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Development and case study of an Industry 5.0 ready human-centric related brewing plant

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Abstract. This article explores the transformative potential of learning factories in mecha- tronic systems development. Learning factories offer a dynamic, collaborative environment that bridges the gap between academia and industry, creating a mutu- ally beneficial ecosystem. The LEONARDO project aims to develop innovative teaching methods, materials and tools for human-centric industrial engineering and management education leveraging on an industry 5.0 replica of a brewing system. Brewing as a process can be considered as highly complex, while brewing as a procedure serves as a 'sexy vehicle' for appealing student's interest in industry 5.0 applications and human-centric production. The brewing process is and will increasingly be more automated and highly supervised. For the latter, modern implementations of sensors such as electronic nose, electronic tongue, and infrared spectroscopy are required to be installed on the brewing equipment. To efficiently use the sensor outputs, the produced signals need to be merged locally and pro- cessed adequately, researched and investigated deeply by the authors up-front with the results to be summarized. Furthermore, to enable the physical bridging of various involved institutions across Europe, connecting the relevant sites virtually presents another technological challenge. Adequate IoT equipment needs to be selected and included in the whole setup as well. Furthermore, an emphasis needs to be made on the human-centric approach, as well as data visualization. Each of the aforementioned pieces of technology need a thorough investigation along with a decent focus in integrating the puzzle pieces into the big picture which is the brewing plant. In this paper we describe the interaction along with the system integration strategies of the listed fields to enable a future proof industry 5.0 ready brewing plant, focusing on the human-centric approach demanded in the industry5.0 feature description.

Key words: digital factory, smart manufacturing, gamification, industry 5.0, human centricity.

INTRODUCTION

We are living in interesting and as well challenging times. The current generation has been and still is experiencing the fourth industrial revolution, incorporated in the term industry 4.0. The focus of industry 4.0 has mainly been the development and establishment of technologies among various fields (e.g., communication technology, AI, IoT, robotics, process engineering) to enable the 'Smart Manufacturing for the Future' (Demir et al., 2019; Froschauer et al., 2022). Although, while widely still many companies and countries struggle with digitization technologies, the next development stage of the industry, the fifth industrial revolution, already presents itself at our doors (Demir et al., 2019; Paschek et al., 2019). One key aspect of industry 5.0 is the human-centric approach, meaning focusing on the human as part of the industrial process - in many ways (Froschauer et al., 2021; Khan et al., 2023; Kopylov et al., 2024). While Paschek et al. (2019) provide a literature review based description of industry 4.0 and 5.0 in the context of a study analyzing the expected impact of the fifth industrial revolution on companies' business models, other publications focus on the technical interaction of humans and robots, so called human-robot co-working environments (Schönberger et al., 2018; Demir et al., 2019; Froschauer & Lindorfer, 2019; Emma-Ikata & Doyle-Kent, 2022; Ikumapayi et al., 2023). Fig. 1 illustrates the evolution of the industry from industry 1.0 to industry 5.0, impressively outlining the ever decreasing time intervals upon the arrival of the next revolutionary stage, while Fig. 2 illustrates the industry 5.0 triad, containing the three main corner stones of industry 5.0 as defined by the European Commission (European Commission (2021)).

