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Assessing the Role of Big Data and the Internet of Things on the Transition to Circular Economy: Part I

An extension of the ReSOLVE framework proposal through a literature review

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The debate about circular economy (CE) is increasingly present in the strategic agenda of organisations around the world, being driven by government agencies and general population pressures, or by organisations' own vision for a sustainable future. This is due in part to the increasing possibility of turning original theoretical CE proposals into real economically viable initiatives, now possible with modern technology applications such as big data and the internet of things (IoT). Information technology (IT) professionals have been called upon to incorporate technology projects into their strategic plans to support their organisations' transition to CE, but a structured framework with the necessary IT capabilities still lacks. This study focuses on taking the first step towards this path, by extending the technology attributes present on the existing Ellen MacArthur Foundation (EMF) Regenerate, Share, Optimise, Loop, Virtualise and Exchange (ReSOLVE) framework. The research was conducted based on an extensive literature review through 226 articles retrieved from Scopus® and Web of Science™ databases, which were triangulated, validated and complemented with content analysis using the 'R' statistical tool, grey literature research and inputs from specialists. Part I describes the introduction and methods used in this study.

1. Introduction

IT plays an important role in enabling disruptive organisational transformations, despite the known privacy and confidentiality issues and security risks (1, 2) constantly being run up against with the use of technology itself (3). Recent studies show decision-making processes have become much faster and more precise in companies adopting big data technologies (4, 5) for example. Internal and external communications and knowledge sharing (6, 7), not only in large organisations but also in small and medium-sized enterprises (SMEs) (8), are faster and better due to social networks (9) and instant messaging technologies (10), just to mention a few recent examples. In the corporate sustainability (CS) and other environmental fields it is no different. Many recent studies focus on understanding the role of IT in offering solutions to reduce the negative impacts of organisations and society on the environment (11–13), including those generated by modern technologies, known as 'green IT' (14–17). Several other studies can be found in the literature. Large data vulnerability risks are also present in this context (18). One special concept based on the planet's sustainability issues is gaining attention from organisations and government recently, namely CE.

Although the concept of CE has existed for decades, it has become more evident in the past few years as resources are becoming scarcer and more expensive, mainly because world population and resource consumption continue to grow for a limited-resource earth. Moreover, society is now more concerned about issues such as global warming, plastics and other waste disposal (19, 20) and aware of the need for stewardship of our planet's natural resources (21). Another relevant factor is the quick development of automation technologies brought by what has been called the Fourth Industrial Revolution, also known as Industry 4.0, essentially leveraged by big data and the IoT, which are making the implementation of CE concepts not only possible and more economically feasible, but necessary (22, 23).

The role big data and IoT perform in enabling the transition to CE has been subject of many studies and is attracting the interest of the scientific community.

As organisations and governments are being pushed to take action to transform business and city models to enable CE, more efforts need to be taken in technology by IT professionals to make it a consistent, fast time-to-market and low-cost transition (24–28). However, the IT path to be followed by organisations and governments still lacks a structured framework, with some practitioners even questioning whether technologies such as big data really foster sustainability (29).

Researchers have been putting a lot of effort into establishing CE theories and models to provide useful and usable tools to help scientists and practitioners develop their work. Nevertheless, as such initiatives are usually undertaken independently and motivated by different interests, dozens of separate studies have arisen in recent years. Although CE has been known since the 1970s, more than 50% of all studies are published since 2014, as shown in **Figure 1**. Recent studies show more than 100 CE definitions have already been documented and published (30), along with dozens of frameworks, each one approaching CE from a different perspective. Although all offer significant contributions to science and practice, choosing one to perform as a baseline for research and business strategies development is challenging. When the IT component is added, the situation becomes even more complex, as new disruptive technologies arise very fast and accelerate the obsolescence of previous studies. Moreover, it is being noticed that current CE frameworks rarely explore the IT component (or ignore it, as described in Section 2.2), giving modern and disruptive technologies a secondary role on the transition to CE. An exception is the EMF ReSOLVE framework (31). It not only acts as a basis for other published frameworks, but also recognises the greater role IT performs in the transition to CE, yet it still lacks theoretical deepening, which is a gap to be addressed by this research.

