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Unfolding innovation lab services in public hospitals: a hospital FabLab case study

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Abstract—Along with the first pandemic wave of COVID-19, many makers’ initiatives shed light on the innovative potential of developing computer assisted machinery services for the health sector. Even since before that, collaborative innovation structures such as FabLabs have been arising in public health institutions, which indicates the increasing demand for technological tools as well as innovation assistance in the public health sector. However, how FabLabs facilitate innovation processes contingent on hospital context is a question that needs to be further explored. In this article, a single case study on the Hephaïstos FabLab at the Bicêtre Hospital in France is developed in order to understand the role that a FabLab service can play in fostering innovation in a hospital ecosystem. The results show how innovation is stimulated by the FabLab proximity, the methodological approach developed by the FabLab team and the participants’ profiles. These insights are pertinent for hospital managers to help identify strategies and ensure continuity of a FabLab service.

Index Terms—public hospital; health institution; innovation; design thinking; FabLab

I. INTRODUCTION

Initiated by the Massachusetts Institute of Technology (MIT) in the 90s, the FabLab (from Fabrication Laboratories) concept rapidly spread around the world. Organized in a worldwide network coordinated by the FabFoundation, one must follow the Fab Charter [1] to be part of the movement. In the last 20 years, the FabLab community grew over 2000 members in more than 120 countries [2] and more than 10% of these labs are located in France [3]. FabLabs—and innovation laboratories (or innovation labs) in a broader sense—are part of a larger phenomenon known as the *Maker Movement* in which every individual is considered a potential solution maker if given access to adequate tools [4], such as digital solutions and computer assisted machines. Understanding and encouraging the creation of such spaces can favor new working practices that rely on collaboration, co-design, co-production and co-creation approaches, with a high innovative potential [5]. Hence the growing interest in private companies [6], public institutions [8] and academics [7], [9] where innovation has become a leitmotiv in strategic plans and short-term

objectives. Top-down decisions to stimulate innovation might lead to the creation of innovation labs which provide space and technological resources but are often disconnected from the users’ experience [10]. Furthermore, to succeed in the long term, these organizational forms should also provide a methodological expertise in user-driven design to ensure the facilitation of today’s increasingly more open and collaborative innovation processes [11], [12].

In this paper, we focus on FabLabs—as innovation labs—in the public health sector for which the recent health crisis exacerbated the need for organizational transformations. In early 2020, when the COVID-19 pandemic had become a globally dominating health concern, bringing the healthcare systems in many countries to their absolute limits, the reaction of the maker movement was instantaneous. Maker communities around the globe have been very active during the first wave of the COVID-19 crisis by responding to the shortage of PPE and other medical and healthcare-related products [13]. Consequently, FabLab settings have become a catalyst for makers and healthcare communities to amplify their work by accelerating the development of frugal innovations [14] (i.e., doing more, for less, for people) and fostering more networked and collaborative healthcare ecosystems [15].

Although public hospitals are not usually fast-paced innovative environments given their organizational and regulatory complexity [16], they have been witnessing the emergence of the lab phenomenon as collaborative tools in action to overcome innovation barriers [17], [19]. However, despite the positive impact that collaborative innovation environments such as FabLabs might have to a hospital’s innovation capacity and culture [18], establishing methodological and practical guidelines on how FabLabs orchestrate innovation projects contingent on the hospital context needs to be further explored. How are user-driven design projects carried out in a hospital FabLab? To what extent does a FabLab setting act as a facilitating interface for hospital innovation processes? These are some of the questions that motivate this study and

that we consider to be of high relevance, since they raise the operational and methodological issues that lab managers, researchers and users often have to deal with [20].

In order to better understand the role that FabLabs can play in fostering innovation in hospital ecosystems, this work develops a single case study on the experience of the Hephaïstos FabLab, created in 2019 at Bicêtre Hospital in France. By filling the gap left by discontinued global supply chains in March 2020, the Hephaïstos FabLab proved to be an agile mechanism for adapting production to users, coordinating actors on a local scale, sharing practical ideas and teaching design methodologies to ensure an emergency procurement [21]. This episode contributed to the popularity of the FabLab setting, but beyond its role in supporting the healthcare crisis, Hephaïstos grew into a cradle of innovation for the whole public hospital ecosystem; as of March 2022, more than 160 projects are being led on seven hospitals, some of them leading to intellectual property protection.

Accordingly, the main goal of this paper is thus to provide insights from empirical work on how innovative solutions are developed within a hospital FabLab. This way, we can identify how a FabLab service is used under different configurations in a hospital context. We reflect on the evolution of the services provided by our case and the methodological considerations implemented during this process. To this end, we frame our analysis in three main aspects: participants' profiles, applied services methodology and outcomes. Then, a cross-case analysis is structured to reflect on 10 projects which were completed between the creation of the FabLab three years ago and today. The results allow us to observe that innovation triggered by the FabLab service takes several forms and this approach could allow hospital managers to identify strategies, competences and methodologies that could lead to innovation opportunities.

The remainder of this document is structured as follows. First, an overview on hospital innovation and innovation labs in public health institutions is explored. Then, the research methodology is presented including a hospital FabLab's presentation and our framework design. Finally, results are presented through the description of a single project and a cross-case analysis before concluding with some perspectives for further research.