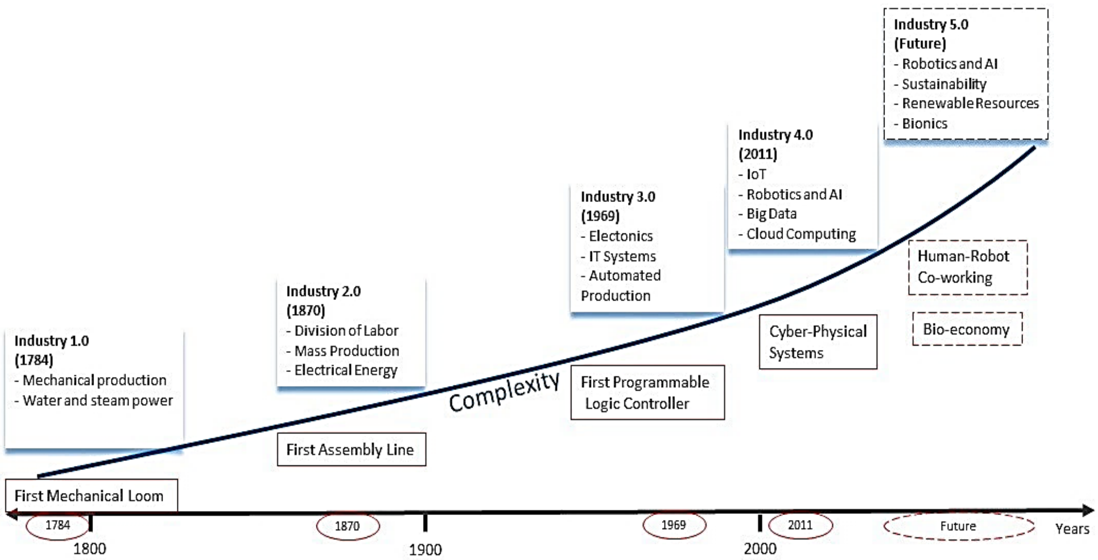

Figure 1. Roadmap from industry 1.0 to 5.0. (Demir et al., 2019).

As discussed by Zizic et al. (2022) and the literature review by Khan et al. (2023), instead of taking technology as the key player of the next industrial revolution, three different key drivers are set as the center of the industrial 5.0 paradigm by the European Commission (European Commission (2021)).

• The human-centric approach, which places human needs at the heart of the production process, asking what technology can do for workers and how can it be useful (Khan et al., 2023).

• Sustainability, which focuses on reuse, repurpose, and recycle of natural resources and reduce of waste and environmental impact (Saikia, 2023; Volpe et al., 2023).

• Resilience, which implies an introduction of robustness in industrial production. This robustness provides support through flexible processes and adaptable production capacities, especially when a crisis occurs (Pandey et al. (2023)).

As provided in an overview-like presentation by Demir et al. (2019), besides the technical challenges, also ethical issues are being discussed in the industry (Murphy et al. (2022); Emma-Ikata & Doyle-Kent (2022)), influence of industry 5.0 on the companies' culture(s) (Cillo et al. (2022)) and non-technical processes (Zizic et al. (2022)) like marketing as studied by Rajumesh (2023). Also, industry 5.0 does not only influence the companies and their employees, but will have significant impact on the whole society (Zizic et al. (2022)), e.g., describing and analyzing the correlation of consequences of 'Smart Manufacturing' towards a 'Digital Society' (Skobelev & Borovik, 2017; Martynov et al., 2019). This investigation shows the complexity of the industry 5.0 movement on the one side and the huge influencing potential, the immense scope of the latter on the overall society, on the other side.

Figure 2. Key corner stones of industry 5.0. (Zizic et al. (2022)).

To make all this happen in an efficient way, academia must be focused at as the initial source of knowledge gaining and spreading and, therefore, main responsible institution of advances and both technological and societal progress. A simple formulation or request may be, that involved parties are required to learn to work with robots (Demir et al., 2019). This does not only include the usage of robots and industry 5.0 approaches in education as discussed by Linert & Kopacek (2016) or Pozo et al. (2022) to foster technological enthusiasm and jump on the train of current youth's learning and studying paradigms, but incorporates a bridge building between industry and academia as, e.g., described by Lanz et al. (2019). The latter is also manifold referred to as learning factory, e.g., analyzed by Balve & Ebert (2019) in a retro-perspective evaluation of competence development based on graduates feedback, or by Doyle-Kent & Walsh Shanahan (2022) as a means of upskilling technical workers for industry 5.0. The essence each is to empower all relevant industrial employees from blue-collar workers (Cimino et al., 2023) to industrial engineers or production planners (Rannertshauser et al., 2022; Shah & Bharathi (2023)) to efficiently use the advantages of industry 5.0 achievements, focused not exclusively but essentially on the human-centric approach. Fig. 3 developed by Zizic et al. (2022) includes some of those findings, being training of the workers, customer as the designers (well-educated customer) and information based decision making, closing the cycle of the interaction of academia (Rasmussen, 2012; Maijala et al., 2014; Zeidmane & Rubina, 2019), industry (Jørgensen, 2018), and entrepreneurship as one specific phase of industry (Põder et al., 2019), along with its influence towards a digital society (Skobelev & Borovik, 2017; Martynov et al. (2019); Motinho & Cavique, 2023).

