Chapter 15
How Fablabs Manage the Knowledge They Create

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ABSTRACT

A collaborative space for stimulating creativity is a place of learning through the exchange and sharing of knowledge and experience among its members. It allows the leveraging of innovation through the use of technological resources available in the space, stimulating the creativity of its participants, enabling the development of products and solutions based on personal projects—do it yourself (DIY)—from ideation, or the construction supported on knowledge developed by other elements together, collaboratively, enhancing the final result—do it with others (DIWO). A research project is being held to create a new lab, or transform and adapt one of the existing lab's, in a Fab Lab or a Maker Space to let students, teachers, and staff give wings to their imagination and develop innovative solutions to solve real problems while they interact and exchange tacit knowledge, making it explicit after concluding their projects when they share their research reports.

INTRODUCTION

Information and knowledge, along with natural and economic resources, proved to be an unprecedented social and strategic expedient (Beuren, 1998; Choo, 1996; 2003; McGee & Prusak, 1995).

The importance of knowledge for organizations is now universally accepted, being, if not the most important, at least one of the resources whose management influences the success of organizations (Davenport, & Prusak, 1998).

Information management relates to the organizational ability to make the right information available for use in decision making (Davenport, 1997), transforming the informational chaos into useful and practical knowledge, leading to benefits for the organizations (Maravilhas, 2014b).

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Maker Spaces, Hacker Spaces, Tech Shops and Fab Labs are collaborative spaces for stimulating innovation, through the exchange and sharing of information, knowledge, and experience among its members (Blikstein, 2014; Troxler, 2014).

They leverage innovation through the use of technological resources available in the space, stimulating the creativity of its participants and enabling the development of products and solutions based on personal projects from ideation, or the construction supported on knowledge developed by other Makers, collaboratively, enhancing the final result (Gershenfeld, 2005; 2012).

With the motto "Learn, Make, Share" (http://www.forbes.com/2008/08/13/diy-innovation-gershenfeld-tech-egang08-cx_ag_0813gershenfeld.html), these spaces aim to empower its members for the realization of sustainable solutions, local and community-based, using open source tools and equipment's whenever possible (open software, open hardware, open design, open learning), promoting Open Innovation (Chesbrough, 2003) to allow all the possibility of creating low cost products, with the ability to very quickly show the viability of these ideas through the acceptance by the community, leveraging improvements that will make these solutions evolve collaboratively (Anderson, 2010; 2012; Gershenfeld, 2005; 2012).

In these collaborative spaces the participation of all community members is nurtured, promoting equality of race and gender, benefiting from cross-knowledge, shared by every culture and subculture, which will enrich the final result.

Teachers, researchers and students, young and more experienced, men and women of all races and religions, small business owners, inventors and entrepreneurs, members of the local community, all in a horizontal relationship, without titles or awards, just competence and mutual respect, working and learning from each other in a common space.

The purpose is to enhance the entry of women in more technical fields and Engineering, but also to attract students and professionals of Arts and Humanities, Design and Architecture, allowing them to materialize their ideas based on available and affordable technology, supporting creative inventions and aesthetic processes that will enrich the research and development results (R&D) (Blikstein, 2014; Troxler, 2014). Youngsters and adults that abandoned formal education can find here the resources to start their own job and company.

It will be analyzed and described how Fab Labs, which are laboratories of digital fabrication, with broad educational, social and economic advantages, manage their knowledge in a formal and informal way, allowing every member to learn by watching and participate in bigger communal projects. ARHTE project from UNIFACS Laureate University in Salvador, Bahia, Brazil will be also described to show how a future Fab Lab is being constructed and be born in a near future.

The methodology used for the successful development of the project consisted, to begin with, on bibliographic analysis from monographs, journal articles, websites, theses and reports, allowing understanding of the topic, its stakeholders and participating entities. Some conversations with key players in the Fab Lab world have helped to structure the project and the knowledge shared helped avoiding some major obstacles and implementation problems that have been dealt with by other Labs in Brazil, Portugal, Italy, Spain, France, and the United States of America (USA).

The analysis of other existing Fab Labs makes possible to propose the introduction of best practices in the collaborative space, through benchmarking, avoiding mistakes and leaping steps for best performance.

BACKGROUND AND LITERATURE REVIEW

Like the inventors and entrepreneurs of the nineteenth and early twentieth century, who worked in their spare time in a shed, basement or, more recently, garage, creating prototypes of what later would become a successful product in a given market (Rifkin, 2011), Maker Spaces provide access to technologically advanced tools and machines, inserted in a network of participants, called Makers or Tinkerers, that can help answering questions and overcoming obstacles, faster than occurred with the lone inventor (Anderson, 2010; 2012).

A collaborative space for stimulating innovation is a place of learning through the exchange and sharing of knowledge and experience (Hargadon, & Sutton, 2002; Piscione, 2014) among its members, the Makers.

At the same time, allows to leverage innovation through the use of technological resources available in the space, stimulating the creativity of its participants and enabling the development of products and solutions based on personal projects from ideation, or the construction supported on knowledge developed by other users, together, collaboratively, enhancing the final result.

