Servitization for Teaching and Research Laboratories

Guidelines for a New Business Model Driven by Practical Use Cases

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Abstract—In this paper, we present a pattern for assessing the feasibility of laboratories and lab networks to operate in a service-oriented form of business. Our focus is on the field of engineering, and on a network of academic labs, and we aim to provide a practical tool for disclosing the opportunity of servitization, or to use Laboratories-as-a-Service (LaaS), for interested companies. By using a traditional pitch deck approach, we define the available digital online offer of the specific labs, and we structure a questionnaire to investigate the market demand. Afterwards, we sketch the main servitization characteristics required to digital online labs from a business perspective. The pattern we propose has been used as a guideline for interviews to selected stakeholders of two specific labs, namely a remotely available RFID lab for internal logistics in the retail sector, and a serious game for operations and supply chain management. The answers we collected suggested the feasibility of the labs servitization, by defining both strengths and weaknesses.

Keywords—digital and online labs, non-traditional labs, pitch deck, servitization, laboratory-as-a-service, LaaS

1 Introduction

The importance of laboratories in STEM education (Science, Technology, Engineering and Mathematics) is unquestionable, as lab-based learning has proved to be an effective learning method to achieve important pedagogical objectives [1]. The possibility to match the practical experience with the theoretical concept, which is often enhanced in labs by the use of real devices to tackle real-world problems, makes laboratories effective tools for STEM disciplines [2]. Due to this fact, the development and use of laboratories has increased significantly in recent years [3]. In particular, [4] showed that Non-Traditional Labs (NTLs), i.e., laboratories which differ from traditional hands-on ones, and Lab Network Initiatives (LNIs), i.e., an environment that combines at least two isolated online laboratories connected to each other, have become more and more common in the last two decades ([3]–[5]). These labs can mostly be accessed via web, and they might offer the possibility to perform both virtual and real experiments, by means of remote use enabled by sensors, actuators, controllers, and smart devices. The implementation of such tools is directly linked to the growing interest of the research and education in topics like Industrial Internet of Things (IIoT) and Industry 4.0 (I4.0) [6]. This new wave can be mainly reconducted to the appeal that I4.0 and IIoT had towards the manufacturing industries and reflect their willingness to adopt such new technologies. The availability of I4.0-related devices gains even more importance since I4.0 moved from an abstract concept to a tangible reality, and nowadays becomes the core of the strategical and research decision [7], fostering (i) the possibility of meeting individual customers requirements, (ii) enhanced flexibility, (iii) optimized decision-taking process, (iv) increased resource productivity and efficiency, (v) valuable opportunities creation through new services, (vi) enabling of disparate and adjustable workplace, (vii) better work-life-balance, and (viii) a high-wage economy that is still competitive.

However, despite the rising importance of laboratories in STEM, IIoT and I4.0, [4] highlighted that the duration of the before mentioned labs is highly depending on project fundings. This information strengthens the need to hoard funds to keep the laboratories active and up to date. Still, these laboratories are seldom used outside of higher education courses and research, and not well connected with enterprises [8]. On the other hand, technological transfer, as an important aspect of the so-called university third mission, represents an already existing space where universities and companies collaborate to spread the technological knowledge from universities to the enterprises, based on a service that answers to the company desiderata. In this direction, labs might connect with the concept of servitization, that is the '*process of building revenue streams for manufacturers from services*' [9]. Servitization can represents a valid solution to enhance the duration of laboratories and to better connect university research with companies [8]. As an example, some solutions and initiatives of laboratories combined with servitization can be found in the works of [4] and [10]. Still, it is not possible to define a common pattern to delineate the services to be provided, due to (i) the multitudinous of existing laboratories, (ii) their peculiar characteristics, and (iii) their availability in terms of time, data provided, accessibility and customization. Moreover, a central role is played by companies, which are the prospects or customers willing to purchase a service, and by the laboratories themselves. So, once the variables linked to the laboratory are known and the customer(s) desiderata are defined, it emerges the need to define a new personalized business model to deal with this opportunity of business not yet fully disclosed.

These considerations led to the need to conduct an in-depth analysis of the current situation of companies concerning the usage of the possible services that a laboratory can provide. This analysis must be done with a specific customization in order to highlight the pros and cons of services that can be provided by the laboratory accordingly with its characteristics, and the willingness of the market to make use of these services. With this objective in mind, this paper focuses on the following research questions: (**RQ1)** is it possible to create a common pattern to identify the potential of laboratory servitization? And (**RQ2)** how can this common pattern be adapted to specific labs? With these questions in mind, the present paper proposes a common pattern based on a tool that takes into account (i) the very characteristics of Laboratory-as-a-Service (LaaS) concept, as one of the most important servitization model in education, and (ii) the specificity of the lab that could be offered as-a-service. The tool is then used in some use cases that qualitatively underline the intention of companies and professionals to remotely access laboratories, their equipment, and the research results. The remainder of the paper is structured as follows. In Section 2 we report a literature overview on the topics of servitization and NTLs; Section 3 presents the research methodology with research design, setting, data collection and analysis. Section 4 reports the results of the survey, which are discussed in Section 5, together with the conclusions.

