VR Applications in Ergonomic and Productive Workplace Design: A Literature Review

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Abstract. During the past decade, virtual reality (VR) technology has been developed rapidly. Many applications of VR are ranging from non-immersive, semi-immersive, and full immersive types that are widely used by researchers to overcome problems in various fields. In industrial field, the most common application of VR technologies is at the planning stage and design of facilities or workplaces. By using VR, we can evaluate workplace design from the aspects of ergonomics and work productivity. This paper gives a literature review on the current VR applications in ergonomic and productive workplace design over the past 10 years (2010-2019). The main discussions of this paper include research objects, research outputs, types of VR technologies, hardwares and softwares that are used for analysis. The result of this study shows that the application of VR is very helpful to evaluate and validate the design of workplace, before the final design is implemented in real world. This paper also discusses several ongoing questions and future challenges for researchers who are concerned to apply VR in industrial workplace design.

Keywords: virtual reality, ergonomic, productive, workplace design

1 Introduction

Workplace is one of the important aspects related to productivity of workers. It does not only apply to the industrial sector, but also to small work units such as retail and private office. If the workplace is safe and comfortable, workers can do their jobs well. Therefore, design of the workplace needs to be planned, designed, and evaluated properly, before the final design is being implemented in the real world. The purpose of these actions is to minimize the costs of design repair and improvement. If in the future the design of the workplace does not provide comfort and safety for workers, then managements have to make improvements to the design in order to to increase worker productivity. Whereas, to improve the design at the end after design failure

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occurs, the cost is far more expensive than the design costs incurred in the early stages of development (Bragança, Vieira, & Andrade, 2014).

To design a workplace, we can use several approaches and technologies. Many options including 2D, 3D, or even 4D designs can be used. Virtual Reality (VR) is a technology that has been used for a long time for various purposes, both in the fields of education, industry, military, health, and even for entertainment purposes (Oh, Han, Lim, Jang, & and Kwon, 2018). But in fact, the use of VR technology for entertainment purposes, such as watching cinema and playing games are more popular than the other purposes. Whereas in industrial purposes, VR technology is a tool that can be relied by companies to overcome various kind of problems. One of those examples is related to the design of ergonomic and productive workplaces. The concept of using VR technology for workplace design is to imitate and visualize the design of the workplace to the perspective of user/operator. The results of VR simulation can be used as consideration to change or to improve the workplace design.

Based on these problems, this paper presents a literature review of VR applications to produce a productive and ergonomic workplace. The main objective of this paper is to examine whether VR is reliable enough to be applied in many fields. In addition, from this literature review, it is expected to get some important findings related to opportunities and challenges for researchers who want to study more about the development and utilization of VR technology for workplace design purposes.

2 VR Technology in Workplace Design

Virtual Reality (VR) is a technology that uses a set of computers and serves to simulate the environment of the real world, so that users can feel the presence of the environment. VR technology began to develop since the beginning of 1965 when Ivan Sutherland introduced The Ultimate Display. After that, he introduced the technology of The Sword of Damocles which was later known as the ancestor of Head Mounted Display (HMD) device. One of the most recent developments in VR technology is the Cave Automatic Virtual Environment (CAVE), that had been introduced in 1992. The most and widely applied VR technologies are HMD and CAVE. From the level of immersivity of technology, VR technology can generally be divided into three categories: non-immersive, semi-immersive, and full-immersive. The main difference of the three depends on how many input sensors and senses of the user that can be connected (Mandal, 2013).

In this era of Industry 4.0, VR technology has been widely used in various fields. Back then, it was used for military research and training only, however now it is used for many other purposes, including workplace and facility designs. Moreover, one of the paradigms that developed in this era is the smart factory paradigm. Smart factories are characterized by cyber-physical systems where important decisions are taken

based on simulations, and various business processes can be run virtually (Caputo, Greco, D'Amato, Notaro, & Spada, 2018). By using VR technology to design workplace, it will provide many benefits for stakeholders. For example, from the perspective of company owners, by using VR as a consideration in conducting evaluations, the company can save more on cost components. Operational costs can be minimized because a good workplace design will provide more comfort for users and will increase worker productivity. In addition, the cost of design improvements can also be reduced because the risk of failed designs can be minimized. On the other hand, from the user's (workers) point of view, the use of VR in designing workplace will also provide many benefits. By applying VR, involvement of the workers in the workplace design process is increased, and thus the new design will provide more satisfaction, comforts, and safety to the workers, and in the end, increase worker productivity. Therefore, the role of VR in the workplace design process plays a very vital role. VR technology can help companies to achieve the effective and efficient workplace design (Bellgardt, Pick, Zielasko, Vierjahn, Weyers, & Kuhlen, 2017).