These spaces have several designations and typologies, like Makerspaces, Hackerspaces, Techshops and Fab Labs. In this project we focus in a model, widely tested and in use in several places of the world, the Fab Lab, or fabulous laboratory (Gershenfeld, 2005; 2012), which is a laboratory of digital fabrication, serving as a prototyping platform of physical objects (Eychenne & Neves, 2013), with broad educational (Mandavilli, 2006; Blikstein, 2014) social and economic advantages (Anderson, 2010; 2012; Troxler, 2014).

These Labs are used by everybody to enrich their projects, in a creative manner, inducing the creation of prototypes to leverage innovation, giving wings to their imagination and develop sustainable, social, local, economic innovative solutions to solve real problems.

Created in 2001 in the Massachussets Institute of Technology (MIT) Center for Bits and Atoms (CBA), directed by Neil Gershenfeld, linked to the famous MIT Media Lab, created by Nicholas Negroponte in 1985, the first Fab Lab was funded by the National Science Foundation (NSF) from the USA, and started based on the success of the course taught by Gershenfeld himself titled “How to Make (Almost) Anything” (Gershenfeld, 2012).

Eychenne and Neves mention that these Fab Labs are the *educational component of awareness to digital and personal fabrication, democratizing the conception of techniques and technologies and not just the consumption* (2013, p.10).

To quickly realize the viability of the solution, the machines and tools available in the space will allow developing a prototype that, if it’s not feasible, will lead to the search for new solutions (http://www.makerinnovation.cc; http://wefab.cc/), learning with the community how to develop solutions that will be accepted and wanted in the market.

Fail early, fail cheap, fail always, continuing to learn and evolve so that entrepreneurship is encouraged and emulated by others (http://www.instructables.com/id/FabYearBook-2010/).

Students are encouraged to be producers of knowledge and not mere passive recipients (http://studentasproducer.lincoln.ac.uk/).

Fab Labs build bridges between the engineers and fabrication of high-tech products, and other actors usually more averse to technical and manual manufacturing.

The purpose is to enhance the entry of women in more technical fields and Engineering, but also to attract students and professionals of Arts and Humanities, Design and Architecture, allowing them to materialize their ideas based on available and affordable technology, supporting creative inventions and aesthetic processes that will enrich the research and development (R&D) results.

When someone has a difficulty operating the equipment's or machines, they can learn by observing other experienced users working, or they can ask for help, guidance or training with them or a Lab technician, enhancing the capabilities of every member of the space. Tacit knowledge is shared among the members of the Lab, working together, watching and learning, with the ones who own it.

The typology of academic Fab Lab, created in universities or research centers, aims to develop a culture of learning by doing, giving students, teachers, independent inventors and entrepreneurs the opportunity to learn by doing, creating a multidisciplinary space open to the outside to receive different insights and inputs (http://fab.cba.mit.edu/about/faq/).

In such cases, funding depends on the university or research center where they are installed, as well as the purchase of equipment and materials necessary for their operation, having its educational aspect assured by teachers and Postdoctoral Fellows (Eychenne & Neves, 2013) that support the management and maintenance of the space and its dynamics (http://www.fabfoundation.org).

Working in a network, like the Internet supporting them, there are currently 1215 Fab Labs worldwide (https://www.fablabs.io/labs), facilitating the sharing of information and knowledge, connecting people and organizations and, thus, enabling the collaborative innovation (Hatch, 2013; Troxler, 2014).

These spaces aim to develop access to knowledge of science and engineering, democratizing the practice of using the technic on the proposed projects (Blikstein, 2014), providing training courses to the community on the use of the equipment available in the space (http://makercity.wpengine.com/docs/makercity-preview-chapter.pdf), allowing the use of machines to carry out participants own projects or to participate in collaborative projects of the Fab Lab network (Walter-Herrmann & Büching, (Eds.), 2014).

Other users of the space, like students or experts in some technical areas, share their know-how through courses or just by participating in collaborative projects.

CONDITIONS TO START A FAB LAB

For the opening of such a space, the initial investment is around USD$100.000, according to the inventory required and proposed by the CBA, plus the monthly cost of salaries and maintenance of the machinery and location.

Usually, the university or research center provides the space and buys the machines, accessories and consumables, trains the responsible team and pays their salaries, and can provide scholars who collaborate in the organization of the space and scheduling times, while taking their projects and internships.

All Fab Labs must function according to the Fab Charter that sets the rules for the maintenance of the spaces, with its guidelines and policy (http://fab.cba.mit.edu/about/charter/).

On the website of Fab Foundation (http://www.fabfoundation.org/fab-labs/setting-up-a-fab-lab/ideal-lab-layout/) instructions can be found of how a Fab Lab could be implemented in relation to its size, organization and necessary equipment.

