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Article

An Overview of Fifty Years of Appropriate Technology Research Using Bibliometric Analysis

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Appropriate technology (AT) has developed from an economic theory in the early 1970s into a broad multidisciplinary research methodology that is incorporated into many sustainable development fields. AT is an important tool in the fight against current global challenges, such as climate change and poverty. Hence, a bibliometric analysis of the AT research field over the last fifty years was performed to provide insights into the field and its current hot topics. Since the early 2000s, there has been a rapid increase in the number of papers and citations in the AT field, indicating that the AT methodology is increasingly applied in research. Over time, the fraction of single-author papers has decreased (and the number of authors per paper has increased), indicating that AT topics are attracting the interest of larger research groups. Although AT is often applied in developing countries, the most influential countries with respect to research were generally the English-speaking countries (e.g., USA, UK, and India), along with China, Germany, and Spain. This was attributed to English being the lingua franca of research, more than an accurate representation of the application of AT. A keyword analysis identified that economic development, environment, health, and agriculture were the most popular AT topics over the last fifty years. Since 2005, topics such as computing and telemedicine began increasing in popularity, while in the past three years, automation-and-control, and smart-city topics have emerged. Bibliometric analysis is a valuable research tool for providing insight into the overall AT field.

KEYWORDS: Appropriate technology, Bibliometric analysis, Sustainable development, Review, Scientometrics

Introduction

We live in an unprecedented era of technological development and abundance of resources. However, because of the poor global distribution of resources and profit motive of the global capitalistic structure, there are still unacceptable levels of poverty and environmental destruction. Despite the trillions of dollars invested globally in research and development (R&D) every year (UNESCO Institute for Statistics 2019), the majority of this R&D does not address the major problems and challenges facing the world. Much of the investment in science and technology ends up benefiting only a few, while technologies that could literally save lives are not available to those who need them. The World Health Organization reported that around 6 million children died in 2018, mostly from preventable causes (World Health Organization, 2019). In most of the major economies in the Americas, Europe, and Asia, the majority of R&D is performed by business enterprises (UNESCO Institute for Statistics, 2019) that need to recoup investments by producing commercial products. The current model of technological development results in the restriction of much knowledge by intellectual property laws (Pearce, 2012).

The appropriate technology (AT) movement originated to address global challenges by developing and applying technology where it is needed for sustainable development. AT has been defined as "*any object, process, ideas, or practice that enhances human fulfilment through satisfaction of human needs*" (Hazeltine, 2003). In this sense, "technology" is considered in its broadest definition as a tool or methodology, rather than a specific piece of hardware. A technology is defined as being "appropriate" when it meets the needs of the specific community, culture, and environment in which is it applied. Hence, AT is designed considering the social, cultural,

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political, economic, and other regional influences. AT is usually small-scale, decentralized, environmentally friendly, energy-efficient, and simplified to the point that it can be implemented with local resources and materials (Schumacher, 1973). In the case of developing countries, many advanced technologies are prohibitively expensive and complex, and intermediate technologies based on locally available materials are often sufficient solutions. In addition, AT describes a method for providing for human needs with the least impact on the planet's finite resources, while being socially appropriate for the target region. AT is not a specific system or device, but a method for evaluating a technology and its social, economic, and environmental impact in a specific application. While often implemented in developing countries, AT is a valuable tool for producing effective and efficient customized solutions to a wide range of problems.

In its most basic form, AT is simply a modification of a desired technology to meet local needs. This has been common among poor rural communities for centuries, where lack of resources had to be replaced by innovation and creativity. The birth of the AT movement and the increasingly popularity of the term "appropriate technology" occurred in the early 1970s. In 1973, Schumacher published a seminal text "Small Is Beautiful: A Study of Economics As If People Mattered," (Schumacher, 1973) which criticized widespread globalization, arguing that the economic development provided by large-scale industry comes at the cost of deteriorating culture and resource depletion. He argued for "intermediate technology" and smaller customized solutions. During the early days of the AT movement in the 1970s and 1980s, this concept was almost exclusively discussed with respect to economic development and distributed grassroots technology for rural self-sufficiency (Hollick, 1982). Today, there is a very broad application of AT in numerous fields, including agriculture, economics, water science, medicine, computer science, materials science, automation and control, and sustainable development.