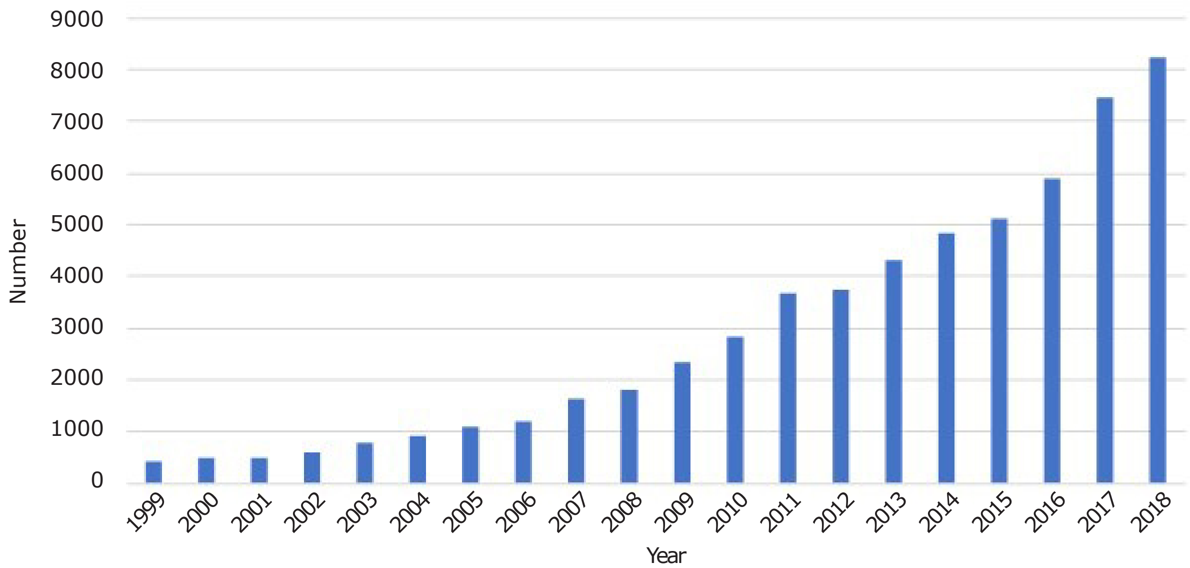

Fig. 1. Publication profile on CE for the years 1999–2018 (Source: Scopus®)

This study intends not only to reinforce the key role technology performs on the transition to CE – specially big data and IoT, both the foundation of the so-called Industry 4.0, as already presented in some novel published studies (32, 33), but also proposes a preliminary framework for IT capabilities, built on EMF's ReSOLVE framework, to be used by IT professionals in order to understand and assess their organisation's gaps for the transition to CE. The framework was conceived based on a literature review composed of four separate sources: a traditional review of 226 big data or IoT applications on CE scientific articles, all retrieved from Scopus® and Web of Science™ databases; content analysis (simple bibliometric review) of the retrieved articles; industry, corporate and government initiatives (grey literature); and industry experts review. This triangulation was a necessary step not only for validity and reliability issues, but also because of the known gap between the academy and industry and private sector initiatives for the research subject (19), so each source provided complementary data. Therefore, this study aims to answer the following research question: What are the big data and IoT capabilities that IT professionals need to address in order to support their organisations in the transition to the CE?

The remainder of the paper is organised into four sections, starting with the literature review, including an analysis of the current CE available frameworks, followed by the methodologies applied to the research and a results and discussion section including the proposed IT capabilities framework. The final section (in Part II, (34)) presents the study's conclusions, its limitations and future research recommendations.

2. Literature Review

2.1 Defining Circular Economy

For the past few years, the current production and consumption model essentially based on a linear flow (take-make-dispose), which generates an increasing throughput of natural resources, has brought back a concept originating during the 1970s and closely related to environmental concerns: CE. It is based on a circular system where both organic and technical wastes are minimised and returned as feedstock, leading to a zero waste generation model (20, 35–37), being restorative and regenerative by design and resting on the following principles: preserving and enhancing natural capital, optimising resource yields and fostering system effectiveness (38). The efficient use of energy (and its transition from fossil to clean and renewable sources) and the promotion of product reuse and lifetime extension actions also contribute to CE.

