for policies and technologies to encourage more recycling.	Torrubia et al. (2023); Akcil et al. (2019); Tejaswini et al. (2022a,b).
10	Manual processing hazards	Reliance on manual dismantling in formal recycling exposes workers to health and safety risks from toxins in e-waste.	Ryabchuk et al. (2021); Abalansa et al. (2021); Panchal et al. (2021).
11	Lack of industrial-scale solutions	Technologies demonstrated at the lab scale have yet to be validated and scaled up for industrial applications in e-waste recycling facilities.	Akcil et al. (2019); Srivastava et al. (2020).
12	Energy-intensive processes	Current pyro-metallurgical approaches are energy-intensive, contributing to emissions. Alternative hydrometallurgical methods require further research.	Swain (2017); Srivastava et al. (2020); Silvestri et al. (2021).
13	High Technologies cost	The high cost of adopting sustainable technologies makes them less attractive to e-waste investors.	Kovacic et al. (2020); Srivastava et al. (2020); Jones et al. (2013).
14	Policy and regulatory frameworks for gypsum waste management	Studies note that further exploring policies and regulations governing gypsum waste handling and recycling could provide valuable insights. Understanding existing barriers and opportunities could help develop strategies to promote circular economy approaches.	Jiménez-Rivero & García-Navarro (2016); Jiménez-Rivero & García-Navarro (2017); Verhagen et al. (2021).
15	Regulations for lithium-ion battery recycling	A study acknowledges limited analysis of policies influencing battery recycling technologies and processes. A comprehensive understanding of the policy landscape is needed to support the widespread adoption and implementation of best practices.	Kumar et al. (2023). Kumar et al. (2023).
16	E-waste and urban mining regulations	Several documents indicate a need for a more in-depth evaluation of regulatory frameworks that enable the circular economy model and sustainable e-waste practices. Clarifying existing rules and identifying gaps would aid stakeholders.	Xavier et al. (2023); Xavier et al. (2021a,b,c); Lopes dos Santos (2023); Junior et al. (2023).
17	Extended producer responsibility (EPR) schemes	A few studies mention how EPR policies could incentivize design for recycling and reduce waste Generation, but they need to analyze their impacts in detail.	Swain (2017); Shittu et al. (2021); Tejaswini et al. (2022a,b); Ali & Shirazi, (2023).
18	Regulatory assessment across geographical contexts	Regulations vary globally but must be sufficiently compared to draw lessons for other regions.	Jones et al. (2013); Arehart et al. (2022); Xavier et al. (2023).
19	Understanding of lifespan cycles	Limited data exist on actual product replacement and end-of-use cycles. Better information could help optimize urban mining projections and strategies.	Bonoli et al. (2018); Kuong et al. (2019); Heisel & Rau-Oberhuber (2020); Bonoli et al. (2021).
20	Disposal and take-back practices	Collection rates and proper disposal remain challenges, particularly for smaller electronic devices. More awareness and convenient waste management systems are needed.	Ottoni et al. (2020); Xavier et al. (2021a,b,c); Guarnieri et al. (2022); de Oliveira et al. (2021); Xavier et al. (2023).
21	Willingness to adopt renewables	Studies note that markets favor virgin materials over secondary resources from recycling or urban mining. Increased consumer acceptance of refurbished/remanufactured goods could help.	Tesfaye et al. (2017); Arora et al. (2020); Shittu et al. (2021); Shen & Liu (2022).
22	Demand for recycled content	Similarly, demand predominantly exists for conventional rather than recycled materials, posing obstacles. Bridging this gap through policy, certification, or marketing could boost circular approaches.	Xavier et al. (2021a,b,c); Shen et al. (2022); Jiménez-Rivero & García-Navarro (2017).
23	Top-down vs. organic growth	Heavy-handed urban mining programs were mentioned as deviating from real consumer needs, highlighting the importance of understanding demand dynamics.	Hua and Poustie (2018); Peng et al. (2019); Tejaswini et al. (2022a,b).
24	Stakeholder perspectives	The limited investigation focused on the views of end-users, communities, and other actors involved in or impacted by resource management decisions. Broader participation helps ensure solutions align with diverse, sustainable consumption values.	Shen & Liu (2022); Torrubia et al. (2023); Agrawal et al. (2023).
25	Informal players	The dominance of informal players who use out-of-date urban mining techniques such as open burning and acid baths poses significant health and environmental risks.	Ali & Shirazi, (2023); Erdiaw-Kwasie et al. (2024).
26	Life Cycle Assessment (LCA)	Life cycle and environmental impact evaluations were not included, providing only a partial perspective on the sustainability implications of resource recovery and circular economy initiatives.	Bonoli et al. (20218); Tsai, (2019); Mostert et al. (2022); Agrawal et al. (2023); Zandonella Callegher et al. (2023).