2 Literature overview

The journey which leads to the servitization as business model for an enterprise is long, slow, and must be supported by all the company functions and departments. Reference [11] has identified four strategies for a company that wants to move its business focus from a product-oriented to a service-oriented one. Still, a common pattern cannot yet be defined, due to the complexity in defining the market for services and to the several different policies available to enhance products and processes with services. Nonetheless, their analysis can be performed from (i) a product-oriented perspective, and (ii) a client-oriented perspective. In the first case, the company focus is on the product development, on the other hand the focus moves on the company willingness to intensify the relationship with customers. The four strategies identified are: (i) product support in which related-services enhance the product performance; (ii) cash generator, in which services are mandatory to be purchased beyond the product; (iii) brand fostering, a strategy focused on strengthening customer loyalty; and (iv) business generator, that is a specific product-service bundle for each customer profile.

2.1 Servitization in manufacturing

The successful examples of manufacturing companies that have transformed their businesses from a product-oriented logic to a product-service or a service-based one are numerous [12]. Rolls-Royce is one of these, a true example of successful servitization. Rolls-Royce first produced and sold aircraft engines. Later they switched from selling them as a product to providing them as a service. This service, named Total care, entailed renting out the engines to customers. They valued the service by counting the number of flight hours of each engine. This way Rolls-Royce could monitor the health state of the engine and predict maintenance operations and failures which saved costs and unnecessary downtimes [13]. Other examples are listed below ([14]). Caterpillar, a company specialized in the production of heavy construction machinery, has reinforced its business by providing a portfolio of assistance, the Cat Product Link. By monitoring its own equipment's remotely, Caterpillar can provide to its customers regular updates on location and preventive maintenance actions that are needed. Alstom, a French company specialized in train assembling, values its maintenance service based on the principle of 'hours lost by the customer'. The objective is to minimize the total amount of delays of its trains, weighted by the number of affected travelers and by the downtime period (peak vs. off-peak). Xerox is another interesting example that moved from selling to business process management, by accounting the number of photocopies, and by offering documents publishing and production services, alongside with digital archives and interfaces to improve document control without printing them.

The common ground here is the exploitation of new technologies, a catalyst for servitization strategies and for the development and application of new servitization [15] and business models [16]. Therefore, the term of digital servitization arouse, associated with the concepts '*Change in service offering that have become digital and smart*' [17]. This concept implies the usage of digital technologies for the creation of new services and/or the optimization of existing ones, still enabling new business models, to find additional ways to (co)create value to improve company operations and environmental performance, and to gain a more competitive advantage [12]. The digital technologies that most affect servitization are (i) Big Data [18] and Analytics [19], (ii) Cloud Computing [20], and (iii) Internet of Things [21]. The basics are the knowledge gained from data to provide tailored solutions for the customers that can access assets from anywhere and anytime [22].

2.2 Non-Traditional Laboratories (NTLs): steps towards labs servitization

Research on NTLs is a wide sector, and the lexicon used by authors is quite various [8]. We will refer here to the lab definitions of [23], and to the four types of laboratories that they distinguish – i.e. (i) online based on the internet, (ii) virtual based on simulations, (iii) remote providing online access to real resources, and (iv) hybrid blending virtual with remote experiments. These labs are good candidates for LaaS application. Also, [4] analyzes 40 NTLs and LNIs, involving different type of NTLs. These 40 solutions are analyzed through different key attributes using the structure proposed by [24]. As [4] reports, it emerge a fairly constant increase of active NTLs and LNIs. The study also reports a significant difference in the lifespan of single labs and lab networks, and an even bigger difference between the average durations of publicly and privately funded NTLs and LNIs. However, [4] reports that only 10% of labs are used by companies. With respect to the type of experiments, four categories are reported, namely (i) repository, (ii) batch experiment, (iii) sensor experiment, and (iv) interactive experiment. The improvements in research and application of different labs and experiments opens up the possibility to provide different kinds and levels of servitization, from simple data sharing (repository) to different levels of synchronism between experimenter decision and experimental application in a location-independent way.

2.3 The everything-as-a-service model

Companies' business models are continuously switching towards approaches based on the provisioning and the exploitation of data and information. This wave of new servitization strategies has led to the introduction of the new concept called Everything-as-a-Service (XaaS) [25]. The concept 'aaS' is nowadays one of the main investment areas from manufacturing and industrial world, and a growing research field, although academic world still lacks a unified view and agreement over the term 'aaS' [26]. In general, XaaS reflects the increasing adoption of the 'aaS' method to deliver any type of service [27], [28], with the primary goal of increasing the value for the customer. One of the first examples is the creation of the term of Software-as-a-Service [29], that applies the 'aaS' approach to software. Shortly afterwards, the Manufacturing-as-a-Service (MaaS) concept followed, an ecosystem that acts as a virtual marketplace bringing production capacity, as well as other virtual and physical assets, closer to the production demand, to aim for their optimal matching [30].

