A Framework to Strengthen Collaboration Between Universities and Industrial-Related Entities Towards Boosting Industry 4.0 Adoption and Development

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Abstract. Industry 4.0 has become a centerpiece of strategic plans and national policies in many countries. Studies have pointed out the many obstacles for the adoption of Industry 4.0 in larger scale towards such strategic plans, including the lack of skilled people and the low level of companies' innovation. Triple-helix-based innovation models have been proposed to reinforce collaboration between different actors, and it is reasonably clear nowadays "what to do". However, the "how to do" is not so trivial, considering the so many existing differences from region to region, in their culture, and in companies' Industry 4.0 maturity levels. Relying on collaborative networks foundations, this paper presents a framework as a contribution to make those actors working together more effectively and systematically in way to mitigate some of those obstacles. This framework has been gradually implemented during the last two years. This paper presents the framework itself and its main results so far achieved.

Keywords: Industry 4.0 · Collaborative networks · Innovation ecosystem

1 Introduction

Industry 4.0 has become a centerpiece of strategic plans and national policies in many countries. From an initial vision pretty much focused on manufacturing and on the use of some technologies to provide flexibility and intelligence to industries, the Industry 4.0 vision has evolved since then. It is no longer seen as a final goal, but rather as a means to leverage social, economic, and technological development of countries [1].

Many studies have pointed out the several obstacles for the adoption of Industry 4.0 in larger scale towards such strategic plans. They include the lack of prepared engineers and instructors to understand and to work on the several areas impacted by the Industry 4.0 model; the need to increase the scientific and technological development in the many areas involved; the lack of proper regulations and secure communication infrastructures; the low level of management and technological modernization in the SMEs; the several open points and risks related to ethical and social implications of Industry 4.0; the low

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level of companies' preparedness to be part of larger and more profitable value chains; the low level of innovation initiatives inside the companies to strive their competitiveness; the cost of some technologies and the need for high investments to deploy them sustainably; the risk of investments in 4.0-related initiatives against expected ROI; the lack of innovative business models; among others [2, 3].

Inspired on the classical triple-helix innovation model, diverse actors (such as industrial associations, governments, innovation ecosystems, and universities) have been creating specific Frameworks, dedicated physical spaces, etc., to face those obstacles, nationally and regionally [4]. Despite the benefits being got from this and the intrinsically collaborative vision of the model, practice has been showing the low level of their effectiveness in many cases [5]. These initiatives have not been able to create a systemic innovation culture inside the SMEs, to make them adopt (at least) "less closed" innovation models, and to consider the involvement of universities in such model [4]; or to make companies to get real acquaintance on Industry 4.0 to adopt it more effectively [6]. Several works have highlighted that strengthening collaboration between universities and industrial-related entities considering SMEs reality represents an adequate approach to boost Industry 4.0 adoption and technological development [6, 7]. The underlying research question of this paper refers to how universities can be organized to help in tackling these problems.

In this direction, this paper presents a framework as a contribution to make those actors working together more effectively and systemically. Its ultimate goal is to mitigate some of those obstacles towards a smarter and more sustainable collaborative networked environment. The framework considers those actors as members of an ecosystem of independent organizations that strategically decide to work more collaboratively aiming at reaching better common objectives. It supports most of the many activities/business models involved in education, research, outreach and assistance to companies, in what the needs of Industry 4.0 are concerned.

This paper is organized as follows. Section 1 has introduced the problem and the objectives of the work. Section 2 summarizes the framework's rationale. Section 3 presents the framework. Section 4 lists the business cases implemented with the proposed framework and preliminary results. Section 5 presents some conclusions.

2 Development Methodology and Rationale

2.1 Existing Pre-conditions

There is a vibrant innovation ecosystem in the Greater Florianopolis City, South of Brazil. It is composed of almost four thousand IT, technology, and automation-based companies and startups, services providers, incubators, innovation hubs, science parks, industrial institutions, and some private and public universities. Complementarily, special regulations and funding mechanisms have been created by local governments and banks to irrigate the ecosystem functioning and growth. Groups of investors complete the list of actors of this ecosystem.

Due to historical factors, there is a long culture of cooperation between industries and local universities, and many startups and companies of the region have emerged from this. Nevertheless, this cooperation does not happen systemically and homogeneously.

Yet, not as intense as it could be given the number of companies and the potentials of all that. It mostly involves the same large companies that come to the university to look for cooperation to carry out research on very sophisticated methods or technologies that they are not fully able to develop alone. SMEs – both Industry 4.0 technology adopters and developers – are not used to working with universities.