Eychenne and Neves (2013), after visiting several spaces in different countries, found some common points, such as: an area between 100 and 250m^2; at least one separated and closed room for the use of the large computer numeric control (CNC) milling machine; a large open central area with side stands containing on one side the less noisy machines and in the other the potentially dangerous machines or the ones who generate dust; computer equipment for work and conference or meeting tables; space for quick meals equipped with coffee machine and refrigerator; exhibition space for the completed projects and a place to store materials and tools.

Regarding the machinery and equipment to start the space, five CNC machines make up its base: a vinyl cutter, a laser cutter, a 3D printer, a precision milling machine, and a large format milling machine.

Being its concept based on the philosophies of open software and open hardware (Troxler, 2014), this reduces its cost, as there are several machines that can be built by themselves, allowing to replicate the equipment at a very low cost (Gershenfeld, 2005; 2012; Troxler, 2014).

The open software and other open source projects like Arduíno – a printed circuit having a microcontroller that allows you to control chips and sensors – also enable the realization of several low-cost projects (Walter-Herrmann & Büching (Eds.), 2014).

Fab Foundation (http://www.fabfoundation.org) also lists the necessary staff for the proper functioning of the space, and the pattern is constituted of: A Director, a Fab Manager, a Guru and three Interns (Eychenne & Neves, 2013).

Economic and Financial Return

The big challenge is to find industrial partners who want to use the space, financially maximizing the continued acquisition of materials and the maintenance of the equipment.

Ford Motors developed a partnership with a Techshop, another type of Maker Space more commercially focused, and the results are astonishing with an increase of about 50% of patent applications from the Ford employees in one year (https://media.ford.com/content/fordmedia/fna/us/en/news/2013/06/01/techshop-and-ford-celebrate-one-year-of-innovation-in-metro-detr.pdf).

This solution allows a very quick and effective market research with the possibility of increasing the ultimate solution based on acceptance and critics received.

Technology transfer between Fab Lab and industry can also be enhanced globally as a product developed in one Lab can solve a problem or need in another place in the world where the network is present.

It's important to remember that in a collaborative space with a conducive environment for innovation, the most important are not the machines and equipment, but people and their ideas (Dodgson & Gann, 2014), that should be encouraged and cherished for the production of new solutions that can be used to solve local community problems and empower its creator and the ones benefiting with the solution. Technology is only an enabler for this purpose.

If successful, the practices introduced can be replicated, creating a new model of innovation support, which will have a significant impact on the social and economic development of countries.

KNOWLEDGE: CREATION AND SHARING

Knowledge derives from data and information. Organized and contextualized data becomes information through contextualization, categorization, calculus, correction and condensation (Davenport, & Prusak, 1998). Information interiorized and applied to a practical task or function, once dominated by the user, becomes knowledge through comparison, consequences, connections and conversation (Davenport, & Prusak, 1998). Knowledge generation occurs when information is compared, combined, analyzed, and rearranged by people.

Knowledge is inside people's head, not in computers and databases. In a book or scientific paper there's the knowledge of the author, what he/she knew and could made explicit to others, which is only a small part of what he/she really knows. For the reader there is only data and information there, until it's possible to act upon that information and integrate it in a process where we can apply what was read and do it ourselves with proficiency (Davenport, 2007; Davenport, & Prusak, 1998). Knowledge is related with action. Someone can read all the books and articles about riding a bicycle. It will be helpful undoubtedly. But, only when someone act with the information received and pedal while maintaining equilibrium, is common sense to accept that the knowledge to ride the bicycle exists, and, curiously, will never be forgotten. That's why learning mathematics implies solving problems and perform hundreds of exercises. No one learns mathematics just by reading books or reports, or watch the teacher solving problems in the blackboard. Although useful, it's not enough. Medical Doctors perform dissections to learn about the human body. They don't just read books. That part is also needed, but we must do it ourselves to learn and internalize the sequences and mechanisms to adopt.

That type of knowledge is called tacit. Socrates, the Greek Philosopher, used to say that a person only knows something when it's possible to teach it to another person, with the same results.

Tacit knowledge can only be learned through practice and experience and is what we call know-how, that knowledge that is acquired through life, but very difficult to explain to others. Constituted by subjective insights, intuitions and hunches of individuals, is not easily communicated or shared. To gain access to such knowledge one may have to be practicing in other related areas of knowledge. What is held in someone's head and includes facts, stories, biases, and insights.

According to Davenport and Prusak we shouldn't learn anything without relating that apprenticeship with practice. They believe that a healthy tension between knowledge and action is the key to the organizational success and, probably, the individual success also (1998).

Trying to make that knowledge available to others, since it is ingrained in people's heads and attitudes, it's imperative to turn it explicit. Explicit knowledge is obtained from facts, from information, almost always through formal education. It is expressed through metaphors, analogies, concepts, hypothesis or models. It's the key for the creation of new knowledge. It is codified, communicable through formal and systematic language. It can be stored in manuals, documentation, patents, blueprints, reports and other accessible sources.

Tacit knowledge is subjective. It is knowledge obtained from experience, with the body, simultaneous, here and now, and analogous, related with practice.

Explicit knowledge is objective. It's a rational knowledge, with the mind, sequential, there and then, digital, related with theories (Nonaka, & Takeushi, 1997).

