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INDUSTRY 4.0: GLITTER OR GOLD? A SYSTEMATIC REVIEW

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ABSTRACT

Publications on the fourth industrial revolution have skyrocketed since its establishment in 2011, both in academic and non-academic channels. Even though their measurable results have been published in non-academic material, especially among industry and business reports, within the academia it is still unclear how they are shown. This study aims to review and analyse the presence of industrial results within the academic context in a systematic manner by using the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) methodology. The findings indicate an increase trend of this type of publication within the academia and further directions are suggested.

Keywords: Industry 4.0; outcome; results; PRISMA.

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1. INTRODUCTION

The manufacturing industry context has been taking big steps towards innovative advances leading to paradigm shifts. Starting from the use of mechanisation (the so-called 1st industrial revolution in the 18th century), going through the intensive use of electrical energy (the so-called 2nd industrial revolution in the 19th century), and culminating in the widespread digitalisation (3rd industrial revolution in the 20th century) (Lasi *et al.*, 2014).

In the early 2010s, Germany has taken the lead in what has been called "The 4th industrial revolution". Kang *et al.* (2016) take this movement as a revolution and summed it up as a "collection and a paradigm of various technologies that can promote strategic innovation of the existing convergence of humans, manufacturing industry through technology, and information". However, no universal agreement on what constitutes an "industrial revolution" has been met yet (Maynard, 2015).

Whether the recent technological advances can be taken as a revolution or not, it triggered several different innovations such as: the development of new business models, an application-pull and a technology-push in industrial practice (Lasi *et al.*, 2014). It is relevant to emphasise that this pathway of new technologies has a sustainable engineering bias embedded within it. For instance, Siemieniuch, Sinclair *et* Henshaw (2015) made a collection of 'global drivers' (such as population demographics, food security; energy security; community security and safety) to pose a direction of thinking when deploying such actions.

Governments and industries worldwide, aware of this trend, have been taking actions to benefit from what this set of advances can provide. Table 1 shows a list of programs by country (Liao *et al.*, 2017).

Even though many countries have been joining efforts towards this "revolution", the academia/industry bonding is still hard to stablish. In recent years, there has been an increase in publication on this topic; however, the state of knowledge is still relatively fragmented and tentative (Perkmann *et al.*, 2013). One possible explanation for why such framework exists is the challenge in linking tangible and intangible inputs and outputs and capturing their relationship and value. This relationship is especially intractable when one tries to link intangible inputs (knowledge and skills) with tangible outputs (money or another measurable ROI) (Carayannis *et al.*, 2014). This lack of systematisation hinders both research and cross-sectional studies.

Because of this weak link between the academia and the industry, the tangible results coming from the Industry 4.0 might not be placed in a systematic way among indexed databases. Looking at this context as well as the different technologies that they encompass a question arises: *Within the academic database SCOPUS, what is the current status of the measurable results from the industry?*

Therefore, in order to provide an appropriate answer to the stated research question, the objective of this paper is to review and analyse the presence of industrial results within the academic context in a systematic manner.

The rest of this paper is organised as follows. Section 2 presents the fundamental review principles and the systematic literature review method. Section 3 illustrates the obtained results via charts and tables. Section 4 contains the discussion of the findings, aiming to answer the research question. Section 5 concludes this paper and suggests next steps.

2. PRINCIPLES AND METHODS

A literature search of internet-based bibliographic databases was completed identifying research that had looked at tangible outcomes within the possible uses of Industry 4.0.

Table 1. Initiatives by country

Date	Country	Plan/Initiative	Source
2011	United States	Advanced Manufacturing Partnership (AMP)	(Reif; Jackson; Liveris, 2014)
2012	Germany	High-Tech Strategy 2020	(Henning; Wolfgang; Johannes, 2013)
2013	France	La Nouvelle France Industrielle	(Ministère du Redressement Productif, 2013)
2013	United Kingdom	Future of Manufacturing	(Government Office for Science, 2013)
2014	European Commission	Factories of the Future (FoF)	(European Commission, 2013)
2014	South Korea	Innovation in Manufacturing 3.0	(kang et al., 2016)
2015	China	Made in China 2025	(Li, 2015)
2015	Japan	The 5th Science and Technology Basic Plan	(Cabinet Office, 2015)
2016	Singapore	RIE 2020 Plan (Research, Innovation and Enterprise)	(Ministry of Trade and Industry, 2015)

Source: Compiled from Liao *et al.* (2017)

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Table 2. Inclusion and exclusion criteria and their explanations.