3 Research Methodology

The focus of this research is to examine previous articles that related to VR application in the design of ergonomic and productive workplaces. In collecting those papers, several keywords had been used such as "virtual reality workspace", "virtual reality facility", "virtual reality ergonomic facility design", "virtual reality safety design", "productive virtual reality workspace", and "virtual reality layout design." The abstract databases and journals used to collect the papers were Scopus, Springer, and ScienceDirect. After the search for articles was conducted by using those keywords, not all of the articles were relevant to the research topic in this study. For example, there were a number of articles that are not applied articles and only discuss theories and concepts of technology, and even some articles are not related to virtual reality at all. Therefore, only some of the papers that are relevant to the topic of VR applications on the design of ergonomic and productive workplace were taken and collected.

In this paper, the collected articles are only limited to the last 10 years (from 2010-2019). The main purpose of these restrictions is to strengthen the position of this paper in the aspect of renewal. In addition, recently, there are no literature review that discusses similar topic study. So that the limitation of 10 years is the ideal range. From the articles that had been collected, they will be classified according to the type of article (whether proceeding, journal, or book chapter), year of publication, country, and subject area. In addition, in the next section, we will analyze further about the VR application domain, the type of VR technology, and the hardware and software used.

4 Result and Discussion

4.1 General Classification

Based on the results of the article search with the specified keyword and database, more than 500 articles had been found. From all of those articles, there are only 81 articles that are relevant to the research topic in this study. As shown in Figure 1, 22 articles come from proceedings, 44 articles from journals, and 15 articles from chapter books. Based on the distribution of these types of articles, it is clear that the article from journals has the largest proportion, more than half of the total. This means that the level of participation of researchers in making good articles is high. As we know the articles published in journals usually have a more complete structure than the articles from proceedings. Moreover, the impact factor and the level of rejection of the journal are also higher than proceedings (Eckmann, Rocha, & Wainer, 2012).

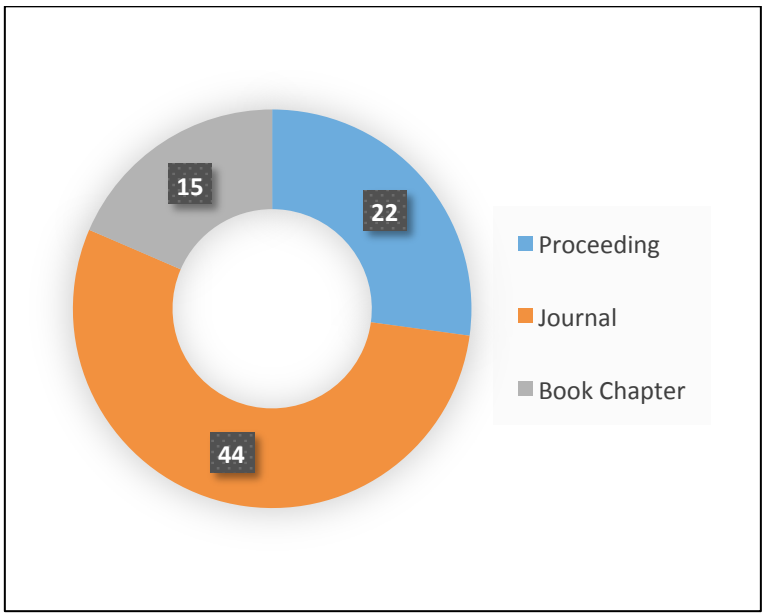

Fig. 1. Skill Analysis

From the year of publication, 4 articles were published in 2010, 6 articles in 2011, 8 articles in 2012, 8 articles in 2013, 6 articles in 2014, 7 articles in 2015, 12 articles in 2016, 10 articles in 2017, 16 articles in 2018, and 4 articles in 2019. The results of the distribution are shown in Figure 2 below.

