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Operational Structure for an Industry 4.0 oriented Learning Factory

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***Abstract* – Learning Factory (LF) – as a concept - is fully in line with the Industry 4.0 and also with the novel Industry 5.0 major trends, creating an integrated, realistic learning environment, combining didactics, layout and processes with testing and experimentation opportunities. There are already well functioning LFs but their main emphases are very different, fitted to the given, regional industrial potentials. To manage a LF, a precise and structured activity set is needed which formulation is the main contribution of the given manuscript. The paper reviews the main global trends and various existing LFs' activities. The comprehensive set of LFs' expectations is defined through the identification of the key target groups and their objectives together with the three main related pillars of "A": Regional and market connections, "B": implementation and operation of the physical and virtual Learning Factory and "C": development and delivery of customised Learning Factory services. The paper suggests having an activity set consisting of ten, precisely formulated Work Packages. This novel framework also supported the concept formulation of a new LF in Hungary, Europe.**

***Keywords* – Learning Factory, Activity Optimization and Control, Responsible Consumption and Production; Industry, Innovation and Infrastructure**

I. INTRODUCTION

Domestic companies have recognised the importance of implementing Industry 4.0 (I4.0) solutions and key enabler technologies (e.g. IoT, big data, 5G, AI), but several factors are hindering their exploitation, e.g., the uncertain return on investment; significant individual investment required; disruption to business continuity; furthermore the lack of employee competences as well as industry standards and certifications [1][2][3][4][5][6].

Digital transformation as a human-centred concept also gained momentum, thanks to major framing policies all around the world, elaborating more sophisticated interventions to improve general and sector-specific digital skills and competences of businesses and workers, promoting the widespread use of novel technologies; like in European policies regarding the 2021-2027 EU MFF framework [7][8][9][10][11]. In particular, re-industrialization, together with sectoral targets and industrial excellence also emphasize the importance of the human factor and the renewal of the industrial innovation ecosystem, as a prerequisite for rapid development and application of new technologies. It fits into the vision of the European industry "5.0" as - "sustainable, *human-centric* and resilient European industry" [12][13].

Learning Factory (LF) – as a concept - is fully in line with this major trend, creating an integrated, realistic learning environment, combining didactics, layout and processes with testing and experimentation opportunities. A LF can be defined as an experiential learning environment that contains up-to-date manufacturing infrastructure [14][15][16]. It offers training, education and several additional services for manufacturing stakeholders but none of the functioning LF facilities exists alone. Context, strategic partnerships and multiple (including social) interests may have a great impact.

This paper aims to create a work model of a proposed LF with more elaborated approach regarding additional value creation – beyond the core training and competence development.

A. Learning Factories as innovation powerhouses

An elaborated research has been conducted to collect and evaluate individual learning factory business models [17] [18][19][20][21][22]. As a result, several sources have been identified regarding the core value proposition as a reference for a LF framework, including didactics, layout, processes, products, planning and implementation of such a centre. Less result has been discovered regarding stakeholder collaborations or SME transformation, customer journey and description of the LF contributions. Indirect outcomes, impact on industrial and innovation ecosystem might need more attention [23][24][25]. The key factors of the related LF activities are:

- Service design
- Collaborative ecosystem
- Technical standards and roll-out
- Convergence between manufacturing and service
- Emergence of technology platforms
- Strategic partnerships

B. Training in Learning Factories

I4.0 impacted manufacturing education and training in several and multiple ways, at the level of content, context, places and frequency as well:

- The future of manufacturing has to be more human-centric, with the scope on workforce transformation ergonomically, psychologically (empowerment, acceptance) [26] and as a grand political concept [12];
- Supporting manufacturing SMEs should be a priority;
- To continuously explore and adapt quickly to new technical (STEM, AI), to soft or transversal and to sectoral competences;
- "Upskilling" and "reskilling" need to be standard-based, translated into new job profiles [27];
- Didactics have to be based on smaller (modular) quantities with high frequency learning situation, using a flexible – "just-enough, just-for-me, just-in-time" – training approach [4][28].

C. Digital Learning Factories

The digital twin, as one of the major Industry 4.0 components, is a virtual representation of a physical product containing information about the product, underlying product life-cycle management [29][30]. The virtual model can be employed to study opportunities for operational improvements and analyse the establishment of new technology in current production [31][32].

D. Successful cases on Learning Factories

This paper examines the opportunity of an extended concept of a theoretical LF through a state-of-the-art literature research, highlighting R&D and innovation services, SME training and transformation, introducing the concept of Manufacturing as a Service. The outcome, and the cross-examination verified the assumption on convergence of original learning factories (as primarily educational facilities) and pilot/model factories (as for industrial testbeds).