About two years ago, some SME companies begun to collaborate with the university as a strategy to leverage their innovation levels. Starting with *ad-hoc* and individual actions, this became more common and new types of cooperation arose. It was then necessary to create a more comprehensive framework, including mechanisms to scale the model and to keep it flexible for newer actions.

2.2 Framework's Requirements

Four main drivers have been considered to conceive the framework: the aforementioned obstacles; the diagnostics from the Brazilian policies related to Industry 4.0 and to the lack of stronger cooperation between actors [8]; the local interests and regional priorities looking at future possibilities and trends in Industry 4.0; and the lessons learned from those previous ad-hoc initiatives.

The priorities were: i) SMEs need a very special attention due to their importance in the local and national economies. This includes SME technology adopters and developers. They have a big potential of competitiveness growth, but they are generally limited (mainly in terms of financial and human resources) to adopt and develop new and innovative industry 4.0-related solutions; ii) the regional industrial pressure to cope with Industry 4.0 needs, which demands more and better human resources training and technology development; and iii) the need to increase the level of technological development and of potential market *solutions* (e.g. products, patents, software, algorithms, instrumentation, etc.) for Industry 4.0 by the ecosystem's SMEs, also involving undergrad and graduate students entrepreneurship.

Collaborative Networks [9] has been used as the main foundation for conceiving the framework. In a time where working with higher efficiency, effectiveness and innovation is becoming a must to underpin organizations' sustainability, individual initiatives prevent organizations from the sort of advantages that collaborative actions can provide, such as: the non-duplication efforts when dealing with given demands; the sharing of costs and risks between the members of the collaborative action; the sharing or use of complementary human, technological and knowledge resources; the sharing of infrastructures for research, education, professional training, businesses, etc.; the co-creation of new and less endogenous ideas, solutions, etc., when attending to new business opportunities; and the access to resources and technologies they do not have or even could not hire or buy individually [9].

There are many possible "entry points" to foster the cooperation between universities and companies. One of them refers that several implementation actions related to Industry 4.0 require the deployment of equipment and technologies as well as the assessment of new production methods and more recent ICT by companies. This is too costly and risky (mainly) for SMEs as Industry 4.0 also involves the adoption of new theories and technologies [10]. In this line, the core of the collaborative initiatives of the framework is mostly based on the use and sharing of physical universities' infrastructures and

industrial labs. This aims to make them act as different types of *demonstrators*, like testbeds, showcases, living labs, learning factories, and didactic plants [10], depending on their conditions and sophistication.

2.3 Methodological Aspects

There are many general frameworks to make universities and industries working more integrated. However, we could not find in the literature neither an existing framework that coped with the needed requirements nor one specifically devised to boost Industry 4.0 adoption. Thus, some frameworks were selected, analyzed, the aspects considered as the most appropriate ones to be applied for Industry 4.0 purposes and local goals were identified, some practices and mechanisms were combined and adapted to the local conditions, and some new actions were added considering the local culture, goals, and pre-existing conditions. To be highlighted four frameworks: *Babson College*, EUA, in the area of entrepreneurship; *Virginia Tech*, EUA, in terms of involvement of companies in the courses' curricula; the *Fraunhofer* institute, Germany, in terms of cooperation between companies and universities for applied research; and the Dual Study initiative from the *MOKSH* German Program, in terms of cooperation between industries and students for integrated internships[1].

The Action-Research methodology [11] was adopted to devise the framework. Adopting a constructivist and evolving approach, this meant that a given artifact (the framework) was gradually, jointly, and interactively built up with its users (the university and the other ecosystem's actors) with the aim of facing the general issues involved in the collaboration endeavor related to Industry 4.0. The framework has been implemented in different paces and phases, depending on the issues to address.

3 The Collaboration Framework

The elicited priorities (Sect. 2.2) were decomposed into four very concrete goals to be delivered by the framework:

i. Improving the skills and increasing the number of undergraduate and graduate students trained in Industry 4.0-related subjects to become future workers, entrepreneurs, and instructors/professors;
ii. Increasing the number of works from undergraduate and graduate students whose Final Works and Theses have the potential to be transformed into future Industry 4.0 solutions or as technology transfer artifacts;
iii. Improving the skills and increasing the number of SME managers trained in Industry 4.0-related subjects;
iv. Improving the innovation level of Industry 4.0 technology developers SMEs.

