Industrial Revolution (IR) 4.0 in Construction Engineering Education: A Bibliometric Analysis

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Abstract
Industrial Revolution 4.0 (IR 4.0) is a high technology digitization to enhance communication networks, organization and management, as well as production and processes across industries. The rate of changes and its convergence towards IR 4.0 would require new talent, knowledge and skills for current and future generations to retain and generate new workforces. As technology in the construction industry is evolving at a fast pace, the current teaching-learning syllabus and pedagogy should transform accordingly to accommodate future job requirements. Due to the rawness of this concept in the construction industry and to its education, this study aims to explore the state of the art as well as the state of practice of IR 4.0 and Education 4.0 from the perspective of construction engineering. Therefore, a systematic review was conducted to analyze the relevant research papers related to IR 4.0 and Education 4.0 within the Scopus database, ranging from year 2011 until present. A bibliometric analysis has been outlined following the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) statement. Findings from this study would provide a thorough understanding on the past efforts in advancing the construction engineering education aspect, subsequently highlighting gaps to be filled for future endeavors, particularly in equipping the construction engineering education for IR 4.0.

Keywords: bibliometric analysis, construction engineering, education, industrial revolution 4.0, systematic review

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INTRODUCTION

The new paradigm of Industrial Revolution 4.0 (IR 4.0) that significantly enhances the economic sector and operational environment was introduced back in 2011, at the Hannover Fair by the German Government (M.Baygin et al., 2016). The impact of IR 4.0 across different countries and industries varies due to the different capital investment and high technology adoptions such as intelligent equipment, advanced information technologies and innovative processes. Despite the steady investment on technologies, the rate of change and its convergence would require new talents, knowledge and skills for the current and future generation in retaining and generating the relevant workforces.

Along the same vein, the construction industry is also captivated with the idea of IR 4.0 adoption since this sector acts as one of nation's economic catalyst. The efficiency and good return of investment by adopting IR 4.0 elements in the dynamic and complex construction industry sector is one of the best opportunity to improve construction processes and productivity, which is currently lacking behind other sectors such as manufacturing and services (Holt & Kearney, 2015). The complexity of emerging technology IR 4.0 in the construction industry heavily influences the educational system in supporting future job requirements.

In order to bridge the gap between construction industry and construction engineering education, collaboration within the two sectors are needed to address the rapid changes and to obligate with IR 4.0 adaptations by creating an experience-based knowledge education (Baena et al., 2017). The higher educational institution is a good platform to introduce Education 4.0 as an on-going development process to strengthen the connection between existing learning content with the elements of IR 4.0. The vision for adopting and adapting IR 4.0 in the construction engineering education is to equip the current pedagogy and syllabus content with the new paradigm towards preparing current and future graduates for future job requirements.

Therefore, it is important to develop a construction engineering education principle based on the IR 4.0 concept to meet future challenges in the industry. This study aims to explore the current applications of IR 4.0 and Education 4.0 from the construction engineering perspective. The first objective of this study is to identify the current states of IR 4.0 and Education 4.0 adaptation from the engineering perspective. Secondly, this study investigates the application of IR 4.0 and Education 4.0 in the field of construction engineering.

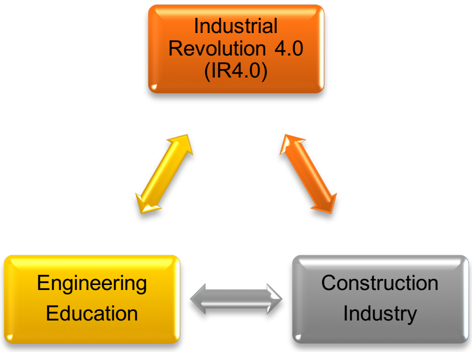

Figure 1: The relationship between IR 4.0, construction industry and engineering education

In reference to Figure 1, the relationship between IR 4.0, construction industry and education are very important to increase the value of construction engineering, as it is very important to build awareness and provide access to know-how, skills, education and technology through the educational system and in the workplace environment, further highlighting the role of younger generation (Rüßmann et al., 2015).

