The Business Model of Do-It-Yourself (DIY) Laboratories
– A triple-layered perspective

Abstract

As the question of funding for DIY laboratories remains a matter of central interest for the financial sustainability of laboratories, this paper studies Do-It-Yourself (DIY) laboratories from the under-researched business model and management perspective. We have applied the triple-layered business model canvas (TLBMC) to explore and understand DIY laboratories from the economic, environmental, and social value creation aspects. Based on our comprehensive literature review and exploratory case studies, our research findings reveal that DIY laboratories are essentially technology hubs offering technology enthusiasts and entrepreneurs physical and social spaces and business incubation to help them survive and thrive. Engaged with all the Triple Helix stakeholders, DIY laboratories offer a platform of science innovation and technology incubation at the grassroots level for technology entrepreneurs to grow economically, socially, and sustainably.

Key words: DIY laboratories; business model; Triple Helix Model

1. Introduction

The global movement of Do-It-Yourself (DIY) laboratories, since the formation of DIYbio.org in Boston in 2008, has created many community-based science hubs in cities, towns, and villages around the world. Originally aimed at spreading biotechnology usage, DIY laboratories have now gone beyond the borders of industrial and academic institutions and are open to the public (Sarpong et al., 2020). This has become possible due to decreased costs in laboratory equipment, order-ready materials, and boundless scientific information (Million-Perez, 2016). Enabled and further promoted by the Internet and digital business environment, discourse around the DIY movement evolves on dedicated websites and online forums (Wray, 2012) such as DIYbio.org, facebook.com (specifically closed groups for DIYers), and slack.com. With the easily accessible knowledge and information on the Internet, fueled by the decreasing costs in hardware and the increasing sophistication of smart phones, DIY science is now more feasible than ever before (Grey et al., 2017).

Compared with mainstream science, one of the key differences of DIY science is that many DIY science experiments are conducted in the unconventional venues of DIY laboratories (Sarpong et al., 2019). These DIY laboratories can be associated with names such as DIYbio laboratories, hackerspaces, makerspaces, Fab Labs, hack labs, TechShop, and so on. They also co-locate with related spaces, such as artist communities, co-working spaces, or start-up incubators (Davies, 2017). The "scientists" that are involved in the DIY laboratories, often non-specialists, hobbyists, and amateurs, but also an increasing number of professional scientists (Griffiths, 2014), are conducting scientific experiments or making scientific discoveries outside conventional institutional settings in these DIY laboratories (Nascimento et al., 2014). These scientific experiments and research are generally conducted in areas such as biology, environmental health, and epidemiology. Due to their free format by design, they often appear as transdisciplinary projects that engage the sciences, the arts, and the law (Nascimento et al., 2014). With less than adequate means (Ledford, 2010), using open-source tools, and adhering to open paradigms to share knowledge and outputs with others, these DIY scientists appear as science enthusiasts who tinker, hack, fix, recreate, and assemble objects and systems through transdisciplinary projects in creative and unexpected directions in DIY laboratories (Ledford, 2010; Nascimento et al., 2014).

Since the emergence of the DIY laboratory phenomenon, significantly increased numbers of DIY "scientists" are taking part in and engaged with DIY laboratories. More and more venues that are associated with DIY laboratories are "popping up" in cities across the world

(Sarpong et al., 2019). Currently, some salient examples of DIY laboratories are under different names (e.g. DIYbio labs, hackerspaces, and Fab Labs), and this reveals that the number of venues associated with DIY laboratories grew exponentially under these different names. For instance, Fab Labs started from the first six Fab Labs in 2004, to 413 labs in 2013, and currently there are 1,830 Fab Labs in the Fab Foundation Network in more than 100 countries across the globe (Fab Foundation, 2020). As for DIYbio.org, founded in 2008, the community expanded from 14 groups across the continents of Europe and North America in 2013 to the current 108 groups in five continents (i.e. North America, South America, Europe, Asia, and Oceania) (DIYbio.org, 2020a). When it comes to hackerspaces, the movement started with less than a dozen spaces within Germany in the 1990s, and there are currently 2,344 listed hackerspaces, of which 1,415 are marked as active and 357 marked as planned (Hackerspaces.org, 2020). Figures 1, 2, and 3 below provide an overview of the spread of Fab Lab, DIYbio, and hackerspace centers around the world. However, many groups have mushroomed over the years, making it challenging to quantify the number of people who are engaged in DIY labs, and also the number of community-based laboratories (Landrain et al., 2013; Meyer, 2013; Tocchetti and Aguiton, 2015). Nevertheless, the following figures may shed some light on the magnitude of the DIY movement: it is estimated that 135 million Americans, or 57% of the American adult population, could be considered makers (Stone, 2015), and participants joining Maker Faires – an event to celebrate arts, crafts, engineering, science projects, and the DIY mindset – grew from 83,000 in 2009 (Trabulsi, 2015) to about 1.4 million in 2017 globally (Maker Faire, 2020).