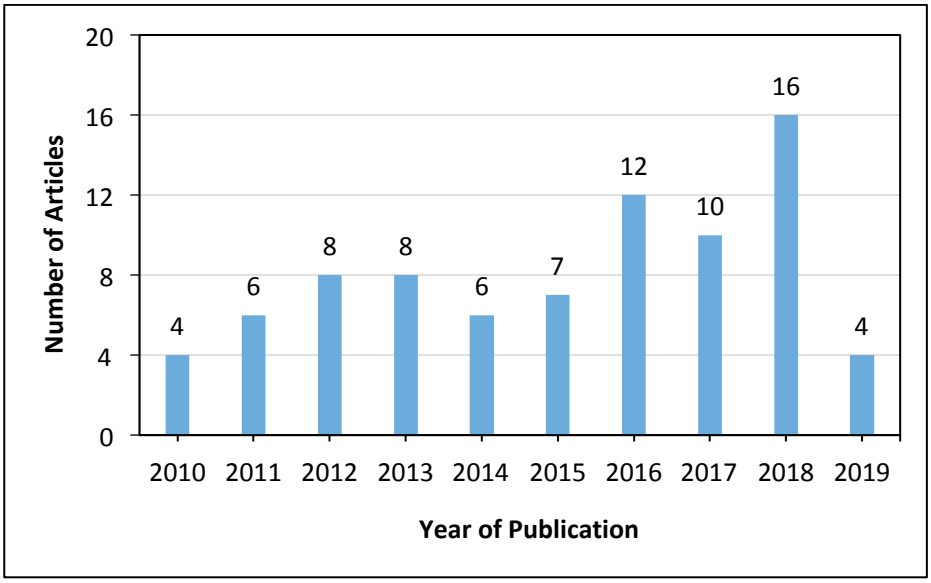

Fig. 2. Number of articles based on year of publication

Based on the number of published articles starting from 2010-2019, it shows that there is a significant trend of increase. During 2010, there were only 4 articles published related to the VR application for workplace design. In the next 5 years (2015), there were 7 articles published. While in 2018, the number of articles published has reached 16 articles. In 2019 (until February), the number of articles published has reached 4 articles. This shows that VR technology is still popular. Many researchers still continue to develop the application of VR technology, especially for designing workplace. The results of this analysis support the results of the research conducted by (Kim, Wang, Love, & Li, 2013), about the use of VR for building environments.

Based on the distribution of the author country that conducted the research in 81 articles, Germany occupies the highest position in the number of publications on VR utilization for workplace design. The top 5 countries after Germany are the United States, Poland, France, and Italy. Then followed by Portugal, China, United Kingdom, Sweden, Brazil, India, Canada, Norway, Australia, and a small number from Europe, Asia, Africa, and the Australian continent. Distribution of the number of publications related to the application of VR for design of workplace is shown in Figure 3.