A systematic literature review on subjects related to IR 4.0 and Education 4.0 from different journals and conference proceedings within the Scopus database was conducted. The methodology for this study is based on the concept of Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) which consists of four major phases, which are: 1) identification; 2) screening; 3) eligibility; and 4) inclusion to critically investigate the subject matter (Moher et al., 2009).

LITERATURE REVIEW

The term Industrial Revolution 4.0 (IR 4.0), Industry 4.0 or Industrie 4.0 has been introduced by the German federal government in 2011 as one of the key initiatives of its high-tech strategy that has been proposed as a new, emerging structure and integrated communications network for a widely automated exchange of information between production and processes (Bahrin et al, 2016). IR 4.0 combines the strengths of traditional industries with cutting edge internet technologies as the embedding of smart products into digital and physical processes that interact with each other through geographical and organizational borders (Schmidt, 2015).

IR 4.0 is the conversion of computer and automation into cyber-physical system, significant to a combination between real world and virtual world in operations based on information and communication technology (Geissbauer et al., 2014).The concept of IR 4.0 will enhance operations into fully integrated, automated and optimized process flows for greater efficiency and change in traditional work ethics among people, machine and system (Vaidya et al., 2018). The main features of IR 4.0 are system integration, industrial internet, cybersecurity, cloud computing, big data analysis, artificial intelligence, augmented reality, simulation, additive manufacturing, advanced robotics and advanced material (Geissbauer et al., 2014; Vaidya et al., 2018).

Generally, the application of IR 4.0 in the construction industry involves technologies, communication and collaboration to enhance the current methodology. A wide range of technologies and concepts to automate construction processes and to create a new construction environment have been observed through the adoption of smart factories, simulation and modelling, digitization and virtualization as key enablers for project management applications and digital document management platforms for information access (Oesterreich & Teuteberg, 2016). Hence, the radical change in the construction industry would subsequently transform construction education, especially in the engineering discipline so that the current education system could educate future graduates in accordance to the current technological trend based on IR 4.0, through the establishment of Education 4.0. (Sackey & Bester, 2016).

The global transformation of IR 4.0 is basically an enormous conversion for the education needs in the field of engineering in order to achieve the goals of integrating industrial skills, knowledge and experience in the pedagogy (Ting, 2016). The needs of IR 4.0 in education is as a platform to introduce future graduates to IR 4.0 through real working environment exposures towards fulfilling future job requirements and to overcome industrial challenges worldwide. It is vital to address the current on-going developments of various technologies in strengthening the connection between existing learning content and related disciplines as key development in education institutions, towards embracing Education 4.0. (Eichinger *et al.,* 2017).

METHODOLOGY

A systematic literature review (SLR) is an essential method to define clear and relevant investigation of previous research based on research topics, area or phenomenon of interest. This method is defined as a form of secondary study that uses a distinct methodology to pinpoint, appraise and interpret all reachable evidence in relation to specific research queries in an unbiased and repeatable ways (Kitchenham & Charters, 2007). The characteristics of SLR is to identify relevant paper selections based on question, appraise the paper critically to assess the research strategy, analyse the data by including and excluding information through certain principles and to report the analysis based on results from previous research papers (Zurynski, 2014).

The SLR conducted in this study is guided by the main question: *What are the current applications of IR 4.0 and Education 4.0 in the construction engineering discipline?* More specifically, other guiding sub-questions are listed as follows:

I. Q1: What is the current state of IR 4.0 and Education 4.0 from the engineering perspective?
II. Q2: How has IR 4.0 and Education 4.0 been implemented in the field of construction?

Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA)

The PRISMA statement could be used to provide a comprehensive contextual understanding of previous studies to be published as a transparent and critically assessed report (Moher et al., 2009). PRISMA enables critical appraisal of information through the different phases of systematic review. In this study, we have used the PRISMA method to extensively summarize the application of IR 4.0 and Education 4.0 in the science of systematic reviews. PRISMA comprises of four-phases in a flow diagram, which are: 1) identification; 2) screening; 3) eligibility; and 4) inclusion (Liberati et al*.,* 2009). Figure 2 presents the results of PRISMA analysis.

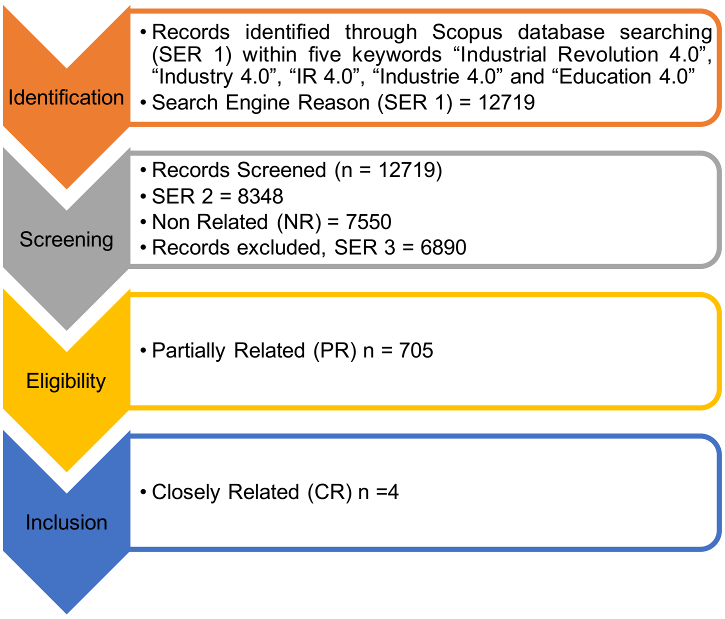

Figure 2: The systematic literature review flowchart.

The efficiency of a SLR flow diagram and its results is closely related to the Inclusion/Exclusion (I/E) criteria of the SLR methodology, as given in Table 1. In General, the first stage of identification consists of five major keywords which are “Industrial Revolution 4.0”, “IR 4.0”, “Industry 4.0”, “Industrie 4.0”, and “Education 4.0”. A total of 12719 papers resulted from the Scopus database (SER 1 in Table 1). At the second stage, a total of 8348 papers were found published after Industrial Revolution 4.0 has been officially introduced in 2011 at the Hanover Fair by the German Government (M.Baygin et al., 2016) (SER 2 in Table 1). Then, 7550 papers were published in journals, conference proceedings or books and finally, a total of 6890 papers were found to be written in English language (SER 3 and NR in Table 1). The third stage is to ensure all eligible papers related to the four keywords are studied in detail using the “engineering” and “construction” topics keywords (PR in Table 1). The papers found at this eligibility stage were 705. Finally, only 4 relevant papers closely related to “education” in construction engineering were found within the four keywords selected (CR in Table 1).

Exclusion and Inclusion Review Principle

The assessment criteria for this study is shown in Table 1, which comprises the principles of exclusion and inclusion to convey accurate research findings

Table 1: Inclusion/ Exclusion Criteria

I/E	Criteria		Criteria Explanation
Exclusion	Search Engine Reason (SER)	SER 1:	The search engine used was Scopus
		SER 2:	All searches were limited to works published from 2011 until the current year because the IR 4.0 have been officially introduced in 2011 at the Hanover Fair by the German Government
		SER 3:	Papers with relevant title, abstract and keywords in English only
	Without Full-text (WF)		Papers without full texts were assessed
	Non-Related (NR)		Excluded articles published in letter, editorial, note, short survey, business article or press and erratum
	Loosely Related (LR)		The content is irrelevant with keywords searched “Industrial Revolution 4.0”, “Industry 4.0”, “IR 4.0”, “Industrie 4.0” and “Education 4.0”
Inclusion	Partially Related (PR)		Search mentioning construction engineering based on the four keywords
	Closely Related (CR)		Focus on papers containing the descriptions of Education in Construction Engineering within the four keywords

DATA ANALYSIS AND RESULT

Within the 705 papers collected containing the “education” keyword, the top five subject areas related to IR 4.0 are medicine (39%), engineering (22%), social science (17%), computer science (17%) and decision science (5%). Figure 2 shows results of the top five documents by subject area.