Recently, there has been a push toward open-source AT (OSAT), which includes technologies that enable sustainable development while being freely available, in the same way as open source software (Pearce, 2012). By removing the restrictions placed on technology by intellectual property laws, OSAT can be rapidly implemented anywhere and by anyone. The enormous success of Linux and other open-source software has clearly demonstrated that development of open-source software is faster and results in a better product than licensing (Amrollahi, Khansari, and Manian, 2014). This is due to the many thousands of people using, debugging, and improving Linux code. This same methodology is now being applied to hardware. In particular, the recent advancements in 3D printing have been very rapid due to projects such as RepRap ("RepRap.Org" 2020), which provides open source designs for self-replicating 3D printers. Appropedia ("Welcome to Appropedia" 2020) provide an extensive wiki of AT hardware and software. Open Source Ecology (Thomson and Jakubowski, 2012) are developing a "civilization starter kit", including open source designs for a tractor, hydraulic power system, and brick press. Feedback from an increasingly large community of people who build, test, and improve the designs results in rapid advancements. Open-source solutions are expected to be highly disruptive, as they are becoming superior products to those currently on the market. When a technology is licensed or patented, there is an incentive to keep producing the same product (i.e., that defined by the intellectual property document) to pay off the investment in R&D and licensing. However, as such technology is not extensively developed, it will quickly become obsolete and not be able to compete in the rapidly changing market. OSAT is changing the paradigm of technology and providing resilience in this rapidly changing world as it is supported by a distributed network of contributors. The barriers of location, education, and income are broken down, as backyard inventors have the same opportunities to contribute to a technology as professional scientists and engineers. This provides an unprecedented potential for creativity and the development of AT to address critical global issues.

As the AT methodology is applied in a wide range of fields, and is often not identified by consistent terminology, it is difficult to obtain an overview of the trends in the research field as a whole. Most recent reviews of AT have focused on its use in specific fields: such as water and sanitation (Murphy, McBean, and Farahbakhsh, 2009), education (Carmichael and Honour, 2002), sustainable development (Pearce and Mushtaq, 2009; Pearce et al., 2012), engineering (Sianipar et al., 2013), and materials science (Pamatang et al., 2014); or in specific regions (Fressoli and Arond, 2015). In addition, much AT is developed by grassroots groups that generally do not publish their research in peer-reviewed journals. For this reason, it is difficult to provide a brief literature review than sufficiently reflects the diversity and overall trends in the development of

AT research. A good review of AT literature was published in 2015 (Lissenden, Maley, and Mehta, 2015). The authors make the point that academic literature does not provide a clear framework for AT for informing the development of successful projects, and the scholarly discussions are "vague and disjointed."

Considering these difficulties in extracting insights about the AT field using conventional literature reviews, AT is a prime example of a field suitable for analysis by emerging methods. The recent development of tools for analyzing big data is providing new opportunities for obtaining novel insights into research fields by evaluating the scientific literature. Bibliometric analysis uses the information contained within abstract databases to answer specific research questions, or provide an overview of a broad field. The aim of this study was to analyze the development of the broad AT research field over the past fifty years. Bibliometric tools were used to analyze the available data for AT research, and to develop insights into the trends and future research directions that are difficult to obtain via standard reviews of the literature.

Methods

The citation data used in this study was extracted from Dimensions, an inter-linked research information system provided by Digital Science (Digital Science, 2020). In addition, The Bibliometrix package in R (Aria and Cuccurullo, 2017) and the Biblioshiny web interface were used for extracting and analyzing the data. The search term "appropriate technology" was used to locate literature in the citation database with this term appearing in the title or abstract of the paper. Hereafter, "articles" will be used to refer to all of the data sources, which were predominantly peer-reviewed scientific papers, but also included conference proceedings and some books. Few articles were published before 1975 as the term "appropriate technology" was still quite unknown. Therefore, the search was conducted from 1975-2020. The data for 2020 was omitted from some analyses as the year was incomplete when the analysis was performed. The obtained list of citations was filtered to remove incomplete or duplicate articles, giving a final dataset of 3213 documents. Errors in the dataset highlighted by the analysis software were manually checked and corrected. This dataset is undoubtedly incomplete, considering that many technologies that would fit under the definition of AT are not specifically described as such. However, the main motivation of this study was to identify research that is clearly following the design principles of AT. Hence, this was considered a representative dataset for further analysis. Network visualization of the data was performed using VOSviewer, which organizes the data into a network based on clusters of related topics and displays a network map based on the interconnectedness of the clusters (Van Eck and Waltman, 2010). This software uses state-of-the-art algorithms for network layout and clustering and was specifically developed for bibliometric data, where the user can fine-tune the layout based on selected parameters of interest. In addition, the data can be cleaned to limit the influence of publications with many authors, citations, or references. The data for preparing the VOSviewer maps was extracted from the Microsoft Academic database (Hug, Ochsner, and Bra, 2017) using the same date range and keywords as used in the Biobliometrix analysis.

