ARRIVET

DIGITAL TWINS: BUILDING YOUR OWN VIRTUAL LAB FOR ENHANCED VOCATIONAL EDUCATION TRAINING

Igor Azkarate[1], Aimar Lasa[2] and Aitor Otaño[3]

Mondragon Goi Eskola Politeknikoa[1], CIFP Don Bosco LHII[2], Tknika[3]

DOI: 10.56007/arrivet.v1i1.18

ABSTRACT:

The emergence, in the context of Industry 4.0, of tools for developing Digital Twins of automated industrial systems brings about a paradigm shift in the development of control systems. Their virtual commissioning allows for shortening delivery times of automated solutions, among other benefits, but also highlights the need for competent technicians in these technologies. The academic classroom is a breeding ground for future professionals. This article presents an initiative carried out by the Technological Innovation and Intelligent Systems area at Tknika to exploit and transfer results of projects and services developed with these tools to vocational training teachers.

Keywords: digital twin; virtualization; digitalization

1. INTRODUCTION

This section introduces the reader to the context in which this work is developed and the contribution of the Digital Twin (DT) to it, in order to define the work and the issue to which it is intended to give response.

1.1 Automated industrial systems

The Programmable Logic Controller (PLC) is the most widely used control device in industrial environments. It is oriented to discrete event systems and is based on process and operator information (David, 1993). Its use is due to several characteristics that differentiate it from a conventional computer (Michel and Duncan, 1990): (i) cyclic program execution; (ii) reliability; (iii) adaptability to the presence of electrical noise, vibrations, extreme temperatures and humidity; and (iv) easy maintenance.

PLC code is usually tested throughout its development and based on the writing of inputs and/or variables, and the visualization of outputs and/or variables in the device manufacturer's own environment, without direct vision of the process behaviour.

Working exclusively in the development environment of the controller, without a rigorous test procedure and a good knowledge of the process to be automated can cause the control system to arrive incomplete or with errors at commissioning. This final phase of the project can have a considerable duration, with unexpected and/or unnecessary expenses, a personal and social cost for the technical personnel in charge, and possible damages/injuries to equipment/persons. The consequent loss of positioning of the manufacturer in the market, as the downtime of machinery in reconditioning projects and the delivery time in new complete developments are key factors, can affect its reputation and condition future orders. Conventional commissioning does not guarantee short delivery times or their fulfilment.

Industry 4.0 brings with it a paradigm shift in the described field. Established for a planned 4th industrial revolution, the term is reminiscent of software versioning. Within this revolution, digitalization technologies application in manufacturing systems brings higher productivity

(Uhlemann et al., 2017), simple integration of intelligent components (Negri, 2017), and real-time control and monitoring of devices and cyber-physical elements (Lee, 2015), as well as virtual product and process planning from data analysis by simulation tools (Boschert, and Rosen, 2016).