Currently only 9.1% of the world economy can be considered circular (39), meaning that around 90% of everything that is produced and consumed on the planet still follows the take-make-dispose flow. Furthermore, the world population continues to grow for a limited-resource earth (19, 20) with scarce commodities becoming more expensive (40). For instance, if we look at Brazil alone, only 1% of all organic waste is treated and beneficiated in a country where 50% of all wastes are organic, producing every year the amount of greenhouse gases equivalent to seven million cars (41).

Recently the United Nations Environment Programme (UNEP) developed a study focused on the issue of disposal of plastics in the ocean that led to the 'Marine Plastic Debris and Microplastics: Global lessons and research to inspire action and guide policy change' report. (42). Some estimates from the report indicate that the 'visible' part of marine debris (what is floating on the sea's surface) represents only 15% of all marine debris while those on water columns account for another 15% and 70% of all marine debris is simply resting on the seabed. Moreover, most of this plastic breaks up into microplastic over time, representing a hazard to wildlife, fish and people.

These and many other documented facts demand action from governments, organisations and society, and CE is performing a critical role in this necessary transformation. For example, in 2018 the European Commission – the executive branch of the European Union – launched the 2018 Circular Economy Package, which is a set of measures aiming to transform Europe into a more sustainable continent (43), including challenging goals such as making all plastic packaging recyclable by 2030. It consists of several documents focused in legislations about plastics, waste and chemicals and proper communication to citizens. This was an outcome of the EU Circular Economy Action Plan established two years before. China is also making considerable progress transitioning to CE, being one of the first countries to have laws for CE development (after Germany and Japan) since 2009 and further detailed in 2013 with its Circular Economy Development Strategies and Action document, establishing directives for companies, industrial parks and even cities and regions (44).

In addition, not only can CE address social and environmental issues, but it can also help develop the economy. In Europe alone, benefits of around €1.8 trillion may be achieved by 2030 (45).

Those and other initiatives led a number of organisations, including public administration and academia, to put more effort into developing or applying solutions and research to promote the transition from the linear to the circular model economy. Science has recently made significant progress in CE research. This can be seen by observing the academic research evolution presented in **Figure 1**, which shows that most CE research is relatively new (26% in 2017 and 2018 alone).

Nevertheless, as a consequence, a number of different theories and principles or constructs are still emerging, making the process of defining CE formally difficult. Therefore, one of the challenges faced by scholars is agreeing on a common theoretical scientific definition of CE and its various ramifications, as most of the successful initiatives have been almost exclusively led by practitioners.

Discussions about the concept's incipience have already been the object of recent studies. For example, recent research put together 114 different CE definitions and coded them on 17 dimensions (30). Other studies propose taxonomies based on different methods (19, 46), while others try to establish a consensus for the adequate use of the term CE (47) and compare it to the concept of sustainable development (36). There is also some justified criticism regarding the correct use of the term CE (48) and even questions whether CE captures the environmental value propositions (49).

For this research, we identified a straightforward classification based on a comprehensive literature review article covering 20 years of CE studies, that groups it into six basic principles (20): (a) design, (b) reduction, (c) reuse, (d) recycle, (e) materials reclassification into technical or nutrients and (f) renewable energy. The study had more than 300 citations in three years since its publication in the *Journal of Cleaner Production* (ISSN 0959-6526), which is a very high impact factor journal. Details on each principle obtained from the literature can be found in the original publication.

2.2 Circular Economy Frameworks

There are several CE frameworks available in the literature. A query in Scopus® with the expressions 'circular economy' and 'framework' in title, keyword and abstract retrieved 21 different models, the oldest published in 2016. Of those, we compared the nine most relevant ones (i.e. from journals with scimago >20 and with at least five citations), which are presented in detail in Appendix 9 (for all Appendices: see the Supplementary Information included with the online version of this article). Here we describe the top three: the most popular, 'A comprehensive CE framework' (50) was proposed through an extensive literature review and is based on economic benefits, environmental impact and resource scarcity and is focused in the manufacturing industry. The second is called 'The 9R Framework' (30). It extends the classical concept of 3Rs to nine definitions and suggests an increase of circularity for each one: Recovery of Energy (less circular: incineration), Recycle, Repurpose, Remanufacture, Refurbish, Repair, Reuse, Reduce, Rethink and Refuse (more circular: make product redundant). The third, 'Circular economy product and business model strategy framework' (51), proposes the need for design and business model strategies to be implemented in conjunction in order to better drive circularity. Although all are unique and proved to be valuable given their popularity, along with authors and publications relevance, two common characteristics were observed: they do not consider the 'technology' aspect; and all reference directly, as a main source of information, the EMF, known to lead and foster both theoretical and practical initiatives regarding CE since 2010. EMF created a framework called ReSOLVE, which is used as a basis by some of the top frameworks mapped (for example, the backcasting and eco-design for the circular economy (BECE) framework (52)) and is the most popular in internet search (see Appendix 9). It is considered part of the grey literature rather than a scientific document. It offers organisations a tool for generating circular strategies and growth initiatives, composed of the levers: (a) regenerate, (b) share, (c) optimise, (d) loop, (e) virtualise and (f) exchange. Moreover, technology is key: transformation of products into services, leveraging big data and automation and incentives to adopt new technologies (for example, three-dimensional printing) are all aspects considered by the ReSOLVE framework. Therefore, rather than proposing a new framework in this study, the authors decided to build the model on ReSOLVE.

