Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 88 (2020) 36–41

www.elsevier.com/locate/procedia

13th CIRP Conference on Intelligent Computation in Manufacturing Engineering, CIRP ICME '19

Added value of a virtual approach to simulation-based learning in a manufacturing learning factory

Nina Tvenge[a,*], Olga Ogorodnyk[a], Niels Peter Østbø[a], Kristian Martinsen[a]

[a]NTNU, Faculty of Technology, Economy and Management, Teknologivn. 22, 2815 Gjøvik, Norway

* Corresponding author. Tel.: 0047 40636548. *E-mail address:* nina.tvenge@ntnu.no

Abstract

More and more learning factories (LF) are set up supporting the vision of Industry 4.0 connectivity and automation levels; thus, digital twins, virtual and augmented reality are emerging tools. Literature review is the basis for the discourse on possible constraints and opportunities these tools have for the cognitive learning processes in a simulation. State of the art give insight in the lack of research on value of digital learning activities in learning factory setting. This paper is a concept description, giving input to the community on aspects to be considered regarding the use VR/AR/digital twins in a learning factory context.

Peer review under the responsibility of the scientific committee of the 13th CIRP Conference on Intelligent Computation in Manufacturing Engineering, 17-19 July 2019, Gulf of Naples, Italy.

Keywords: learning, simulation-based learning; manufacturing learning factory; cognitive processes; VR; AR

1. Introduction

Learners, in higher education as well as vocational training, come in all shapes and sizes, and thus also have different approaches to learning and, some also claim, different learning styles[2]. Although there are critiques to learning styles - theories, it is a recognized fact that teaching and learning resources need to adapt to the individual learners needs to achieve best possible learning outcome. In a learning factory setting there are multiple opportunities to vary between teaching and learning methods and give opportunity for different approaches, being a physical learning space where both theoretical and practical approaches are relevant. A relative new dimension are digital environments like augmented reality (AR) and virtual reality (VR), giving even more opportunities for different ways of learning. This paper will further discuss this concept and different aspects to be considered regarding the use of VR/ AR/ digital twins in a learning factory (LF) context – especially its constraints and opportunities concerning cognitive processes when working in, or with, such learning environments, i.e. different aspects of the interlinkage between the digital and physical twin concerning cognition and learning in a learning factory – setting.

1.1. Cognition - in augmented/ virtual learning environments

The article ”Benefits of multisensory learning” [3] unravels how the human brain has evolved to learn and operate in natural environments consisting of constant, and multisensory, impulses and input. Shams and Seitz (ibid.) argue that multisensory-training processes can image real-life more extensively than lesser -modality scenarios, and thus produce greater and more efficient learning. But the senses in action must be activated in congruency with the situation *the learned* is going to be applied. And, as the most frequent limitation of AR is student cognitive overload [4, 5], alignment between the sensory input from the simulations, learning outcome and activities in the learning process is crucial for reaching enhanced learning[2]. Thus, as AR can easily present too much information and too much context, congruency and alignment are key factors[6, 7]

Location based augmented reality, spatially linked to an object - in manufacturing education this could be a “learning factory”- can, when being immersive enough, give opportunities for “enhanced education in at least three ways: by allowing multiple perspectives, situated learning, and transfer”[4]. Spatial cognition; how people obtain and exploit knowledge to orientate and make decisions on actions to take

Peer review under the responsibility of the scientific committee of the 13th CIRP Conference on Intelligent Computation in Manufacturing Engineering, 17-19 July 2019, Gulf of Naples, Italy.
10.1016/j.procir.2020.05.007

there and then - make people able to manage cognitive complex tasks in everyday life[8]. AR affords new ways of intuitively interacting with information[6]. AR/VR can also create a more efficient feedback loop for the learners, as the «real» LF activities may take longer[9].

2. Definitions

2.1. Digital and virtual learning factories definition

In addition to a physical learning environment, a learning factory can include digital and/or virtual extension [10]. Digital and virtual learning factories can be used for testing scenarios that otherwise are hard to implement due to lack of time, equipment or high level of complexity, as well as to increase quality of teaching [11]. *"A digital learning factory maps all processes, products and resources of a real learning factory in a digital model"* [10]. Virtual learning factories provide digital ones with visual software tools and means for visualization of digital models.