I/E	Criteria	Criteria explanation
Exclusion	Search engine reason (SER)	A paper has only its title, abstract, and keywords in English but not its full-text
	Without full-text (WF)	A paper without full text to be assessed or invalid DOI
	Non-related (NR)	There is no measurable result from the application of 'the fourth industrial revolution' tools
Inclusion	Partially related (PR)	A research about the outcomes of the fourth industrial revolution without mentioning Industry 4.0 or using it as background/keyword
	Closely related (CR)	The research efforts of a paper are explicitly and specifically dedicated to the results produced by the deployment of the Industry 4.0

Source: The authors' own (2017)

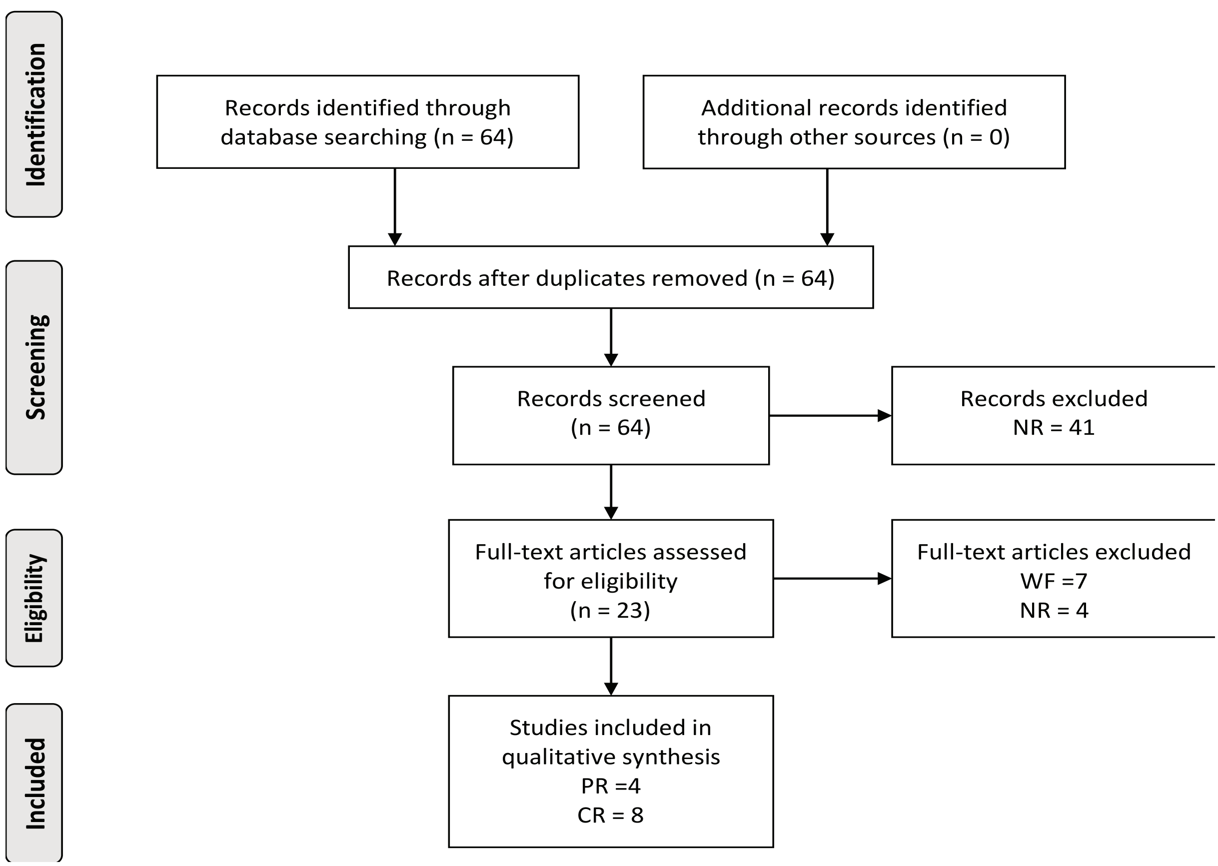

Figure 1. The PRISMA flow chart that reports the different phases of the systematic literature review

Source: The authors' own (2017)

The search was conducted using the Scopus database. All searches were limited to the following conditions:

1. Document type: Academic article
2. Language: English
3. Year: From 2011 to 2017

In order to define the search terms, three post-graduation researchers on the topic discussed and reached a consensus[1]. Then, the terms were tested in the databases to check whether they would fit the purpose. The final search was made by using the following terms: *"Industry 4.0" AND (outcome OR result)*.

1 The definition was made by a major meeting to pose the research proposal and align the expectation among them. After one week, another meeting was made in order to reach an agreement towards the search terms.