II. PREVIOUS WORKS

A. Hospital innovation

With rising costs and an aging population, innovation has become a critical factor in the development and survival of organizations within the healthcare system [22]. One of the measures taken by the Regional Health Agency (ARS) a year after the first pandemic wave is to reinforce its action in public healthcare innovations [23]. Although medical (and technological) innovation has dominated the research on the transformation of the public healthcare sector [16], as a consequence of the production function that hospitals took over time and technologies development, Djellal and Boullaj [24] argue that medical innovation is not synonymous with hospital innovation and that the field of exploration should

be broadened to other areas to improve hospital performance. Hospitals are in fact complex service organizations composed of a network of healthcare units and support functions that provide an extensive range of services supporting the quality of care [24].

Accordingly, hospitals as public institutions are not exempt from organizational barriers to innovation. In fact, there is a call from recent studies for addressing issues hindering innovation in the hospital context such as complexity, risk aversion, organizational flexibility, lack of competence (for innovation), bureaucracy and external cooperation [18], [19], [25]. In this sense, Dias and Escoval [26] explain that “*the organizational innovations that promote communication and interaction across departments and other organizations are key factors to accelerate innovation in the hospital sector*”. Lee and Kong [27] also highlight that in order to achieve knowledge sharing and innovation behavior, hospital workers should be encouraged to share their expertise and innovation with their counterparts through diversity, autonomy and open communication.

B. Innovation labs in public health institutions

Torvinen and Jansson [18] present innovation labs as an opportunity to tackle the barriers of public sector innovation by adding interaction in complex organizations, enhancing mutual learning across hospital units but also with potential external partners and allowing a smoother journey when bureaucracy can slow down promising projects. Such labs have the ability to make innovation prospects more tangible, which motivates frontline organizations to take an active role in the innovation process.

As organizational structures, innovation labs take several forms such as FabLabs, makerspaces, living labs, open labs among others, each one of them being the manifestation of the innovation intent of an organization (or group of organizations) operationalized through specific resources, methods, techniques and competences ([17]). Amid the diversity of lab concepts we mainly observe two approaches that have spread significantly among practitioners and researchers: Living Labs and FabLabs. In a general context, a Living Lab is defined as a space dedicated to collective experiment and assimilation around a community of thinkers while a FabLab revolves around a community of makers who conduct experiments and share practices on digital technologies [28]. Although there is often interest in establishing clear distinctions and differences between such approaches, there are also scholars who encourage how they are complementary and closely related. As an example, researchers from the ERPI research institute (Nancy, France) unified both concepts by creating their Fab Living Lab [29] in which users can develop, co-design, prototype, evaluate and diffuse their ideas with the assistance of the lab team [30] (Fig. 1). Relatively to those definitions, our hospital FabLab case is closer to the Fab Living Lab approach as it relies on both a technology platform and an innovation methodology.

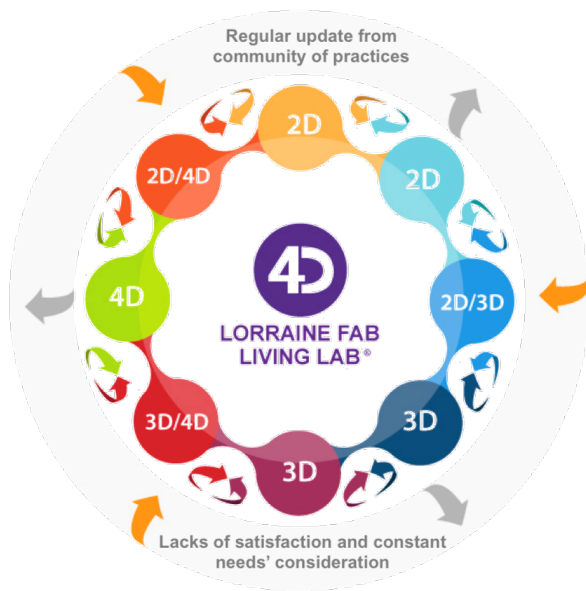


Figure 1. Fab Living Lab approach [31]

In public hospitals, multiple innovation lab-related initiatives have been developed and oriented toward clinician innovation but Svensson and Hartman [19] deplore that, although this setting proves to be very efficient to develop innovations of high value, in terms of usage it mostly benefits directly to the innovation makers and less to the overall hospital functioning, especially regarding the patients experience, and the potential of diffusion which is limited. In a modern healthcare context, patients are playing a role in the co-design of services they need [33] and some lab structures in public health institutions are putting them as central actors of their healthcare journey [32], generating for instance innovations in the technical aid field like at the Rehab Lab (Lorient, France) [34].

This literature confirms that an innovation lab with a making culture is relevant to a public health institution as it has already been developed with successful results in clinician- and patient-centered settings. However, there remains fields of exploration in hospital innovation that are yet to be covered by such collaborative spaces. Thus, in the next session we present the case of the Hephaïstos FabLab as an innovation lab in a public hospital which has been conceived as a complex multi-connected service provider where a user at any stage of the hospital network has a potential to innovate.

III. RESEARCH APPROACH

This study seeks to shed light on how an embedded FabLab service can enhance hospital innovation processes. We aim to reflect on the evolution of the services provided by a FabLab initiative through time while identifying key practices, routines and competences that shape its operation. To this end, a case study is proposed on the Hephaïstos FabLab to examine the operational and methodological considerations that have allowed to consolidate the FabLab service in a hospital context.

In this section we describe the main characteristics of our case followed by the definition of the analysis framework.