2.2. Digital twin definition

Digital twin (DT) is one of the main enablers of digital transformation and an important part of Industry 4.0 [12]. According to [13], the DT can be defined as *"an integrated multi-physics, multi-scale, probabilistic simulation (...) that uses the best available physical models, sensor updates, etc., to mirror the life of its corresponding twin"*. It is more than pure data or a model, as it includes algorithms to process data obtained from the physical world in order to make decisions about further actions of a related system [14]. It is also important to distinguish such concepts as digital model, digital shadow and digital twin, as they differ *"in the level of data integration between the physical and digital counterparts"* [12]. Digital model means digital representation of an existing or planned physical object without any kind of direct data exchange between them. Digital shadow, on the other hand, includes an automated one-way data flow from the physical world to the digital model. Digital twin, in its turn, includes data flows between digital and physical objects in both ways [12]. However, at the moment the DT concept is still in its development phase and there are many aspects that need to be dealt with before this technology is widely available [15]. [16] suggest that further on digital twin can be used to utilize different types of data, create a mirror of the physical environment and help to optimize this environment. It is also of high interest to use this concept within education and learning to create new knowledge and demonstrate benefits of its application to industrial users [17]. In addition, linking digital twin, virtual reality and/or augmented reality to enhance learning experience is of high interest.

2.3. Virtual and augmented reality definition

One of possible definitions of virtual reality (VR) is "a computer-generated simulation of a 3D image or environment that can be interacted with in a seemingly real or physical way by a person *using special electronic equipment" [18, 19]*. An important concept that is often mentioned in relation to VR is "spatial immersion". It means having an impression of being fully involved in a nonphysical/digital/virtual world [19]. It is created through use of sounds, images, videos or other media objects.

Augmented reality (AR), on the other hand, is a technology that *"utilizes mobile, context-aware devices (e.g., smartphones, tablets) that enable participants to interact with digital information embedded within the physical environment" [20]*. The main two forms of AR are location- and vision-based. Location-based AR uses GPS in small electronic devices such as smartphones and tablets to show learners parts of a digital world while they are moving through the physical one. The digital inserts can be pictures, videos and audios related to a location the learners have approached. Vision-based AR, on the other hand, uses special objects or targets (QR code, for example) to present digital media, when camera of the mobile device is pointed at them. As it is easy to see, the main difference between concepts of virtual and augmented realities is that in the first case, it is attempted to create a complete virtual world around the technology user, while in the second case parts of digital/virtual world are augmented/embedded into the physical world.

3. State of the Art/Usage today

3.1. Digital twin

There is a significant number of learning factories that are attempting to adopt and demonstrate their interpretation of Industry 4.0 concept[21-24], however, almost none of them address the digital twin concept [17]. As of authors' knowledge, one of very few papers that uses it within the learning factory scenario is [17], here a learning activity was created where learners analyse application of value stream mapping and digital twin to an existing learning factory/environment. Another example is virtual representation of the ESB Logistics Learning Factory (LLF) at Reutlingen University [25]. Here a digital model of the learning factory is presented, which allows students to simulate and test different factory settings before their implementation in reality.

At the same time, there are examples of implementation of elements of the DT in the industry, however, as mentioned previously, the concept itself is still in the development phase. According to [26] the biggest amount of publications related to industrial application of digital twin are within the fields of product design, production, prognostic and health management, however, use of the DT term is not limited to those.

In satellite assembly the digital twin simulation was used to evaluate different production activities to be able to optimize the production strategy [27]. [28] attempted to adopt the digital twin concept to the real-time geometry assurance in individualized productions, the sheet metal assembly station was used as a case. In additive manufacturing, [29] tried building a digital twin using a 3D model of a product and taking into account such parameters as temperature, velocity fields, cooling rates, solidification parameters, etc. At the same time, [30] connected a computer simulation with a physical production system to reduce material waste and prolong machine lifetime. [31], on the other hand, have created a digital twin model based on a multi-physics simulation of a non-standardized material specimen to predict its failure along two different crack paths. [32] used a high-fidelity DT model in order to perform fault diagnostics of composite material components without damage initiation. As it is easy to see, the digital twin concept can be applied to variety of different topics and education and learning is one of them. Integration of the digital twin concept into a learning factory setting is important and necessary, as in such way it will be easier to run relevant research activities and demonstrate benefits of DT's application to the industry.