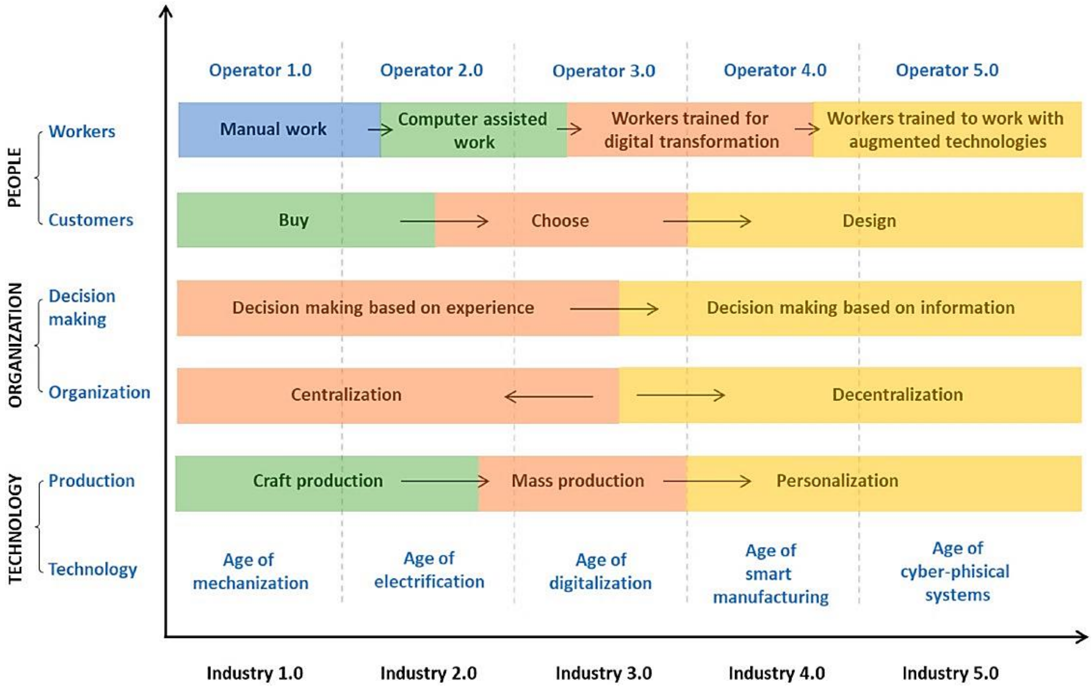

Figure 3. Transformations through the paradigms according to the important participants and segments of industries (Zizic et al., 2022).

The focus of this article is to grasp all of these points in the context of an open-access learning & experimentation factory, to be developed in the European Union funded Erasmus+ LEONARDO project (Padovano et al., 2023). The LEONARDO project aims to transform Industrial Engineering and Management (IEM) education by establishing innovative teaching methods, materials, and tools with a human-centric approach in the context of the industry 5.0 paradigm. In practice, the project will leverage an industry 5.0 replica of a brewing system as a hands-on learning environment for IEM students. LEONARDO will thus foster the entrepreneurial skills of IEM students by providing an applied learning environment to develop and test ideas. The brewing system called Learning and Experimenting open-Access Factory (LEAF) will facilitate innovative learning approaches as well as new teaching methods (Padovano et al., 2023). Some of the project partners already introduced the idea of a industry 5.0 ready brewing equipment as a business model in 2020 (Schlechter et al., 2020), aligned with some industry 5.0 corner stones like 'customer as the product designer' and the main concept of human-centricity. As well, current trends and technologies to modernize the current brewing community has been popular scientifically (Schlechter, 2023) and extensively (Vošahlík & Hart, 2021; Schlechter, 2024) discussed.