2.3 Big Data and Internet of Things

The big data concept represents the ability to gather, process and analyse massive amounts of structured and non-structured data continuously (53, 54),

Table I Circular Economy-Related Concepts Leveraged by Big Data or IoT According to the Literature Review

Concept	Description	References
Servitisation	Shift from selling products to providing services with an emphasis on use rather than possession. Providers such as Netflix and Salesforce.com are examples of businesses born using the concept. Traditional companies such as Philips (selling lighting services instead of bulbs), Michelin (pay-by-the-kilometre services instead of tyres) and Renault (leasing batteries for electric cars) are shifting some of their business models to servitisation	(19, 70–77)
Sharing economy	Underused products, services or assets made available to third parties, paid or not. Businesses such as TaskRabbit, Thumbtack, Uber, DogVacay, Airbnb and WeWork are examples	(78–84)
Smart cities	Urban spaces leveraged with the use of technology focused on improving the living conditions of citizens or inhabitants	(80, 85–110)

transforming it into useful information for decision-making activities. Researchers have reduced the definition into the basic 4Vs (55, 56): (a) volume, (b) variety, (c) velocity and (d) veracity, representing its main characteristics. Other scholars have improved the definition and extended it with: (e) value (57, 58), (f) validity, (g) visualisation, (h) vulnerability, (i) volatility and (j) variability (59). Big data has already proved its importance for organisations, as for example in the health industry (60), general management (61) and government (24).

IoT is an emerging technology that enables data acquisition, transmission and exchange among electronic devices and targets enabling integration with every object through embedded systems (62). It has three main components: asset digitisation, asset data gathering and computational algorithms to control the system formed by the interconnected assets (63). One relevant data source may be considered for big data. Not only can it support applications such as providing better disease diagnostics and prevention, monitor stocks in real time (64) or aid the transportation of goods, but it also applies to basically any activity involving data monitoring and control, and information sharing and collaboration (65). This emerging term is considered key to enable technological solutions and is receiving industry-specific extensions such as in mining (metallurgical internet of things (m-IoT)) (66), industry (industrial internet of things (IIoT)) (67) and for environmental causes (environmental internet of things (EIoT)) (24, 68).

There are other concepts related to CE being leveraged by big data or IoT. They are described in **Table I**. In the context of CE for this research, servitisation relates to the reuse principle. It improves asset usage rates to their highest utility and value as the product ownership remains with the manufacturer, who is responsible not only for the proper product collection and disposal, but also for extending its lifetime and recapturing value through refurbishment and reuse. Sharing economy also explores the reuse and reduce principles as product owners can collaborate with each other in order to maximise the use of their own assets during their idle periods. For example, studies show cars stand idle for about 95% of the time (69). Smart cities relates essentially to the design principle as it consists basically in planning and reorganising urban areas.

3. Methodology

In this section, all methods applied in this study are explained to ensure research replication and allow validity and reliability confirmation (111, 112). Also, in order to establish an acceptable degree of reliability in the research, the data analyses were triangulated (112) through different methods and techniques as necessary for social science literature reviews (113) to provide a consensus regarding the proposed capabilities list: traditional literature review, basic content analysis, grey literature mapping and experts review and confirmation (proposed model presentation and conformity verification), thus reducing the risks of common biases from inaccurate or selective observations and overgeneralisation (114), as shown in **Figure 2**. Details for each step are presented below.