1.2 Digital Twin overview

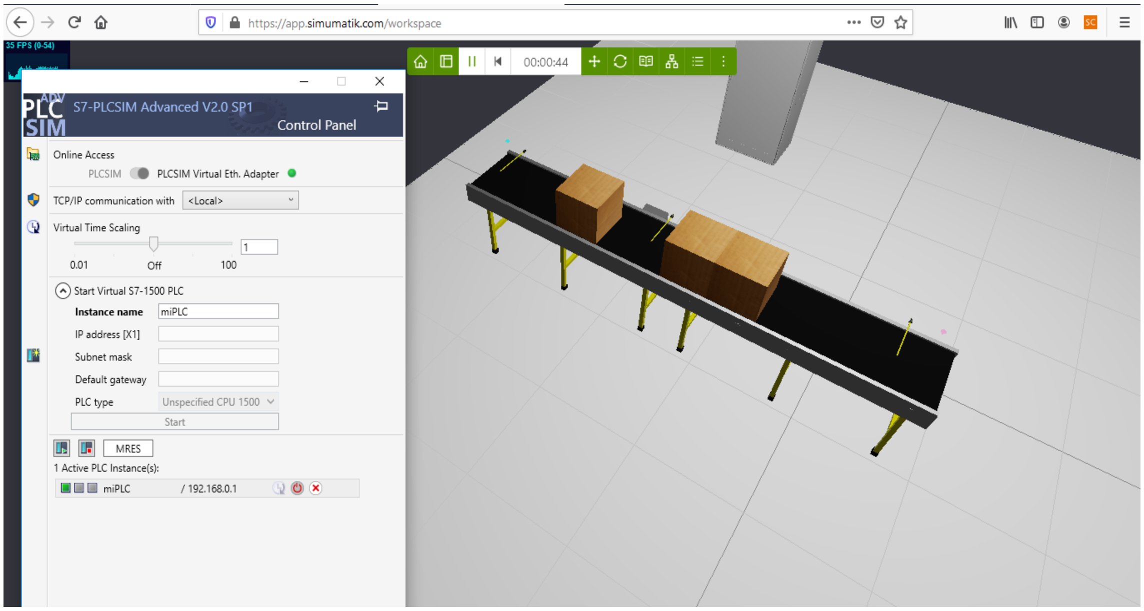
One of the terms emerging in the context of Industry 4.0 is DT. It is one of the digitization technologies with the greatest potential in numerous fields in industry (Tao et al., 2018) and consists of the virtual and computerized equivalent of a physical system (Kritzinger et al., 2018).

It is based on emulation, which attempts to imitate the behaviour of a system to perform the same work and produce the same results. Unlike simulation, it requires a control system, so it can be used to test the functionality or logic of a PLC, or a robot program (Lee and Park, 2014; Johnstone et al., 2007). It replicates the real world with enough concreteness that the device is indistinguishable from it (McGregor, 2002).

The techniques applied in the development of virtual models are the I/O level and the component level, the former being the most common strategy for the construction of virtual commissioning (VC) models:

- I/O level: suitable for the validation of PLC programs, it is the minimum level required for testing the control software. It lacks the potential to support other tasks.
- Component level: also serves to support design or energy optimization, among others. Each component is modelled individually from geometric, kinematic, functional and interface aspects.

OPC UA has become the standard for communication between industrial control systems and third-party software, such as emulation tools. Based on the client-server principle, it is vendor-independent, i.e., it allows connecting computer and PLC of any manufacturer (Johnstone et al., 2007). This makes it possible to test control systems by means of a DT of the process, with device variables being read and written transparently. The latest generation PLCs include OPC UA connectivity. For those controllers that do not provide this feature, external software can be used.



Online Access
PLCSIM PLCSIM Virtual Eth. Adapter
TCP/IP communication with <Local>
Virtual Time Scaling 1
0.01 Off 100
Start Virtual S7-1500 PLC
Instance name miPLC
IP address [X1]
Subnet mask
Default gateway
PLC type Unspecified CPU 1500
1 Active PLC Instance(s):
miPLC / 192.168.0.1

Fig. 1 Virtual commissioning according to software-in-the-loop configuration.

The connectivity between the control device and the DT of the automated industrial system is carried out according to one of these configurations (Schamp et al., 2018):

- Virtual plant and virtual controller, or Software-In-the-Loop (SIL): consists of combining an accurate model of the plant to be controlled with an emulated PLC (see Figure 1). It is a relatively inexpensive alternative, but because it does not use equipment it neglects safety aspects such as robot collisions or personal injury.
- Virtual plant and real controller, or Hardware-In-the-Loop (HIL): all possible hardware such as PLCs, auxiliary modules and field devices are used. One of its advantages is that an identical or very similar environment to the real plant is created and the code is tested directly on the control device. On the other hand, this configuration is more costly and less flexible to changes during the design phase. In addition, the risk of accidents and injuries is higher.

1.3 Digital Twin support in automated industrial systems

A DT makes it possible to test the manufacturing systems and the associated control programs virtually and prior to the assembly of the physical plant (Hoffmann et al., 2010). Anomalous behaviours are detected in advance. A DT makes it possible to carry out tests without shutdowns and to check situations that could be expensive or complex to reproduce in a physical system (Dahl et al., 2017), both in PLCs and in robots and artificial vision systems. The commissioning time of an automated solution is shortened as a result of the use of digitization.