Before full implementation of digital twin is possible, several issues need to be resolved, such as: (1) convergence between physical and virtual environment needs to be increased [13]; (2) presentation, consideration and interaction with the real-time data needs to be improved [16]; (3) it needs to be guaranteed that the collected data is complete and clean [16], (4) an efficient way of making sure that digital models are correct needs to be provided, etc.

3.2. Virtual reality

Virtual reality has significantly evolved over years since the first mechanical device called Sensorama was created in 1960s to engage multiple senses to create the feeling of immersion into a virtual situation [33] One of the main purposes of this device was to use it for training of personnel that might be involved into dangerous situations without the accompanying risks. Nowadays VR is used for different levels of education. There are examples of application of virtual reality at universities and schools. [34] merged virtual reality, natural language processing and artificial intelligence techniques in order to develop an intelligent learning environment that is applied in several courses of a Computer Science degree. [35], at the same time, gives recommendations for early design and implementation of a virtual university hospital. In [36] neutrino physics education is addressed with help of a virtual reality application called Neutrino-KAVE which is used for visualization and interaction with data from neutrino detectors. [37] use an innovative approach for secondary education that exposes students to concepts of manufacturing with help of VR simulation of a manual assembly task in a CAVE. In adult training, virtual reality and serious games approaches are used in, for example, adult's oral hygiene education [38] and general healthcare training [39]. In addition, VR is applied for training [40, 41] and rehabilitation [42] of people with disabilities.

In the context of learning factories, virtual reality can be used as a complementary teaching method to further enhance the learning experience. [10] introduce such concepts as digital and virtual learning factories, where additional software tools are used to create a learning environment accessible online that can be used for simulation activities such as layout planning, concurrent engineering, etc. In [43] the authors take a learning factory at TU Datmstadt (CiP) and propose guidelines to integrating digital environments and models into the factory setting. In such a way learning factory becomes combination of a learning and digital factory turning it into a hybrid one. [44], on the other hand, use VR to develop a digital learning factory, where students can create their own test companies for exercises. In [45] a prototype of a virtual reality system for learning to operate in an intelligent factory according to the concept of Industry 4.0 is presented. Another example of the VR application in the learning factories setting is a virtual learning factory of McKinsey & Co [46]. Participants from all over the world can use the virtual learning factory to observe execution of production processes to further identify and discuss optimization possibilities.

Despite of numerous examples of use of the VR in the learning factories setting as well as in education in general, [43] suggest that the virtual reality should be considered as a useful supplementary tool to the traditional physical teaching system. This is due to complexity or inability to incorporate some of senses, such as touch or smell, and concepts, such as teamwork into the virtual setting.

3.3. Augmented reality

However, in addition to use of VR, augmented reality can be also applied for educational and learning purposes. *"Utilizing a virtual extension to the physical learning factories and with a simulated environment, valuable yet physical impossible or time-consuming actions can be included as well"* [47]. [48] provide a literature review on the topic of use of augmented reality games in primary and secondary education. [10], at the same time, state that use of virtual and augmented environments in the context of learning factories is not uncommon. Among other examples of application of the AR in combination with a physical learning factory is KTH XPRES LAB [49]. Here digital models of products, manufacturing processes as well as the factory itself are visualized to support cross-disciplinary learning when designing manufacturing systems. [50] propose a system architecture for a learning environment that combines physical objects and visualization of their digital contents using augmented reality. Such system can be used to help learners acquire necessary skills for use of cyber-physical systems and to become more familiar with the Industry 4.0 concept. [51] present an approach for use of AR for better integration of data obtained from real-time sensors to effectively control the augmented reality content on students' devices. [52] introduce application of AR to incorporate advanced visualization into their teaching factory to help engineering students to interact, evaluate and improve current product design of a radio-controlled car.

According to the literature review on main issues related to use of AR by [53], some of the challenges related to the use of technology are: (1) AR technology is sometimes hard to use due to low user-friendliness of interfaces; (2) possible cognitive overload of the students using AR [20]; (3) various application-related technical issues such as GPS error or low sensitivity in trigger recognition, etc.