These methods allowed analysis of various aspects of the citations, including: the annual production of papers (total and per country); annual citations (total and per country); most relevant sources; most productive countries; most frequent keywords; and statistics related to the authors and their affiliations. Before analysis of the keywords, general terms related to the type of study (such as "study", "evaluation", "analysis", and "approach") were omitted to focus on the more relevant terms related to the field of study and application area. When "author" was used as a parameter to group the data, the first author was used. To define the country of publication, the country listed as the affiliation of the corresponding author was used.

Results

Figure 1 shows the total annual production of articles and annual mean total citations (MeanTCperYear = mean total citations per paper divided by the number of citable years) for the time period of 1975-2019. Before 1980, there were less than 50 articles published per year related to AT. This was probably due to the fact that the term "appropriate technology" was only starting to gain popularity in the 1970s and was therefore an uncommon keyword. Between 1980 and 2005, the annual number of papers was quite constant (40-50 per year), followed by an exponential increase from 2006 to the present, with nearly 300 papers published in 2019. The

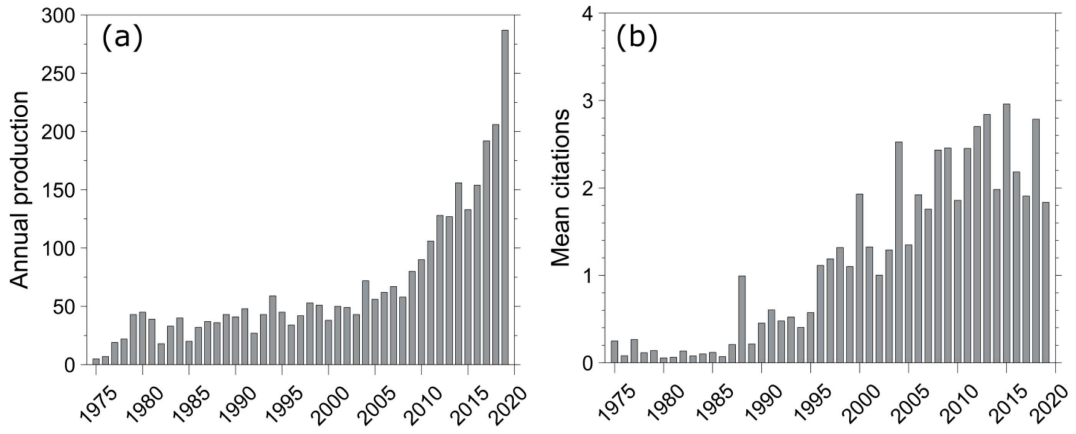

Figure 1. (a) Total annual production of articles and (b) total number of citations per article per year, for the time period of 1975-2019.

MeanTCperYear was very low before 1990 and has experienced approximately linear growth since then. It is interesting that there is an offset of around 15 years between the rapid increase in the number of citations and that of the research output. This perhaps indicates the lag in the research environment between interest in topic being sparked, and a major increase in published output.

Overall analysis of the dataset of 3213 documents (1975-2020) showed that the articles were published in 1860 different journals and books. This clearly shows that AT research is published in a wide range of topical journals, rather than being focused in several popular journals. Interestingly, nearly a third (1030) were single-author articles, with an average of 2.68 authors per paper. The fraction of single-author articles and the number of authors per article are shown over time in Figure 2. Note that data before 1985 were omitted due to the very small datasets with high scatter. The horizontal lines on the graphs indicate the average values over the entire time period analyzed. Up until the early 1990s, the majority of articles were published by a single author. The fraction of single-author papers has decreased quite linearly over time, to around 10-20% in recent years. A similar trend is observed for the number of authors per paper, which has increased steadily over time. A high fraction of single-author papers and few co-authors could indicate that most AT research is being performed in small research groups. However, the trends over time suggest that the degree of collaboration is increasing, along with the number of researchers involved in AT research (consistent with the rapid increase in scientific production shown in Figure 1). At its core, AT is highly customized, which makes it inherently unsuitable for producing a generic and profitable product. In this sense, AT is not attractive to large R&D groups in business enterprises (where most research funding is directed (UNESCO Institute for Statistics

