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3D PRINTING IN CIVIL ENGINEERING: A SYSTEMATIC LITERATURE REVIEW

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New technological developments determine the course of the construction industry. Three-dimensional (3D) printer technology has become one of the technologies that determine the production logic of the 21st century. The concept of Industry 4.0 gained importance in the construction industry with a 3D printer. In this study, a systematic literature review was performed. The publications related to the 3D printer have been examined within the scope of civil engineering implementations. The 3D printer researches associated with BIM, Industry 4.0, NASA, additive manufacturing, and point cloud technology subjects was reviewed through an intensive systematic literature review. As a result of the study, it has been understood that the studies in the field of civil engineering were insufficient compared to manufacturing industry. For this reason, the number of researches on 3D printer applications should increase in construction industry.

Keywords: BIM, Point cloud technology, Industry 4.0, NASA, Additive manufacturing.

1 INTRODUCTION

3D printer technology was a complex, expensive and predictable technology in 1984 when it was discovered. However, it is used in many industries such as medicine and manufacturing in today's newly revolutionized industrial environment (Hager *et al.* 2016). Successful applications medicine and other industries attracted the interest of different sectors and fields of science. The three-dimensional printing of concrete is currently being implemented in construction industry (Tay *et al.* 2017). Today, buildings can be printed with a three-dimensional printer with the developments in technology and engineering (Feng *et al.* 2015).

2 MATERIAL AND METHODS

3D printing technology researches related to BIM, Industry 4.0, NASA, additive manufacturing, point cloud technology have been reviewed in this study (Figure 1). The research trend that is connected to 3D printing in the field of civil engineering is assessed. In addition, NASA's 3D printing technology researches, which developed progressive technologies in the construction sector in order to build extraterrestrial habitats, have been reviewed. The Web of Science database was reviewed in all disciplines between 1983-2019 without any other restrictions. Literature Review; TI = (3D printing); TS = (3D printing AND BIM); TS = (3D printing AND Industry 4.0); TS = (3D printing AND NASA); TS = (3D printing AND additive manufacturing); TS = (3D printing AND point cloud technology). The screening was carried out in the English language papers. The publications were examined according to the disciplines and years.

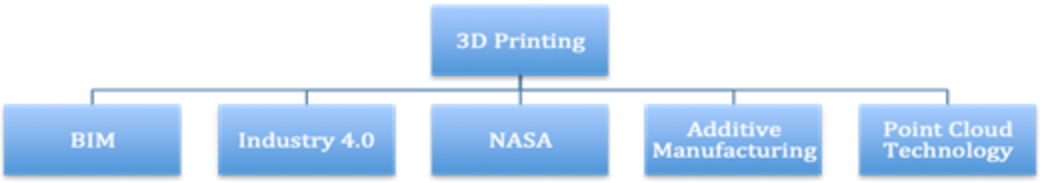

Figure 1. 3D printing related researches.

3 RESULTS AND DISCUSSION

5104 publications containing the word "3D printer" in title were found in the Web of Science scan. The first ten Web of Science categories with the largest number of publications are listed in Table 1. The number of publications containing "3D printing" phrase in the title in Web of Science through 1983 and 2019 is given in Figure 2. The number of publications in the field of "Civil Engineering and Construction Building Technology" is given in Table 2.

Table 1. The distribution of "3D printing" titled articles and proceedings in Web of Science categories.

Web of Science Categories	Number of Articles and Proceedings
Materials Science Multidisciplinary	1084
Electrical and Electronics Engineering	784
Physics Applied	514
Nano-science Nanotechnology	448
Manufacturing Engineering	371
Biomedical Engineering	368
Chemistry Multidisciplinary	353
Materials Science Biomaterials	302
Mechanical Engineering	299
Optics	290

When we consider all the disciplines on a global scale, the number of publications related to 3D printing increases compared to the years. The highest number of publications on 3D printing was in the field of "Materials Science Multidisciplinary." Globally published publications in "Civil Engineering and Construction Technology" were less than the other engineering areas. For example; the total number of publications in the field of "Civil Engineering and Construction Technology" is 93, and total number of publications in the field of "Electrical and Electronics Engineering" is 783, the ratio of latter to former is 11.8%.