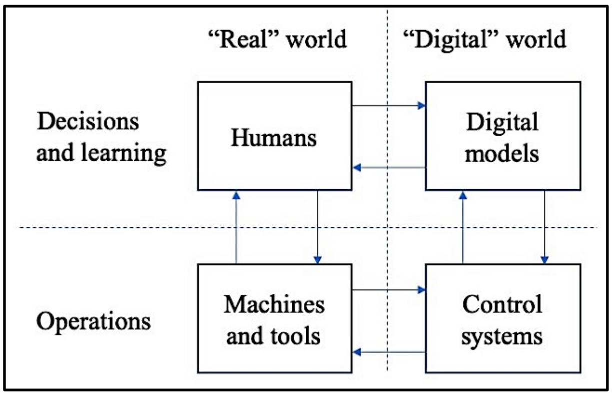

Fig. 1. Model of a manufacturing plant based on the Milgram's reality - virtuality continuum [1]

4. Immersive digital twin / AR / VR

Creating learning spaces for students in augmented-/ virtual reality demands stringent planning, making sure the content is relevant and aligned with the desired learning outcomes. The human brain is vulnerable to overload and relatively easy distracted, thus strict congruence regarding what sensory inputs are really necessary in a scenario where enhanced learning is the main goal is a key factor. To give students the opportunity to an immersive experience requires focus on the learning path. Utilizing technology as a tool to constructively align the elements; being learning objects, learning activities and relevant assessment of learning outcome, rather than being led by the technology itself.

Fig. 1. Model of a manufacturing plant based on the Milgram's reality - virtuality continuum shows a simple graphical model of a manufacturing plant divided horizontally into a decision/learning level and an operations level, and vertically into a physical or "real" world and a digital/computer or "virtual" world. Humans utilize models for decision support and learning and apply this on the machines and tools. Modern numerically controlled machines have embedded (operations) control software. Furthermore, the growth of monitoring and sensor systems, Manufacturing Executing Systems (MES) and Enterprise Resource Planning (ERP) is evolving and current manufacturing operations is more and more a cyber physical-system. As mentioned, a true "digital twin" is dependent on an interaction and exchange of data and information between the digital and the physical "twins". This has to be enabled through a link between the machines and the computer models through the operations computer systems.

Feil! Fant ikke referansekilden. will also be a model of a high-fidelity "Industry 4.0" or CPS - focused learning factory, with digital models representing the physical LF digitally. As the physical LF, the digital models must be modular and flexible and is more or less "fixed" based on the scenarios selected by the teachers.

In this paper we wish to highlight how the interaction between digital and real "twins" can be utilized in the learning process. Figure (2) shows the steps in the learning process using the LF and the digital model. As mentioned, it is important to develop learning materials and methods that allows in-depth understanding and are preferably stripped for unnecessary information; "noise". In step 1 the teacher and the students can use the digital models for pre-briefing. What will happen at the physical LF? This can easily be done with remote students as well, through the use of virtual classrooms. During the LF simulation, the students are the "humans" in model 1, and are acting as operators, engineers etc. simulating an actual factory. The learning gained form the simulation runs need to be analysed, discussed and reflected on in a debriefing-phase. This stage is proven to be especially important for the learning outcome. Here again the digital model is the base of this analysis. Finally, the studens can link the two "worlds" and gain increasing knowledge on both manufacturing as such, but also on the interaction between the digital and physical world in a modern "industy 4.0" manufacturing plant.

This paper is thus a concept description, giving input to the community on aspects to be considered regarding the use VR/AR/digital twins in a learning factory context - and its constraints and opportunities concerning cognitive processes when working in, or with, such learning environments.

5. Future work

We are, at present, looking at two different directions in future work, one is social science directed: evaluating the learner's individual gain in the continuum of digital and physical reality. The authors wish to create research arenas for testing whether focus on congruency and alignment helps creating immersive learning situations and enhanced learning outcomes in learning factories in manufacturing education.

Also, a more machine-centered approach (**Feil! Fant ikke referansekilden.**), using AR/VR together with artificial intelligence (AI) - machine learning, various system applications, context aware authentication, human-machine interaction (HMI) to develop use-cases. A learning factory as research arena for human-centric (e.g. user-defined system view) and more machine-centric views and technologies, in the context of future manufacturing systems with cyber-physical tools and products.

Acknowledgements

This paper was based on activities within SFI Manufacturing in Norway and is partially funded by the Research Council of Norway under contract number 237900. The authors wish to thank the Research Council for funding and the companies participating in the discussions for this paper.

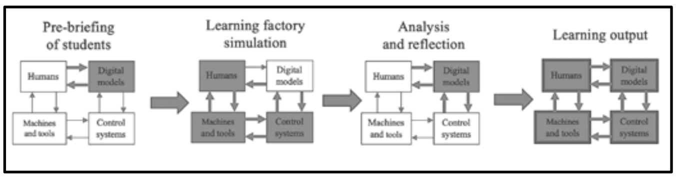

Fig. 2. Steps in the learning process, using a LF and digital model.