Individual LF facilities may differ in focus but in general all the major pillars and services are present in each cases, either directly (offered by the LF centres), or indirectly (serving by strategic partners). This is the case of the Centre for Industrial Production (CiP) in Darmstadt (DE), where the centre highlights education and R&D in I4.0 and Lean 4.0 [33], however, SME outreach and digital transformation projects are managed by a "Mittlestand" competence centre [34][35].

Value proposition of a Learning Factory is manifold, beyond the innovation-oriented risk reduction and technology development, it plays a key role in the regional industrial training system supported but also enabled by various digital and artificial intelligence solutions [36][37]. **However, to manage a Learning Factory efficiently, a precise and structured activity set is needed which formulation is the main contribution of the given manuscript.**

This introduction is followed by the identification of the key target groups and their objectives and the three main pillars for the structure of LF services. Their implementation aspects as key business processes are described in the fifth paragraph. Conclusions with Outlook, Acknowledgements, and the References close the paper.

II. OBJECTIVES AND TARGET GROUPS

The Learning Factory has set out mutually reinforcing industrial objectives in four areas:

1. entrepreneurship development, strengthening technological and business competences
2. developing and testing AI-based, Industry 4.0 technologies and services.
3. demonstration and testing of the application and implementation of AI-based, Industry 4.0 technologies and services
4. rapid and effective implementation and application of the results of international, in particular European, initiatives.

The Learning Factory operates within an integrated business model (in a set of business models) to achieve its objectives. The physical and virtual infrastructure and services provide both the framework for sensitisation, engagement and systematic competence development; the testing environment for effective iteration; and the structural conditions for experimentation. As a centre, it can be an important venue for setting new industry standards and for establishing compliance with standards.

Main areas of expertise and services: strategy, management and organisational development incubation, project development; engineering services (including artificial intelligence), test environment and innovation consultancy, LAB services, R&D and innovation cooperation, organisation of professional events and programmes.
The physical design of the Learning Factory, the internal processes and the design of the organisation, services and business model will consider European, and in particular Hungarian recommendations, experiences and parameters of Learning Factory and Model Factory centres.
The national economic and sectoral added value of the operation of the Learning Factory are the following:

- The operation of the Digital Learning Factory facilitates the development of industrial enterprises, faster and larger-scale transformation of leading SMEs and the introduction of new business models.
- It supports the improvement of conditions for fair employment, raising visibility of the importance of digital skills development, career development and entrepreneurship opportunities related to AI-based Industry 4.0 technologies.
- It will accelerate the development and market uptake of new solutions - enabling technologies, applications, manufacturing technologies and services - by providing niche services to the domestic RDI ecosystem.

The target groups of the Digital Learning Factory are the following:

- SMEs in industry and value chains, especially SMEs with high growth and development potential,
- Technology centres, engineering and RDI companies, deep tech start-ups,
- Application-oriented universities and research institutes,
- Large companies (as secondary target group)

An important goal of the Digital Learning Factory is to organise the local, regional industrial/innovation community, expanding opportunities for project-based collaborations and joint development, linking to the European community of learning factories and model factories, relevant E-DIH partners and Horizon Europe Partnerships, RIA (Research and Innovation Action), CSA (Coordination Support Action) and IA (Innovative Action) consortia.
An important objective is the development of the domestic industry and manufacturing sector therefore the weight of industrial enterprises and the developing professional culture provide a good basis for the operation of the Learning Factory. The appropriate engineering and technological expertise are available at national, regional and local level. There are also support partnerships (platforms, associations) and flagship programmes at national level.

III. OPERATIONAL CONCEPT

The Digital Learning Factory is a physical and virtual infrastructure and the related service package that effectively provides a framework for sensitisation, involvement and systematic competence development, experimental, structured experience acquisition for the target group, in our case primarily for development and development-oriented Hungarian medium-sized enterprises.
The unique value proposition of the Digital Learning Factory for clients is that it offers the opportunity for step-by-step, systematic engagement, digital readiness improvement and project development. The physical environment of the Learning Factory, the installed manufacturing technology and the demonstration processes enable stakeholders to test and evaluate new technologies and Industry 4.0 / AI applications in a real production environment, without interrupting the business operations and manufacturing processes. In its operations, it generates critical use cases for developers and creates opportunities for technology and innovation collaboration. The Learning Factory not only supports demonstration (sensitisation), but also allows for an understanding of modules, processes, entire cells and production systems at user level.

IV. STRUCTURE OF SERVICES

The operation of the Learning Factory is based on 3 main pillars.