Table 2. The distribution of "3D printing" titled articles and proceedings about civil engineering in Web of Science categories.

Web of Science Categories	Number of Articles and Proceedings
Construction Building Technology	48
Civil Engineering	45

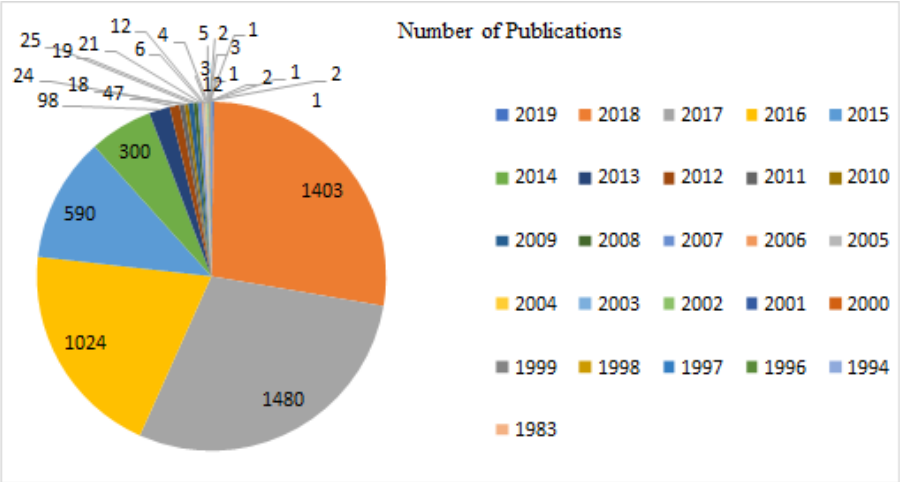

Figure 2. The number of publications containing "3D printing" phrase in the title in Web of Science categories through 1983 and 2019.

3.1 3D Printing and BIM

19 publications containing the word "3D printer" and "BIM" in topics together were found in the Web of Science scan. The first three "Web of Science" categories with the largest number of publications are listed in Table 3. The distribution of publications by year is given in Figure 3.

Table 3. The distribution of "3D printing" and "BIM" topics together in articles and proceedings in Web of Science categories.

Web of Science Categories	Number of Articles and Proceedings
Construction Building Technology	5
Education Educational Research	4
Civil Engineering	4

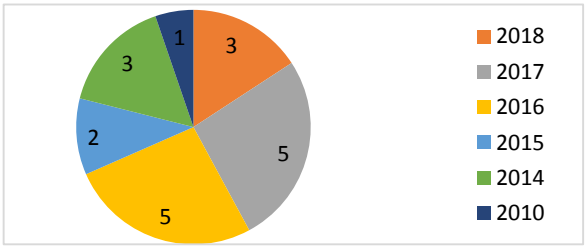

Figure 3. The number of publications containing "3D printing" and "BIM" topics in Web of Science categories through 2010 and 2018.

3.2 3D Printing and Industry 4.0

33 publications containing the word "3D printer" and "Industry 4.0" in topics together were found in the Web of Science scan. The first five "Web of Science" categories with the largest number of publications are listed in Table 4. The distribution of publications by year is given in Figure 4.

Table 4. The distributions of "3D printing" and "Industry 4.0" topics together in articles and proceedings in Web of Science categories.

Web of Science Categories	Number of Articles and Proceedings
Industrial Engineering	10
Manufacturing Engineering	9
Computer Science Artificial Intelligence	5

Figure 4. The number of publications containing "3D printing" and "Industry 4.0" topics together in Web of Science categories through 2014 and 2018.

3.3 3D Printing and NASA

15 publications containing the word "3D printer" and "NASA" in topics together were found in the Web of Science scan. The first four "Web of Science" categories with the largest number of publications are listed in Table 5. The distribution of publications by year is given in Figure 5.

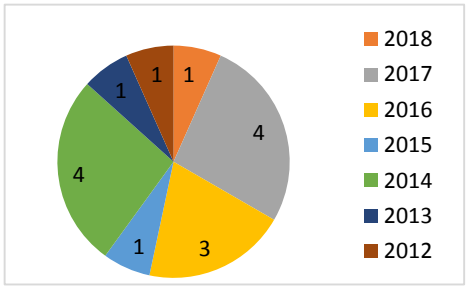

Figure 5. The number of publications containing "3D printing" and "NASA" topics together in Web of Science categories through 2012 and 2018.