A. Case description

The Hephaïstos FabLab is an innovation lab providing digital fabrication tools (3D printers, laser cutting machine, 3D scanner, injection molder...) to the seven hospitals of the APHP Paris-Saclay University Hospital Group. Founded in 2019 after a successful first project with the Humaniteam design team as service provider, Hephaïstos is located at the heart of the Bicêtre Hospital, the largest hospital of the group. The Hospital FabLab is defined as a distinct hospital support unit with a cross-disciplinary connection to healthcare units but also support functions (analysis laboratories, pharmacy, biomedical, transport, general procurement, maintenance etc.) and is dedicated to the creation of solutions to make hospital users' life easier whether they are patients, healthcare workers or any hospital staff. More than a physical space, the FabLab is also a team composed of a Fab-manager (permanent position) and *digital makers* (fixed-term positions such as internships or civic services) which are mobile and available to animate brainstorming sessions, to guide hospital staff on the machines utilization, to update an open source database (called the *Wiki*) documenting all projects and to give a methodology support.

The format of the Hephaïstos FabLab service allows any hospital staff to submit his project or to participate in a brainstorming session as a collective approach to a problem. The composition of the FabLab team offers an abundance of skills, from a machines technical support, to a design methodology assistance but always with an educational approach and a proximity in the hospital space. The Fablab space itself have been thought to be an open hospital unit, located in the main building of the biggest hospital of the group, close to healthcare units and at the same floor than most support functions units, the service is very accessible. As for further hospital units, the FabLab team can come directly on site with the light machinery. The technology chosen at the FabLab is accessible and easily taught to any user. The FabLab team is giving guidance and support on modeling and prototyping for all users, and adapts to all profiles.

The FabLab's approach is inspired by the agile methodology, lean management and design thinking to stimulate usage-driven innovation. Iterations between the FabLab team, the users and the experts allow to explore the problem space with a concrete ground approach, to converge toward a specific problem, to explore several ideas to generate prototypes that can be tested in real-time conditions then perfected with experience. This process is illustrated as a double diamond (Fig.2) and shows that design thinking helps to keep in touch with the problem relevant environment and can use this information for refining and revising the chosen solution path(s) [36].

The double diamond design process comes in parallel to the 2D-3D-4D approach in which users are integrated in the FabLab environment from different interfaces of a project : idea generation (2D), concept creation (3D) and evaluation of usage scenarios (4D) [30].

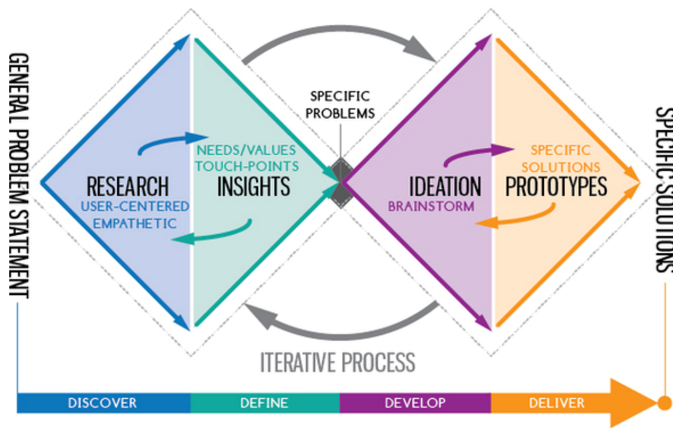


Figure 2. Double diamond design process [35]

After 3 years of service, the Hephaistos FabLab has been involved in more than 160 projects (Fig.3) on seven hospitals with different duration, participant profiles and entry points. A project is considered completed when an object have been designed and prototyped. Some projects may be paused as a consequence of material procurement delivery time or the users' lack of time to invest in the project. Very few projects have been rejected until now, the main reason is that either the solution is already available on the market, or the user is mistaken on the FabLab's purpose, i.e., regarding the FabLab as an external service provider with which an order is placed with no intention of taking part in the design or production process. The Hephaistos FabLab was not created in one step, it was shaped by the users' needs and is still evolving.

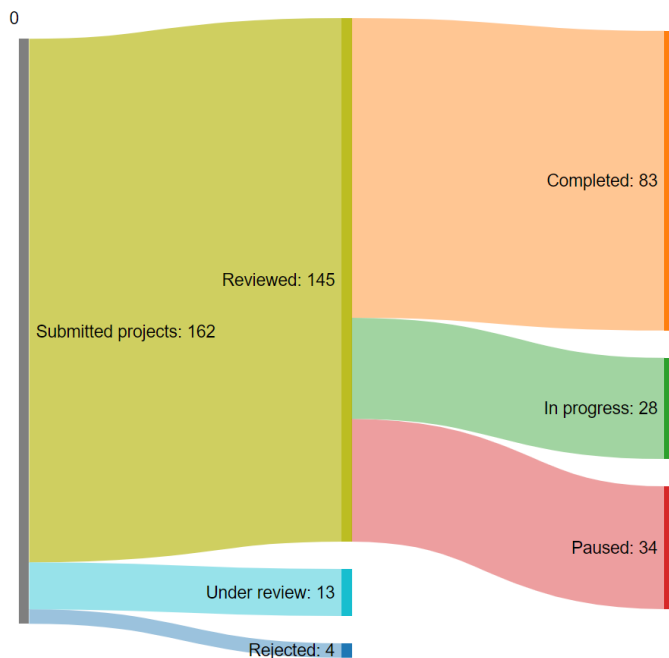


Figure 3. FabLab's projects overview on March 1st, 2022

B. Analysis framework

From the literature we have reckon the importance for innovation lab and FabLab initiatives in hospital settings to consider not only infrastructural or technological aspects but rather to (1) prioritize a user-driven approach, (2) to be aware of the methodological tools and activities that could facilitate the hospital community engagement and (3) to be sensible that hospital innovation outcomes may go beyond medical and clinician solutions to instead tackle organizational issues. Subsequently, to build our framework of analysis, we isolated three dimensions in a FabLab project: the participants' profiles (how a project is started, who leads it), the project methodology (how it is developed) and the outcomes (what resulted from it) to then identify comparison points in a cross-case analysis.