The process of generating and converting knowledge has four phases. Explicit and tacit knowledge complement each other and, through their interaction, create new knowledge. According to Nonaka and Takeushi (1997), the four phases are:

1. **Socialization:** From tacit to tacit knowledge. Creates shared knowledge. It's a process of sharing experiences, like mental models or technical competencies. This is what happens when someone in an apprenticeship learns with its master. Can be obtained directly from others, without using language, through observation, imitation, and practice.
    a. In Fab Labs, people learn by watching, imitating and practicing with their peers. Different backgrounds and experiences allow internalizing different procedures and activities.

2. **Externalization:** From tacit to explicit knowledge. Creates conceptual knowledge. Tacit knowledge becomes explicit through dialog and collective reflection using metaphors, analogies, concepts, hypothesis and/or models. Books, reports and journal articles are examples of explicit knowledge through externalization. It combines deduction and induction.
   a. In Fab Labs, Makers document their projects, especially on open days when the use of the space is free, and share it so others can learn and improve upon that knowledge, avoiding mistakes and adopting the best practices that conducted to those results so their projects can be successful too.
3. **Combination:** From explicit to explicit knowledge. Creates systemic knowledge. Combining different sets of explicit knowledge allows the creation of some new knowledge. Through education and formal training in schools and universities, different explicit knowledge from the combination of books, texts, activities and the different disciplines combined, generates some new knowledge that can be further developed with time. Computer databases can help categorize some explicit knowledge conducting to new knowledge.
   a. In Fab Labs, the users can search and retrieve documents from different projects from all the Fab Lab world network, in databases involving different disciplines like mechanics, robotics, electrical and computing engineering, design and other aspects that can help solving their own problems and give insights for the construction of new solutions or surpassing technical blocks.
4. **Internalization:** From explicit to tacit knowledge. Creates operational knowledge. The process of incorporating explicit in tacit knowledge, it is related with learn by doing. When internalized in the knowledge base of every individual as mental models or technical know-how, those experiences through socialization, externalization and combination become valuable assets.
   a. In Fab Labs, Makers learn from the analysis of technical documentation and the projects of their peers worldwide, internalizing the new knowledge and consolidating it in its practical use in their projects, learning by doing. That way new knowledge and procedures are integrated to the way of doing things by Makers that can advance to new levels of know-how.

Nevertheless, to make viable the creation of organizational knowledge, the tacit knowledge accumulated needs to be socialized with other members of the organization, starting, that way, a new spiral of knowledge creation that will pass the four phases again, generating new knowledge in an increasing successful non-stopping activity (Nonaka, & Takeushi, 1997).

A new vision must be considered in relation to knowledge and the role it plays in organizations. The efficient exploitation of knowledge as an economic resource and one of the production sectors has become a factor of strategic, economic, social and political importance (Choo, 1996; 2003).

If, on the one hand, an organization cannot function without information and knowledge, on the other it is important to know how to use this resource to improve its use.

Thus, the faster the identification of the relevant knowledge to the organizations and the quicker the access to it, more easily their goals will be achieved (Terra, 2001).

Intellectual Capital can be seen as a competence, skill and/or entrepreneurial intelligence and is recognized as an intangible asset of superior value for organizations (Edvinsson, & Malone, 1998; Stewart, 1998; 2002; Sveiby, 1998).

But, most important is that information and knowledge play a key role in business since they affect the competition at three levels:

1. Modifies the industrial structure and, therefore, changes the rules of the competition (Stewart, 1998; 2002);
2. Creates competitive advantage for organizations offering new ways to overcome their rivals (Sveiby, 1998; Terra, 2001);
3. Create new business opportunities, most often from the organization's internal processes (Almeida, Freitas, & Souza, 2011; Neto, 2013; Rodriguez, 2013).

Fab Labs should follow some recommendations in order to successfully achieve their goals, such as: Value and manage knowledge as a resource so or more important than any other that it needs to function (Maravilhas, 2015b); Pay attention not only to the internal knowledge generated within the Lab, necessary to carry out the organizational tasks it undertakes, but also external knowledge, from various Fab Labs worldwide, in order to maintain their activity cost-effective.

Effective Fab Lab managers should not ask about the cost of obtaining the knowledge needed to increase the successful projects of the Lab. They should ask instead how much will be lost if they don't have it (Maravilhas, 2013a).

Knowledge Management, Creation and Transfer in Fab Labs

In this definition, all the practices that organizations use to represent, create, identify, and distribute knowledge, usually with the support of the computer and Internet, come together. In many organizations a Chief Knowledge Officer (CKO) exists, and mediate all the programs between the workforce and the Board of the organization.

Almost all the for-profit companies depend on technology and software for their knowledge management projects like: knowledge repositories, knowledge bases, expert systems, corporate intranets and extranets, collaborative websites, like wikis, and document/content management software, that allow and promote the knowledge sharing and transfer process between its members.

Knowledge management focuses mainly in the mechanisms used to share and transfer the knowledge assets.