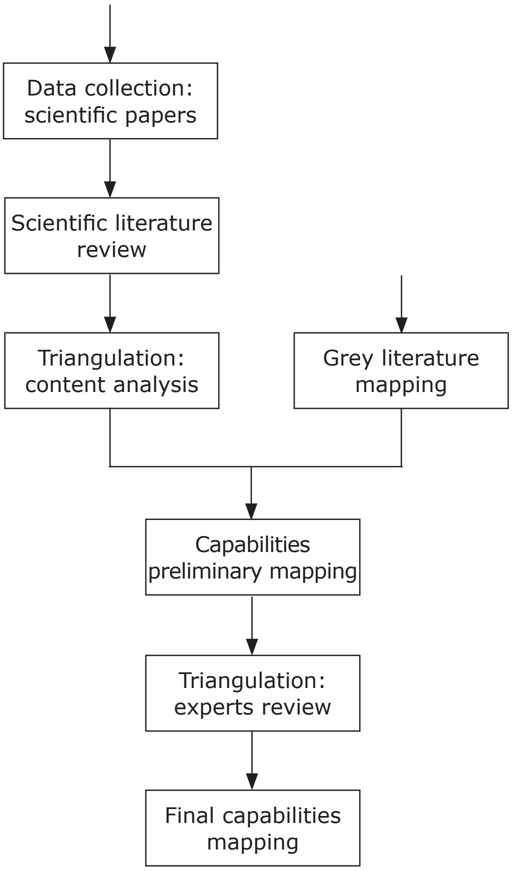

Fig. 2. Research methods applied to the present study

3.1 Data Collection: Scientific Papers

Data collection from scientific databases consisted in two basic steps: data source identification and data extraction criteria definition.

Although some previous published research used only one database source, for this study we combined data from two relevant and robust databases. The first was Scopus®, which is considered to be the largest abstract and citation database of peer-reviewed literature, while the second independent and unbiased database was Web of Science™, known as one of the largest citation databases available and the first in the market. Both provide significant results for English-language journals according to comparative studies (115) and are very consistent with each other (116).

The same query logic was applied for both databases, along with the same filters and constraints, following the recommendations found in a previous published study, thus using similar expressions and precautions with specific taxonomies (19). Query logic for both CE and big data and IoT expressions are shown in **Figure 3** and were applied for document title, keywords or abstract. Coding of key terms and themes to represent both CE and big data or IoT on database queries were obtained from previous research (19) in the absence of a comprehensive taxonomy and are reproduced in Appendix 5. Coding categories criteria are presented in Appendix 6 and the complete and detailed results in Appendix 7. After running the independent queries individually for both databases, the results were combined, generating an integrated result of 370 unique documents for analysis. At this point, no restrictions to document types or relevancy had been applied. Step two consisted of applying the authors' analysis to eliminate incoherent documents. In order to avoid author biases during this phase, objective criteria for document elimination were defined: items retrieved from keywords or abstract but with no direct relation to document contents (for example, abstract mentioning, but document not about big data – term appears in abstract but is not related to it); term appears in document body but as a future research recommendation or indirect implication; namesake term used (such as 'blue economy'). A total of 110 documents were removed from the set after reading. This represented an improvement from previous research (19) that focused only on the bibliometrics part without applying authors' detailed in-depth proofreading and review. Then, non-applicable items such as conference reviews, errata or documents with no content were also discarded, representing a total of 29 documents. Finally, a total of five documents not in English were removed. The final set of documents used in the research consisted of 226 documents. The complete filter process is presented in **Figure 4**.

Previous literature review research was consulted to try to identify other criteria to narrow the number of documents to be analysed to the most relevant. Cut-off methods based on scientific recognition were mapped (48, 117, 118), some of them applying Pareto principles to focus on the most cited articles and author research relevance. Nevertheless, as shown in **Figure 1**, most of the papers retrieved were less than two years old, so relying on scientific recognition by number of citations could have produced undesirable results. Because of this the authors decided to analyse the entire set of articles (226 documents) for this research.