Literature reflects the benefits of the use of virtual models beyond code testing, i.e., from project conception and planning to the plant's operation. The application fields are varied:

- The overall engineering process (Rossmann et al., 2007), such as the design of a production line by analysing the results of modifications without performing them (Damiani et al., 2018), or material flow simulation combined with VC tools (Meyer and Strabburger, 2013).
- Educational and/or training applications for operation and maintenance operators in factories. Both normal operation and failure scenarios are reproduced without forcing production stoppages. Learning platforms for VC in the laboratory (Mortensen and Madsen, 2018) and virtual classrooms for industrial automation courses (Vazquez Gonzalez et al., 2018).
- Diagnosis and maintenance (Rosen et al., 2018; Freeman Gebler et al., 2017). Industry 4.0 allows addressing problems such as fault and anomaly detection in industrial systems in real time through emerging technologies (Velasquez et al., 2022) such as Internet of Things (IoT) and machine learning.
- Component sizing, parameter setting and optimization of performance and/or energy consumption, e.g., the adjustment of faster process speeds to that of the bottleneck of the facility (Expósito and Mujika, 2017).

1.4 Issues in classroom in vocational education and training context

The academic classroom, where future professionals are educated, is not exempt from the difficulties faced by R&T staff or developers. In basic simulated exercises it is difficult to reproduce the signals that would occur in the real process. In complete implementations, students work against models representing industrial machinery. The teaching staff organizes access to the material on a rotating and time-limited basis, due to the price of the equipment, the limited number of units available and the limited space in the laboratories. In addition to the difficulty to simulate, in the programming environment, all the scenarios that can occur in the process, the implementation of the project becomes a test bench. Errors in the code can lead to dangerous situations and element wear and/or breakage, which is worsened when there are sensitive mechanisms that require frequent adjustments, further reducing the availability of the model. Finally, and given the difficulty in acquiring control software development skills in the classroom, the dedication to these skills is extensive and other skills of interest such as those related to the adjustment of operating parameters and energy efficiency are left aside.