We chose to represent 10 projects out of the dozens that have been completed at the FabLab in a chronological order to illustrate the evolution of the service methodology of our case and understand how it was built over time. Tab. 1 summarizes the main project insights. The first project is special as it started when the FabLab was not existing yet. Hephaistos was funded as one of the outcomes of this project, the initial intent also evolved as we will see later in this article. Projects 2, 3 and 4 are intended to show the plurality of actors and profiles that are enrolling in FabLab projects as it is one of the differentiating features among the literature. Projects 5 to 10 highlight the chronological evolution of the FabLab users and how projects are more and more linked through the participants. This way, we can perceive how this innovation lab has been built.

IV. RESULTS

A. Single project analysis

We detail Project 1 to understand the results of table 1 in a vertical reading as an example.

The first project, entitled "The Hanger tools", took place in late 2018 and funded the Hephaistos FabLab. Starting as a top-down decision, the hospital logistics director wanted to conduct an immersive project directly with the internal patient transport team at Bicêtre Hospital to find a solution to frequent lateness.

A dozen of volunteer stretcher-bearers, including patients transportation regulators, were involved in the project: some have more than twenty years of experience, they have a great knowledge of practices and organization in patients transportation. Some are recent graduate, they have a basic knowledge in modeling and 3D printing recently provided in the secondary school curriculum. Others have an intermediate profile, they are motivated by the use of their cross-disciplinary skills. The experiment is based on the internal transport of hospitalized patients in the Cardiology department whose Health executive and nursing team took part in the project. The Cardiology unit is responsible for preparing the patient for transport. The Health executive is also in charge of ordering equipment and brings its experience to overcome compatibility problems. At

Tab 1. Projects sample at Bicêtre Hospital FabLab

Project Title	1	2	3	4	5	6	7	8	9	10
Participants profiles	The hanger tools Sept 2018 - Jan 2020 20 Stretcher-bearers, health executives, nurses, technicians Patient transport, Cardiology Some had basic knowledge in 3D modeling and 3D printing from high school, but mostly no background	The widow's bearing June 2020 2 Technicians Technical service	The small theater Nov 2020 - Sept 2021 12 Health executive, health care workers, patients Psychiatry	The Biochemistry lab's machine Jan 2021 - May 2021 1 Engineer Biochemistry laboratory	Phantom V.1 April 2021 6 Health executives, nurses Intensive Care Surgery	The petri dishes rack Sept 2021-Nov 2021 1 Laboratory technician Bacteriology	The magic box Nov 2021 1 Laboratory technician Bacteriology	The hemocue's box Dec 2021 4 Health executives, nurses Obstetrics emergency department	The reagent rack Jan 2022 1 Laboratory technician Bacteriology	Phantom V.2 Feb 2022 6 Health executives, nurses Intensive Care Surgery
Personal background	No history	No background	No background	No background	No background	Basic knowledge in 3D modeling	Experience with 3D modeling and machines use	No background	Autonomous	Awareness to co-design and rapid prototyping
History with the FabLab	No history	Participated in project 1	No history, motivated by the FabLab communication	Word-of-mouth between the sterilization team and the biochemistry engineer	No history, motivated by the FabLab communication	No history, motivated by the FabLab communication	2 nd project with the FabLab (previous 6)	3 rd project with the FabLab (previous 6&7)	2 nd project with the FabLab (previous 5)	
Entry point	4D (Immersive experience)	3D (Existing object scan)	4D (Immersive experience)	2D/3D	3D/4D	2D (Sketch ideas)	3D/4D	2D/4D	2D (sketch ideas) + 4D (Immersive experience)	4D
Context	Patient transport's lateness is unpredictable. Stretcher-bearers are being set down by the equipment necessary to patients' transportation. How to allow stretcher-bearers to solve broken equipment and fitting problems without searching around the whole place?	The 'windows' bearing of an entire building are breaking the one after the other. The main theater is shut down in the 80s so there is no possibility to buy the broken spare part. How to expand the 'windows' lifespan?	A lack of social bonding is observed with the pandemic situation. How to set boundaries between TV and reality? How to make a social bonding tool?	One of the machines in the laboratory regularly under maintenance because of a waterproof dysfunction during self-maintenance. How to adapt the machine without touching its structure to avoid infiltration?	With the pandemic, health workers have been using new personal protective equipment (PPE) each time they enter a patient's room. PPE is placed on trolleys in front of each room. The setup takes up too much space and is in the workers' way. How to save up space in the ICU by reducing the PPE holder setup?	2 popup sessions + 1 flash workshop: co-design and prototyping sessions at the FabLab	Creation of four racks for sterilizable material allowing the transport of 4 columns of 12 dishes.	Creation of a strap, wrapped around the doors, on which self-locking rules can be inserted depending on the elements to hang.	Project of an industrial development with the manufacturer's R&D service (supported by the institution's Innovation Department)	Project of an industrial development with the manufacturer's R&D service (supported by the institution's Innovation Department)
Methodology	3 popup sessions: co-design sessions with the FabLab team	Flash workshop: co-design and prototyping workshop at the FabLab	2 popup sessions: co-design sessions with the FabLab team to develop ideas	1 popup session + 1 flash workshop: co-design and prototyping sessions at the FabLab	2 popup sessions: co-design sessions with the FabLab team to develop ideas	3 flash workshops: FabLab team assistance to the lab technician at every step	2 flash workshops: assistance from the FabLab support team for the 3D modeling	2 popup sessions: short co-design sessions with the FabLab team directly in the service to minimize work disruption	Flash workshop: technician's autonomy in the FabLab, a guidance was only needed to use a new machine	Feedback session + 1 popup session
Outcomes	Creation of a 3D printed animal-object with adjustable parameters to situations when transportation equipment are not in good conditions but not enough as to buy new ones.	Several dozen spare parts were made using recycled single use plastics from hospital wastes. The good chance to make the windows last a bit longer.	Launch of a movie event, creation of a customized theater-like in wood, reusable movie tickets, a brainstorming tool for the movie selection and allow patients to express themselves once the TV setting is closed.	The 3D printed gutter-like part was inserted into the machine by the manufacturer's technician.	Creation of a strap, wrapped around the doors, on which self-locking rules can be inserted depending on the elements to hang.	Creation of four racks for sterilizable material allowing the transport of 4 columns of 12 dishes.	A sterilizable plastic movable box with a handle, each of the 4 labs and one for the sterilization roll. Movable dividers accommodate different sizes of bottles and pipettes.	Creation of a prototype case for the work area to allow the change of the medical device and its easy grasp with no risk of falling.	Project of an industrial development with the manufacturer's R&D service (supported by the institution's Innovation Department)	Project of an industrial development with the manufacturer's R&D service (supported by the institution's Innovation Department)
Diffusion format	Creative commons license	Creative commons license	Creative commons license	Creative commons license	Creative commons license	Creative commons license	Creative commons license	Creative commons license	Creative commons license	Potential of an industrial development with the manufacturer's R&D service (supported by the institution's Innovation Department)
Diffusion prospect	3 = interest for any health care facility	1 = specific to a single building's windows	3 = interest for any long-term care facility (geriatrics, psychiatry,...)	3 = industrial scale interest	3 = interest for any health care facility	2 = public hospitals scale interest	2 = public hospitals scale interest	3 = industrial scale interest	2 = public hospitals scale interest	3 = interest for any health care facility