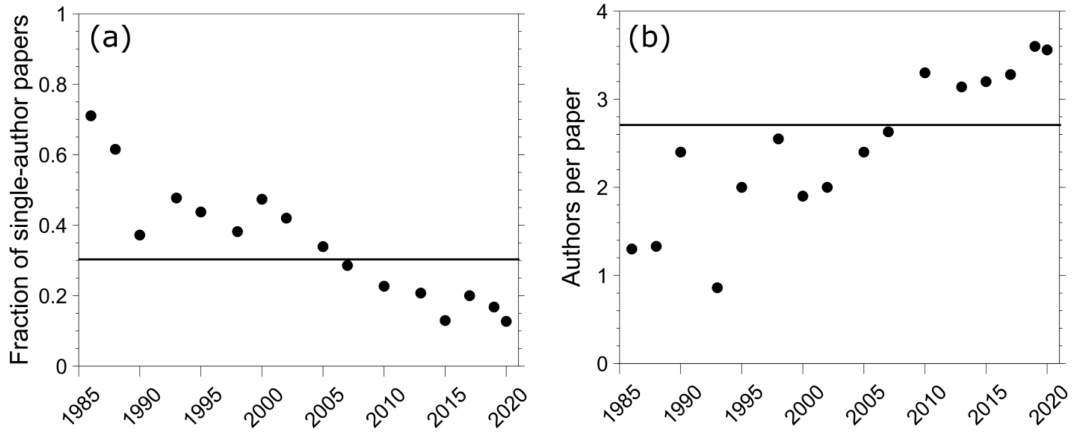

Figure 2. (a) Total annual production of articles and (b) total number of citations per paper per year, for the time period of 1975-2019.

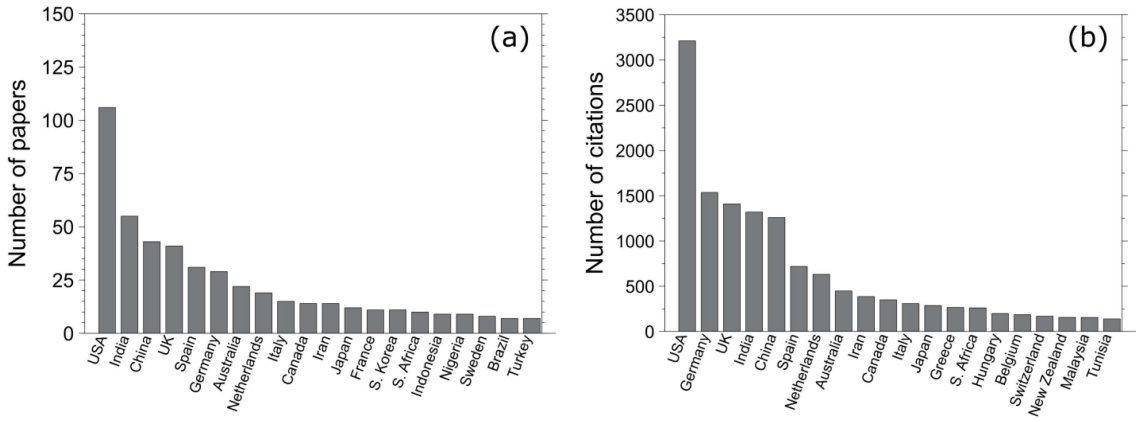

Figure 3. (a) Most relevant countries by corresponding author; and (b) the total number of citations by country.

2019)). Hence, AT research is commonly performed in government-funded and academic institutions, along with smaller non-profit and community groups.