Moving to academia and research, a first attempt to redefine the experience and approach to remote laboratories as a service was made by [31]. The paper proposed a remote laboratory that was integrated with the 'aaS' concept, defined as 'Collaborative Web Labs as a Service'. In 2014, the concept of LaaS was 'officially' introduced by [32], followed by a scarce number of documents in the following years. New articles were mainly focused on the technological aspects of specific cases, on the adoption of architecture and components, or on the suggested steps towards a LaaS approach [33]. To the best of our knowledge, there is no study that addresses the potential of NTLs and LNIs outside the boundaries of the didactical and academic field, based on the 'aaS' model.

3 Methodology

3.1 Research design

The present research has been designed to collect feedback on the possible servitization of laboratories, or LaaS, in private companies. Collecting opinions, hints, and perceptions is fundamental to define pros, cons, and potentials of this intended use of technology. To do so, the authors decided to conduct a qualitative analysis to provide the highest level of freedom for the interviewees. Actually, the usage of a semi-structured questionnaire has been evaluated as the most fitting tool to receive the broader feedback possible, due to the possibility to adapt the questions accordingly with the flow of the interview. These interview guidelines have been designed, as can be seen in Figure 1, by combining three different sections.

The first section is a preliminary set of questions referred to the interviewed subject such as name, affiliation company, and so on.

Secondly, it has been decided to build the main section of the interview guidelines on a traditional pitch deck. Being the pitch deck a preliminary analysis which is usually taken to understand if there are the conditions to justify the further development of a new business model [34], it has been considered a suitable tool to our intended scope.

Finally, a third section of interview guidelines has been designed by combining the literature analysis conducted on the concept of XaaS and LaaS and the specific characteristics of the laboratory which is object of the analysis. We believe that this combination could provide both an up-to-date point of view on the 'aaS' approach, together with a personalized questionnaire which is optimized for the lab under examination. In this part, a key role is played by the cross-analysis which enable the possibility to adapt questionnaire according to the investigated use cases, to better focus on strengths and weaknesses of the specific instance. We note that the second section builds up the frame of the interview guidelines, whereas their customization is performed in the third section, where the LaaS characteristics and the points of the pitch deck are intersected and adapted to the specific use case(-s).

Once the questionnaire has been finalized, it underwent a validation process, which was performed by 6 senior and junior experts from both academia and the industry, to provide a first opinion on this tool. Having positive feedback from the validation process, the interviewees have been identified and the interview meetings have been carried out.

3.2 Research settings

The traditional pitch deck as main section of the semi-structured questionnaire. The choice to rely upon the pitch deck for the frame of the of the semi-structured questionnaire is due to the similar scopes of these tools. The details are reported in Figure 1. The scope to provide a quick but comprehensive overview of the company during interview meeting with stakeholders can be assimilated with the aim to present a LaaS and to investigate stakeholders' reactions. Pitch deck consists of two parts, (i) a presentation and (ii) an elevator pitch, in which the business plan is clearly presented to leave an impression. The ten points of the pitch deck are (i) introduction, (ii) problem, (iii) solution, (iv) market size and opportunities, (v) product, (vi) traction, (vii) team, (viii) competitors, (ix) financials, and (x) investment and use of funds [35]. Similarly, we chose this model to give a first overview of a LaaS, using the ten points of the pitch deck structure, to investigate the possibility for a new business model. The idea of business model foreseen by authors is composed of two different services, the supply of 'standard' data produced during lab experiments, and (ii) customized data obtained in personalized experiments executed according to company desiderata.

By analyzing the ten points of the pitch deck, the authors observed a division between the odd and the even ones. The odd points essentially list the desired characteristics of the intended business model. Thus, we considered to embed in the odd points the LaaS concept and its business model, covering the lab characteristics and the servitization option of online laboratories. On the other hand, the even points investigate the potentiality of the company/business, together with customers and stakeholders' characteristics, looking for market position and information to define the new business. So, the authors decided to follow the even points to build the skeleton of the questionnaire, to be applied to LaaS concept. These five prepositions are used to explain the potential business which is identified through an analysis that is conducted with potential customers. The aim is to start from the five (even) prepositions and to use them to lead stakeholders and potential customers through the interview. These five sections are: (i) problem, (ii) market size and opportunities, (iii) traction, (iv) competitors, and (v) investments and use of funds, and represent the main points of the questionnaire, related to the following objectives:

- **Problem:** investigate the core problem preventing companies from using the university services, in form of digital labs.
- **Market** size and opportunities: identify features that can improve the market share of the service are investigated.