[1] https://www.babson.edu/; https://vt.edu/; https://www.fraunhofer.de/en.html; https://www.moksh16.com/dual-study-opportunities-in-germany/

As part of the constructivist approach, the way these goals were planned has considered the general Teaching, Research, and Outreach dimensions, set up in the university when it was founded 70 years ago.

Figure 1 shows the general framework's elements. One can see it as "yet another collaboration framework between universities and industries", and even less comprehensive than other ones (mentioned in the previous section). Its value proposition is actually grounded on the way the framework's elements work integrately as well as on how the different actors collaborate to achieve the framework's goals considering the local culture.

- *Teaching*: it means training undergraduate and graduate students on topics more directed to Industry 4.0 throughout the several engineering courses and internships. Students will supply the market needs, acting as engineers in the companies, consultants, professors/instructors, or future entrepreneurs.

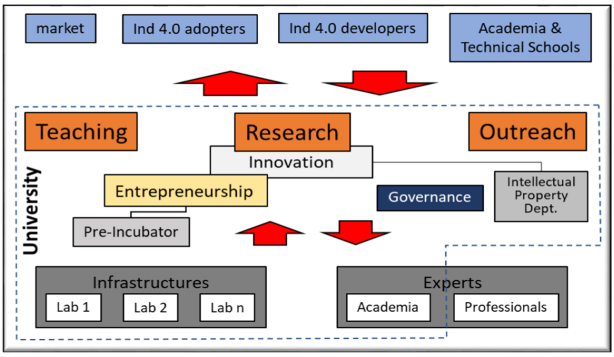

Fig. 1. Framework elements

- *Research*: it means investigating and developing new techniques, models, algorithms, prototypes, etc., directed to Industry 4.0 needs. This mostly comes from Industry 4.0 developers and adopters (*tech pull*) based on their needs. By 'needs' it does not mean developing solutions for companies' current problems, but rather proof-of-concept prototypes, technologies assessments, innovations, etc., as bases for future companies' products and services.

Entrepreneurship is stimulated. Researchers do works that can either be further interesting to companies (*science push*) or can use their works for launching their future startups or spin-offs. The university offers methodological and mentoring support for that through its *pre-incubator*.

Although innovation is present in the teaching and outreach activities, it is essentially present in research. The way innovations are developed can vary from case to

case, requiring a more formal means to manage them. This includes e.g., dealing with *intellectual property rights* when pertinent.

- *Outreach*: it means a set of "services" that universities offer to society. In the context of Industry 4.0, this usually involves specific courses to companies and professionals; consultancy to companies; and technical evaluations, advisory, and technical reports to government/industrial councils.
- *Infrastructures*: considering the focus on Industry 4.0, it refers to the strategy of starting using existing infrastructures that industries (mainly SMEs) do not have to test or develop technologies and solutions on their own. From the business models viewpoint, this means seeing infrastructures as a "platform" over which "services" can be offered and used in different modalities by different "actors".
- *Experts*: it means the group of professionals, both from the academia and the market (including former students who are eager to retribute the training got from the university) that are skilled to help companies in coping with their needs. This group is equivalent to the concept of *Virtual Professional Community* [9], where *Virtual Teams* (i.e., subgroups of experts) can be dynamically and temporarily created to attend those needs.
- *Governance*: it means the set of principles and regulations that are set up to rule and guide the diverse types of framework's actions.

4 Business Cases and Governance

Business cases represent the sort of concrete activities to be supported by the framework to boost Industry 4.0 adoption and development, especially based on the existing infrastructures. They are described in the next sections.

4.1 A Shop Floor as a Framework's Physical Instance, and Piloting Actors

The current infrastructure is composed of two *FESTO MPS* set of stations placed in two physical locations. These infrastructures are able to communicate with each other, so they can do some integrated work. One, placed at one of the university labs, is constituted by six assembly-related stations, which works sequentially (although they are modular), equipped with *Siemens* PLC series 1200, and that communicate via *wifi* and a *Profinet*/*OPC* protocols. It includes some IoT devices and sensors, and a SCADA system, via the Siemens *TIA Portal*. The other plant, placed in an industrial training center 5 km far from the university, has three stations and one AGV, equipped with *Siemens* PLC series 1700, which communicate via *wifi* and *Profinet & Fieldbus*/*OPC-UA* protocols, also having IoT devices and sensors.