Table 5. The distributions of "3D printing" and "BIM" topics together in articles and proceedings in Web of Science categories.

Web of Science Categories	Number of Articles and Proceedings
Electrical and Electronics Engineering	4
Optics	3
Physics Applied	3
Civil Engineering	2

3.4 3D Printing and Additive Manufacturing

2616 publications containing the word "3D printer" and "Additive Manufacturing" in topics together were found in the Web of Science scan. The first three "Web of Science" categories with the largest number of publications are listed in Table 6. The distribution of the publications by years is given in Figure 6. A total 63 publications containing the word "3D printer" and "Additive Manufacturing" in topics together were found in "Civil Engineering" and "Construction Building Technology" categories.

Table 6. The distributions of "3D printing" and "additive manufacturing" topics together in articles and proceedings in Web of Science categories.

Web of Science Categories	Number of Articles and Proceedings
Materials Science Multidisciplinary	696
Manufacturing Engineering	507
Electrical and Electronics Engineering	338

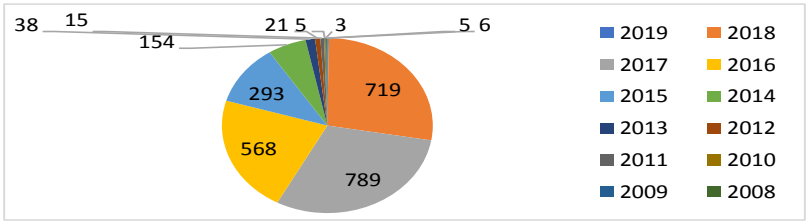

Figure 6. The number of publications containing "3D printing" and "additive manufacturing" topics together in Web of Science categories through 2008 and 2019.

3.5 3D Printing and Point Cloud Technology

24 publications containing the word "3D printer" and "Point Cloud Technology" in topics together were found in the Web of Science scan. The first three "Web of Science" categories with the largest number of publications are listed in Table 7. The distribution of publications by year is given in Figure 7.

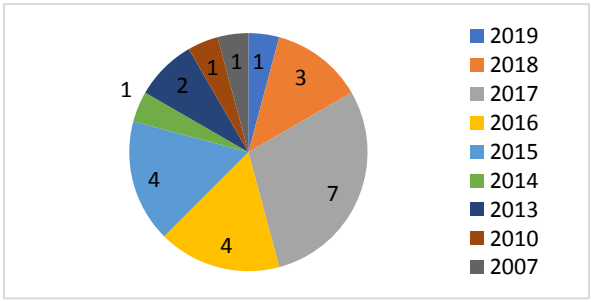

Figure 7. The number of publications "3D printing" and "point cloud manufacturing" topics together in Web of Science categories through 2007 and 2019.

Table 7. The distributions of "3D printing" and "point cloud technology" topics together in articles and proceedings in Web of Science categories.

Web of Science Categories	Number of Articles and Proceedings
Optics	4
Electrical and Electronics Engineering	3
Manufacturing Engineering	3

4 CONCLUSIONS

Scientific research on 3D printing is increasing over time. The print quality and diversity of the printing raw materials will increase by research in the field of Materials Science. The development of this technology alone is not enough to put pressure, for larger, more viable, more robust, more stable prints. Therefore, researchers must study raw materials. Most of the studies in the field of engineering are in the discipline of "Electrical and Electronics Engineering." BIM and 3D printing subjects together are studied more in the field of "Civil Engineering." The publications about the connection between 3D printing and BIM have increased over the years. Building Information Modeling is a prerequisite and necessary for the use of 3D print technology in civil engineering. The results of the systematic literature review on 3D printing, BIM, Industry 4.0, NASA, Additive manufacturing and point cloud technology shed light on the increase in research trends of the subject. NASA, as a pioneer in the 3D printing technology, will shape the future of research on subject. The adoption capacity on 3D printing of construction industry may affect the competitive edge of industry stakeholders. Therefore, an agile response in scientific research and industry adoption is needed in near future.

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