Figure 3 shows the top twenty most relevant countries in AT research, ordered by the country of the corresponding author, or by the total number of citations. The full list of data is shown in Supplementary Information Table S1. In both cases, the top eight countries were the same (USA, India, China, UK, Spain, Germany, Australia, and the Netherlands). The USA was clearly rated in first place in both cases, consistent with it being the country that invests the most in R&D (UNESCO Institute for Statistics, 2019), while the order of the other top countries changed slightly. The 15 most influential AT institutes are shown in Figure 4(a), where the Asian universities (particularly in Indonesia) held many of the top places. The full list of data is shown in Supplementary Information Table S2. The collaboration map in Figure 4(b) shows the relationships between the countries of the collaborating institutes. It is clear that the USA is the most common collaborating partner, usually with institutes in Europe, Australia, or Asia; this is consistent with the well-established research links between these countries. The African countries nearly exclusively collaborate with European institutes, attributed to the recent focus of the European Union on partnerships with Africa, such as the Joint Africa-EU Strategy, which was adopted at the second EU-Africa Summit in Lisbon in 2007 (The European Union, 2007).

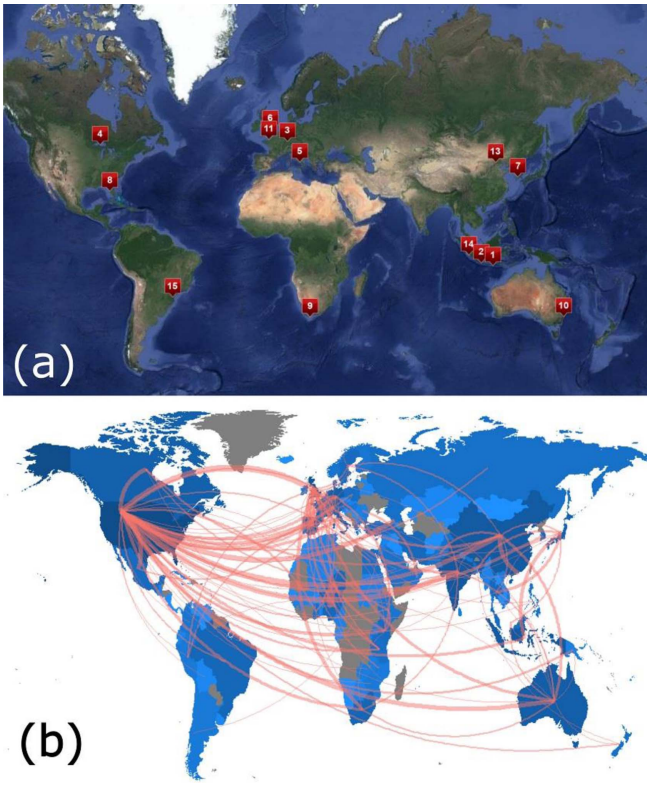

Figure 4. (a) Map of the 15 most relevant AT institutes; and (b) a collaboration map showing the relationships between the countries of the collaborating institutes.

Figure 5(a) shows a visualization of the common keywords clustered into topics. Larger circles and text indicate higher occurrence of the phrase as a keyword. Analysis of the keywords yielded 6 main topic clusters. As expected, nearly 50% of the most-frequent words were related to AT, while the five other major clusters were related to development and economics; water and the environment; education; medicine; and agriculture. Simplifying the map to remove "appropriate technology" and using keywords with a minimum of 10 occurrences gave the map shown in Figure 5(b), where the most significant keyword became "developing country". This