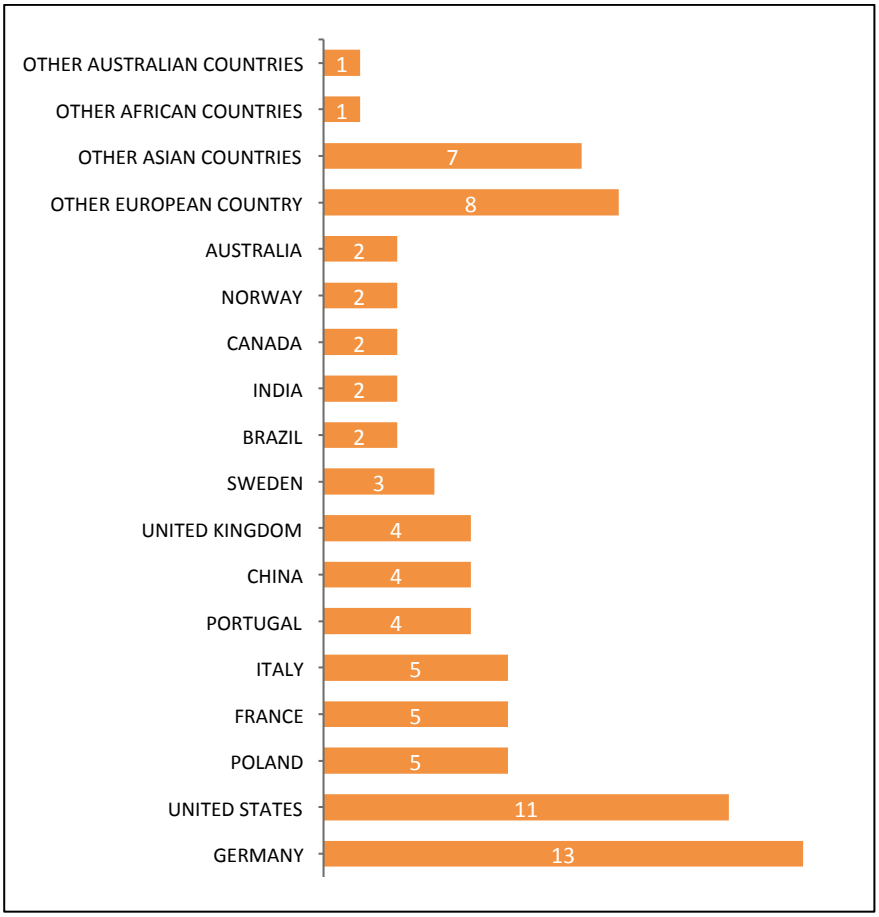

Fig. 3. Number of articles based on country

Based on Figure 3, it shows that the use of VR technology, especially for applications in workplace design, is still dominated by modern countries such as Germany, United States, China, and other major European countries. As we know Germany and United States are one of the two leading countries that have high technological development progress in the world. This clearly correlates with the number of studies and articles that have been published in both countries. In the other hand, the number of research from developing countries is still low. This fact shows that businesses in developing countries have not applied VR technology for designing workplace. Either because of the factor of human resource readiness level or financial factor. Whereas, if the VR technology can be implemented, it can help the company and government to improve the effectiveness and efficiency of their business, in order to face the global competition.

Figure 4 shows the classification of the number of articles based on the subject area. From this literature review, it is found that most researchers applied VR technology to the field of Manufacturing studies, followed by Healthcare, Construction, Social Science, Energy, Education, Computer Science, Entertainment, and Transportation. The Manufacturing and Healthcare subject area are highly studied by researchers because those two fields have a long history in the development of VR technology.