the beginning of the project, most of the participants had no history with any kind of innovation lab nor 3D printing for rapid prototyping.

As for the first project's *methodology*, there was not yet a specific frame. The logistics director, a fervent supporter of agile methods and lean management, made the decision to surround himself with designers of the Humaniteam studio whose goal is to drive innovation in hospital environment through design thinking and user experience. The *entry point* of the project was an immersive experience where the designers team *explored* the daily life of stretcher-bearers and the Cardiology department in order to discover together the causes of patient transport delays.

After 3 days of observation and cross-talks between the different participants, the statement is that lateness in patients transportation is random and unpredictable. Stretcher-bearers are being slowed down by the research time of the equipment necessary to patient transportation. The project team brings together the *definition* of the causes for the extended equipment search: the different brands of equipment are the cause of a fitting problem between transportation equipment (beds, stretchers, wheelchairs) and IV poles, along with a degradation of the fitting parts (blocked receptacles, broken poles). This precise definition of the causes by the users themselves allows the *problem formulation* from which the form of the solution will derive: How to allow stretcher-bearers to solve broken equipment and fitting problems without searching around the whole place ?

The *development* of the solution was based on the most frequent pain points: to replace a broken bag holder on an IV pole, to set a new IV pole receptacle on a wheelchair, to adapt a large hole to a thin IV pole on beds or stretchers, to turn a bed gallows into an IV bag holder, to roll around the equipment's cables during transportation or to set a urinal. The *project format* consisted of 3 co-design sessions. The first began with a period of inspiration through similar projects, projecting the problem in other contexts, defining user paths, sketching solutions and confronting them. Several ideas emerged, the selected one was to design objects that fit on each type of transport equipment to create a new support for IV's pole.

During the second workshop, the stretcher-bearers materialized their ideas in 3D using hardening modeling clay in order to define the shape of these objects. Finally, during the third workshop, the stretcher-bearers discovered how to quickly develop a prototype with 3D modeling and 3D printing *machines* to prepare for user tests. At this point, the idea of a FabLab structure emerged: by centralizing and sharing the modeling files, the objects designed by hospital staff could remain configurable according to the evolution of the hospital's equipment fleet, but also serve as inspiration for future prospects.

"The Hanger tools" project's *outcome* is the delivery of a collection of 3D printed animal-objects with adjustable parameters (Fig.4). They solve in-between situations when transportation equipment is not in good enough conditions to be used but not degraded enough to be purchased new. The

diffusion of this collection by Creative Commons license may be of interest to any healthcare facility.