An important aspect to use these infrastructures is the adoption of a 'plug and play' & SaaS (Software-as-a-Service) general strategy. Based on a bus integration approach, and given that the infrastructures strongly rely on ICT standards, the developed software solutions (from Industry 4.0 company developers and researchers) are made available as "services", accessed as SaaS, deployed at different clouds. In the case of hardware and equipment, they should be locally deployed (Fig. 2).

The initial implementation of the framework started as a pilot, and new actions have been gradually added as results appear. The main actors involved in the pilot are: UFSC (the department of Automation engineering); some selected professors from other UFSC departments; the computer science department of the State University of Santa Catarina; the Industrial Center for Apprenticeship; and some companies from the manufacturing cluster.

4.2 Teaching

The main activities supported by the framework on Teaching are:

- New courses (mostly as elective) at both undergraduate and graduate levels specifically directed to Industry 4.0 foundations (e.g., maturity models, digital transformation, etc.) and enabling technologies (e.g., AI, digital twins, IoT and cyber-physical systems, etc.);
- These courses are flexible to introduce new specific contents, technologies, visits to industries, classes inside companies, talks by entrepreneurs, etc.;
- Some courses' topics are taught by professors from other departments or universities, by specialists on the given topic; and/or by professionals from the market, also experts, but more focused on real problems, practices and commonly used tools or methodologies;
- Strong emphasis on hands-on activities, where students can work on selected Industry 4.0-related problems brought by the ecosystem's own companies. During the scholar semester and following milestones, undergraduate students are mentored by these professionals, together with the professors.
- Some more promising ideas and prototypes developed in such courses have been deepened – also helped by the Pre-incubator – and become initial seeds/MVPs for future products to the market, or technologies that can be incorporated into companies' existing solutions, or themes to be chased in future graduate Theses;
- Adoption of up-to-date tools used in the market, provided by companies, free of licenses, instead of old-versioned or limited academic tools;
- Use of the lab infrastructure to teach the students.

Achieved results of this include: i) increasing the number of trained students on Industry 4.0; ii) according to the piloting companies, students are clearly better prepared to more comprehensively handle problems related to Industry 4.0 projects; iii) companies have saved time and costs in initial training when hiring students as internships or engineers; iv) students' mindset shift in the way they see the potentials of their final works in becoming new solutions for Industry 4.0; v) students are trained about how transforming ideas in potential future businesses; vi) increasing the number of startups and spin-offs created by the undergraduate students in the several areas embraced by Industry 4.0; vii) students are more excited with the university itself, with the courses and related daily activities, and with better potential future jobs.

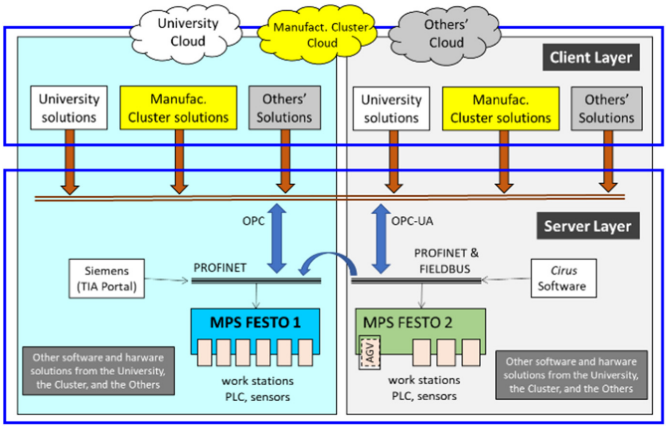

Fig. 2. General view of existing infrastructures

4.3 Research

The main activities supported by the framework on Research are:

- From a *Tech pull* innovation perspective, MSc and PhD students are presented to problems brought by companies. Problems can be both "infrastructure-related" and about higher-level topics (e.g., Supply Chain, AI-based control, etc.).
- Companies either sponsor students with scholarships or stimulates their employees to pursue a graduate course to research on an agreed theme. Considering the usual restrictions from SMEs in terms of human resources and technologies, this represents a feasible way to outsource their R&D activities;
- From a *Science push* innovation perspective, results from some MSc and PhD students are presented to companies (via *pitches*), showing envisioned benefits of the developed "technology" to companies;
- Solution providers make their products available to students and professors to add some value. This can be subject of IPR and specific business agreements. Some graduate works can become small research projects, funded by companies and/or research funding agencies, and can involve other students (including undergraduate) or professors/researchers.