- **Traction:** understand what features must be improved in the future to define next steps and further business opportunities.
- **Competitors:** define possible competitors and understand why they can be different from the LaaS proposition.
- Investments and use of **funds:** investigate how willing the interviewed subjects are to use and to pay for the proposed service(-s).

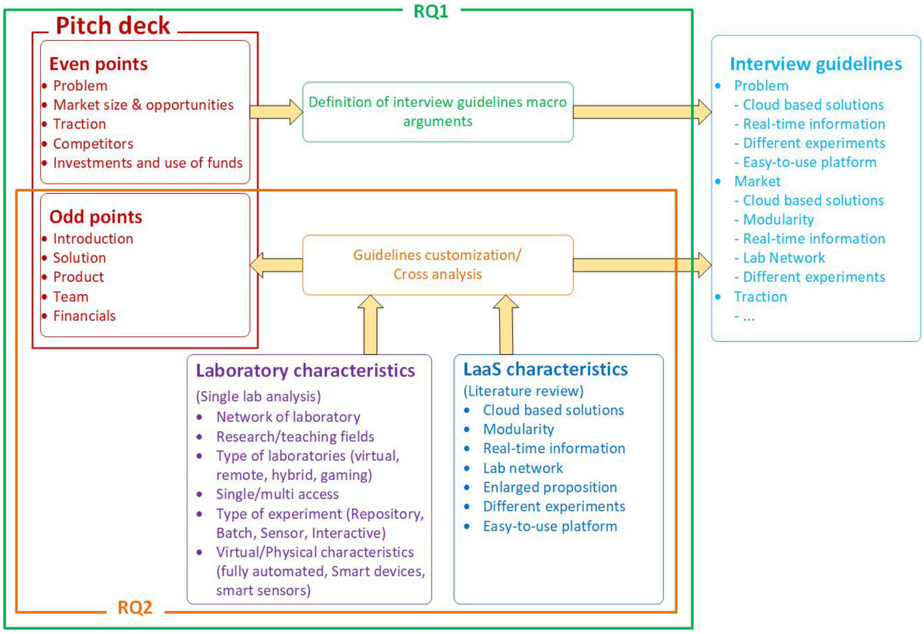

Fig. 1. The design process of interview guidelines

Guidelines for customization. The survey of the literature has been conducted by consulting the scientific databases Scopus and Google Scholar. We noted that the XaaS topic is well covered, with several hundreds of publications as of May 2021, the field of LaaS is quite underinvestigated, with only a few tens of publications in the same search period. By combining the findings of this literature search, it has been possible to define servitization items which characterize NTLs. Namely, we identified seven items: (i) cloud-based solutions, (ii) modularity, (iii) real-time analytics and statistics, (iv) lab network, (v) enlarged proposal of experiments, (vi) different types of experiment, and (vii) easy-to-use platforms.

On the other hand, the laboratory characterization has been made by choosing different factors among the ones reported in [24] and the LaaS characteristics to better cover all the points required. The factors chosen are (i) being part of a network of laboratories, (ii) research/teaching fields, (iii) type of laboratory (virtual, remote, hybrid, gaming), (iv) single/multi access, (v) type of experiment (repository, batch, sensor, interactive), and (vi) virtual/physical characteristics (fully automated, smart devices, smart sensors).

The two groups, laboratory characteristics and LaaS characteristics, are finally combined and integrated in the cross analysis to populate interview guidelines with the appropriate questions/items. The final semi-structured questionnaire has been built on two laboratories of University of Parma, namely RFID Lab and the Serious Game for Operations and Supply Chain Management (Op&SCM).

Laboratory-as-a-Service characteristics. The authors performed the literature review research on Scopus database by using the following query (May 2021): *TITLE-ABS-KEY ("laboratory as a service" OR "lab as a service").* The query search resulted in 38 scientific papers, 26 of which were written in the last two decades, with the peak of publications in 2014-15. The main subject areas are (i) Medicine (11), (ii) Computer Science (10), (iii) Social Science (10), and (iv) Engineering (9), and only 16 papers are identified by keywords like "Laboratories", "Remote Laboratories", or "Laboratory". Despite the low number of results, we identified the seven main LaaS characteristics, as they are detailed below.

Cloud based solutions. Cloud computing is defined as a model for enabling convenient 'on demand' network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) [36]. The advantages of using a cloud technology are numerous, and self-evident. They include greater efficiency of the booking process, the support of different lab platforms, lower costs of lab administration and greater availability of instruments due to the remote access [37].