Essentially, this article will present the technical and academic infrastructure of the 'to- be' developed brewing plant as vehicle for the industry 5.0 educational open-access factory example, which is currently implemented in one of the project partner locations (Wels, Austria), A second one, which is not focused on in this publication but contains similar functionality on a smaller scale, will be installed and further developed in the area of further project partners (Calabria, Italy).

The article is structured as follows. Section 2 provides a detailed system description of the hardware and software setup and requirements of the relevant brewing plant(s). The reader shall get an impression on what is existing, how does the existing setup need to be enhanced (automation, connectivity, additional sensors) and what are immediate and future use-cases for the developed setup. Section 3 provides an overview, how the technical setup is to be used in the project context and how it is anticipated to contribute to industry 5.0 training and execution. The relevant considered fields of interest along with potential teaching material are sketched. Section 4 presents an implementation architecture of the LEAF. Finally, Section 5 summarizes the findings.

System description and purpose

In this section the system design of the brewing plant used to fulfill the core topics of the LEONARDO project is described, starting from the currently existing system design via the necessary technological steps to be established towards the final anticipated knowledge platform delivering essential process data for educational purposes, vulgo the LEAF.

The Wels local LEAF brewing equipment installation will be carried out in a local small- scale brewery, the Gerstl Bräu (Der Brauereiführer (2024)). The advantage of this local brewery is, that a close relationship between the brewery (the brewery operator) and key players within the LEONARDO project at the University of Applied Sciences Upper Austria exists. Therefore, access of the brewery and therefore of the project related installations is guaranteed at all times. Fig. 4 shows an overview of the existing 10 hl brewing equipment in Wels, which will be extended by an automation unit and IoT components to enable remote access. The figure is of representative objective to underline the practical character of the given project and emphasize the actual implementation of the concept in a real brewery. In the picture the mash tank is shown, which in an other stage of the brewing process is as well used as wort cooker.

Figure 4. Gerstl brewery picture showing the mash tank.

Additionally, Fig. 5 illustrates the general overview of a professional brewing site taken from Wunderlich & Back (2009). This illustration represents as well the layout of the Gerstl Bräu (Der Brauereiführer (2024)) being a professional small-scale brewery with state of the art equipment found among all small to medium-size brewing sites. An overview of the study with relation to the human-centricity is given in Fig. 9 as well, showing the interaction of the human with various points of measurement in the brewing system and therefore brewing process.

In addition, as the Gerstl Bräu is a productive brewing plant, real life data of the brewing process will be available in continuous intervals and regularly, more than theoretically possible in an experimental setup. The overall project goals of LEONARDO will therefore be met more easily, complementing the to be installed 50 L experimental brewing equipment in Calabria and the 1,000 L operating brewing plant in Wels.