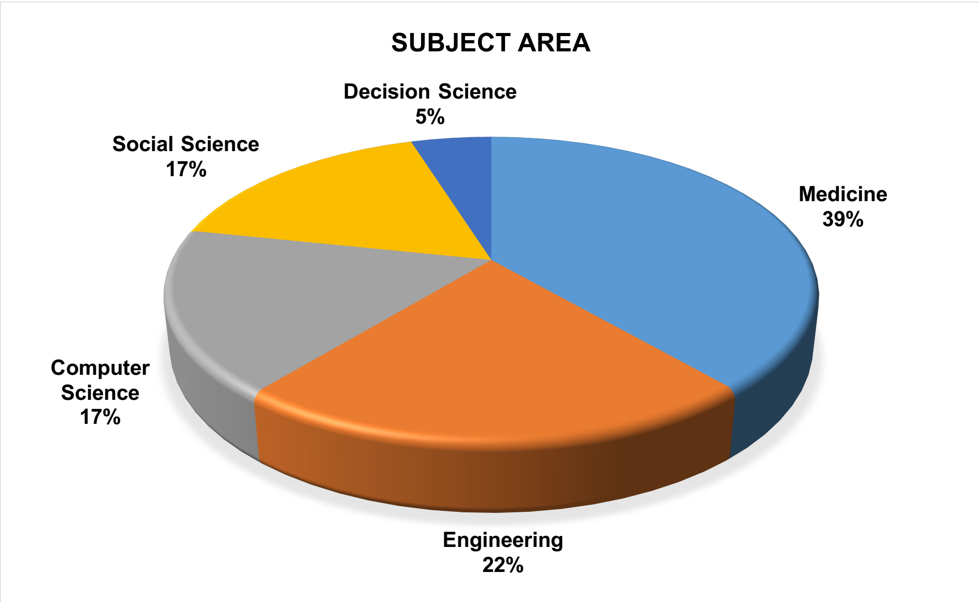

Figure 2: Percentage of top five subject area

Narrowing down into the 22% of the findings in the engineering aspect, 134 documents were found in the database. Based on Figure 3, six categories of subjects were found in this engineering research areas, which are science and technology (57%), manufacturing (34%), electrical (4%), construction engineering (3%), mechanical (1%) and Chemical (1%).