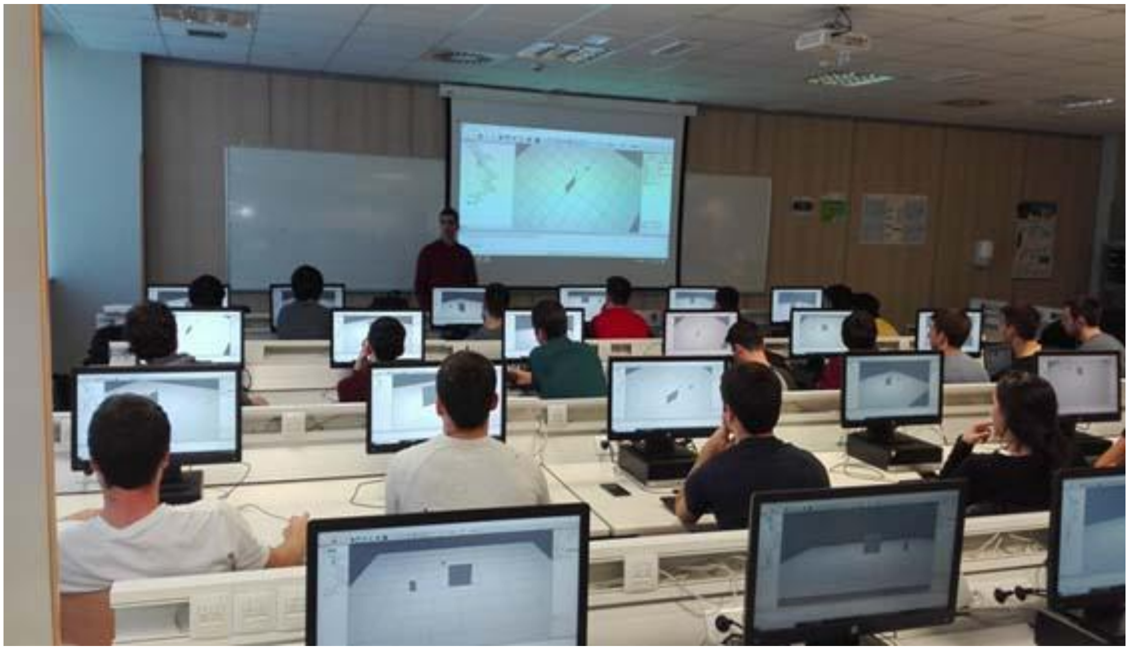


Fig. 2 Lecture on industrial automation handling DTs.

Being the academic classroom a context where situations faced by technical staff are reproduced, the use of DTs can bring with it the series of benefits already described (Figure 2).

1.5 Motivation: what is proposed and why

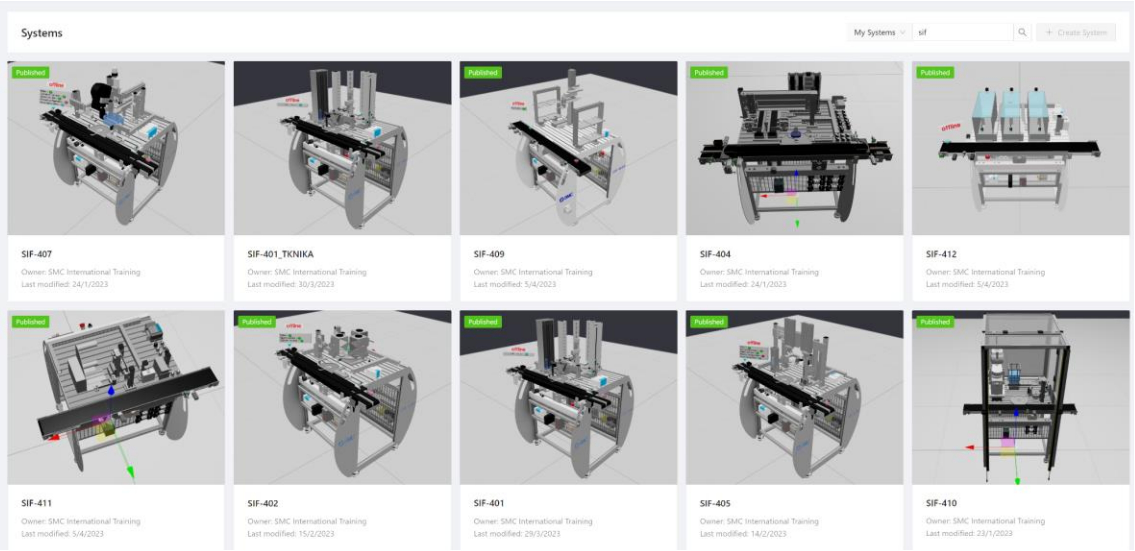
Tknika (Eusko Jaurlaritza, n. d. *a*) is a centre promoted by the Deputy Ministry of Vocational Education and Training of the Education Department of the Basque Government (Figure 3).

Innovation and applied research are at the core of Tknika in its ongoing efforts to place Basque Vocational Training at the European forefront. Tknika is modelled after some of the world's most advanced vocational training centres. Through networking and direct involvement by the Basque Vocational Training teaching staff, the Centre develops innovative projects in the areas of technology, education and management.

Fig. 3 Industry 4.0 Factory Lab in Tknika.

Technological innovation and intelligent systems is one of the areas in which Tknika is structured. Its objective (Eusko Jaurlaritza, n. d. *b*) is to reduce the time that elapses between the emergence of a technology and the fact that Basque society benefits from it, and to research technologies that allow the development of new market niches in the Basque Country. Different training actions are carried out related to the exploitation and transfer of the results of the projects and services developed, e.g., courses for teachers or piloting activities. In this context, a piloting action on the use of DTs in training in the field of industrial automation is introduced.