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In order to reduce the subjectivity when analysing the selected papers, two fundamental review principles were defined:

- Explicit inclusion and exclusion criteria: As shown in Table 2, there are five outlined criteria for including or excluding collected papers, as well as their subsets.

- Reducing subjective judgement: Each paper with unclear link between Industry 4.0 and its outcomes should be reviewed by a second examiner (researcher with enough knowledge in the area and able to discuss a better placing within the categories from Table 2.

The search was carried out using the guidelines of PRISMA, which stands for Preferred Reporting Items for Systematic reviews and Meta-Analyses (Moher *et al.*, 2009). This methodology was developed based on the definitions used by the Cochrane Collaboration (The Cochrane Collaboration, 2011), a global healthcare network focused on the way health decisions are made. The main ideas embedded in PRISMA are the iterative process and the efforts towards the reduction of assessment bias. The PRISMA framework is presented in Figure 1 and a simplified pie chart of the classification is shown in Figure 2.

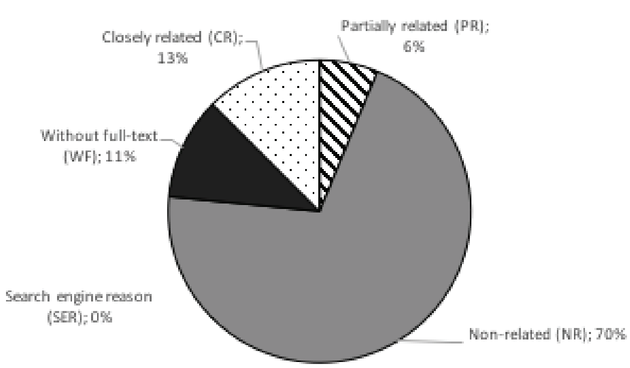

Figure 2. Proportion of papers in each category
Source: The authors' own (2017)

2.1 Paper Collection

The systematic search used SCOPUS as database to collect academic research that (1) were published online before the beginning of September of 2017; (2) contained at least one of the identified terms in either the abstract, title and keywords; (3) were published in academic journals; (4) were written in English.

The first screening process was carried out to exclude articles where their abstract did not contain measurable results coming from the application of 'the fourth industrial revolution' tools (NR). Then, all papers that passed the initial screening process had their full texts downloaded and analysed in order to exclude papers where there was no access to their full texts (WF). Some papers could not provide a clear judgement from the abstract screening and were fully read to be categorised according to whether the article has no application of any measurable result from the use of Industry 4.0 tools (NR); whether the research talks about the outcomes of the fourth industrial revolution without mentioning Industry 4.0 or using it as background/keyword (PR); and whether the research efforts of a paper are explicitly and specifically dedicated to the results produced by the deployment of the Industry 4.0 (CR).

3. RESULTS

According to the fifth inclusion and exclusion criteria presented in Table 2, the number of papers in the last stage of the PRISMA flow chart (Figure 1) accounted for 12 papers out of 64 that were used for the qualitative/quantitative analysis. These papers are listed in Table 3.

The applications presented in the papers from Table 3 were clustered according to their profile: related to the context or related to a specific item. General information about the technology applied by the author as well as the area and the paper classification according to the inclusion and exclusion criteria were also listed. The result is shown in Table 4.

4. DISCUSSION

The abstract screening process was performed looking for values or indicators that could suggest the presence of measurable results of the research within the full text. During the screening process, several words or expressions were found not to have a strong link with measurable results when taken by their own, such as: "potential", "feasibility", "can lead the way for the development", "theoretical simulation", and "promising". All these expressions were used either as indicators of possible uses or results obtained into a simulated environment.

The selected papers (those classified as Partially related or Closed related) represent 19% of the total. It is curious to note how recent they are; all of them were published within two years of the research date (2016-2017). This might indicate a more advanced stage in the Industry 4.0 maturation process, where there are enough studies with tangible results being published. It is important to stress that these results are among non-indexed papers, what could be seen as a research limitation.