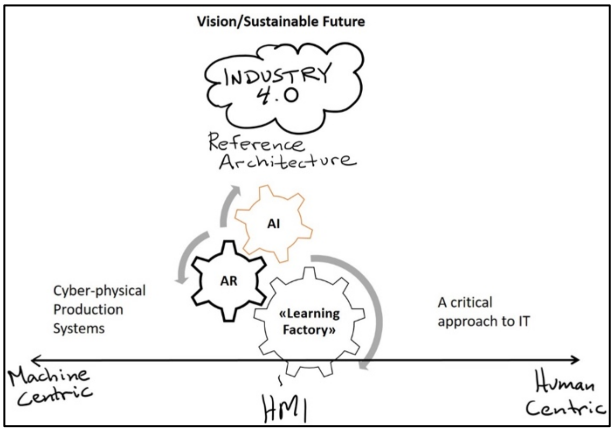

Fig. 3. Suggested future research model

References

[1] Govindarajan, U. H., Trappey, A. J., and Trappey, C. V., "Immersive technology for human-centric cyberphysical systems in complex manufacturing processes: a comprehensive overview of the global patent profile using collective intelligence," *Complexity,* vol. 2018, 2018.

[2] Biggs, J., "Enhancing teaching through constructive alignment," *Higher education,* vol. 32, no. 3, pp. 347-364, 1996.

[3] Shams, L. and Seitz, A. R., "Benefits of multisensory learning," *Trends in Cognitive Sciences,* vol. 12, no. 11, pp. 411-417, 2008/11/01/ 2008.

[4] Dunleavy, M. and Dede, C., "Augmented Reality Teaching and Learning," in *Handbook of Research on Educational Communications and Technology*, J. M. Spector, M. D. Merrill, J. Elen, and M. J. Bishop, Eds. New York, NY: Springer New York, 2014, pp. 735-745.

[5] Mayer, R. E., "Cognitive theory of multimedia learning," *The Cambridge handbook of multimedia learning,* vol. 3148, 2005.

[6] Santos, M. E. C., Taketomi, T., Yamamoto, G., Rodrigo, M. M. T., Sandor, C., and Kato, H., "Augmented reality as multimedia: the case for situated vocabulary learning," *Research and Practice in Technology Enhanced Learning,* vol. 11, no. 1, p. 4, 2016.

[7] Biggs, J., "Constructive alignment in university teaching," *HERDSA Review of higher education,* vol. 1, no. 5, pp. 5-22, 2014.

[8] Hung, Y. H., Chen, C. H., and Huang, S. W., "Applying augmented reality to enhance learning: a study of different teaching materials," *Journal of Computer Assisted Learning,* vol. 33, no. 3, pp. 252-266, 2017.

[9] Tisch, M., Abele, E., and Metternich, J., "Overview on Potentials and Limitations of Existing Learning Factory Concept Variations," in *Learning Factories : Concepts, Guidelines, Best-Practice Examples*Cham: Springer International Publishing, 2019, pp. 289-321.

[10] Abele, E., Chryssolouris, G., Sihn, W., Metternich, J., ElMaraghy, H., Seliger, G., Sivard, G., ElMaraghy, W., Hummel, V., and Tisch, M. J. C. a., "Learning factories for future oriented research and education in manufacturing," vol. 66, no. 2, pp. 803-826, 2017.

[11] Manesh, H. F. and Schaefer, D., "A Virtual Factory Approach for Design and Implementation of Agile Manufacturing Systems," in *2010 ASEE Annual Conference & Exposition*, 2010: University of Bath.

[12] Kritzinger, W., Karner, M., Traar, G., Henjes, J., and Sihn, W., "Digital Twin in manufacturing: A categorical literature review and classification," *IFAC-PapersOnLine,* vol. 51, no. 11, pp. 1016-1022, 2018.

[13] Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H., and Sui, F., "Digital twin-driven product design, manufacturing and service with big data," *The International Journal of Advanced Manufacturing Technology,* vol. 94, no. 9-12, pp. 3563-3576, 2018.

[14] Boschert, S. and Rosen, R., "Digital twin—the simulation aspect," in *Mechatronic Futures*: Springer, 2016, pp. 59-74.