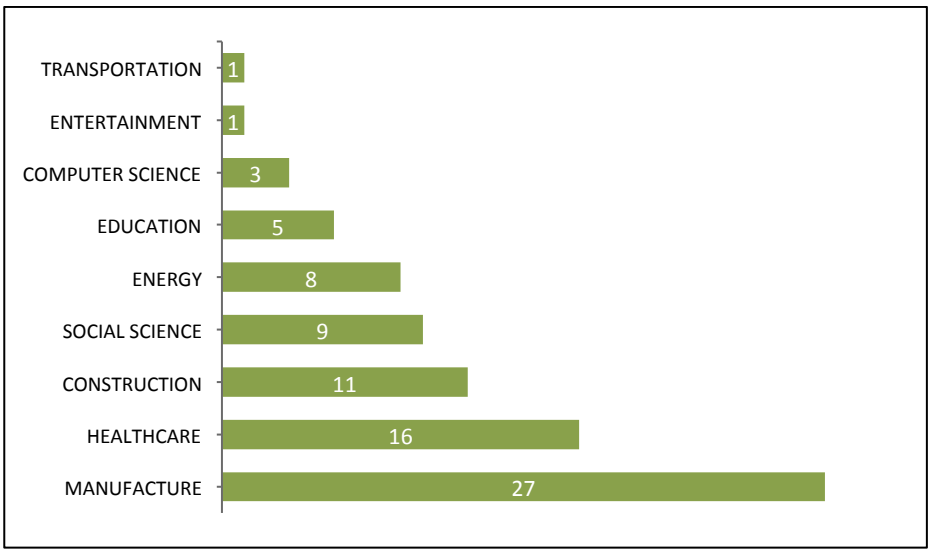

Fig. 4. Number of articles based on subject area

4.2 VR Technology and Case Study Environment

As shown in Figure 5, from the aspect of immersivity level of VR technology, 12 articles discussed the use of non-immersive VR technology, 33 articles discussed the use of semi-immersive VR technology, and 36 articles discussed the use of full-immersive VR technology. The most used types of hardware from 81 articles reviewed is CAVE (28%), Oculus Rift (17%), and HTC Vive (10%). While the most popular software that used to simulate VR in workplace design environment is Unity3D (22%), Autodesk 3ds Max (14%), and Autodesk Revit (9%).

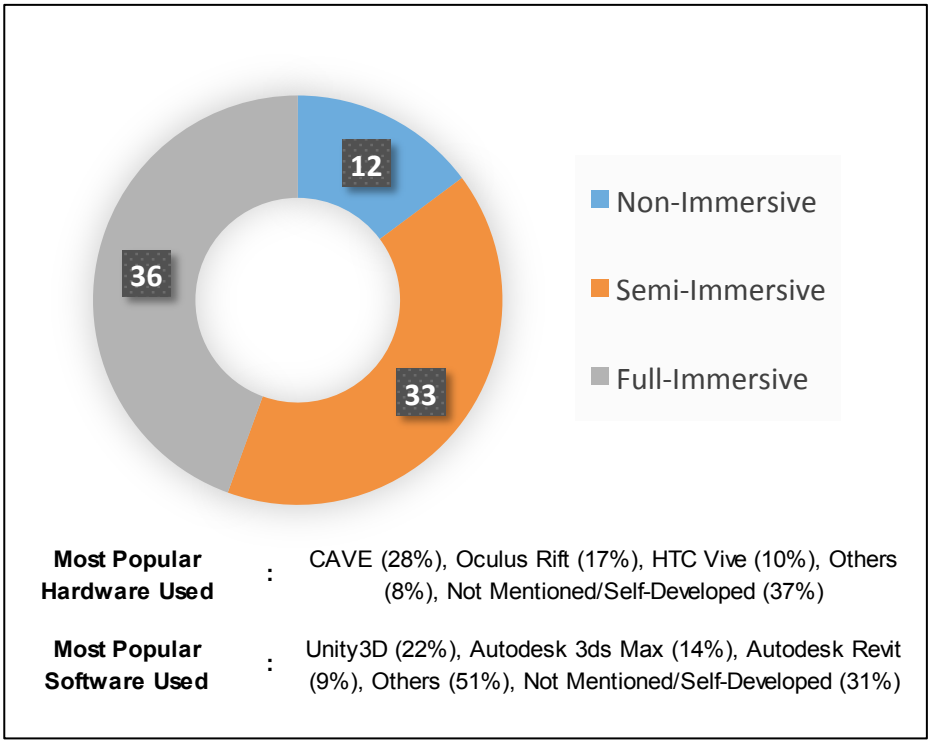

Fig. 5. Number of articles based on VR technology

From the 81 reviewed articles, it shows that VR is mostly used to simulate manufacturing factory environments (44%), office building environments (10%), public facility environments (7%), residential buildings environments such as housing and apartments (6%), construction site environments (4%), hospital building environments (4%), university classroom and laboratory environments (4%), and other environments (7%). The distribution of case study environments is shown in Figure 6.