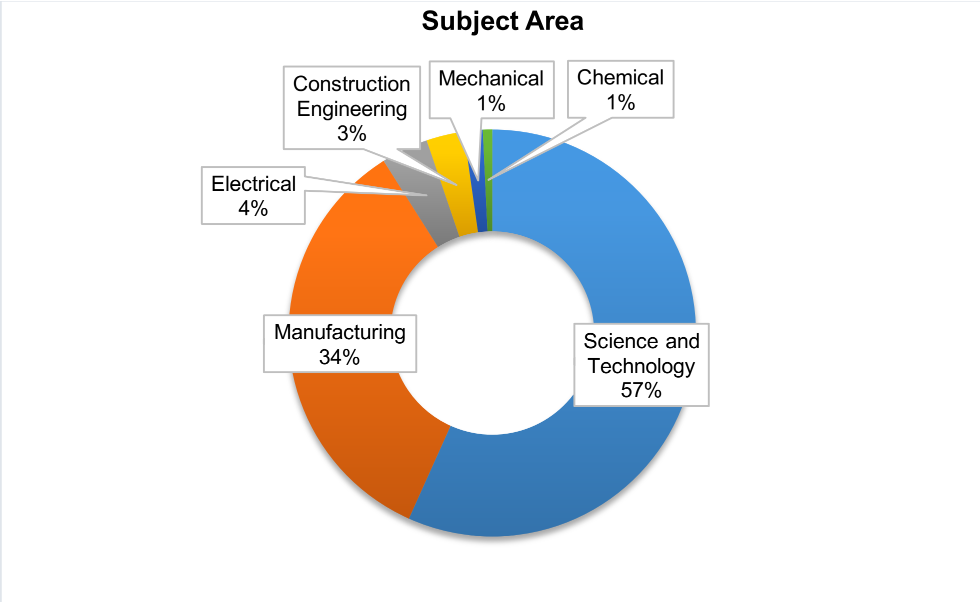

Figure 3: Percentage of subject area categories

Finally, only four papers were observed in relation to this SLR's objective, which is to investigate the current application of IR 4.0 and Education 4.0 in the construction engineering disciplines. Details of the four papers are tabulated in Table 2.

Table 2: Papers related to this research

Title	Author	Year	Country
Augmented Reality gaming in Sustainable Design Education	Steven K. Ayer, John I. Messner and Chimay J. Anumba	2016	United States
HOME I/O and FACTORY I/O: A virtual house and a virtual plant for control education	B. Riera and B. Vigario	2017	France
Freshman project launches the cultivation of future engineering talent	Chun-Wen Teng	2017	Taiwan
Incorporating Pre-recorded Environmental Lifecycle Assessment Modules in a Classroom Setting	Liv Haselbach and Quinn Langfitt	2017	United States

DISCUSSION

The first paper is entitled "Augmented reality gaming in sustainable design education" by Ayer et al (Ayer et al., 2016), who stated that it is important for students to be able to generate, envision and evaluate the performance of alternative building design and construction options that will effect buildings' performance. This research has introduced 108 students from architectural engineering, architectural and civil engineering discipline to the use of augmented reality-based educational game called ecoCampus. In order to explore the pedagogical value of this technology, two groups have been established, where one group was assigned to use the ecoCampus tool, while the other group used paper-based design activities. The findings suggest that, the students who used ecoCampus were able to overcome the inclination towards design fixation, further enabling them to use the application to assess design and also to generate additional concepts, as compared to the students who have used the paper-based format.

The second study is entitled "HOME I/O and FACTORY I/O: A virtual house and a virtual plant for control education" by Riera and Vigarioe (Riera & Vigário, 2017), who introduced serious games for control education named HOME I/O and FACTORY I/O software. This indicator was used to raise the awareness on the use of new technologies to advance programming and analysis skills between information technology and operating technology. The purpose of the simulation and modelling was to evaluate the system such as environmental parameters, power consumption and many more before developing the physical commissioning processes.

The third paper is by Teng (Teng, 2017), entitled "Freshman project launches the cultivation of future engineering talent" that discusses the conceive, design, implement and operate (CDIO) framework. According to this research, CDIO framework has emphasized on integrated curriculum so that students can master the basic principles and professional knowledge as early as in the first-year of university. The participants of the freshman projects have approved this educational framework. process as it helps them to improve their understanding on the courses and the importance of collaborations between other disciplines at universities.

Finally, is a research entitled "Incorporating pre-recorded environmental Lifecycle Assessment (LCA) modules in a classroom setting" by Haselbach and Langfitt (Haselbach & Langfitt, 2017), where its objective was to examine the effectiveness of using short pre-recorded software modules on LCA class or a smart classroom. A small group of 15 students at Washington State University (WSU) have participated in this module, where surveys were later conducted to assess their understanding on the modules' outcomes. The results of this research were positive because the new educational framework modules and smart classroom were appropriate and attractive for students' aid in the rapid diffusion of sustainability topics in engineering programs.