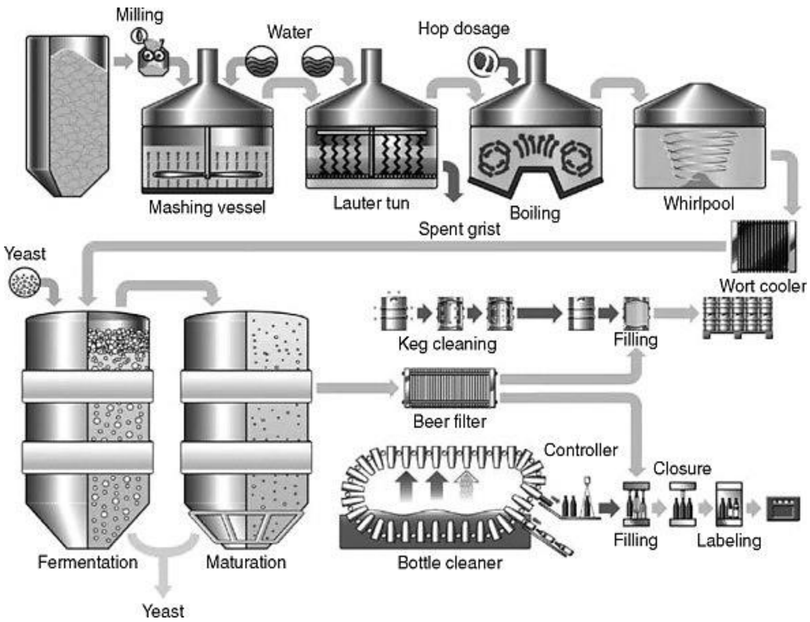

Figure 5. General overview of a typical brewing process.

Fig. 6 illustrates the rough basic system design of a brewing installation. Those include the main components like the various mashing, lautering, wort cooking and fermentation tanks, but as well needed pumps and valves to make the brewing process work. The illustrated setup should be seen as a rough overview to clarify the main technical challenges of the project fore-front enabling the to be setup innovative teaching concept.

The current installation is fully electrified, meaning, no manual valves need to be operated. The degree of automation, however, is limited. Therefore, the installation will be further developed towards a fully automated setup. The automation concept will be developed within the University of Applied Sciences Upper Austria, while the hardware installation (wiring, switch cabinet

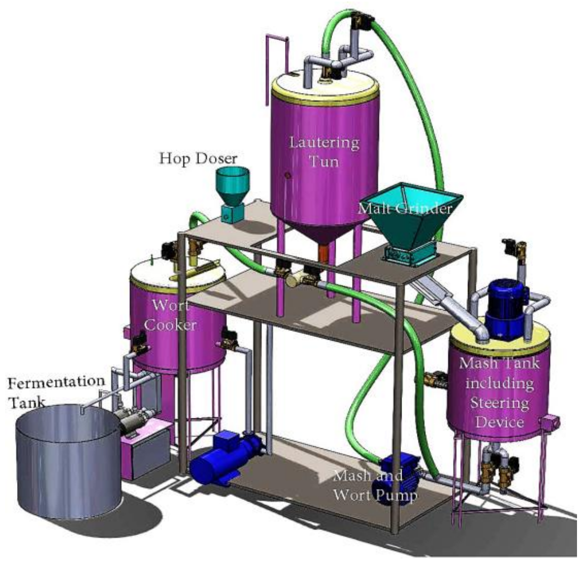

Figure 6. System design of the industry 5.0 brewing equipment.

installation, etc.) will be carried out by an electric professional. Fig. 7 shows the current control panel with manual operation, which will be extended by a second panel enabling full automation. To guarantee productive operation of the brewing plant at all times, the automated functionality will not replace the current installation but complement it.

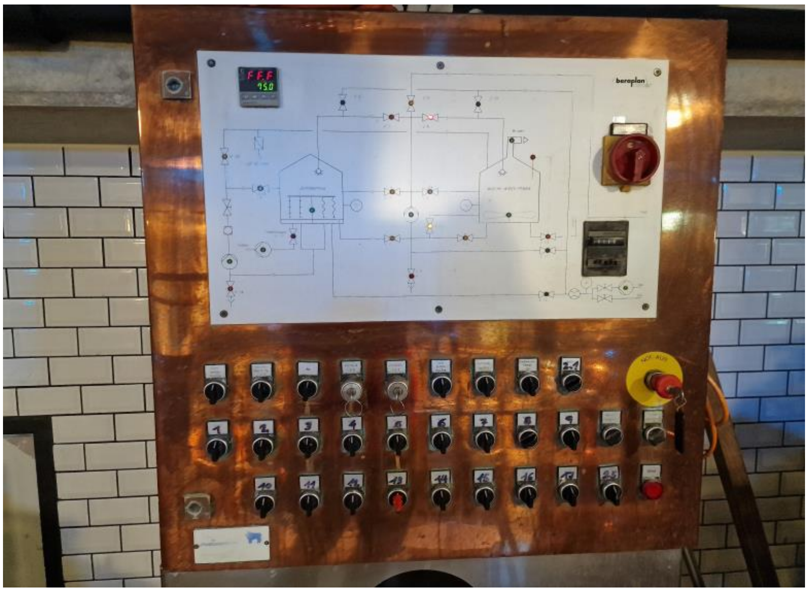

Figure 7. Gerstl brewery control unit.