In the referred area, there are active collaborations with (i) researchers from vocational training centres, such as CIFP Don Bosco LHII (CIFP Don Bosco LHII, n. d.) and Mondragon Goi Eskola Politeknikoa (MGEP) (Mondragon Unibertsitatea, n. d.); and (ii) relevant companies such as Simumatik AB (Simumatik, n. d. *a*) and SMC International Training (SMC International Training, 2022) (Figure 4).



SIF-407
Owner: SMC International Training
Last modified: 24/1/2023

SIF-401_TKNIKA
Owner: SMC International Training
Last modified: 30/3/2023

SIF-409
Owner: SMC International Training
Last modified: 5/4/2023

SIF-404
Owner: SMC International Training
Last modified: 24/1/2023

SIF-412
Owner: SMC International Training
Last modified: 5/4/2023

SIF-411
Owner: SMC International Training
Last modified: 5/4/2023

SIF-402
Owner: SMC International Training
Last modified: 15/2/2023

SIF-401
Owner: SMC International Training
Last modified: 29/3/2023

SIF-405
Owner: SMC International Training
Last modified: 14/2/2023

SIF-410
Owner: SMC International Training
Last modified: 23/1/2023

Fig. 4 DTs of SMC international training stations, based on Simumatik Platform.

2. METHODS

This section describes the challenge designed and carried out to achieve the proposed objective.

2.1 Background

Given the successful outcome of the 2021/22 academic year, in which five participating teams from different training centres completed virtual laboratories, a new piloting project has been launched in the same terms to be carried out in the 2022/23 academic year.

Note that the tool used in both cases is Simumatik Platform (Simumatik, n. d. *b*). It harnesses the power of the cloud and is secure and accessible from anywhere, anytime. All that is needed is a device with an Internet connection and a browser to access the environment. On the one hand, public DTs can be accessed free of charge. On the other hand, subscribing to an organization allows teams to work more efficiently, as modelling time is reduced by creating any component using an editor and organizing them in libraries for reuse. Independent of the control system, this tool (i) helps technical staff to develop and deliver automated solutions efficiently through their

VC, and (ii) enhances the student learning experience in industrial control-related content (PLCs, robots, etc.).

2.2 Dynamics

- Schedule

This activity has been developed, as in the previous edition, for 7 months, starting in October and ending in May.

- Roles

The teams designated in each training centre have taken charge of the development of a DT of an automated industrial system in an autonomous and proactive way. This automated system could be controlled not only by PLC, but also by robot, and could be selected from two approaches:

- The virtualization of a system already existing in their laboratories, so that from now on the developed projects can be supported by VC.
- An exclusively virtual application initially, but whose physical part is simple and accessible to manufacture afterwards, for complete implementations.

The role assumed by Tknika collaborating researchers is to accompany and advise.

- Actions

On the one hand, researchers have visited the participating centres to get first-hand knowledge of the work to be carried out and its evolution. On the other hand, on-demand online tutorials have been carried out to resolve technical doubts, as well as online discharge or follow-up meetings.

- Piloting closure

The closing of this experience has consisted of an online event to present the applications developed, with the participation of the centres involved and open to the general public.

In addition, the completion of the DTs brings with it two awards from Simumatik AB for the development team: (i) the next publication of the systems, after the required adaptations and the generation of the complementary documentation, in the platform; and (ii) a series of free one-year licenses.