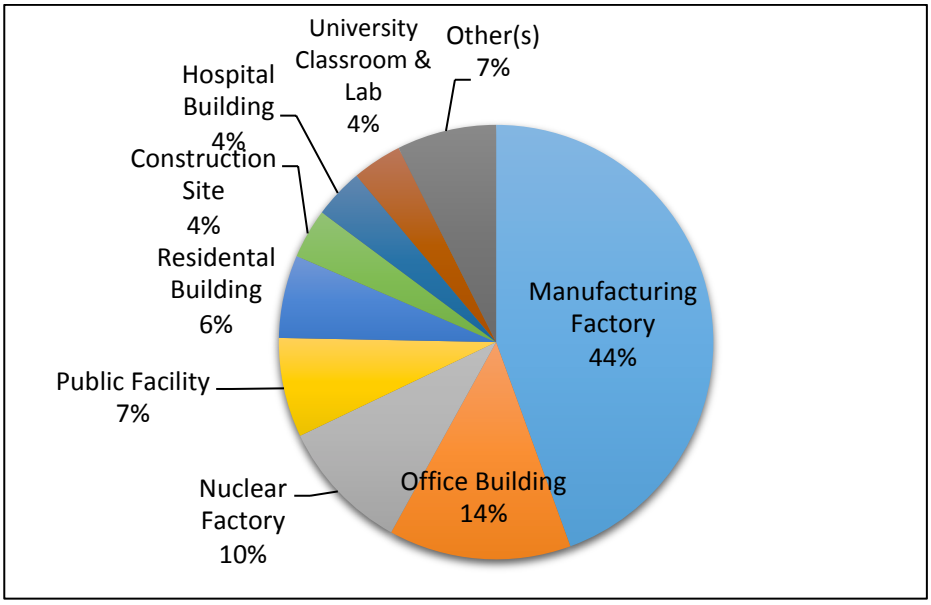

Fig. 6. Proportion of articles based on case study environments

Based on the results of the literature review, the use of VR technology was highly used to simulate environments in layout of production processes, improvement of warehouse layout, analysis of assembly processes, and other activities on the production floor related to ergonomic aspects and safety of factory workers.

4.3 Applicants Domain (Point of Interest)

VR Applications in Workplace Design: Ergonomic Aspect. The role of VR technology in designing ergonomic workplace is very important. An ergonomic work environment helps workers and other users in the environment to provide a sense of comfort. By using VR, the user can express their perceptions, respond, and can interact with the design of facilities and work tools. The feedback from users will help designers to develop the workplace design.

Based on the analysis results of the literature review in this article, 34 articles (37% of the total) discussed ergonomic aspects in the use of VR for designing workplace, such as in the environment of manufacturing factories/plants, offices, residential buildings, nuclear plants, and public facilities. For example, (Budziszewski, Grabowski, Milanowicz, Jankowski, & Dzwiarek, 2011) used VR using the Z800 3D Visor (a HMD device) to design a comfortable workplace for persons with disabilities. Experimental studies had also been conducted by (Heydarian, Pantazis, Wang, Gerber, & Becerik-Gerber, 2017) in an office room. By using VR, the effect of lighting on user performance can be tested. VR technology can also be applied in a hospi-

tal environment. Visual simulation of interior design in hospitals using VR can be used as an evaluation material for emotional responses for users, both hospital workers and patients (Dinis, Duarte, Noriega, Teixeira, Vilar, & Rebelo, 2013). In the environment of public facilities, VR can be used to evaluate the design of public transportation. For example, (Wu, 2018) conducted experiments using VR built-in eye movement to design theme subway in China. Even in retail environments, VR technology can also be used to determine the perceptions and buying behavior of customers (Lombart, Millan, Normand, Verhulst, Labbé-Pinlon, & Moreau, 2019).

VR Applications in Workplace Design: Safety Aspect. In the aspect of safety, VR technology has a role in ensuring the safety of workers and other users in a system of working environments. For example, by using VR, the safety standards for the workplace design can be directly tested and simulated. If it shows that the workplace design achieves satisfactory results in safety testing using VR, then the workplace design can be immediately implemented. If not, then the workplace must be redesigned to adjust the technical aspects and also the feedbacks and requirements from users.