Fig. 8 illustrates the additional components in an overview style.

As a follow up, IoT connectivity along with the integration of additional sensors is planned to be implemented. Those sensors include various temperature sensors for monitoring the homogeneity of the mash, an electronic nose as described in Schlechter (2024); Gonzalez Viejo et al. (2020), health parameter checks of the operator (e.g., heart beat rate, blood pressure, stress estimation, all using a fitness wrist band), NIR sensors, CO_2 sensors and many more. IoT connectivity is needed for several reasons.

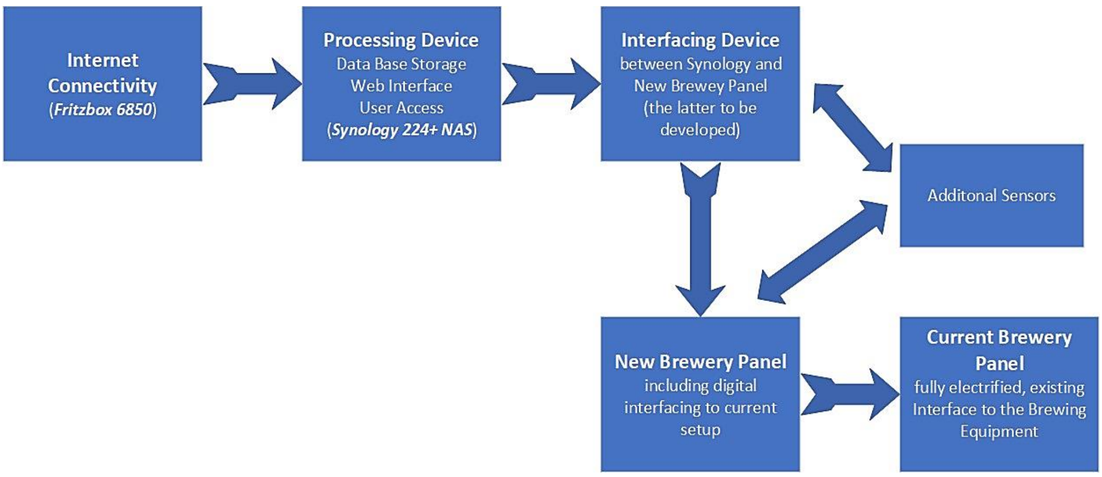

Figure 8. Block diagram of complete IoT implementation.

First, as one of the main features of the current project is remote accessibility, this connectivity needs to be established. This enables students using the to be developed industrial engineering educational concept in conjunction with the LEAF from everywhere in the world, given access is granted individually. Within the partner consortium of LEONARDO, human machine interfaces along with smart processing of gained information from the brewing process are developed. To feed those essential puzzle pieces of the final concept, the connectivity to the productive plant must be established. Secondly, to gather more relevant process data, additional sensors (in addition to standard sensors like temperature sensors, fraction sensors used for degree Plato measurements, fill level sensors, ...) will be added to the LEAF to enhance the functionality. Schlechter (2024) provided an extensive overview about the historical (Pearce et al., 1993; Gardner & Bartlett, 1994; Gardner et al., 1994; Gonzalez Viejo et al., 2020; Pornpanomchai & Suthamsmai, 2008 and current (Aouadi et al., 2020; Anisimov et al., 2021; Gonzalez Viejo et al., 2021; Seesaard & Wongchoosuk, 2022; Fuentes & Gonzalez Viejo, 2023; Kim et al., 2023; Liboà et al., 2023; Schlechter, 2023) technification development in the brewing branch. Already in 2020 Schlechter et al. (2020) proposed a concept in Agronomy Research on a business model with the LEONARDO project requirements - just not to use it for educational purposes, but for a real business. The outcome of this project may therefore be ulteriorly used in various fields, like innovation management, new product development, open innovation, entrepreneurship studies, etc. along with the training setup of industrial engineers which is the main scope of the LEONARDO project (Padovano et al., 2023). The efficient implementation of the proposed concept in addition will be supported by the Wels-local expertise in simulation workflow elaboration for complex automated system design, incorporated and described by Edlinger et al. (2023).