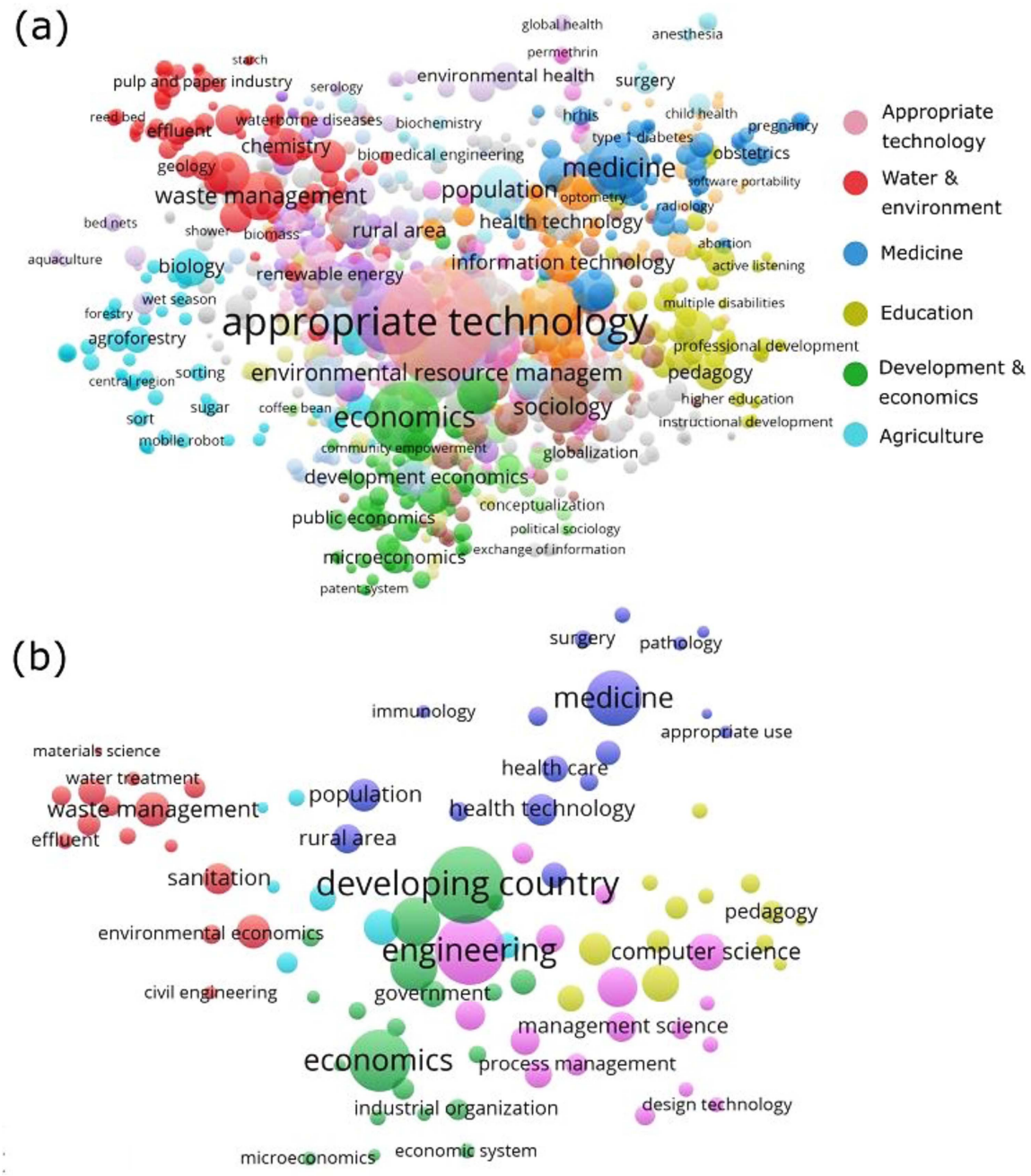

Figure 5. Visualization of the common keywords clustered into topics. (a) Detailed and (b) simplified keyword maps.

indicates that, despite the dominance of research groups from the developed world (as shown in Figure 3), the intended application of most AT is for aiding development. The full list of keyword occurrences is shown in Supplementary Information Table S3.

The 20 most relevant sources (e.g., journals and proceedings) are shown in Supplementary Information Table S4. The top three journals were Water Science and Technology, IOP Conference Series Earth and Environmental Science, and IFAC Proceedings Volumes. From the top 20 sources, 6 of these were categorized as development and sustainability; 4 as materials science, engineering, and physics; 3 as water and the environment; 3 as energy; 2 as medicine; and 2 as automation and production. These topics are similar to those identified by the keyword analysis shown in Figure 5.