Currently, innovative products are developed based on rapid prototyping in universities R&D departments and research institutes, and in some larger companies.

Only a small group of experts has the possibility of making prototypes in a short period of time and using simple means and resources (Anderson, 2010; 2012). In a Fab Lab this process is democratized and any new technologies are taught so that everyone can enjoy the space and equipment's. Knowledge shared is new knowledge created.

My view is that people are creative animals and will figure out clever new ways to use tools that the inventor never imagined (Steve Jobs in Isaacson, 2011, p. 241).

In relation to its effectiveness, since 2001 at MIT and since 2005, when the first Fab Lab was created outside of MIT, the model has proved to be a facilitator for the creation of regional innovation, building bridges and relationships between experts in technology, design, education, small business owners and entrepreneurs, architects, artists, non-profit organizations, etc.

The idea of a Fab Lab rests on social interaction, in projects involving both academics and craftsmen, the handyman and garage skilled inventors, bringing to the manual and practical learning the ones that in recent years have distanced themselves from the technology and have chosen a more intellectual and less physical training, less hands-on.

The interaction between people with such diverse skills and features, along with the acquired training on the use of the available equipment's, will create a creative and stimulating environment thanks to the power of intellectual and cultural diversity (http://www.thefreelibrary.com/Fabricating+dreams+in+3D%3A+FabLab+Luzern.-a0336489127).

These spaces aim to develop access to knowledge of science and engineering, democratizing the practice of using the technic on the proposed projects (Blikstein, 2014), providing training courses to the community on the use of the equipment's available in the space, allowing the use of machines to carry out participants own projects or to participate in collaborative projects of the Fab Lab network (Walter-Herrmann & Büching, (Eds.), 2014). All the projects are registered and shared so other Makers can replicate them freely, all around the world, making this new explicit knowledge free to the Fab Lab community.

As for the potential of transfer of the generated knowledge, the Fab Lab benefits from an extensive worldwide network which promotes the adoption of knowledge created in several laboratories spread across several continents, allowing to test the acceptance of a huge number of potential users and adapt, improve or complement the initial versions with the return, the feedback, obtained in this way.

There is a special ability in playing with creative ideas developed for a segment or project to explore their innovative application in others. Playing in this environment enables both cross inspiration as the connection, and happy and unexpected combination of unrelated ideas (Dodgson & Gann, 2014).

Regarding the interdisciplinary collaboration, this is enhanced, as mentioned above, by the number of technical, academic and skillful handy men that will cross the space and contribute with tips, advices, warnings and suggestions.

Several areas of knowledge are present in these spaces, such as: electronics, mechanics, computer science, design, chemistry, administration, fine arts, and humanities.

This mix turns the space into a melting pot of cultures and sciences that will enable all to teach and to learn, enriching each of the worldviews involved and profiting all with the multiplicity of the knowledge obtained (http://www.instructables.com/id/FabYearBook-2010/).

Several examples demonstrate the importance of these places for science and technology education, like learning concepts of Engineering and Mathematics (Blikstein, 2014), stimulating creativity and the development of inventions that allow to solve local problems of the communities where these Labs are located, promoting innovation and social economy, empowering people who are part of these networks allowing them an autonomy never imagined before (Mandavilli, 2006; Troxler, 2014).

Because all materials from the projects are made available to the entire network, the potential of dissemination of information allows building on prior knowledge, leveraging innovation and maximizing the previous research (Nonaka, & Takeushi, 1997). That way, the open innovation and the ascent innovation are privileged (Eychenne & Neves, 2013), transforming the Do It Yourself (DIY) model in Do It With Others (DIWO), or Do It Together (DIT) (http://makercity.wpengine.com/docs/makercity-preview-chapter.pd), maximizing the educational and research function, with social and local impacts.

Working and learning collaboratively enhances the final result of the projects, because it's possible to do a sort of market research immediately, getting feedback on how to improve your idea and prototype, failing fast and cheap, allowing to make a better model with the suggestions of the community, using crowdsourcing and the wisdom of the crowds (https://www.diplomacy.edu/resources/books/reviews/wisdom-crowds-why-many-are-smarter-few)

With a markedly educational and research side, interdisciplinary, multidisciplinary and intradisciplinary (Blikstein, 2014; Troxler, 2014), it will allow to develop innovative projects of high scientific quality and high social relevance, following the model "faster, higher, better, more precise", determined by the Fab Lab network. This will be achieved by following the criteria of effectiveness, transfer of knowledge potential, originality and interdisciplinary collaboration (http://fablab-luzern.ch/).

The advantage of being based on an international model that has been tested, offers a place with an innovative atmosphere that will make possible the exchange of knowledge based in fortuitous but fruitful encounters among its members (http://www.thefreelibrary.com/Fabricating+dreams+in+3D%3A+Fab Lab+Luzern.-a0336489127), similar to what happens in the more innovative companies like Google, IDEO, Idealab, Pixar, Apple, among others (Dodgson & Gann, 2014; Isaacson, 2011; 2014; Kahney, 2009; 2013; Majaro, 1990).