A. Pillar "A": Regional and market connections

Simultaneously regional and global demands and trends have to be followed continuously:

- It is essential for the Learning Factory to be aware of current regional manufacturing challenges, short and long-term manufacturing progress potentials and market expectations, i.e., to be in constant contact with manufacturers active in the region and their related value chain actors.
- Given the global, accelerating technological developments of our times (e.g., global trends of Industry 4.0, the dynamic advance of new methods of artificial intelligence), only regional needs and knowledge are not sufficient for successful operations: international innovations also need to be monitored, processed and channelled.
- To this end, the Learning Factory works with national innovation organisations and digital hubs, in our particular Hungarian case with the future European Digital Innovation HUB network. It has a key role in monitoring technological, manufacturing and industrial processes:
  - the Global and European Alliance of Learning Factories,
  - the European Artificial Intelligence

platforms, and
- activities of the International Association of Learning Factories (IALF) [31],
- international conferences on the subject.

The international and national information collection and processing is carried out by the Knowledge Centre within the Learning Factory, which reviews regional business development needs and international technological innovations and changing business models on a semi-annual basis. In accordance with a properly designed selection criteria this Knowledge Centre proposes from time to time the launch of collaborative manufacturing model projects to increase the maturity, scale-up and diffusion of a new area.

B. Pillar "B": implementation and operation of the physical and virtual Learning Factory

One of the main functions of the Learning Factory is to provide a venue (physical and virtual):

- For collaborative innovation, including applied research and development, demonstration activities and subsequent innovation, activities, market upscaling and dissemination.
- The Learning Factory is partly a factory, partly a laboratory and partly a training site (mainly for partner manufacturing companies). This requires the physical availability of suitable factory premises for the learning activities.
- An important feature of the Learning Factory is that it also produces a specific product. It is therefore essential to provide a production hall to house the various technologies, machines, raw materials, tools and processes. This also requires the provision of specific conditions: e.g., a sufficiently strong electrical network, sufficiently large and flexible access and delivery points, gates, etc. The production site must therefore meet the requirements of a "normal" factory, but also be able to perform specific training factory functions: welcoming visitors, collaborative innovation and training, allowing prototype production for external visitors, etc.
- To ensure efficient operation, it is essential to set up and constantly update and renew the in-house production system, as this is the step that will make available to the region's companies the latest and most advanced technologies, which can be used for concrete production, laboratory experiments and corporate training programmes
- Similarly, to the physical factory building, a virtual Learning Factory will have to be developed, as well as the conditions for the implementation of the virtual Learning Factory (e.g. cyber security, data protection, access rights, interfaces to the outside world, etc.).
    - For example, virtual production services may include virtually accessible test environments (partially coupled with physical environments), production data services, test environments for virtual interfaces, cloud-based database background, etc.

The choice of specific technologies (production and virtual) should be adapted to the region's specificities and needs.

- The first launch of the Learning Factory will offer only a few of the most relevant basic technologies. Taking into account the needs and developments of its partners, the Learning Factory will continuously expand and develop these offerings from year to year. Furthermore, if a technology is already regionally deployed at the appropriate TRL level, it will be replaced by other, newer technologies, thus ensuring the continuous renewal of the Learning Factory.
- In one part of the Learning Factory (demo showroom), leading technology suppliers can showcase their latest products and future technologies in a continuous renewal and demo update, making the Learning Factory a regular meeting/learning place for companies in the region.

A key requirement is that the apprenticeship factory's technical leader should be a motivated, professionally qualified, locally based player with the right technological affinity and business development experience, who sees this as an important career step and can work full-time. The suitability of the professional manager should be a key evaluation criterion in the procurement process.

C. Pillar "C": development and delivery of customised Learning Factory services

A Learning Factory is a well-known expression, however, according to our viewpoint it is a Pilot Factory as well. It means that it has to support and realize matching direct production and indirect production support services.

- The production service is offered by the Learning Factory in several forms:
    - Machine and operator renting,
    - Non-scheduled, stock-only production,
    - Production on a framework agreement basis,
    - Project-based manufacturing.

It is done by providing ad hoc, specialised and project-based consultancy, organising professional events and workshops, directly using the available production and virtual tools.

- Learning Factory provides consultancy and expert assistance for business development, technological and business strategy development, and organisational development.
- In addition to its services, the Learning Factory provides several value-added components: a network of experts with manufacturing expertise in different fields, manufacturing consultancy services, audit services related to Industry 4.0 development and strategy, and quality assurance services for

manufacturing projects.