From the results of the literature review, 27 articles (29%) out of 81 total articles discussed about the use of VR in terms of safety aspects. The simulated workplace environment is also very diverse. For example in the field of energy, VR technology can be utilized to simulate nuclear facilities (Chao, et al., 2017; Silva, Santo, Marins, Siqueira, Mol, & Mol, 2015). As we know, nuclear facilities are one of the workplaces with very high radiation risks. In manufacturing, VR technology is widely used especially for environments with high hazard risks. For example, in the placement of safety signs (Amaral, Duarte, & Rebelo, 2017), material handling (Golabchi, Han, AbouRizk, & Kanerva, 2016), and in testing and identifying human errors in production equipment operators such as cranes (Dhalmahapatra, Pradhan, Das, Singh, & Maiti, 2018). In the construction field, several articles used VR to assess hazard risk, conduct work safety training for operators, and also to ensure the high level of safety and security of the building (Sacks, Perlman, & Barak, 2013; Hilfert & König, 2016). Besides, VR is also widely used in the field of education. VR technology is used to ensure the condition of building facilities and equipment, such as classrooms and laboratories, to have a high level of safety and can provide security for students and staffs (Cruz & Mendoza, 2018; Leder, Horlitz, Puschmann, Wittstock, & Schütz, 2019).

VR Applications in Workplace Design: Productivity Aspect. Productivity is one aspect that often serves as a benchmark to measure efficiency. In various work environments, this productivity aspect must always be considered because this is directly related to the ability of a system to generate profits, especially in the industrial environment. Therefore, stakeholders involved in designing process often assess the design of the workplace environment from the aspect of productivity. If the workplace design has low productivity values, repair and correction actions must be made.

Based on the results of literature review mapping in this article, there are 31 (34%) of the total 81 articles discussing the use of VR technology for workplace design in a productivity perspective. The simulated workplace environments are diverse, ranging from manufacturing plants, construction sites, public facilities, and offices/residential houses. Overall, manufacturing plants are the most simulated environments. For example, VR technology can be used as an evaluation in assessing and improving the flow of production processes (Buchholz, Kind, & Stark, 2017; Koechling, Berssenbruegge, Schluessler, & Stoecklein, 2016), the assembly process (Dorozhkin, Vance, Rehn, & Lemessi, 2012), until the quality process control (Peruzzini, Carassai, Pellicciari, & Andrisano, 2016). For residential and office environments, VR can be used to minimize energy requirements in building design (Niu, Pan, & Zhao, 2016). Whereas in the public facilities environment, for example VR technology can be relied on to improve the design of train stations based on passenger density data (Tang & Auffrey, 2018).

5 Conclusion

The use of VR in workplace design has a very important role. This is based on the results of literature review. From year to year, the VR technology can really be reliable to workplace designers, users, and decision makers to assess and evaluate workplace designs based on ergonomic aspects, safety, and productivity. It will then be used as a reason for improving the design of the workplace. Not only in manufacturing environments, the VR technology is also widely applied in other work environments, such as residential buildings, offices, hospitals, universities, until public facilities. Another interesting fact is that the use and development of VR, especially for the design of workplace is still dominated by modern countries. If developing countries do not immediately rush to catch up, it is feared concepts such as industry 4.0, smart factory, intelligence and green manufacturing, etc. will stop only as a discourse.

One of the challenges in developing the application of VR in workplace design is the cost aspect and the hardware and software used (Halarnkar, Shah, Shah, Shah, & Shah, 2012). In terms of costs, the VR technology certainly requires a high amount of costs. These costs include equipment procurement costs, workplace architecture design costs, testing costs, etc. The higher the level of immersivity we want, the higher the cost that must be incurred. But with a higher the level of immersivity, then the evaluation results of the workplace design will be more accountable. From the hardware and software aspects used, the challenge now is how to develop the right combination of devices according to needs. Based on the results of the literature review, it appears that there are little variations of hardware used by researchers. Most researchers face lack of VR technology variation. For example, they only used hardware from commercial platform such as CAVE and HMD (Oculus Rift, HTC Vive). In other hand, from the software used to design workplace perspective, the variation is quite high. A lot of researchers also had developed their own software to get data and con-

duct analysis from VR simulations. This is because the evaluation and analysis needs of the VR simulation results from each researcher can vary. In fact, hardware and software are a unified set of technology. Failures in determining the type of technology used can result in inability to conduct good analysis, increase costs, and cause bias/error.

From the business perspective, all costs that must be incurred at the early stage are investment costs. If the planning process is managed well, the workplace designing process will provide more added values to the business owner. Therefore, stakeholders, especially business owners, must be able to balance the technical aspects of VR technology that are needed with the output of the analysis that they desire.

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