Modularity. The real novelty and paradigm of a LaaS can be found in the introduction of the concept of modularity of the experiments and laboratory hardware infrastructure [32]. Traditional laboratories assume that, once designed, the hardware components are soldered together, making it difficult if not impossible to reuse them in the re-creation of new laboratories and experiments. One of the first common steps of the LaaS approach is in fact the deconstruction of the laboratory into various basic modules, thus defining all possible use cases. Thanks to this step, the various lab functionalities are separated from each other, making it possible to create experiments which can be customized according to the case study by selecting only some of them [33]. These considerations can be summarized into two statements ([32]).

1. 'Modular remote laboratories with the aim to convert laboratories into modular components (…) to facilitate maintenance, reusability, and interchangeability of components seamlessly and programmatically.'
2. 'The LaaS paradigm aims to convert modular remote laboratories into a set of services that are consumed by users with a high level of abstraction and virtualization.'

Real-time information. An advantage of a LaaS is the possibility to combine the user experience with the execution of real-time analysis and statistics. Thanks to the cloud feature, data is stored and can be used in real time. One example is the implementation of third-party services which allows analysis. It is possible to visualize information such as the users' geo-location, the type of device used, the running time of the experiment, the progression in accuracy and quality of the results produced, as well as several other metrics [38].

Lab network. Nowadays there are many remote and virtual labs connected to the internet. However, at the same time they are isolated systems that operate independently and are often unable to cooperate with each other. This fact produces a duplication of efforts in activities that could be easily shared. The creation of an LNI is therefore a basic aspect of an efficient LaaS framework [39]. In fact, the possibility to connect several laboratories in various places (be them universities, enterprises, or other institutions) could be a crucial improvement that ensures significant advantages. All the users connected to the network could have access to all the laboratories, enabling them to share the labs and the experiences that are available on the different locations, whether in place or remotely.

Enlarged proposition. A LaaS approach could create new business opportunities by extending the online experimentation offers to external users and institutions. Consequently, indicators such as return on investment could be improved. A LaaS could also look outside the university boundaries to extend the use of its service model from teaching (only) to other business opportunities. Indeed, it is necessary to expand the range of services offered to third parties (e.g., federated institutions, companies), giving them the opportunity to book and perform experiments in cooperation with the technical staff of the lab [31].

Different experiments. The same laboratory can be used for different types of experiment (see for example [24]). This fact has also an impact on the potential revenues, as it can extend the purpose of the experiments at a relatively low cost. It is also possible to access the old batch of data previously collected and stored on the cloud, and this opportunity makes the user experience even more complete [38].

Easy-to-use platform. To perform experiments in a LaaS, users must interface with a web application. This platform allows them to manage their lab experience by logging in with their credentials, selecting and scheduling an experiment, displaying experiment statistics, reporting, and analyzing results, and so on. The platform must be designed to facilitate the user's experience [36].

University of Parma Use Case. DigiLab4U is a cross-Institutional network of IoT and Industry 4.0 lab infrastructures. The consortium, whose details can be found at the project website (http://digilab4u.com/), counts 5 founding institutions, and 9 more worldwide partners joined the consortium in 2021. The network was funded by the German Federal Ministry of Education and Research (BMBF) for developing the project 'Open Digital Lab for You', with the goal of creating an integrated and hybrid learning and research environment providing different types of labs for a digital offering reaching different kinds of users. This environment is completed by the use of alternative teaching and learning methods like self-regulated and collaborative learning, and serious games [1]. Nowadays, the consortium presents a well-defined technical framework [40] where laboratories are connected through a centralized Learning Management System (LMS) and provided of a billing and booking system. Labs are provided with one or more didactical scenarios, guiding users through the acquisition of theoretical and practical knowledge, which can be acquired by means of experiments performed in different labs. Also, different scenarios have been linked together to build an exhaustive experience that deepens the comprehension of a topic.

The University of Parma is connected to the DigiLab4U network with two different labs, its RFID Lab and the Op&SCM serious game. Founded in 2006, the RFID Lab pioneered RFID applications, and became a reference research center both in the Italian and international scenario. The lab brings outcomes of research activities to master degree classes in Industrial Engineering and Management of University of Parma, in particular to the class of 'Auto ID in Production and Logistics'. During the course, students can perform two different types of experiments, they can (i) reproduce a Received Signal Strength Indicator (RSSI) starting from raw data, or (ii) find the best combination of factors to optimize RFID readings. Up until 2019, these hands-on experiments required the physical presence of students in full time. After the lab joined the DigiLab4U network, a systematic upgrade has provided new hardware and software to automate the lab, enabling the remote definition and supervision of experiments, thus moving the lab from hands-on only to the possibility of remote experiments (although we note that the hands-on option still exists).

The scenario of RSSI Curve Creation uses three different products, filling three boxes each for a total number of nine boxes, each of which is equipped with several UHF passive tags. The experiment is carried out by running each product multiple times between a reading gate, and by changing the power level and type of antennas. The data collected enable the possibility for the learners to draw the RSSI Curve and study its path according with different parameters. Similarly, the Reading Optimization uses three boxes filled with the same product but provided with eight UHF RFID passive tag each. Moreover, sixteen different tags are used to simulate the noise that can be found in an industrial environment. Different antennas and power levels are considered to give enough data to students to calculate the alpha error and the beta error. Both these scenarios are in depth described in [41].