Achieved results of this include: i) increasing the number of cooperation projects with the industry in the area of Industry 4.0; ii) increasing the number of graduate works with potentials to be exploited at business level; ii) increasing the number of professionals from companies starting their MSc thesis; iv) increasing in the average awareness level of students, professors, and companies about pros and difficulties to work collaboratively in a business-oriented project; v) increasing in the average awareness level of companies about the intrinsic risks, time, and costs of innovation projects; vi) increasing in the average awareness level of companies about the role of the university (that it is not a 'company'); and vii) increasing the number of startups created by the graduate students in the several areas embraced by Industry 4.0.

4.4 Outreach

The main activities supported by the framework on Outreach are:

- Professors use the infrastructure to deliver courses and continuous training to industries and professionals about specific subjects related to Industry 4.0;
- Companies (both Industry 4.0 adopters and developers) can use the infrastructures' facilities to evaluate technologies, methods, devices, etc., in near-real environments before deciding to buy them, or as a support for their decisions if they keep investing in some innovation project whose technical feasibility is not well known. This can be subject to fees for the university;
- Companies can make use of the infrastructure as a support for product demonstrations, integrated to a near-real environment, and for training customers on the developed solution. This are subject to fees for the university;
- Use of the infrastructure for teaching students and instructors from other universities and technical schools;
- Formation of Virtual Teams [9] of professors (and eventually also involving professionals) to attend requests from companies and from funding agencies for consultancy in issues related to Industry 4.0.

Achieved results of this include: i) increasing the number of courses and training activities to industries on Industry 4.0 as well as to external students; ii) increasing the number of companies looking at the university to assess some technologies and to make some general tests of their products; iii) increasing the number of companies looking at the university to show how their products can work in real-life; and iv) increasing the number of advisory services to companies in Industry 4.0.

4.5 Governance Model and Framework Sustainability

Considering there are: i) different institutions and many possible companies interested in using the available infrastructure and offer their solutions; ii) some equipments (that need maintenance, can break, etc.), technical staff, scheduled classes in the labs, and legal restrictions related to cooperation university: industries; and iii) existing regulations for installing software and hardware at the university, etc.; a governance model had to be devised. In general, it means defining the "rules of the game" for the different business cases and actors involved in each scenario with the aim of mitigating possible conflicts and problems that can bring the framework down.

Inspired in the life cycles of the VBE and VO (Virtual Organization) types of collaborative organizations [9, 12], the governance model is basically composed of a bylaw-like instrument and operating rules. The former generally depicts the main working principles of the network that is formed to cope with the different business cases (e.g., the existence of a common management committee, aspects related to payments, and rules related to sensitive information and to competing companies). The latter comprises the basic rules for a company: i) to be accepted to work with the university under this framework (e.g., rules to make software available, to donate funds and resources, to licensing, etc.); ii) to operate within this framework (e.g., rules to use the infrastructure and other resources,

the involvement of professors, technicians and students in research and outreach, etc.); and iii) to leave the framework (e.g., rules to cancel the permission of a company to use the infrastructure under the framework, to remove companies' resources previously installed, etc.).

5 Final Considerations

This paper has presented a tailor-made framework developed to boost the adoption and the development of the Industry 4.0 in the Greater Florianopolis City, the South of Brazil. Considering a set of identified obstacles that have been preventing a larger adoption of Industry 4.0, the developed framework was conceived taking advantage of some pre-conditions. In more particular, the existence of a solid innovation ecosystem and a good number of local Industry 4.0 solution developers.

The main motivation for the framework was that universities and companies/industries are not used to cooperate at a large scale, systemically, despite the big potentials. The framework can be seen as a kind of 'answer' from the university to the industrial community, trying to attract companies to work more effectively in terms of generating more concrete and useful results in terms of Industry 4.0 needs.

A set of concrete actions were conceived regarding the way the university is organized, namely in terms of teaching, research, and outreach, also involving innovation, entrepreneurship, and apprenticeship.

The results so far achieved are very promising given the improvements obtained in all the supported dimensions and the specific goals the framework was tailored to. However, there is a long way to go. Especially in terms of measures to increase the level of awareness and general mindset – both from the university and entrepreneurs – related to the initial difficulties and to the learning and evolving process a cooperation between them represents. This also involves some legal obstacles to be overcome as some situations were not explicitly supported by current regulations as some situations were new. Thus, the framework cannot be taken as finished. Instead, it is constantly updated as newer scenarios and better practices appear.

Besides identifying the set of business cases for the diverse cooperation scenarios, a governance model was necessary to be established to regulate the functioning of the framework, and to preserve and reinforce the relations between the involved actors.

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