The first intent of the Hephaïstos FabLab was born, based on a problem-solving approach through experience and users consultation. Many projects came after this one and the Hephaïstos FabLab setup and methodology evolved in parallel to adjust to the hospital's needs.



Figure 4. The "Hanger tools" collection

B. Cross-case analysis

The profile of the participants of the Hephaïstos FabLab projects are very diverse: healthcare workers, healthcare executives, technicians, engineers... of every hospital field and different hierarchical levels. In some other projects that are not depicted in the tab, medical, pharmacy, hygiene, information system and logistics staff are also represented.

Hospital staff with technical functions (engineer, technicians) are more likely to be tech-savvy so they don't hesitate to start a project on their own (projects 4, 6, 7, 9), whether they have a background in design methods and computer assisted machines or not. Healthcare workers tend to participate in groups to encourage collective thinking and cross-disciplinary synergy among the unit's team (projects 5, 8, 10) but also with patients (project 3) and with support functions (project 1).

Apart from project 1 which originally founded the Hephaïstos FabLab, projects are either motivated by the FabLab communication efforts (as in projects 3, 5 and 6 : usually the team introduces the role the FabLab and previous projects during staff meetings and emphasize on the collaborative and user-driven aspect), or word-of-mouth from colleagues of a different unit (projects 4 and 8) which previously participated in a FabLab project, or a spontaneous project idea of staff who previously participated in FabLab projects (projects 2, 7, 9 and 10).

Based on the the multiple starting configurations of the projects illustrated in our framework, having no background on design and computer-assisted machinery or no previous history with the FabLab is not an obstacle to complete a project, whether in group or alone. However, once a project is completed, the empowerment feeling it provides is an additional reason to come back for another project. Some users come back with the intention to deepen an aspect of a previous

project: project 9 extends problems encountered in project 7 to a surrounding element, project 10 is the improved version of project with a few months feedback. Others, who grasp the FabLab concept and manage to visualize a new way to make the most of it, come back with new ideas: project 7 came right after project 6 in time as it raised multiple ideas of the same main pain point (storage efficiency for lab tools), project 2 have been submitted by users involved in project 1 for the same reasons (equipment dysfunction) but on a whole different field (IV poles enhancement VS windows' repair).

For the project methodology, group projects tend to start from a 4D approach with an immersion on site and a brainstorming session animated by the Hephaïstos team to co-design an idea that will be prototyped at the FabLab or in live if machines have been brought to the session. Such interventions in a hospital unit are called a *popup session* to insist on the punctual and efficient rhythm of participation because long project implication can be a deterrent for hospital staff who already have an operational full-time function. For project participants who need to come in the FabLab space to develop ideas, *flash workshop* can be organized and are more tool-oriented.

For projects with one participant, the entry point is generally a 2D approach as the problem definition is more object-centered. The FabLab team ensures a methodological support on such projects to question usage and explore existing solutions. By suggesting a 4D approach, the team makes the most of the user's experience to link design features to operational usage and take into account potential side users.

Once a problem have been explored and precisely defined, an idea is developed, leading to the prototyping of one or several objects. During this development phase, design is adapted to the exact need of users and it can sometimes lead to ideas of elaborated project titles. In project 1 for instance, the need was made explicit : "*I need something to hang the IV bag, the equipment cables, the pee pot...*", so the collection of "Hanger tools" was designed.

In every completed project, development leads to the design and delivery of at least one prototype. In our sample, 2 projects out of 10 lead to more, mainly because of the profusion of ideas during co-design sessions with large users' teams (project 1 and 3). Far from being high-tech objects, the FabLab production can be quite simple: a gutter, a rack, a strap, a box... In project 3, the created objects themselves are not particularly new ideas (movie tickets, brainstorming tools...) but imagining a new event to improve patients' sense of reality and linking the objects to this event is a very innovative approach. As of March 2022, the project have been submitted to the Hospital Innovation Award of the year.

Some projects even have a low-tech approach, such as project 2 in which spare parts were produced from recycled plastic to extend windows' lifespan or project 4 in which an extension was created to avoid a machine's degradation. After such outcomes on several similar projects, a larger project have

been launched in February 2022 with technical and biomedical units to work on several ideas to extend equipment's lifespan.

Saving the projects' design files was first intended to allow reproduction of the prototypes with different parameters to adapt to any isolated case in other units. The Wiki was created as an open-source platform to share those files and document the design process to allow a community to get inspiration and a modeling basis to design similar prototypes, as opposed to an industrial production. This is particularly important because producing these products in an industrial environment, which is ruled by many norms, would have much higher costs and less flexibility to fit a specific need. Hence the creation of Creative Commons Licenses to share the modeling files while protecting it from any commercial use.

For some projects, the diffusion potential is nonetheless interesting to take into account. This indicator is still being elaborated at this time so we classified the 10 projects of our sample into three categories to simplify comparisons: 1) Very local interest, 2) Public hospitals interest and 3) Interest beyond public institution.

We notice than even though most users design solutions for their specific needs, the potential of diffusion is 2 or 3 on our scale because the problem they encounter can be common in public institutions or health structures. Many problems with equipment is linked to regulations of public procurement, in which a new contract is made every 3 to 5 years for an entire hospital or a group of hospitals. In consequence, equipment's features are very heterogeneous and not always adapted to users' needs.