The Op&SCM SG designing started with the definition of the users, the objectives, and the structure of the game (i.e., web-based, multiplayer, cooperative and competitive). The serious game has been developed to convey practical notions of operations and supply chain management to fill the gap between the theoretical knowledge learned by students during classes and the practical skills required by companies. Moreover, by creating a web-based game with different companies acting in the same universe, the game aims at boosting critical thinking, problem solving, enjoinment, and collaboration skills [42]. Full details of the game are described in [43], where game parameters are fully reported, and the impact of difficulty levels on players' results is preliminarily investigated. The game can be used to create teams or improve teamwork, according to the specific scenario, and it could be deployed internationally, being currently accessible in three different languages (i.e., English, Italian, German). Although the big number of different parameters and levels that customize Op&SCM could provide a huge set of different scenarios, we will still treat the game as a single scenario capable of providing an ad-hoc universe for specific players' needs.

Cross-analysis. The questionnaire for the semi-structured survey has been produced by integrating the seven LaaS characteristics with the five even prepositions of the pitch deck. The cross analysis, which is reported below, adapts the seven LaaS items to the characteristics of the labs under analysis (RFID Lab and Op&SCM), and integrates these items in the five even points of the pitch deck. This operation represents the crucial part for the customization of the interview guidelines by investigating how these metrics could be seen from a business point of view, how they can be discussed to identify the possible business opportunities, and to detail the questions of the interview according to the lab's characteristics. Table 1 reports the results of the cross analysis. As can be seen in the table, each LaaS characteristic is connected to one or more pitch deck points, and vice-versa. Still, this merge has to be done only once and does not change during the questionnaire customization phase.

Table 1. Connection among pitch deck points and LaaS characteristics

		Pitch Deck Points				
		Problem	***Market***	***Traction***	***Competitors***	***Funds***
LaaS Characteristics	***Cloud based solutions***	x	x	x		
	Modularity		x	x		
	Real-time information	x	x	x		
	Lab network		x	x	x	
	Enlarged proposition				x	x
	Different experiments	x	x		x	
	Easy-to-use platform	x		x		x

Problem. The use of university laboratories by external organizations must cope with problems such as the lack of knowledge and information about lab existence and concerning the type of experiments that can be performed, lab availability, and the presence (or rather absence) of a known and structured booking process. The fragmentation of laboratories due to various factors such as geographical location and lack of common standards or scope is a problem that affects several laboratories, and it does not allow them to take advantage of the possibilities provided by an LNI. Within the RFID Lab in Parma, tags are tested on a belt conveyor, and this testing system could be beneficial for companies, as the in-house implementation of a similar system would both increase capital and operational expenses of a company for the design, development, and deployment of such a pilot line. Moreover, a company might not possess the necessary know-how to carry out a project like this. Companies can carry out internally, through their own instruments, the R&D and the certification phases of their products, or they can rely on specialized third parties. It should be investigated if, and to which extent, the lack of a service provided by a LaaS is an industrial need in this field.

Market size and opportunity. Modular experiments could range from simple experiments with a few variables that can be easily set by the end user to complex personalized experiments with a big number of variables for very specialized needs. As such, modular experiments might increase the basket of potential customers. Digitization of experiments and cloud presence of data allows potential customers to access them regardless of their geographical location. The concept of mass customization has gained more importance and it is used by companies as a discriminating factor to attract new customers. Similarly, the ability to retrieve experimental data in real time is a LaaS feature that might enable mass customization by providing the users with the possibility of modifying and adjusting test variables in real time, based on the achieved results. Also, the possibility to choose between a wide set of laboratories could enable integrated experiments, and it could increase both LaaS flexibility and effectiveness.

As an example, less experienced companies can look for simpler experiments, whereas more specialized ones can look for solutions to more complex and specific problems.

Traction. Increasing the number of labs affiliated to the LNI should be one of the main goals, as this choice obviously increases the number of experiments or tests that can be performed and proposed in a LaaS bundle. Also, partnering with other LNIs for a cross docking platform should be sought after, to expand the number of possible customers that can be targeted.

Competitors. A typical way in which universities connect and cooperate with commercial organizations is by means of technology transfer. Even if this service can involve the use of labs, traditional laboratories are often dedicated to academic purposes. Still, to realize a LaaS approach, labs must play a bigger part in technology transfer and service to companies, moving However, in traditional technology transfer, enterprises are often 'passive' actors that commission the resolution of a specific problem to the university, while, when the LaaS is introduced, they should become active actors. This change might be reached thanks to the possibility offered by LaaS to the companies of performing the relevant experiments by themselves, by supervising and modifying the variables in real time without the essential requirement of an external person, team, or institution. Given these premises, potential LaaS competitors can be:

- **Consulting companies:** their main objective is to be economically profitable, whereas the main university missions are teaching and research, with the possible additional revenue stream from selling LaaS.
- **System integrators:** could be seen both as competitors and customers.
- **Other NTL/LNIs**.