Creativity comes from spontaneous meetings, from random discussions. You run into someone, you ask what they're doing, you say 'Wow' and soon you're cooking up all sorts of ideas. So he [Steve Jobs] had the Pixar building designed to promote encounters and unplanned collaborations (Isaacson, 2011).

A Fab Lab attracts more actors from companies than the university itself can do. With its innovative DIY concept, opens innumerous possibilities for universities and ensures a productivity index that will be relevant to the increased volume of innovations, and the consequent creation of wealth resulting from it (http://www.instructables.com/id/FabYearBook-2010/).

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The interaction between people with such diverse skills and features, along with the acquired training on the use of the available equipment's, will allow a creative and stimulating environment thanks to the power of intellectual and cultural diversity (http://www.thefreelibrary.com/Fabricating+dreams+in+3D%3A+FabLab+Luzern.-a0336489127), and the knowledge exchanged this way.

In almost all the Labs, users check other Makers files for inspiration, but usually just in the files from their own Lab. Only in bigger projects, conducted by more experienced users, and involving several Labs, the files from other Labs are retrieved for the purpose of getting insights for the new project at hand or for problem solving. In others, there is no habit of doing so, letting creativity flow only from the participants of the projects, without inspiration from their peers' previous projects.

Usually, users record their projects in their own language for easiness of the task (in English, in Dutch, in Spanish, in French, in Afrikaans, in Tsonga, in Xhosa, in Portuguese, in Italian, in several Chinese dialects, etc.). This makes very difficult the retrieval of information and the appropriation of knowledge, because the linguistic differences will make very hard to analyze and interpret the information gathered by other interested Makers from other countries. Photos, designs, videos, and schemes, are very helpful and should be always included.

In almost all the Labs examples of Makers that had benefited from the information sharing in the Lab exist, but especially in oral form. The written documentation is not as valued as the oral transmission and the observation experience.

The privileged form of information and knowledge exchange goes to videoconference solutions available in all the Labs. Seems to be easier for Makers to watch and debate with their peers, than to read what has been done previously. It's a form of transforming the tacit in explicit knowledge.

All this information should be in English for the use of other Makers in other countries or, at least, have an English Abstract for international user's aid. The Abstract can be done with the Fab Director or Fab Guru help, or using a web translator. A Lab colleague can help performing this task.

This information can be made available in a Cloud Server maintained by the Fab Foundation, allowing the access to everyone involved to improve results and knowledge sharing.

Extensible Markup Language (XML) and databases can be used to assist in the information visualization and finding from all the Labs, along with other technology solutions that allow to search by keyword, subject, title, name or codename of the Makers, subject area, country, city, etc., mixing them all to filter the results. That way, the knowledge sharing will be improved.

Although a lot of computer specialists frequent the Labs, their core business is not managing knowledge. They are more concerned in developing new products or solutions, than in maintaining and sharing the knowledge created in the space.

Examples of Solutions Created in Fab Labs Using Collaborative Knowledge

There are several examples of original products created in Fab Labs that originated innovations shareable amongst all the Labs. *Once prototyped the object and tested the processes, the project can easily be replicated by other Fab Labs in the network* (Eychenne, & Neves, 2013).

Some examples of innovations produced in these spaces include (Gershenfeld, 2012; Mandavilli, 2006):

1. Monitoring sheep herds using Global Positioning System (GPS) and radio frequency developed in Norway, and now used by anyone who needs a similar solution in any location of the world;
2. From the Boston Fab Lab, a project was started to make antennas, radios, and terminals for wireless networks, to provide Internet access. The design was refined at a Fab Lab in Norway, tested at another one in South Africa, deployed from one in Afghanistan, and now is running on a self-sustaining commercial basis in Kenya;
3. Circuit boards and computer chips produced by an eight-year-old girl in Ghana using an MIT design and methodology;
4. Also in Ghana, villagers built large 'collectors' to harness solar energy and built machines to grind seeds into fufu powder for their nourishment;
5. Puzzles 2D, convertible to 3D, were also produced by an eight-year-old girl in the USA (Neil Gerschenfeld's own daughter);
6. In Pabal, India, also based in a MIT model, farmers built sensors to measure the fat content in milk, allowing them to charge for a fair price to industrial buyers;
7. In South Africa, women that never had used a computer, now use it daily to design and send projects to the vinyl cutter, to create decorative products and accessories. Some are girls who left school due to a teenager pregnancy and here can find a profitable and dignifying activity;
8. Also in South Africa other Makers produced a light switch controlled by cellphone, a motion-sensor light and an alarm system, very useful for their unsafe neighborhoods;
9. In the USA, a student produced a sensor that protects women from attackers that can come from behind them, opening a sharp edge spear.

Another way of exchanging knowledge developed from Maker Spaces is the Maker Faire. *The Greatest Show (& Tell) on Earth.* Maker Faire *is part science fair, part county fair, and part something entirely new!* (http://makerfaire.com/). Disseminated all around the world, the Maker Faire allows the exchange of knowledge through the exhibition of bigger projects developed by several Labs in the community.