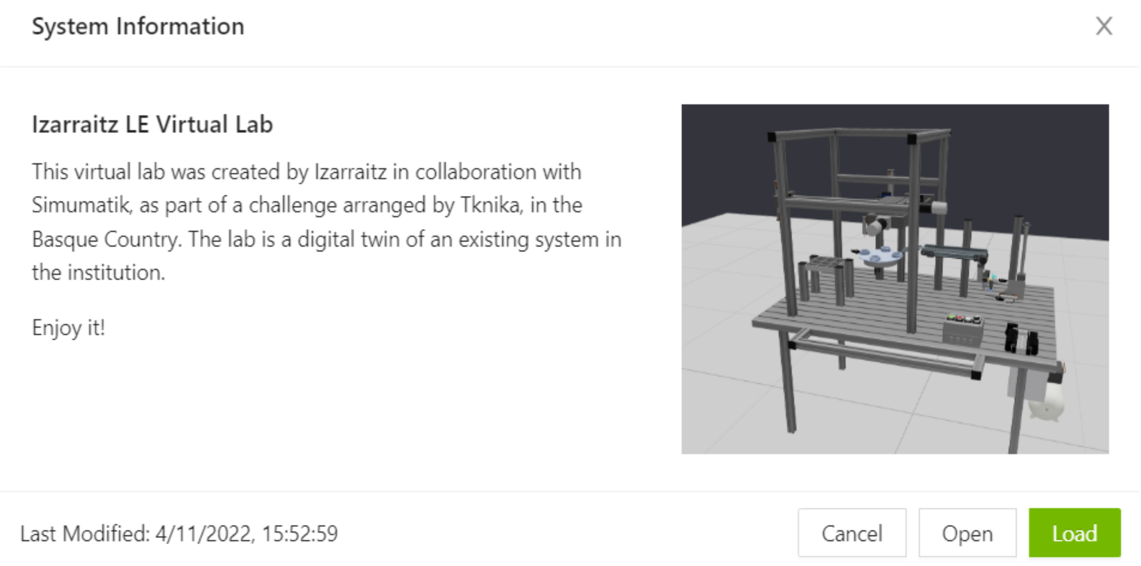
3. RESULTS

Table 1 quantifies the number of applications completed in the piloting. Information is shown for both the previous academic year and the current academic year.

Academic year	2021/22	2022/23
DTs completed	5	5

Table 1: Applications completed.

Pending the appearance of public systems on Simumatik Platform, Figures 5 and 6, related to the previous academic year, serve as an example.



System Information

Izarraitz LE Virtual Lab

This virtual lab was created by Izarraitz in collaboration with Simumatik, as part of a challenge arranged by Tknika, in the Basque Country. The lab is a digital twin of an existing system in the institution.

Enjoy it!

Last Modified: 4/11/2022, 15:52:59

Fig. 5 System developed in the 2021/2022 challenge available on the Simumatik Platform.

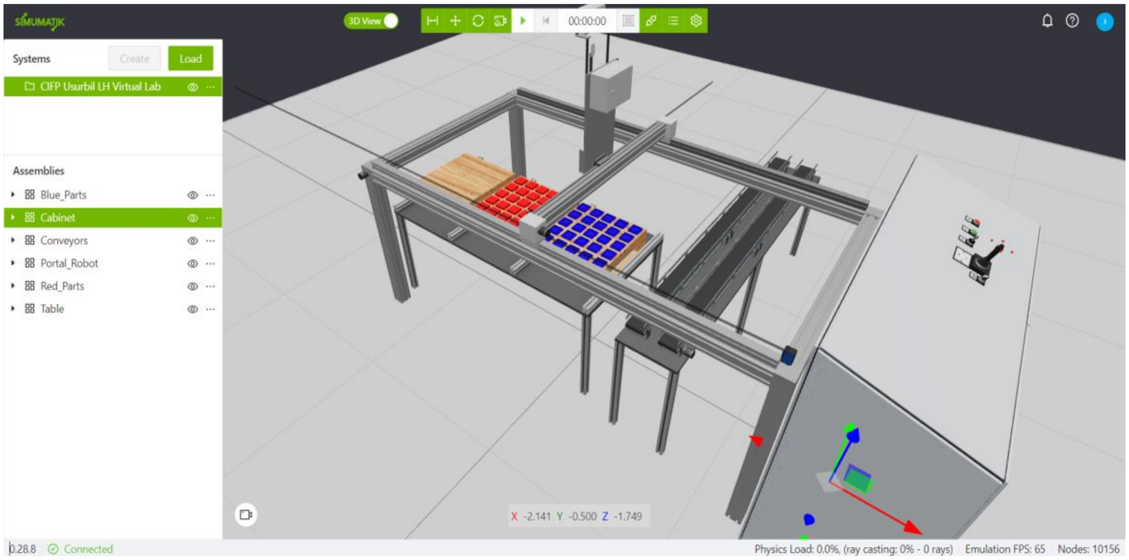


Fig. 6 System developed in the 2021/2022 challenge available on the Simumatik platform.