Figure 1. Geographical spread of Fab Labs in the Fab Foundation Network as of July 2020 (based on https://www.fablabs.io/labs/map)

Figure 2. Geographical spread of DIYbio laboratories as of July 2020 (based on https://sphere.diybio.org/)

Figure 3. Geographical spread of hackerspaces as of July 2020 (based on https://wiki.hackerspaces.org/List_of_Hackerspaces)

Despite the rapid growth and expansion of different kinds of DIY laboratories globally, little is known about DIY laboratories in academic literature, especially regarding management and business models of DIY laboratories. Previous studies reveal that DIY laboratories aim to ease the social structure of laboratory work, which generally is within a rigid formal organization with little room for collaborative work (Guthrie, 2014), while some academics have attempted to review the strategies implemented by DIY laboratories with the ecosystem theory (Bloom and Dees, 2008) and discussed how stakeholders take part in the laboratories themselves. Building on such research, this paper intends to provide a more nuanced understanding and develop the business model framework for DIY laboratories. The goal is to offer some insights as to how DIY laboratories can achieve financial independence to support their ultimate goal of open information. Drawing from business model literature, we take an exploratory and holistic approach to understand the phenomenon and business model of a DIY laboratory. Our study contributes to the literature streams of DIY laboratories and business model canvas.

2. Literature review

As this study approaches the phenomenon of DIY laboratories from the perspective of business model canvas, two strands of relevant literature are reviewed in this section. First, DIY laboratory literature as a whole, yet with a look into the different umbrella terms and their definitions and how they are connected to DIY laboratories, followed by the various venues of DIY laboratories and the funding model of various DIY laboratories. Second, business model canvas, in which a specific focus is set on the business model of DIY laboratories.

2.1 DIY Laboratories

2.1.1 Umbrella terms of DIY laboratories

Despite the growing popularity and propensity of DIY laboratories in practice, based on an unstructured literature search, the term "DIY laboratory" does not seem to have a clear definition in extant academic literature. Numerous umbrella terms (Rip and Voss, 2013) though, namely topical terms of labels that are associated with DIY laboratories, do exist, and they include such terms as DIY science, citizen science, civic science, community-based research, DIYbio, participatory action research, transdisciplinary research, public engagement with science and technology, and open science (Gobel, 2019), to name a few. As the setting stone in establishing a definition of "DIY laboratory", a list of the umbrella terms associated with DIY laboratories is summarized and presented in Table 1.

Table 1**.** Umbrella terms associated with DIY laboratories

Term	**Definition/description**	**Source/s**
Do-It-Yourself Science, or DIY Science	"Do-it-yourself (DIY) science'" is described as a phenomenon in which numerous private and community-based initiatives use scientific methods alongside other forms of inquiry such as hacking and remixing to engage with techno-scientific concerns and societal challenges. It includes a great variety of tendencies, variously described as amateur, 'garage', 'citizens', 'extreme citizen', and activist.	Nascimento et al. (2014)
Do-It-Yourself Biology, or DIYbio, biohacking, garage biology, or kitchen science.	"Do-It-Yourself" Biology is described as non-institutional science, particularly the engineering of living organisms, which is performed outside of professional laboratories, and influenced by open source principles regarding their tools and results.	Bolton and Thomas (2014); Nascimento et al. (2014); Landrain et al. (2013)
Living Lab	A Living Lab is a user-centric innovation milieu built on everyday practice and research, with an approach that facilitates user influence in open and distributed innovation processes engaging all relevant partners in real-life contexts, aiming to create sustainable values.	Bergvall-Kåreborn (2009)
Civic science	Civic science refers to science with an infusion of democracy. It is science that is political, transparent, and responsible; science that is open to citizen input.	Berkes (2005)
Citizen science	Citizen science refers to the inclusion of members of the public in some aspect of scientific research, where in most cases projects are led by institutions, such as universities or other research institutions,	Eitzel et al. (2017); Nascimento et al. (2014)