All the examples show, and several others exist, that the common element in this new creative class is the fact that the creators have been consumers that wanted something previously inexistent. So, instead of being satisfied with the options available, they did something better for themselves (Anderson, 2012).

THE ARHTE PROJECT IN UNIFACS

The Academic Interdisciplinary Program Archimedes, Robert Hooke and Thomas Edison (ARHTE) is a set of educational activities developed within the academic coordination's, involving teachers and students of all courses from the School of Engineering and Information Technology (IT) at UNIFACS – Laureate University, Salvador, Bahia, Brazil, for the development of interdisciplinary activities, involving Computer Science courses, Environmental and Sanitary Engineering, Civil Engineering, Computer Engineering, Production Engineering, Electrical Engineering, Materials and Manufacturing Engineering, Mechanical Engineering, Mechatronics Engineering, Petroleum Engineering, Chemical Engineering, Information Systems, Computer Networks, Internet Systems and Oil and Gas for the development of interdisciplinary activities in an attempt to overcome the fragmentation of knowledge of some specialized areas and the lack of its relation with the problems of modern life (http://www.arhte.unifacs.br/).

The main objective of this program is to create a relationship between technical knowledge and the reality of the student, encouraging the practical application of theoretical concepts covered in class and lectures, making it the most playful and challenging course for the student, as well as prepare much better professionals for the job market (http://www.arhte.unifacs.br/doc/Manual_do_ARHTE_2015.2.pdf).

ARHTE is a mandatory curricular activity to all graduate students enrolled in the school of Engineering courses and IT, from the first to the third semester, and optional for the fourth semester students.

The program started nine years ago and involves about 4.000 students each year. There are 38 teachers involved as Coordinators of the participating teams. The University has about 30.000 students and about 10.000 of them have been enrolled in the program.

The methodology of the ARHTE program operates with the following procedures:

1. In the first semester of the course, all students from Engineering, Information Systems, Computer Science, Networks, and Internet Systems have to participate and be approved in an Entrepreneurship course, which is mandatory to all these students. They also have to attend one of the two days of the project presentation works from other students from the second semester.
2. In the second semester the students will form teams and they need to choose a Coordinator and make their inscription on the program website (http://www.arhte.unifacs.br/index.php). They propose a project and teams must think and have a big idea, plan it accordingly and then present it to an examination board to check if there is a chance of creating a business with their idea (this will be watched by the first semester students to gain knowledge and insights). The goal is to evaluate if there is a market for the idea proposed and start a business to explore it.
3. In the third semester teams must develop the idea proposed previously in the second semester or start a new one if the previous didn't get support to be followed. The goal here is to build a pro-

totype, always with the support of the Coordinator, write a paper and present the results, in slides and video format, to a new examination board.

4. The previous three semesters are mandatory to all the students involved but this fourth semester is optional. The team with four to six students that had good reviews in the previous steps and have a good idea and product to start a business will continue developing their project. The teams will have the support and Coordination of the University Business Incubator team and the support of the business developing team to evolve their entrepreneur vein and learn how to make a business plan, CANVAS plan, and a prototype and present all the results to a specialized business examination board.

The students receive two points in each discipline of their semester. If the teams have four or more students from different courses, they will receive a 10% surplus in the program final grade. The purpose of this advantage is to stimulate the multidisciplinary knowledge exchange that will occur between the team members.

Students have several well-equipped Labs to develop their ideas and prototypes, which can be reserved in the dates they need to fulfill their work and projects.

It is possible to have students from other courses outside of the ones described above in the teams, but they only operate as volunteers and don't have a grade in their courses for that, as happens with these students.

In a near future, the possibility of starting a scientific initiation program that will direct student's projects to start a business or to research and development, with a scientific paper publication in a top journal with peer review, will be implemented.

Becoming a Fab Lab

Although students have Labs at their availability, with all the digital fabrication machines and software that are necessary to fulfill their projects, we cannot call those a Fab Lab yet because they are not open and available to the public, as recommended by the Fab Foundation. Furthermore, the Labs can only be used outside class time and after a request was made and accepted with the reason for using the Lab's and its tools.

Security reasons prevent the access to people not enrolled with the university, because the machines and other equipment's are very expensive and the entrance is not available from the outside. To get to the Labs its necessary to pass through several rooms and it's not secure for the University and their people (teachers, students, and staff) to let outside people walking around everywhere in the building because that can pose several security threats, especially in a city like Salvador where high crime rates occur.

The previous situation prevents students from the contact with external Makers with their knowledge and expertise, that could enrich their own projects. Likewise, prevents the general public in the nearby community from learning with these high skilled students, not stimulating the inventive and innovative vein of the external community.

Steps are being done to analyze the possibility of constructing a new Lab, with the necessary security conditions to operate with everyone interested in participating, or to adapt one of the existing Labs so it can be accessible directly from the outside, avoiding the wrong people can enter the all building.

That's the only measure needed to propose the Lab to the Fab Foundation because all the other elements necessary to become a Fab Lab are already in place.