Figure 6 shows an analysis of the top 50 most cited papers

for the entire time period analyzed (1975-2020). Table S5 in the Supplementary Information lists these data. Overall, environmental topics were the most cited, followed by medicine, energy, and automation and computing. Despite the fifty year history of the field, most of the well-cited papers were published in the last twenty years. Further, these data were analyzed in 5-10 year ranges to observe the changes in the research trends over time. In the 1980s, most of the most cited papers were related to economic development, health and medicine, and agriculture. In the 1990s, the predominant topics were health, environment, and agriculture. In the 2000s, the most frequently cited papers were mainly related to agriculture, water use, and other environmental issues. From 2005, topics such as computing and telemedicine began increasing in popularity. In the last five years, energy and the environment have continued to be the most cited topics. However, in the past three years, there has been an increasing trend towards topics such as automation and control, signal processing, computing, and smart cities. This is consistent with the rapidly increasingly research interest in a *smart world,* otherwise known as the "Internet of Things (IoT)" (Stankovic, 2014), which is being enabled by advances in sensing devices, telecommunications, big data analysis, and artificial intelligence. This move into high-tech fields is an interesting expansion of AT research, which had its origins in low-tech rural self-sufficiency applications. The previous generations of telecommunication technology, namely, mobile phones (Rashid and Elder, 2009) and internet (James, 2020) have been shown to greatly aid development, particularly in small-scale entrepreneurship and education. On a national scale, implementation of such networks is valuable for e.g., predicting the spread of diseases, monitoring participation in democratic processes, and providing warning of impending natural disasters. Therefore, as the IoT is expected to be a disruptive technology with wide ranging benefits for public health, education, energy efficiency, and communication, it is important that corresponding AT is developed to facilitate the global application of IoT to allow all countries to benefit from its potential.

Discussion

Some limitations of this study should be noted. First, although care was taken to choose an appropriate dataset for evaluation, the quality of the original data can be affected by data input errors in the database. Certain journals use different standards for e.g., journal abbreviations, citation types, and the use of the volume/number. In addition, there are different indexing standards used for different databases. Previous bibliometric studies highlighted such inconsistencies and compared the results of bibliometric analyses using data from some of the most popular databases (Hug, Ochsner, and Bra, 2017). However, the extracted data is thought to be a sufficiently representative sample of the field for observing broad trends in the research directions. Many of the trends observed in the bibliometric data are consistent with global trends, such as the increasing importance of environmental topics, the emergence of IoT technology in the last ten years, and the growth of open-source technology. Hence, the findings of this study are considered qualitatively consistent. Compared to previous literature reviews of AT, bibliometric methods have the potential of providing less-biased and more complete conclusions.

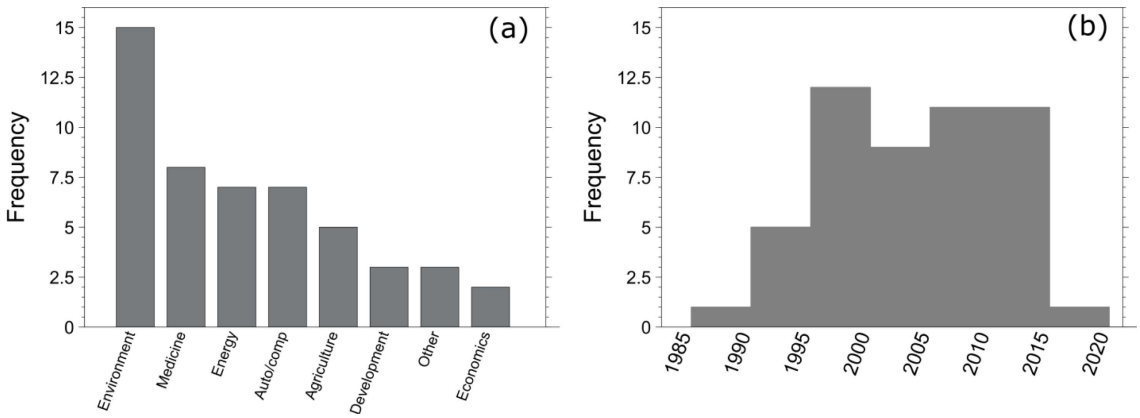

Figure 6. Analysis of the top fifty most cited articles sorted by (a) topic or (b) 5-year range of publication dates.

For example, in the literature review of Lissenden et al. (Lissenden, Maley, and Mehta, 2015), 43 papers were manually selected by the authors with the aim of reflecting the diversity of the field over a period of 35 years, and were used to extract some insights into the changes in the basic tenets of AT over time. This is a very small number of studies (compared to the more than 3000 included in the present analysis), and selection of papers by the subjective opinion of the authors can introduce bias.