	which organize, call, or promote different forms of citizen involvement in their endeavors.	
Community-based research	Community-based research is described as a collaborative approach to research which acknowledges the unique contributions of each partner, seeks to meaningfully involve all partners in the research process, and strives for social change through the integration of knowledge and action.	Minkler and Wallerstein (2003)
Participatory Research	Participatory research is defined as research in which stakeholders participate and benefit jointly from the outcome.	Goma et al. (2001)
Transdisciplinary research	Transdisciplinary research refers to scientific inquiry that cuts across disciplines, integrating and synthesizing content, theory, and methodology from any discipline area which will shed light on the research questions.	Gray (2008)
Open science	Open science refers broadly to efforts intended to increase transparency and replicability in the research process, and the term is also used to refer to a broad movement among researchers seeking changes in the way scientific research is conducted, evaluated, and disseminated.	Nosek et al. (2015)
Open innovation	Open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively	Chesbrough et al. (2006)

The umbrella terms related to DIY laboratories listed in Table 1 share some similarities but also critical differences. In order to better understand the interconnectivity of these terms, they have been plotted into a Venn diagram in Figure 4. The three circles represent the broader terms of Open Science, Open Innovation, and Transdisciplinary Research and how the more specific terms are related to the broader terms.

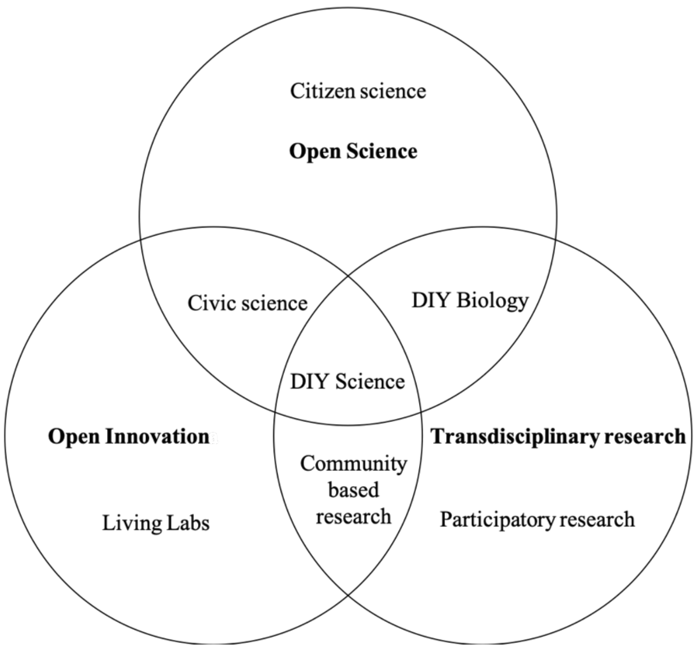

Figure 4. Interconnectivity among the umbrella terms related to DIY laboratories

2.1.2 Definitions and descriptions of various types of DIY laboratory venues

DIY laboratories are community hub independent laboratories, which involve conducting basic to advanced experiments with new scientific technologies in private settings (Sarpong and Rawal, 2020). There are various names to denote venues of DIY laboratories, which include makerspace, hackerspaces, and Fab Labs (Davies, 2017), but are there differences and similarities among these terms? Some scholars, such as Moilanen (2012), treat these varying organizational types as synonymous, while other scholars such as Colegrove (2013) and Maxigas (2012) and practitioners such as Cavalcanti (2013) treat them as independent. Particularly, in addition to hackerspaces, Fab Labs, and makerspaces, Moilanen (2012) also mentioned other names of DIY laboratory venues, such as TechShop, 100k garage, sharing platform, and open source hardware, and it appears that he does not consider these different terms to denote significant differences between these DIY laboratory venues. On the contrary, Colegrove (2013) suggested that although these DIY laboratory venues are in fact very different in practice, such terms as makerspaces, hackerspaces, Fab Labs, and co-working space are often used incorrectly as if they are synonymous. Hackerspaces are normally venues that are dedicated to computers and technology. In particular, this organizational type is attractive to users who work in the digital domain. Co-working space is regarded as an extension and a natural evolution for users in hackerspaces that desire to move from a hobbyist to professional production in a shared working environment. On the other hand, Fab Labs are venues that have a specific focus on digital fabrication and are typically equipped with tools for such a purpose, providing laser cutters, CNC milling machines, and 3D printers to participants. Furthermore, Maxigas (2012) studied the differences between the terms Hackerspace and Hacklabs, and he noted a wide range of terms that have been developed to describe