4. DISCUSSION

In the search for a tool to facilitate the testing and validation of control software in automation projects developed in the academic environment and given the successful industrial use cases existing in the literature, the use of this technology has been introduced in a piloting activity with faculty from vocational training centres. The number of applications completed in the last academic year, five, has been equalled.

The participants have become familiar with modelling their own systems, as well as the connectivity with these and any other existing systems, in all cases of an industrial nature and with equipment and control devices from leading suppliers in the market. The next phase would consist of didactic material generation and transferring this knowledge to students by integrating these tools into the curricula. Subsequently, the virtues of using DTs in terms of reduced commissioning time, understanding of the system to be automated and better management of material resources, among others, can be tested.

The modelling effort and its cost are difficult to estimate. This experiment has served to advance in these issues, with teachers developing skills and designing components and a DT that can be reused. This is an investment prior to enjoying the virtues of these tools in the classroom and projects.

Finally, in order for the reader to get to know this work better, it is recommended to experiment with the systems published on the aforementioned platform, free of charge with the basic registration. Browsing the components and mechanisms, or developing your own control system for laboratories built by others, may help to identify particular needs or interests. The authors of this article remain at the disposal of all those readers who may have questions, contributions and/or the aim of transferring an initiative of these characteristics to their area.

REFERENCES

Boschert, S. and Rosen, R. (2016). Digital twin—the simulation aspect. Mechatronic Futures (59-74). Springer.

CIFP Don Bosco LHII (n. d.). Home page. CIFP Don Bosco LHII. https://www.donbosco.eus/en/home

Dahl, M., Bengtsson, K., Fabian, M. and Falkman, P. (2017). Automatic Modeling and Simulation of Robot Program Behavior in Integrated Virtual Preparation and Commissioning. Procedia Manufacturing, 11, 284-291. https://doi.org/10.1016/j.promfg.2017.07.107

Damiani, L., Demartini, M., Giribone, P., Maggiani, M., Revetria R. and Tonelli F. (2018). Simulation and Digital Twin Based Design of a Production Line: A Case Study. Proceedings of the International MultiConference of Engineers and Computer Scientists, 2.

David, R. (1993). Petri Nets and Grafcet for Specification of Logic Controllers. *IFAC Proceedings Volumes 26*(1), 683-688. https://doi.org/10.1016/S1474-6670(17)49215-9

Eusko Jaurlaritza (n. d. *a*). About Tknika. Tknika. https://tknika.eus/en/about-tknika

Eusko Jaurlaritza (n. d. *b*). Technological Innovation and Intelligent Systems. Tknika. https://tknika.eus/en/areas-2/technological-innovation-and-intelligent-systems

Expósito, I. and Mujika I. (2017). Reductions in Energy Consumption through Process Optimisation and Variable Production [Doctoral thesis]. Högskolan i Skövde, Sweden. https://his.diva-portal.org/smash/record.jsf?pid=diva2%3A1211843&dswid=-6536

Freeman Gebler, O., Hicks, B., Harrison, A. and Barker, M. (2017). On the feasibility of inferring the applied mechanical loading of a conveyor system test rig from monitored system parameters. Paper presented at COMADEM 2017, Preston, United Kingdom.

Hoffmann, P., Maksoud, T. M., Schumann R. and Premier, G. C. (2010). Virtual Commissioning Of Manufacturing Systems A Review And New Approaches For Simplification. European Conference on Modelling and Simulation. ECMS 2010. Bargiela, A., Ali, S. A., Crowley, D., Kerckhoffs, E. J. H. (Ed.). https://doi.org/10.7148/2010-0175-0181.