Second, this study was limited to articles written in English. The use of English as the *lingua franca* of science is well known and it has been well documented that the so-called "inner-circle" countries with English as an official language have a disproportionately large share of publications and citations (Tardy, 2004). This was clearly observed here, where the USA, commonwealth countries (UK, Australia, and India), and European countries with a high level of English as a second language (e.g., Germany and the Netherlands), were ranked highest in terms of output and citations. In the case of the USA and China, their enormous R&D budgets compared to other countries certainly contribute to their dominance. Performing similar searches over the same time period for articles in Spanish or French revealed a total of only 38 or 11 entries, respectively (compared to over 3000 in English). Many non-English-language journals are not indexed in abstract databases, resulting in a skewed perception of the research field. Furthermore, the analysis method defined the country of publication as that of the corresponding author, which could introduce further bias as native-English-speaking authors may be selected to perform the correspondence with journals if their co-authors feel uncomfortable doing so. In addition, the natural-language processing algorithm used by VosViewer and other bibliometric software are trained based on English-language papers, which could skew the visualization of the data.

Furthermore, the number of publications and citations are important metrics by which researchers and their institutes are evaluated for funding opportunities. Hence, non-inner-circle institutes are severely disadvantaged. In addition, high-quality science can be rejected based on the poor language skills of non-native English speaking researchers. This is a particular area of concern in AT research as many of the most promising applications are providing solutions to the basic needs of millions of people who development left behind. To effectively implement AT, a good understanding of the social, political, and environmental structure of the location is required. Therefore, the local population is often the most appropriate researchers as they have the required knowledge of these issues, even if their technical knowledge is lacking. This may explain the clear trend of widespread collaboration with institutes in the USA, which may provide better funding opportunities and visibility to research groups in non-inner-circle countries.

Finally, AT is an extremely broad field, and many technologies being developed around the world meet the definition of an AT, without necessarily using this terminology to describe it. However, the term "appropriate technology" was selected to limit the extracted articles to those in the main fields and identify groups who intentionally use the concepts of AT to guide their research. It should also be noted that many ATs are developed by grassroots groups that do not publish their inventions in peer-reviewed journals. Such contributions fall below the radar of such analyses.

Unfortunately, there are few journals specifically targeting AT. The magazine *RAIN* (ECO-NET, 2020) was published from 1974 to 1996 as *"a journal of organizers publishing news, research, and interviews on the topic of building successful community projects,"* and was highly focused on projects in the northwest of the USA. Technical documents are also published by Practical Action (Practical Action, 2020), which is a policy and advocacy group based on the work of Schumacher. They publish books and some journals (*Enterprise Development & Microfinance*, *Waterlines*, and *Food Chain*) and are indexed by Google only. The journal *Appropriate Technology* is published by Research Technology, Ltd. and focuses mainly on AT for agriculture. The publisher is based in the UK, but the journal also has a French version. These publications are outside the major publishing houses and are not indexed in the most common databases. Hence, the research is not highly visible to other researchers. One benefit of such journals is that they often have less stringent publishing requirements than indexed journals, which can facilitate the dissemination of case studies and community projects that may not meet the standards of complete scientific studies, but have valuable knowledge to share. Although AT encompasses a broad range of topics, the implementation of all AT faces similar challenges. The *Journal of Appropriate Technology* is currently the only comprehensive well-index journal focused entirely on AT and

its common challenges. The advantages of interdisciplinary research is being recognized in many fields, and hopefully the AT community will have more forums for collaboration in the future. The lack of bilateral knowledge exchange has been cited as a major gap in AT development (Lissenden, Maley, and Mehta, 2015).

Conclusions

This study analyzed the past fifty years of AT research through bibliometric analysis of datasets from a citation database. The bibliometric method proved to be a valuable tool for providing insights into the historical development and research trends in AT. While early AT research in the 1970s and 1980s was mainly related to economic development and agriculture, the scope of AT has grown significantly to encompass a wide range of fields. The scientific production and number of citations of AT-related articles are increasing every year, indicating that AT is becoming increasingly important in global research. By definition, AT aims to provide technological solutions to current global challenges. Hence, the dominant research topics have changed over the years, reflecting the increasing social preoccupation with environmental issues and public health. An interesting recent trend is the major increase in AT applied for automation, computing, and IoT applications. AT research is expected to increasingly contribute to these high-tech fields, further expanding its reach from its origin in low-tech rural applications. Although AT is applied to many different multidisciplinary fields, the application of AT has similar challenges, and the field would benefit from having specific journals and forums to share these experiences.

Acknowledgements

Data sourced from Dimensions, an inter-linked research information system provided by Digital Science (https://www.dimensions.ai) and Microsoft Academic.

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