FUTURE RESEARCH DIRECTIONS

Further research should be performed to analyze other solutions in place in other Fab Labs around the world, to adopt those best practices in all the Labs to improve their management, knowledge sharing, and sustainability.

Also, measures should be done to verify the benefits of that knowledge diffusion for the users. If it is beneficial for the knowledge creation of the Makers and allows them to find solutions to solve problems, and give them insights for new projects, then it should be suggested to all the Labs as a way of reducing the time to market for their products. All the help is welcome and the network can think of it collaboratively to find new ways to improve their results.

The managerial significance and applications of this research, resides on the importance that knowledge creation and diffusion plays on the advancement of the economy, generation of employment, increasing life conditions of the population involved, making all the community beneficiary of these solutions offered by the developments conceived in Fab Labs.

CONCLUSION

After describing the concept of Maker Spaces, the analysis focused in a specific type: The Fab Lab. Several educational advantages promoted by these spaces were described, mainly in the learning of concepts related with Engineering, Calculus, Mathematics, etc., and described the benefits from them to the attraction of women for these specific areas, and in the training of youngsters that didn't pursue their formal education, so they can have useful technical competencies for the labor market.

The different backgrounds of the Makers present in the space will be potentially advantageous for the share and exchange of experiences and knowledge that will enrich all the participants. The Maker movement encourages Master Makers to transfer their knowledge of production techniques to Makers who are less experienced (http://makercity.wpengine.com/docs/makercity-preview-chapter.pdf)

The knowledge created is shared among the network, allowing comments and improvement suggestions that will enrich the result of the projects.

The basic necessary conditions to open a Fab Lab are described, allowing understanding the possibility of creating such a space in a community allowing designing useful solutions for the residents and users of the Lab.

Some examples are presented to demonstrate the viability of these learning spaces and its creative and innovative advantages to empower the people involved, motivating them to create solutions based in rapid prototyping that allow to evaluate the potential of their invention and its acceptance by the community of Makers that can motivate the creation of a new business or improve the competencies at their current jobs.

The Fab Lab aims to develop a culture of learning by doing, giving students, teachers, independent inventors and entrepreneurs the opportunity to learn by doing it themselves (DIY), and learn together (DIWO or DIT) with other Makers from their Lab or another from the network, creating a multidisciplinary space, open to the outside, to receive different insights and inputs (Gershenfeld, 2005; 2012).

Information from projects, collective and individual, and from the courses to learn how to operate all the machines and equipment's in the Lab, together with rules and regulations about the use of the space, can be a knowledge disseminator task.

All this internal and external knowledge needs to be managed, to improve the knowledge creation among the users of the space (Sordi, 2008).

Although, without a general strategy implemented in all Labs, small steps adequate to the Labs publics and technology competence are being taken, being a starting point for a future best practice to be implemented in the entire Fab Lab network.

ARHTE project can be a huge disseminator of new knowledge amongst the students and other publics participating in the activities of the Lab.

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KEY TERMS AND DEFINITIONS

Creativity: Reasoning that produces imaginative new ideas and new ways of looking at reality. Creativity is an individual process, arises from the idea that popped into someone's head. Relates facts or ideas without previous relationship and is discontinuous and divergent. No creative process exists if there is no intention or purpose. The essence of the creative process is to seek new combinations.

Explicit Knowledge: Knowledge of the facts obtained from information, almost always through formal education. Expressed through metaphors, analogies, concepts, hypothesis or models. The key for the creation of new knowledge. Codified, communicable through formal and systematic language. Can be stored in manuals, documentation, patents, blueprints, reports and other accessible sources. Explicit and tacit knowledge complement each other.

Fab Lab: A laboratory of digital fabrication, serving as a prototyping platform of physical objects, with broad educational, social and economic advantages. These spaces aim to empower its members for the realization of sustainable solutions, using open source tools and equipment's, to allow all the possibility of creating low cost products which meet the need for one, one hundred, or a thousand people.

Information: A set of data arranged in a certain order and form, useful to people to whom it is addressed. Reduces uncertainty and supports decision-making. Information is considered to support human knowledge and communication in the technical, economic and social domains. Results from the structuring of data in a given context and particular purpose.

Innovation: The application of new knowledge, resulting in new products, processes or services or significant improvements in some of its attributes. A new solution brought to the market to solve a problem in a new or better way than the existent solutions.

Invention: The creation or discovery of a new idea, including the concept, design, model creation or improvement of a piece, product or system. Even though an invention may allow a patent application, in most cases it will not give rise to an innovation.

Knowledge: Is a fluid composed of experiences, values, context information and apprehension about their own field of action that provides a cognitive apparatus for evaluating and incorporating new experiences and information. It originates from data and information and allows acting upon it.

Tacit Knowledge: Knowledge that can only be learned through practice and experience. Know-how. Knowledge that is acquired but difficult to explain to others. Subjective insights, intuitions and hunches of individuals. Not easily communicated or shared. To gain access to such knowledge one may have to be practicing in related areas of knowledge. What is held in someone's head and includes facts, stories, biases, and insights. Tacit and explicit knowledge complement each other.