Johnstone, M., Creighton, D. and Nahavandi S. (2007). Enabling industrial scale simulation / emulation models. 2007 Winter Simulation Conference, IEEE, 2007. https://doi.org/10.1109/wsc.2007.4419701

Kritzinger, W., Karner, M., Traar, G., Henjes, J. and Sihn, W. (2018). Digital Twin in manufacturing: A categorical literature review and classification. IFAC-PapersOnLine, 51(11), 1016-1022. https://doi.org/10.1016/j.ifacol.2018.08.474

Lee, C. G. and Park, S. C. (2014). Survey on the virtual commissioning of manufacturing systems. Journal of Computational Design and Engineering, 1(3), 213-222. https://doi.org/10.7315/JCDE.2014.021

Lee, J., Bagheri, B. and Kao, H.-A. (2015). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. Manufacturing Letters, 3, 18-23. https://doi.org/10.1016/j.mfglet.2014.12.001

McGregor, I. (2002). The relationship between simulation and emulation. Proceedings of the Winter Simulation Conference, 2, 1683-1688. https://doi.org/10.1109/WSC.2002.1166451

Meyer, T. and Strabburger, S. (2013). Integrated Virtual Commissioning-Improved scalability by connecting material flow simulations and virtual machines, 70.

Michel, G. and Duncan, F. (1990). Programmable logic controllers: architecture and applications. John Wiley & Sons, Inc.

Mortensen, S. T. and Madsen O. (2018). A Virtual Commissioning Learning Platform. Procedia Manufacturing, 23, 93-98. https://doi.org/10.1016/j.promfg.2018.03.167

Negri, E., Fumagalli, L. and Macchi, M. (2017). A Review of the Roles of Digital Twin in CPS-based Production Systems. Procedia Manufacturing, 11, 939-948. https://doi.org/10.1016/j.promfg.2017.07.198

Rosen, R., Boschert, S. and Heinrich, C. (2018). Next generation digital twin. Paper presented at, The Twelfth International Symposium on Tools and Methods of Competitive Engineering. University of Las Palmas de Gran Canaria and the Delft University of Technology, 7-11.

Rossmann, J., Stern, O. and Wischnewski R. (2007). Systematics with a corresponding software tool for the integrated virtual commissioning of production lines from planning over to simulation to operation, 707-716.

Schamp, M., Hoedt, S., Claeys, A., Aghezzaf, E. H. and Cottyn J. (2018). Impact of a virtual twin on commissioning time and quality. IFAC - PapersOnLine, 51(11), 1047-1052. 16th IFAC Symposium on Information Control Problems in Manufacturing INCOM 2018. https://doi.org/10.1016/j.ifacol.2018.08.469.

Simumatik (n. d. *a*). Our company & about us. Simumatik. https://simumatik.com/company

SMC International Training (2022). Our reference: INDUSTRY. SMC International Training. https://www.smctraining.com/en

Simumatik (n.d. *b*). What are digital twins? https://simumatik.com/what-are-digital-twins/

Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H. and Sui, F. (2018). Digital twin-driven product design, manufacturing and service with big data. The International Journal of Advanced Manufacturing Technology, 94(9-12), 3563-3576. https://doi.org/10.1007/s00170-017-0233-1

Uhlemann, T. H.-J., Schock, C., Lehmann, C., Freiberger, S. and Steinhilper, R. (2017). The Digital Twin: Demonstrating the potential of real time data acquisition in production systems. Procedia Manufacturing, 9, 113-120. https://doi.org/10.1016/j.promfg.2017.04.043

Vazquez Gonzalez, J. L., Barrios Aviles, J., Rosado Muñoz, A. and Alejos Palomares, R. (2018). An Industrial Automation Course: Common Infrastructure for Physical, Virtual and Remote Laboratories for PLC Programming. International Journal of Online and Biomedical Engineering (iJOE), 14(08), 4–19. https://doi.org/10.3991/ijoe.v14i08.8758

Velasquez, D., Perez, E., Oregui, X., Artetxe, A., Manteca, J., Escayola Mansilla, J., Toro, M., Maiza, M. and Sierra, B. (2022). A Hybrid Machine-Learning Ensemble for Anomaly Detection in Real-Time Industry 4.0 Systems. IEEE Access, 10, 72024-72036. https://doi.org/10.1109/access.2022.3188102

TABLE OF FIGURES