The system architectural review of the current system along with the required changes, adoptions, and extensions to the system given in this section acts as the base for the pedagogical approaches incorporating the final target of the LEONARDO project a stated by Padovano et al. (2023). The latter will be explained in more detail in Section 3.

Methodology and impact

In this section, the second meta-level of the given investigation and development will be sketched, which is more focused on the pedagogical objective as a main aim. Brewing, as a complex technological process, involves a nuanced blend of skills encompassing equipment operation, quality control, knowledge of biological and chemical processes, business acumen, and adept problem-solving. The application of a learning factory approach in the teaching context of the LEONARDO project serves as a noteworthy case study, exemplifying the effective use of this pedagogical concept in multidisciplinary settings.

LEONARDO establishes fruitful synergies with school education, adult education, Higher Education Institutions (HEI), and youth, and the project results can be exploited also in these fields, using the technical platform as an engaging platform to transport the learnings. For example, tools and materials developed for teaching industry 5.0 in higher education can also be incorporated into HEI programs. The project aims to understand future work qualifications in human-centric factories of the future, which will also be relevant to HEI, and create work-based learning opportunities at the LEAF Labs for

HEI students. This way, LEONARDO provides guidelines for developing and adapting HEI programs to meet the needs of the labour market and industry trends.

In terms of school education, LEONARDO will develop pedagogical approaches and materials, such as interactive simulations, videos, and multimedia resources, that high- school teachers can use to promote interest in STEM disciplines. LEAF lab managers and young people ‘working’ at the lab will act as ambassadors and mentors to inspire young people to pursue careers in the field, leveraging the beer brewing process as a motivation.

Specific connections will be established with high-schools that will be able to consider the LEAF lab as a venue for ‘work experiences and internships’ for highschool students. The upskilling pathways that LEONARDO will develop can also be applied in the field of adult education to reduce the skill gap and promote adult participation in learning. The education content and material can be also used by adult learning and guidance staff to improve their teaching methods. Digital and blended learning opportunities will be developed to offer a flexible learning offer not only for HEI students, but potentially also for adults, based on validation of acquired skills certified by micro-credentials or badges released at the end of a micro-courses carried out with the LEAF. Therefore, the LEAFs will become innovative local learning centres to attract and offer everyone in the community lifelong and life-wide learning opportunities. Finally, the adoption of a LEAF brewing system, which simulates real life, will enhance engagement and motivation of students. This makes the learning content more appealing as young people will be driven by the willingness to produce the beer, while at the same time, solving old and new problems related to H-IEM. This will promote young people’s sense of initiative and entrepreneurship, creative learning and intercultural dialogue among all the people working at the LEAFs. Last but not least, given the affordability-by-design of the LEAF, the labs can be installed also at institutions that do not have large economic resources, thus giving marginalised young people in underdeveloped regions the opportunity to see with their own eyes how a human-centric production system works and creating the preconditions for their future employability by identifying the hard and soft skills and competences required for students to work in human-centric factories of the future (and become a workforce 5.0) and to define a pedagogical approach and curriculum design guidelines to support the teaching of the Industry 5.0 content via a combination of digital technologies, e.g., e-learning, in combination with/as well as the LEAF.