- The know-how required for these services cannot be covered by the Learning Factory alone and it is therefore essential to develop a network of experts connected to the Learning Factory.
- In this way, the Learning Factory can be a typical place for spin-off and start-up companies to become stronger and more independent. This function can take many forms, e.g., joint pilot projects between manufacturing companies and the Learning Factory (and its partners), conducting production tests. Additionally, joint bidding for R&D projects in the home country and in Europe, possibly further afield globally, raising funds from investors and developing or adapting new technologies, etc.

In the Learning Factory, these activities are crucial, continuous and large-scale, and it is therefore essential to ensure the necessary flexibility and openness. Learning Factory aims to take the results of collaborative innovation into pilot production systems and to take them through the ramp-up phase of production, so that they can be directly used in value-creating manufacturing processes.

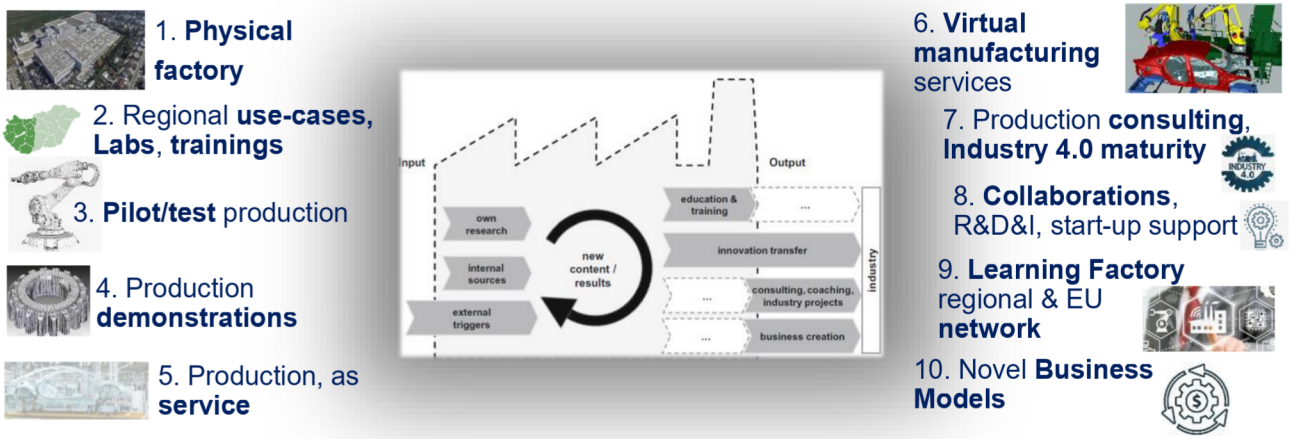

Fig. 1. The structured, proposed activity fields (Work Packages) for managing a Learning Factory efficiently.

V. IMPLEMENTATION OF SERVICES

The proposed activity fields as Work Packages are shown in Fig. 1., their relation to the introduced "A", "B" and "C" pillars are shown in Table 1.

Table 1. Contributions of the identified Work Packages (WPs) to the introduced "A", "B" and "C" pillars.

	Wp1	Wp2	Wp3	Wp4	Wp5	Wp6	Wp7	Wp8	Wp9	Wp10
"A"		X		X				X	X	
"B"	X				X	X	X	X		
"C"		X	X		X	X	X	X		X

VI. CONCLUSIONS AND OUTLOOK

The concept formulation of a novel Learning Factory in Hungary, Europe motivated the comprehensive review of Learning Factories' activities and the related trends to serve with a solid basis for its activities and operation.
Learning Factory (LF) – as a concept - is fully in line with the Industry 4.0 and also with the novel Industry 5.0 major trends, creating an integrated, realistic learning environment, combining didactics, layout and processes with testing and experimentation opportunities. There are already well functioning LFs but their main emphases are very different, fitted to the given, regional industrial potentials and so, their structures and operations are also case based and very diverse. *To manage a LF, a precise and structured activity set is needed which formulation is the main contribution of the given manuscript.*
The comprehensive set of LFs' expectations were defined through the identification of the key target groups and their objectives together with the three main related pillars of "A": Regional and market connections, "B": implementation and operation of the physical and virtual Learning Factory and "C": development and delivery of customised Learning Factory services. *The paper suggests having the pillars coupled activity set consisting of ten, precisely formulated Work Packages*:

- Physical factory
- Regional use-cases, Labs, trainings
- Pilot/test production
- Production demonstrations
- Production, as service
- Virtual manufacturing services
- Production consulting, Industry 4.0 maturity
- Collaborations: R&D&I, start-up support
- Learning Factory regional & EU level & global network

- Novel business models

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