Source: The research.

Table 6
Suggestions for future study.

Qt	Perspectives	Characteristics	Authors
1	Data Collection and Analysis	• Comprehensive characterization of waste materials to identify all constituent materials and quantify their amounts • Investigation of non-metallic fractions of waste electrical and electronic equipment to explore valuable materials recovery potential • Advance data collection methods and harmonize data related to waste streams, critical raw materials, and urban mining activities to improve understanding	Abalansa et al. (2021); Aldebei & Dombi (2021); Tesfaye et al. (2017); Zandonella Callegher et al. (2023).
2	Technological Innovation	• Development of advanced recycling technologies like integrated membrane-based approaches for purifying metal solutions • Exploration of automation and artificial intelligence applications to improve recycling process efficiency • Research on novel membrane technologies for selective recovery of valuable metal ions from leachates	Jones et al. (2013); Jiménez-Rivero & García-Navarro (2016); Zeng et al. (2018); Hua and Poustie (2018); Cheng et al. (2019); Oestreicher et al. (2020); Verhagen et al. (2021); Panchal et al. (2021); Shittu et al. (2022); Xavier et al. (2023).
3	Economic and Environmental Assessments	• Techno-economic analyses of urban mining processes to identify cost-effective implementation pathways • Evaluation of energy consumption and environmental impacts of different recycling routes like mechanical pre-treatment vs thermal treatment • Comprehensive life cycle assessments to evaluate the overall environmental footprint of resource recovery activities	Maia et al. (2021); Martins et al. (2021); Rachidi et al. (2021); Deng et al. (2021); Greggio et al. (2021), Torrubia et al. (2023); Varennes et al. (2023); Honic et al. (2023).
4	Integration with Circular Economy	• Examination of broader implications of sustainable resource recovery for creating economic opportunities and reducing environmental impacts • Exploration of urban mining's role in achieving circular material flows and resilient industrial symbiosis models • Identification of policy incentives and legislative measures to promote circular flows of critical materials	Agrawal et al. (2023); Zandonella Callegher et al. (2023); Ongondo et al. (2015); Jones et al. (2013); Jiménez-Rivero & García-Navarro (2017); Zeng et al. (2018).
5	Stakeholder Engagement	• Involvement of workers, local communities, and industry in assessing social impacts like on job opportunities and community development • Collaboration among researchers, industry, and policymakers to support technology development and implementation planning	Bonoli et al. (2018); Cheng et al. (2019); Kayaçetin et al. (2022); Arora et al. (2021); Mollaei et al. (2021).
6	Specific Applications	• Pilot-scale demonstrations and optimization of processes for recovering materials from waste streams like lithium-ion batteries • Case studies to determine viable recovery routes for different waste materials like electronic goods and construction debris	Giese (2021); Condotta & Zatta (2021); Oestreicher et al. (2020); Ajayebi et al. (2020); Kazançoglu et al. (2020); Peiró et al. (2020); Assi et al. (2020); Akcil et al. (2019). Xavier et al. (2021a); Lopes dos Santos (2023).

Source: The research.

practitioners interested in sustainable resource management and urban mining.

CRediT authorship contribution statement

Omar Ouro-Salim: Writing – review & editing, Formal analysis, Conceptualization.

Declaration of Competing Interest

We wish to draw the editor's attention to the following facts, which may be considered potential conflicts of interest, and to significant financial contributions to this work. We wish to confirm that there are no known conflicts of interest associated with this publication and that there has been no significant financial support for this work that could have influenced its outcome. We confirm that the manuscript has been read and approved by all named authors and that no other persons satisfied the criteria for authorship but are not listed. We further confirm that all have approved the order of authors listed in the manuscript. We confirm that we have given due consideration to protecting the intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, concerning intellectual property. In so doing, we confirm that we have followed the regulations of our institutions concerning intellectual property.

Data availability

No data was used for the research described in the article.

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