LEAF-as-a-service implementation architecture

As previously discussed LEAF is innovative as it is a small-scale but realistic replica of a brewing system which may be easily replicated. This provides an original and creative system compared to existing Learning Factory solutions, thus making education appealing for the younger generation. Furthermore, LEAF provides everyone the opportunity to access (even remotely), play and experiment their own ideas, in a LEAF- as-a-Service approach. This will allow the students to take active responsibility in the Industry 5.0 revolution. The concept of LEAF is based on the cloud based architectural setups, e.g., the Manufacturing-as-a-Service (MaaS) proposed by Rauschecker et al. (2011) and Factory-as-a-Service (FaaS) proposed by Hewa et al. (2023) approaches. By exposing the manufacturing capabilities and process to the user.

As illustrated in Fig. 9 the user, in this case an HEI student, may submit their customized brewing recipe to the LEAF. Through various IoT devices, such as smart sensors, Arduinos, Raspberry Pis, and HMIs, process information can be extracted from the LEAF. LEAF operator data may also be collected, through the use of smart watches or heart rate monitors. This information can be collected locally via an edge device, such as the Endian 4i Edge X. Pre-processing of data can be immediately carried out on site. In this way dimensionality reduction can be achieved through feature extraction and factor analysis. Machine Learning algorithms can then be deployed either at the edge or on the cloud to analyze the data and extract process related information. This can then be visualized through augmented devices such as tablets or VR goggles.

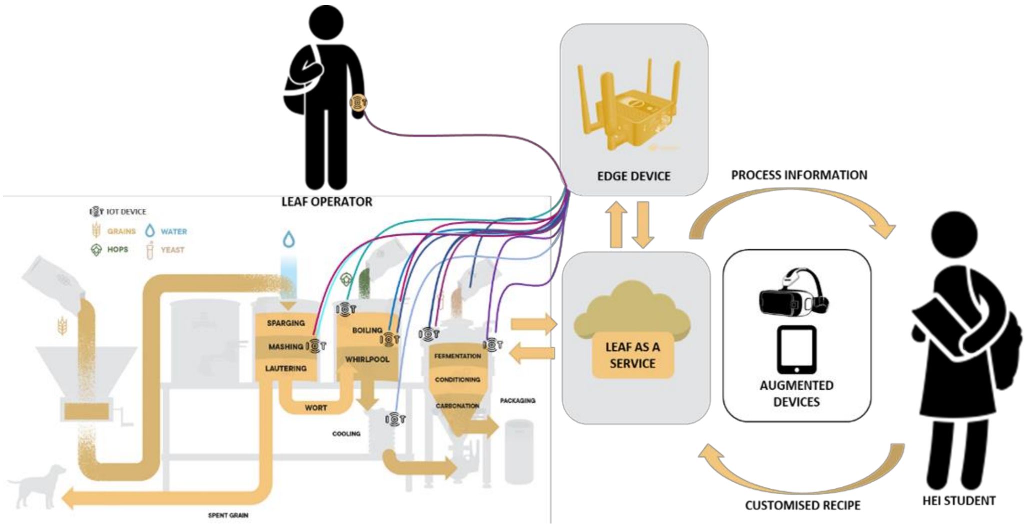

Figure 9. LEAF-as-a-Service Implementation Architecture.

By utilizing this LEAF-as-a-service architecture, this solution will provide remotely accessible services/apps for LEAF-based student game-based education. This will be developed in a way that students have access to practical, hands-on learning experiences that allow them to develop the skills and competences required for the workforce 5.0. This also supports the HEIs to be more resilient in terms of educational provision, since access to the LEAF facilities will be allowed remotely in case that laboratories and facilities are not accessible physically.

CONCLUSION

In this paper we presented the technical modification of a productive brewing plant involving all fields of action, in order to provide a solid technical base for a pedagogical concept towards higher education in the industry 5.0 human-centric approach, proposed by the European Commission (2021). We listed the technical setup along with potential enhancements on a current brewing system, focusing on the core features boosting the educational concept. The technical implementation will be used as a vehicle to train next generations' industrial engineers towards an efficient usage of industry 4.0 technology in a industry 5.0 concept, involving human-centricity, sustainability and resilience.

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