3.2 Scientific Literature Review

Documents were classified according to the following criteria: country and region (Scopus® and Web of Science™ databases do not retrieve

Circular economy query:

```
TITLE_KEYWORD_ABSTRACT = (<List of Terms> OR
     "Reduc*" AND "Reus*" AND "Recycl*") AND
     ("sustainability" OR "sustainable")) OR
     (<Circular economy-like unique terms>)
AND PUBLICATION_YEAR <=2018
```

Big data/internet of things query:

```
TITLE_KEYWORD_ABSTRACT = (<List of Terms> OR
     (("Spark Streaming" OR "MLib" OR "Spark R" OR "Machine Learning") AND "Apache") OR
     (("Hdfs" OR "Cfs") AND "File System") OR
     ("Mizan" AND "Kaust") OR
     ("Presto" AND "SQL")))
AND PUBLICATION_YEAR <=2018
```

Fig. 3. Query logic for Scopus® and Web of Science™, adapted from previous published research with the use of the same lists of terms (19)

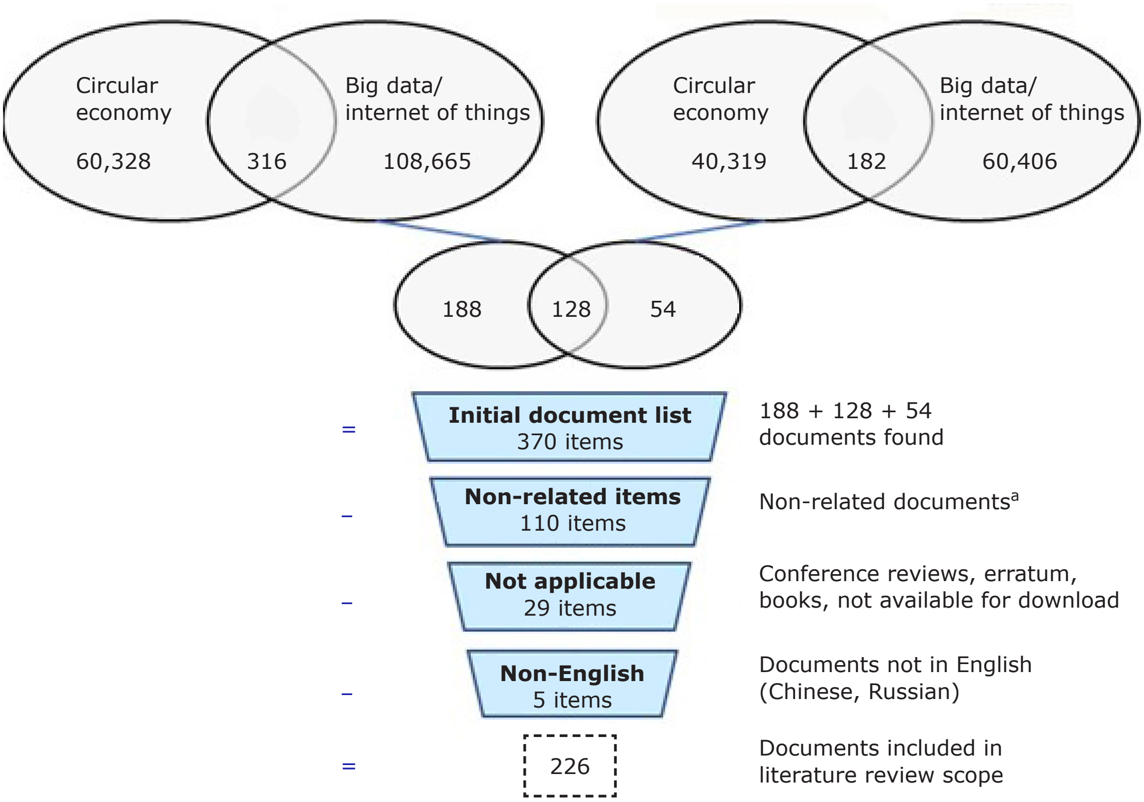

Fig. 4. CE and big data or IoT documents search summary.

([a]Non-related documents: items containing the query keywords but with contents not related to the research subject)

country names. Documents were assigned to countries according to (in this order of priority): author affiliation, main author affiliation, conference location, journal location or source title location, using the same criteria applied in prior research (19)); methodology type, in compliance with similar literature review research (119), composed of: (a) theoretical and conceptual papers, (b) case studies, (c) surveys, (d) modelling papers and (e) literature reviews; industry, according to the Standard Industrial Classification (SIC) codes assigned by the

US government to business establishments to identify their primary business (120); and related CE principle according to the classification mapped for this research (20), divided into: (a) design, (b) reduction, (c) reuse, (d) recycle, (e) reclassification and (f) renewable energy.