[15] Sierla, S., Kyrki, V., Aarnio, P., and Vyatkin, V., "Automatic assembly planning based on digital product descriptions," *Computers in Industry,* vol. 97, pp. 34-46, 2018.

[16] Cheng, Y., Zhang, Y., Ji, P., Xu, W., Zhou, Z., and Tao, F., "Cyber-physical integration for moving digital factories forward towards smart manufacturing: a survey," *The International Journal of Advanced Manufacturing Technology,* pp. 1-13, 2018.

[17] Uhlemann, T. H.-J., Schock, C., Lehmann, C., Freiberger, S., and Steinhilper, R. J. P. M., "The digital twin: Demonstrating the potential of real time data acquisition in production systems," vol. 9, pp. 113-120, 2017.

[18] (2018, 02.11.2018). *Oxford Dictionary - Virtual reality*. Available: https://en.oxforddictionaries.com/definition/virtual_realityoxfor

[19] Freina, L. and Ott, M., "A Literature Review on Immersive Virtual Reality in Education: State Of The Art and Perspectives," *eLearning & Software for Education,* no. 1, 2015.

[20] Dunleavy, M., "Design principles for augmented reality learning," *TechTrends,* vol. 58, no. 1, pp. 28-34, 2014.

[21] Thiede, S., Juraschek, M., and Herrmann, C., "Implementing cyber-physical production systems in learning factories," *Procedia Cirp,* vol. 54, pp. 7-12, 2016.

[22] Schuh, G., Gartzen, T., Rodenhauser, T., and Marks, A., "Promoting work-based learning through industry 4.0," *Procedia CIRP,* vol. 32, pp. 82-87, 2015.

[23] Gräßler, I., Pöhler, A., and Pottebaum, J., "Creation of a learning factory for cyber physical production systems," *Procedia CIRP,* vol. 54, pp. 107-112, 2016.

[24] Kemény, Z., Beregi, R. J., Erdős, G., and Nacsa, J., "The MTA SZTAKI Smart Factory: platform for research and project-oriented skill development in higher education," *Procedia CIRP,* vol. 54, pp. 53-58, 2016.

[25] Hummel, V., Hyra, K., Ranz, F., and Schuhmacher, J. J. P. C., "Competence development for the holistic design of collaborative work systems in the Logistics Learning Factory," vol. 32, pp. 76-81, 2015.

[26] Tao, F., Zhang, H., Liu, A., and Nee, A. J. I. T. o. I. I., "Digital Twin in Industry: State-of-the-Art," 2018.

[27] Zhuang, C., Liu, J., and Xiong, H. J. T. I. J. o. A. M. T., "Digital twin-based smart production management and control framework for the complex product assembly shop-floor," vol. 96, no. 1-4, pp. 1149-1163, 2018.

[28] Söderberg, R., Wärmefjord, K., Carlson, J. S., and Lindkvist, L. J. C. A., "Toward a Digital Twin for real-time geometry assurance in individualized production," vol. 66, no. 1, pp. 137-140, 2017.

[29] Knapp, G., Mukherjee, T., Zuback, J., Wei, H., Palmer, T., De, A., and DebRoy, T. J. A. M., "Building blocks for a digital twin of additive manufacturing," vol. 135, pp. 390-399, 2017.

[30] Vachálek, J., Bartalský, L., Rovný, O., Šišmišová, D., Morháč, M., and Lokšík, M., "The digital twin of an industrial production line within the industry 4.0 concept," in *Process Control (PC), 2017 21st International Conference on*, 2017, pp. 258-262: IEEE.

[31] Cerrone, A., Hochhalter, J., Heber, G., and Ingraffea, A. J. I. J. o. A. E., "On the effects of modeling as-manufactured geometry: toward digital twin," vol. 2014, 2014.

[32] Reifsnider, K. and Majumdar, P., "Multiphysics stimulated simulation digital twin methods for fleet management," in *54th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, 2013, p. 1578.

[33] Heilig, M. L., "Sensorama simulator," USA, 1961. Available: https://patents.google.com/patent/US3050870.

[34] Griol, D., Molina, J. M., Callejas, Z. J. J. o. A. I., and Environments, S., "An approach to develop intelligent learning environments by means of immersive virtual worlds," vol. 6, no. 2, pp. 237-255, 2014.