Investments and use of funds. This point covers the investments needed to achieve the LaaS offer. In our case, the online lab offer is already available by means of the DigiLab4U consortium. RFID is a mature and reliable technology, and the Op&SCM has already been developed, tested, and used in several different courses. Thus, the use of funds will focus on the operational expenses needed to operate the LaaS system, and on the intention of using such a service by external companies. It will thus investigate the willingness to pay, hypothetic price and types of subscription such as pay per use, yearly/monthly access, discounted bundles for loyal customers.

3.3 Data collection

Questionnaire validation and submissions. Before conducting the survey, the questionnaire has been submitted for validation to a team of six academic experts, two senior (i.e., university professors) and four junior ones (i.e., post-doc positions and young researchers). This activity has two different objectives, which is (i) to analyze the content of the questionnaire and gather opinions on its strengths and weaknesses, and (ii) to define a semi-structured tool for conducting preliminary surveys on lab servitization. After the validation round, positive feedbacks have been received in general, albeit some critical issues have been raised:

- **Duration:** the length of the questionnaire would imply a lengthy interview (approx. two hours), which could be exhausting and result in speedy or unprecise answers.
- **Questions formulation:** some questions were considered unclear and reformulated;
- **Highly technical questions:** due to their specificity and high detail, it has been suggested to carefully select the panel to meet the target audience for the survey.

The revision has produced a questionnaire composed by (i) an introduction sections in which the general information is gathered like the date/time, details of the interviewee, (ii) the five macro sections extracted from the even points of a traditional pitch deck and (iii) 38 questions created by the combination of seven servitization items and laboratory characteristics, detailed for each of the five macro sections. Then a common acceptance has been achieved according with the fact that questions well presented the technical contents, and all the pitch deck points were explored.

Interviews collection and data analysis. With several different constraints, the selection of the interviewees became a key step, which was made by keeping in mind the specificity of the labs and the corresponding competences requested by practitioners or company representatives to be interviewed. Two persons were chosen for each lab, hence a total of four interviewees, representing a technical stakeholder and a possible end user of each lab.

- **RFID Lab:** the technical stakeholder is an Italian system integrator of RFID technology, and the interviewed person is one of its Project Managers. The end user is an Italian fashion company long-standing adopter of RFID technology, and people interviewed belongs to the Research and Development department;
- **Op&SCM:** the technical stakeholder is the Department of Engineering of an Italian University, and a full professor has been interviewed. The end user is an Italian Technical Institution for Higher Education, with the lead coordinator of the courses participating to the interview.

The survey has been conducted as a face-to-face conversation between the interviewee and the interviewer in which the questionnaire has been used as a guideline. This kind of approach enabled the possibility to gather a higher quantity of information and new point of view on the possible labs' use. Each interview, which was voice recorded for further elaboration phases, lasted 1.5 to 2 hours. The data elaboration started with a transcription of the recorded interviews by applying uniform rules to ensure that no information was excluded from the analysis. The authors decided to use the method of qualitative content structuring analysis described below and explained in [44]: (i) content categories and sub-categories were defined according with the structure of interview guidelines (i.e. cross-analysis), (ii) the category table resulting from step 1 was filled by extracting and assigning relevant text passages for the final aim, (iii) text passages are make homogeneous and clarified, (iv) category system is revised, and (v) text passages are finally assigned to appropriate categories. The analysis showed a general interest in the servitization of the laboratories, but it also provided two different points of view for RFID Lab and Op&SCM.

4 Results of the survey

4.1 Problem

All the respondents were familiar with the concept of technology transfer. However, most of them listed several difficulties experienced in the past to establish the right contact with the university to start a technology transfer project, due to excessive bureaucracy and to the lack of a defined contact person. Therefore, three respondents suggested a leaner approach for defining contract's details and expected project outcomes. Also, no respondent was aware of the existence and ever used a (digitalized) laboratory with a LaaS approach. All the respondents agreed that using digital laboratories belonging to a network and provided with a web platform may boost the visibility of the service itself. Moreover, all the respondents think that the service might be useful in their sector since they will be able to replace internal R&D development for which extensive knowledge and technology is needed. Generally, the respondents wanted to retain full decisional power on the definition of the objective of the investigation, while they are seeking support in the execution phase. This might suggest a perceived lack of technological capability, and the need to be supported during the definition of research parameters. An interesting hint was also received on financial considerations, as two out of four interviewees considered LaaS as a possible mean to decrease both capital and operational expenses.