Among the projects' deliveries, several could have an industrial interest and a larger diffusion than what the FabLab is entitled to produce. For such outcomes, the FabLab engaged in 2021 in industrial development projects (projects 4, 5 and 8) supported by the hospital innovation department. Two other projects have a potential for an industrial development prospect. However, the format of these partnerships are still work in progress as public regulations are fuzzy around this new topic.

As for the intangible outcomes, the activity of the Hephaïstos FabLab has brought cross-disciplinary visions to daily problems, thus acknowledging every workers' expertise on usage, reinforcing self-appropriation, bringing cohesion inside a unit and collaboration between different departments. Also, completing a project from a problem observation to a tangible solution's delivery is fulfilling for hospital staff who are used to tortuous validation processes and never-ending projects.

V. DISCUSSION

This article described a sample of projects developed at a hospital FabLab which illustrates the evolution of service methodology of our case and its integration in the hospital ecosystem. This in an ongoing research with the main aim to understand how an embedded FabLab can enhance innovation prospects for a public hospital and which format for this new service is best fitted to reach this purpose.

One of the first elements to highlight is the *return rate*. Once a project is completed, participants are likely to come back for another project, or at least to spread the word to colleagues, thus motivating personal initiatives, group dynamics and propagating innovative behaviours. Over time, the FabLab team needs less and less self promotion interventions in staff meetings because word-of-mouth spreads faster with the number of completed projects. The main limitation of our study lies in the lack of quantitative and standardized qualitative data collected for each project. We could gather those data for the sample of projects in this article and give interpretation with the feedback given through a punctual impact study led by external auditors, but further work must be done with the FabLab team to register data more systematically during operational functioning.

Interestingly, a genuine challenge for the FabLab team is to attract female staff to the innovation lab. Women represent more than 70% of all hospital staff [37], [38], but we observed that technical staff (who happen to be males) seem at first more at ease with the tools and technologies, they initiate more personal projects and tend to be more autonomous. Although more quantitative data must be exploited, out of 10 projects, only half have female participants and none is led by a female user alone so there is yet a potential to be revealed. Our case does not intend to become an extension of technical units as it would be missing innovation opportunities for the hospital as a whole [24]. In the general context, FabLabs and makerspaces tend to attract far more men than women [39] and exhibit a primarily “male” culture, reflected in the interior design of places, or by the language and attitudes of their members [40]. Far from being reluctant to evolve, makers community can benefit from the Hephaïstos FabLab’s experience which developed in a female-dominated environment. Further research can be explored on that topic.

Innovation also lies in the new approach that the Hephaïstos FabLab is promoting, through immersion, user-driven projects, collaboration and openness to hospital users as a whole. This dynamic brings additional trust and mutual assistance between hospital units. This users community is particularly important and must not be neglected of the strategic development of a FabLab initiative. Interaction must be facilitated and focused on sharing practices, designs and users’ experiences. The Hephaïstos FabLab is not necessarily shaping a specific innovation process, but the multiple innovation intents of its users are shaping the FabLab service.

Figure 5 consolidates the methodological approach that has been progressively developed from our case experience and which constitutes a FabLab service methodology adapted to the hospital context. This proposition illustrates how the open communication surrounding the FabLab service, whether from the FabLab team or from users, is a driving force to start new projects.

The plurality of entry points and guidance formats provided by the FabLab team is crucial to make users feel at ease with the design thinking process. The figure shows that whatever the starting point (a problem, an idea or an existing object), the users can be guided toward the double diamond process.

Relatively to the project development phase and the users’ needs, the FabLab team organizes digital tools awareness presentations, brainstorming sessions at different stage of the double diamond process or teaching sessions through pop-up sessions in hospital units or flash workshops directly in the FabLab space. Every prototype design process and modeling files are saved on the Wiki for future prospects. The development of the Wiki platform is still in progress and needs additional study to categorize data relevantly for different authorization levels.

These FabLab interventions help users to go past 2D-3D-4D interfaces and reach a 3D production. The double diamond process is not linear in terms of project development as it is generally punctuated by usage feedback to eventually deliver adapted prototypes. This process itself is integrated in a larger 2D-3D-4D cycle in which the created object is always being questioned for possible enhancements [30], [31].

In terms of outcomes, innovation resulting from the FabLab service takes several forms. First, the large majority of projects result in a tangible object that is prototyped and does not exist on the market to fit exactly to users’ need (as it is a project’s rejection criteria), reinforcing self-appropriation. Then, even if the designed object itself is not new, the usage that is done behind and the customized feature to fit with the user’s environment is innovative. The design and production processes can also be low-tech innovations, putting the FabLab in a frontline position to develop more frugal and sustainable practices in public hospitals which are important energy and materials consumers [14]. This branch of development is quite central to our case strategy and could be the object of future research.

The Hephaïstos FabLab methodology is also part of a management paradigm shift in the hospital ecosystem. Hospitals are very pyramidal structures where top-down decisions are governing daily practices. The hospital FabLab encourages bottom-up initiatives. It also restores bonding between professionals which are gathered in a users community around fabrication protocols elaboration, skills development, cross-disciplinary confrontations and project communication. All of these outcomes are shaping what we could define as a hospital innovation culture. The positive feedback on the open communication surrounding a FabLab service is a key-element to make innovation projects thrive at the hospital [18].