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Table 3. Selected papers

#	TITLE	AUTHOR	YEAR
1	Energy Optimization of Robotic Cells	Bukata L., Sucha P., Hanzalek Z., Burget P.	2017
2	Performance Improvement of Kinect Software Development Kit-Constructed Speech Recognition Using a Client-Server Sensor Fusion Strategy for Smart Human-Computer Interface Control Applications	Ding I.-J., Lin S.-K.	2017
3	Large-Scale Online Multitask Learning and Decision Making for Flexible Manufacturing	Wang J., Sun Y., Zhang W., Thomas I., Duan S., Shi Y.	2016
4	Dynamic reallocation and rescheduling of steel products using agents with strategic anticipation and virtual market structures	Neuer M.J., Marchiori F., Ebel A., Matskanis N., Piedimonti L., Wolff A., Mathis G.	2016
5	A computer vision assisted system for autonomous forklift vehicles in real factory environment	Syu J.-L., Li H.-T., Chiang J.-S., Hsia C.-H., Wu P.-H., Hsieh C.-F., Li S.-A.	2017
6	Equipment utilization enhancement in photolithography area through a dynamic system control using multi-fidelity simulation optimization with big data technique	Hsieh L.Y., Huang E., Chen C.-H.	2017
7	From sensor networks to internet of things. Bluetooth low energy, a standard for this evolution	Hortelano D., Olivares T., Ruiz M.C., Garrido-Hidalgo C., López V.	2017
8	A feasible architecture for ARM-based microserver systems considering energy efficiency	Xu S.S.-D., Chang T.-C.	2017
9	Autonomous Channel Switching: Towards Efficient Spectrum Sharing for Industrial Wireless Sensor Networks	Lin F., Chen C., Zhang N., Guan X., Shen X.	2016
10	PLCs as Industry 4.0 components in laboratory applications	Langmann R., Rojas-Peña L.	2016
11	A Cloud-based Architecture for the Internet of Things targeting Industrial Devices Remote Monitoring and Control	da Silva A.F., Ohta R.L., dos Santos M.N., Binotto A.P.D.	2016
12	A Smart Maintenance tool for a safe Electric Arc Furnace	Fumagalli L., Macchi M., Colace C., Rondi M., Alfieri A.	2016

Source: The authors' own (2017)

Table 4. Classification of the selected papers

#	Profile	Technology applied	Area of application	I/E criteria
1	Context	Power Optimisation - Algorithm	Car factory	PR
2	Item	Kinect sensor-SDK: Algorithm	Kinect sensor	PR
3	Item	Algorithm	Online platform	PR
4	Context	SOA (service-oriented architecture)	Plant of ArcelorMittal	PR
5	Context	Adaptive Structural Features (ASF) and Direction Weighted Overlapping (DWO)	Pallet factory	CR
6	Context	Abnormality Detector and the Dynamic Photo Configuration	Foundry	CR
7	Item	Bluetooth Low Energy	Chips	CR
8	Item	ARM-based Server Cluster Board (SCB)	Computer processor	CR
9	Item	Industrial wireless sensor networks (IWSNs)	Industrial wireless protocol	CR
10	Item	Reference Architectural Model Industry 4.0 (RAMI 4.0)	Programmable logic controller (PLC)	CR
11	Item	Cloud-based architecture for IoT	Industrial exhauster	CR
12	Context	Smart Water Monitoring	Furnace - Tenaris Dalmine	CR

Source: The authors' own (2017)

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Regarding the profile of the selected articles, they are almost evenly split between context (5 papers)/item (7 papers) application. Such division brings to light the evolution profile present in the algorithms/sensors and the joint efforts to apply them in an industrial context. It is also possible to be understood as the conjoint development of both tools and applications, instead of a division in two phases: developing tools and then applying them to a context. Another alternative is to take this process as a cycle, where the tools are tested in real life and then improved on demand.

Among the algorithms shown by the papers, there is a prevalence of the operational research (usually Mixed Integer Linear Programming) as optimisation tool. Mostly to improve an energy grid or reduce the power consumption of a specific device.

Moving back to the overall results, the low percentage of academic research that present measurable results might have two possible interpretations (stated by the light of this paper's proposal):

As the "Industry 4.0" is a trend term, many papers that have their main topic within the electronics or computing fields are using the term to suit the stream. Such practice ends up jeopardising the use of "Industry 4.0" as search string, as the filtering process turns into a harder task.

Another possible reason why such low percentage of the results was obtained is the lack of standardisation about the topic. This idea goes along with the first topic; however, the difference lays on the publication profile, that does not focuses on the results that were already provided. Instead, the authors emphasise the possible applications or results coming from simulation into a controlled environment.

On the other hand, it is possible to exist published papers that are partially/closely related to the topic approached in the present study that do not identify themselves as being part of the Industry 4.0 movement.

5. CONCLUSION

The purpose of this article is to review and analyse the academic presence of measurable outcomes of the fourth industrial revolution in a systematic manner. This review provided support to identify the profile of results presented in academic articles within the Industry 4.0 context as well as to explore possible explanations for the findings.

The study was conducted based on a research question that could be answered to the extent of its limitations (mainly the search string used by the authors). However, as stated by the discussion's last paragraph, it is possible that some measurable applications of Industry 4.0 tools have been suppressed by the lack of consensus among academia and practitioners.

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