Due to the considerable number of documents used in the review (226 after initial screening), the complete list with corresponding classifications is available in Appendix 7.

3.3 Triangulation: Content Analysis with Word Cloud

Word cloud is a tool that generates a visualisation in which the more frequently used words in a given text are highlighted. Although it provides good presentation and is visually appealing, it does not provide useful information when applied alone, but can perform well as a supplementary tool to help confirm the findings and related interpretations (121). So to support the research results confirmation, all 226 documents selected were converted into a robust text corpus and went through data mining with the support of 'R' statistical tool (122), so that expressions of more occurrences were ranked.

In order for the analysis to be accurate, compound expressions (bigrams, trigrams and four-grams) were bound together into single words prior to word cloud execution. Despite the existence of formal methods and patents for automated compound expressions generation (123), the authors decided to create the database manually due to the heterogeneity of subjects under analysis (i.e. CE, big data, IoT), so automatic conversion risks were avoided. The complete list is available in Appendix 4.

The authors then cleansed the results according to the following steps: (a) concatenation of expressions (for example, big data to bigdata); (b) unification of same meaning of words (for example, recycling and recycled for recycle); (c) separation of similar word with different meanings (building not the same as build); (d) removal of punctuation, numbers, URLs; (e) case conversion; (f) singularisation (for example, feet unified with foot); and (g) removal of stop words (function words such as 'which', 'the', 'is', 'in', verbs and auxiliary words) based on International Organization for Standardization (ISO) and snowball sources (124), combined with a customised list compiled by the authors and also shown in Appendix 4. The word cloud image was also generated with 'R'. The following libraries were used in the analysis: ggplot2 (125), githubinstall (126), pluralise (127), RWeka (128, 129), SnowballC (124), stopwords (130), tm (131, 132), wordcloud (132).

3.4 Grey Literature Mapping

There are a number of non-academic institutions, such as government agencies, private businesses and non-governmental organisations (NGO) developing successful practical CE initiatives that need to be taken into consideration as both the subject matters – of CE and big data or IoT – are still emerging and evolving scientifically. Finding literature and information on this particular area of research required the use of non-scientific sources (134). Moreover, recent studies indicate that there are benefits for including grey literature in reviews: overall findings enrichment, bias reduction and to address stakeholders' concerns (135), which are all relevant for this research. Furthermore, there is known to be a gap between the academic world and practitioners for this research subject (19).

The complete list of supplementary grey literature sources used to enrich the analysis is presented in Appendix 3.

3.5 Triangulation: Experts Review

The resulting preliminary framework was submitted to a group of eight domain experts who individually analysed the capabilities to assess the content clarity and representativeness, and to provide insights on items that could be revised or added to the list so that the authors could map additional research sources to be studied. The domain experts were selected first according to methods presented in the literature: type of knowledge, type of service and type of expertise (136). After identifying the experts, accessibility was considered as a second filter. A few conflicts identified were addressed with additional grey literature confirmation and were considered positive as they are common and important in social sciences (137). Expert contributions not verified in the literature were discarded. The list of domain experts is presented in Appendix 2.

Part II (34) will describe the results, conclusions and future recommendations of this research.

Acknowledgements

The authors would like to thank the Núcleo de Economia Circular (NEC) Group and Exchange for Change Brasil (e4cb), among other equally relevant experts during data gathering and validation for their outstanding contribution and for the constructive criticism provided throughout all the research activities.

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Brazil: Finance Code 001.

Appendices

The following Appendices may be found in the Supplementary Information included with the online version of this article:

Appendix 1 Top publications by source (scientific journals with more than one publication); publishing institutions; top journal articles on circular economy with the use of big data or IoT ordered by year / author
Appendix 2 Participating domain experts consulted during capabilities validation phase
Appendix 3 Grey literature used in the research
Appendix 4 Word cloud generation considerations
Appendix 5 Complete query logic reproduction for both Scopus® and Web of Science™ databases
Appendix 6 Coding categories criteria for the 226 mapped documents
Appendix 7 Complete document list with corresponding attributes mapped
Appendix 8 Selected practical case studies mapped during the literature review
Appendix 9 CE frameworks
Appendix 10 Statistical software 'R' code applied

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