The findings of this paper show that there were four previous studies that have discussed specifically on the applications of IR 4.0 and Education 4.0 in the construction engineering discipline. The main components include augmented reality, simulation and modelling, smart classroom and CDIO educational framework. According to the IR 4.0 concept, gamification lays in the augmented reality components by providing a real-time information to improve decision making and to enhance work procedures. Meanwhile, simulation is a component that leverages the real-time data to mirror the physical world in virtual model such as 2D and 3D software. Gamification and software in construction engineering discipline plays an important role in order to adapt IR 4.0 in the education system. This application can help to improve students' awareness and enhance their understanding, thus demonstrating the importance of IR 4.0. Even though the science and technology as well as the manufacturing sector dominates the IR 4.0 papers in the Scopus database, the construction engineering promises a greater development towards approaching IR 4.0 in order to meet the future job requirements.

Table 3: Summary of research findings

Title	Author	Findings
Augmented Reality gaming in Sustainable Design Education	Steven K. Ayer, John I. Messner and Chimay J. Anumba	The use of augmented reality-based educational game called ecoCampus to train student to be able to generate, envision and evaluate the performance of alternative building design and construction options that will affect buildings' performance.
HOME I/O and FACTORY I/O: A virtual house and a virtual plant for control education	B. Riera and B. Vigario	A serious game for control education named HOME I/O and FACTORY I/O software to raise the awareness on the use of new technologies to advance programming and analysis skills between information technology and operating technology.
Freshman project launches the cultivation of future engineering talent	Chun-Wen Teng	CDIO framework has emphasized on integrated curriculum to improve student understanding on the courses and the importance of collaborations between other disciplines at universities.
Incorporating Pre-recorded Environmental Lifecycle Assessment Modules in a Classroom Setting	Liv Haselbach and Quinn Langfitt	A new educational framework modules and smart classroom for students' aid in the rapid diffusion of sustainability topics in engineering programs.

CONCLUSIONS AND RECOMMENDATION

Industrial Revolution 4.0 is the latest intelligence spotlight to be adopted and adapted in all education disciplines especially in construction engineering at higher education institution, in order to satisfy future job requirements and to compete in real working environment for human capital development. The essence of IR 4.0 in education could act as a benchmark and guideline to improve the current pedagogy and finally, contributes to a new technology infused approach in improving education for the construction industry discipline.

The transformation of education strategies and approaches in accordance to the latest trend is to improve students' skills and knowledge further meeting the industry's competence development. IR 4.0 components and Education 4.0 application contributes to ease the path towards new construction engineering syllabus, in order to ride along the wave of industrial revolution 4.0 and also to strengthen the education processes, subsequently towards preparing future People 4.0 for the construction industry.

Based on the objectives of this study, the findings have discovered new applications to integrate IR 4.0 in the construction engineering discipline, which are augmented reality and simulations. However, there were only four papers found objectively related to IR 4.0 and Education 4.0 in the field of construction engineering education. The only countries contributed to this finding were United States, Taiwan and France. Due to the very little study found on this very important subject matter, the higher education and decision makers should explore further the pedagogical value and means of adapting IR

4.0 in the current construction engineering syllabus to enhance student's skill and knowledge to facilitate future job requirements.

This study has been conducted methodologically through the processes of PRISMA but is constrained to certain limitations due to the choice of keywords ("Industrial Revolution 4.0"; "IR 4.0"; "Industry 4.0"; "Industrie 4.0"); "Education 4.0") used. Only a small number of findings have been retrieved based on the five main keywords used, which might not represent a complete overview on the construction engineering perspective. These findings disregards detailed or individual terms, application/ components such as big data, Internet of Things, industrial internet and many more.

Future studies could be conducted to widen the findings in regard to IR 4.0 and Education 4.0 in construction engineering education by expanding the keywords used, as well as the use of other database such as Google Scholar for a comprehensive research finding. Nonetheless, findings of this study have demonstrated the huge gap in the study related to IR 4.0 in construction engineering education, subsequently exemplifying future research opportunities in the subject area.

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