4.2 Market size

The potential market obviously depends on the type of service, namely the lab and experiment type. The RFID lab has been linked to retail industry, while Op&SCM for education and training. The main driver here is the service in-and-for-itself, with a special attention to the platform for accessing the labs. Hence, cloud-based access and a smart platform are considered fundamental prerequisites.

4.3 Traction

It is opinion of the respondents that the further development of the service should be centered on modularity, accessibility through the use of a cloud-based service, a high and increasing number of experiments, and a data centered format. All the respondents believe that it is possible to develop new business models and services that are connected to the laboratories such as offering an 'improved' consulting service or providing the laboratory with an observatory for new technologies adoption and use.

4.4 Competitors

All respondents agreed that a LaaS approach is not in competition with traditional stakeholders (i.e., consultancy firms or system integrators). Although three respondents did not see knowledge available at university as an advantage with respect to other stakeholders, the university independence and neutrality has been described as an interesting aspect by all respondents. With respect to Op&SCM, the real-time availability of data was described as one of its most important advantages, with respect to traditional actors, and towards a more data centered service. Also, the possibility to train learners' skills that they could not be easily trained by traditional methods was perceived as important added value. Nonetheless, to ripe the most of its possibilities, Op&SCM should be modular, cloud-based, it should support real-time data with a data centric approach.

4.5 Investments and use of funds

Interviewees did not label themselves as final decision maker on the possible choice to outsource LaaS services, but they generally welcomed the opportunity of committing to a pilot project, especially for the RFID LaaS service. They also showed a positive interest to subscribe to a LaaS service under the payment of a regular fee (Op&SCM). Here the different types of labs played an important part, discriminating between a specific commitment to plan and define possible LaaS research (RFID Lab), and a standard and modular pay-per-use service (Op&SCM). The serious game was considered an innovative tool to ease skills training and development. Moreover, it provides software as a product and a set of services like cloud repository and customizable parameters. The RFID Lab, on the other hand, was appreciated in terms of the customizable and remotely accessible service, provided by an independent player that could provide advice and expertise in the preliminary phases of new projects, carried out in cooperation with end users and system integrators.

5 Discussion and conclusions

NTLs and LNIs have been rapidly increasing in the last decades. However, since public labs and networks mostly rely on public funding, they need to find new ways to provide scopes and revenue streams after public funding ends. The servitization of labs has already proved to be a possible mean to reach this goal. However, to the best of the authors' knowledge, no common pattern is available at present to evaluate the market potential of laboratories, with respect to their characteristics.

This study presented a method to create a semi-structured questionnaire to be used for interviewing subject matter experts, and to perform a qualitative analysis on the collected information. The semi-structured questionnaire has been built on a traditional pitch deck structure. By separating the odd from the even points of the pitch deck, the latter ones might well be used to cover the topics that must be investigated to understand the opportunities to develop a business model based on the laboratory servitization. On the other hand, a literature review on LaaS has provided seven fundamental points that, if combined with labs characteristics, provided the detailed structure for the questionnaire, customized on the laboratory under analysis. Finally, the five macro sections are merged with the combination of LaaS and laboratory characteristics creating a cross analysis which became the base on which the subsections and questions of the interview guidelines are build. The proposed questionnaire has been validated in its general structure, and then used for two practical use cases, the RFID Lab and the

Op&SCM serious game, developed at the University of Parma during an international research project.

Although it has been showed that there is a significant interest for the access and use of LaaS, it is also clear that the possibility and the opportunity to provide a research LaaS mostly depend upon the lab itself. Hence, due to its characteristics, Op&SCM is best suited for servitization and a service-based business model, also due to its data-centric approach. On the contrary, concerning the RFID Lab, the possibility to provide a data-centric service has not been considered very attractive from a market point of view, even if the possibility to access the lab and data anytime-anywhere has been appreciated. Also, it has been noted that digitalization and remote access to labs and their equipment enlarge the offer, and consequently the market size, regardless of the business model.

Still, the present study replied to its research questions, by presenting a pattern to create a questionnaire which, by combining the pitch deck and LaaS characteristics, it can be used to evaluate the potential of laboratory servitization and the feasibility of a service-based business model based for a particular lab. Also, to adapt the questionnaire to different types of labs, a method for customizing the questionnaire has been provided, from the introduction of the lab to the selection of interviewees.

We also note that the present paper shows the following limits. First of all, the use cases presented in this paper are limited in number (only two) and they differ significantly (i.e., a remote lab and a serious game); as such, they obviously do not constitute a relevant sample for inferring general results. Therefore, the research should be extended by a more comprehensive survey involving (i) a bigger number of labs from (ii) different research fields and from (iii) more regions or countries. This extension might provide a further validation of the questionnaire itself and of the preliminary outcomes that we report, namely the possibility of building a data-centric business model related to some lab characteristics, which is, eventually, the final outcome of this line of research. At present, we are working on some of these topics.

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