[35] Kleven, N. F., "Virtual University hospital as an arena for medical training and health education," Institutt for datateknikk og informasjonsvitenskap, 2014.

[36] Izatt, E., Scholberg, K., and Kopper, R., "Neutrino-KAVE: An immersive visualization and fitting tool for neutrino physics education," in *Virtual Reality (VR), 2014 iEEE*, 2014, pp. 83-84: IEEE.

[37] Stratos, A., Loukas, R., Dimitris, M., Konstantinos, G., Dimitris, M., and George, C. J. P. C., "A virtual reality application to attract young talents to manufacturing," vol. 57, pp. 134-139, 2016.

[38] Rodrigues, H. F., Machado, L. S., and Valença, A. M. G. J. S., "Applying Haptic Systems in Serious Games: A Game for Adult's Oral Hygiene Education," vol. 5, no. 1, p. 17, 2014.

[39] de Ribaupierre, S., Kapralos, B., Haji, F., Stroulia, E., Dubrowski, A., and Eagleson, R., "Healthcare training enhancement through virtual reality and serious games," in *Virtual, Augmented Reality and Serious Games for Healthcare 1*: Springer, 2014, pp. 9-27.

[40] Matsentidou, S. and Poullis, C., "Immersive visualizations in a VR cave environment for the training and enhancement of social skills for children with autism," in *Computer Vision Theory and Applications (VISAPP), 2014 International Conference on*, 2014, vol. 3, pp. 230-236: IEEE.

[41] Kim, T.-Y. J. I. T. o. I. and Systems, "A Situational Training System for Developmentally Disabled People Based on Augmented Reality," vol. 96, no. 7, pp. 1561-1564, 2013.
[42] Qin, Y., Vincent, C. J., Bianchi-Berthouze, N., and Shi, Y., "AirFlow: designing immersive breathing training games for COPD," in *CHI'14 Extended Abstracts on Human Factors in Computing Systems*, 2014, pp. 2419-2424: ACM.
[43] Haghighi, A., Zadeh, N. S., Sivard, G., Lundholm, T., and Eriksson, Y., "Digital learning factories: Conceptualization, Review and Discussion," in *The 6th Swedish Production Symposium (SPS14)*, 2014: Citeseer.
[44] Čelar, S., Turić, M., Dragičević, S., and Veža, I., "Digital Learning Factory at FESB–University of Split," in *XXII naučna i biznis konferencija YU INFO 2016*, 2016.
[45] Żywicki, K., Zawadzki, P., and Górski, F., "Virtual reality production training system in the scope of intelligent factory," in *International Conference on Intelligent Systems in Production Engineering and Maintenance*, 2017, pp. 450-458: Springer.
[46] Hammer, M. J. C. C. C. W. G. o. L. F., CIRP General Assembly, Nantes, France, "Making operational transformations successful with experiential learning," 2014.
[47] Thiede, B., Posselt, G., Kauffeld, S., and Herrmann, C. J. P. M., "Enhancing learning experience in physical action-orientated learning factories using a virtually extended environment and serious gaming approaches," vol. 9, pp. 238-244, 2017.
[48] Koutromanos, G., Sofos, A., and Avraamidou, L. J. E. M. I., "The use of augmented reality games in education: a review of the literature," vol. 52, no. 4, pp. 253-271, 2015.
[49] Sivard, G. and Lundholm, T., "XPRES-a digital learning factory for adaptive and sustainable manufacturing of future products," in *3rd conference on Learning Factories*, 2013, pp. 132-154.
[50] Quint, F., Sebastian, K., and Gorecky, D. J. P. C. S., "A mixed-reality learning environment," vol. 75, pp. 43-48, 2015.
[51] Neges, M., Wolf, M., Kuska, R., and Frerich, S., "Framework for Augmented Reality Scenarios in Engineering Education," in *International Conference on Remote Engineering and Virtual Instrumentation*, 2018, pp. 620-626: Springer.
[52] Mourtzisa, D., Zogopoulosa, V., Vlachoua, E. J. E., and Training, "Augmented Reality supported Product Design towards Industry 4.0: a Teaching Factory paradigm," vol. 2351, p. 9789, 2018.
[53] Akçayır, M. and Akçayır, G. J. E. R. R., "Advantages and challenges associated with augmented reality for education: A systematic review of the literature," vol. 20, pp. 1-11, 2017.
https://en.oxforddictionaries.com/definition/virtual_realityoxfor