Finally, it is interesting to recognize the innovation potential of a hospital FabLab service in the implementation of commercial partnerships with industries from income sources perspective. Some projects developed at the FabLab have been judged worthy, by the institution’s Innovation Department, to be invested for an industrial production. The Hospital FabLab outcomes could be deepened in terms of knowledge management, stakeholder trust and communication, which turn out to be key factors to improve external collaborations [26]. However, embedded FabLab services in public hospitals is a relatively new strand of research that has yet to be developed, so further study should consider intellectual property and partnership formats between public hospitals and industries

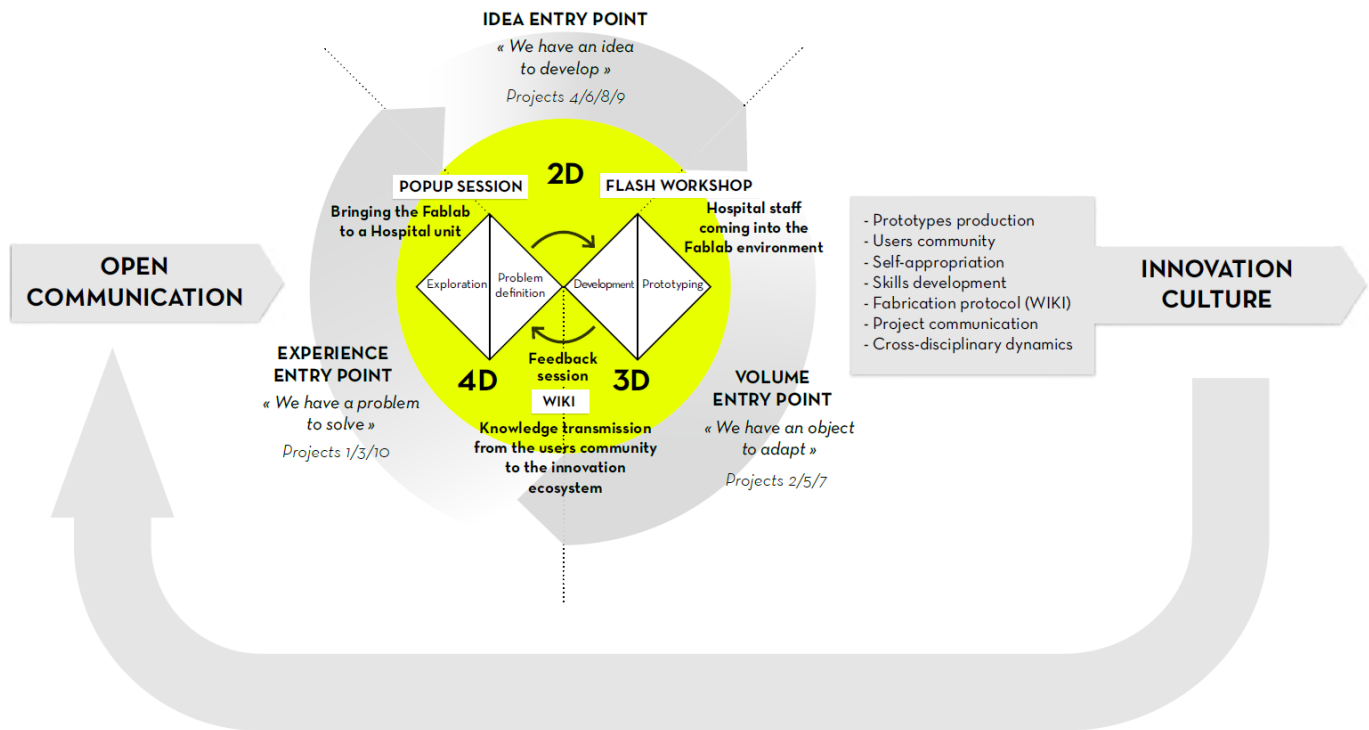


Figure 5. Proposition of a hospital FabLab methodology

which can benefit from the FabLab immersive experience.

VI. CONCLUSIONS

Innovation labs providing computer assisted technology offer an opportunity for public health institutions to stimulate innovative behaviour, especially for hospitals where non medical innovation still has space to be explored and has potential to improve the hospital system performance as a whole. Therefore, the objective of this article is to describe the development of a FabLab service in a public hospital using a framework conceived from empirical observations on several projects brought by hospital staff and completed at the Hephaïstos FabLab. The aim was to explore through a single case study how the evolution of a FabLab setting shapes a hospital innovation process.

One main conclusion of the case study is that fabrication tools and collaborative maker environments in a hospital should be brought to the staff with an open communication and a user-centered and usage-driven methodological guidance. User-centered because the pedagogical approach is adapted to any user's profile and allows many entry points to start a project. Usage-driven because the design methodology relies on the users' experience, immersive exploration and recurring feedback through practical sessions.

Beyond the production of tangible prototypes, a FabLab service strengthens an innovation culture in the hospital by encouraging cross-disciplinary dynamics, empowering staff to create solutions adapted to their needs and uniting users into a community to share practices. Thus, a hospital FabLab service

fosters a culture in which innovative spirit spreads and ensures a virtuous feedback on future innovation prospects.

As the implementation of a hospital FabLab is emerging, qualitative and quantitative data on projects must be strengthened to evaluate the FabLab's impact. This article opens up many perspectives for further researches: future prospects of building public-industry partnerships through the hospital FabLab as an experimental space leading to commercial innovations can be developed, qualitative data of the FabLab's managerial impact can be studied or even gender-related issues can be deepened on the topic of developing a FabLab in a female-dominated environment.

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