similar venues, such as co-working spaces, innovation laboratories (innovation labs), media labs (medialabs), Fab Labs, makerspaces, makerlabs, telecottages, and so on. He suggests that organizations that are associated with these names are unlikely to be considered true hackerspace, indicating how fragmented the understanding of the terms is even within the subset of hackerspace. In an article published in *Make* magazine, Cavalcanti (2013) discussed the four prominent types of DIY laboratories, namely Hackerspace, Makerspace, TechShop, and Fab Lab, and by providing examples for each of DIY laboratory types, he described and categorized them based on what they are fundamentally trying to do. In his description and categorization, traditional hackerspaces focus largely on electronics and programming, which appeal to a certain group of people. In the case of makerspaces, they represent a far more mainstream vision of a publicly accessible creative space and have a unique set of draws and distinctions. As for TechShop and Fab Labs, Cavalcanti (2013) describes them as venues that focus on creation from scratch through various types of media, and he categorizes them as makerspace franchises.

In order to measure whether the term makerspace can accurately define DIY laboratory venues such as hackerspaces and Fab Labs, Van Holm (2014) used content analysis to analyze the self-definitions of makerspaces, hackerspaces, and Fab Labs. He found that, although researchers are divided on whether to treat the three concepts as distinct or synonymous, there is in fact little variation between the terms makerspace and Hackerspace, and that while each of the three organizational types has their own histories, they have converged into similar structures and uses. Following the content analysis, Van Holm (2014, p.15) arrived at a general definition that encompasses the DIY laboratory venues makerspaces, hackerspaces, and Fab Labs: "At present, Makerspaces, hackerspaces, and Fab Labs are shown to be workshops that are open to the community as members. They typically offer equipment allowing work with metal, wood, fabrication, and arts and crafts, and are open to individuals looking to work with any of those tools. They may be specifically focused towards business generation, although not necessarily closed off from hobbyists without professional pursuit". It is important to note that, although the study by Van Holm (2014) suggests that the practices of the three types of individual DIY laboratory venues have enough in common that the collective term makerspace can encompass all of them, this does not necessarily mean that all of these DIY laboratory venues have the same practices, governance, and business models.

Based on the definitions and descriptions of the umbrella terms associated with DIY laboratory as well as the various types of DIY laboratory venues, our definition of DIY laboratory for this study is proposed below:

"A DIY laboratory is a place, set up by interested person(s) or group, equipped for scientific experiments, research, or teaching in which numerous private and community-based initiatives use scientific methods alongside other forms of inquiry such as hacking and remixing to engage with techno-scientific concerns and societal challenges".

2.1.3 Funding sources of DIY laboratories

In the same vein as established research institutions, the question of funding for DIY laboratories is a matter of central interest for the sustainability of the laboratories (Nascimento et al., 2014). Extant literature has identified a few sources and funding bodies for DIY laboratories (see, for example, Nascimento et al., 2014; Ravetz et al., 2015), and they include the government, industry, university, and personal sources. Moreover, this is a fascinating time for research, in that most societies are in a position where scholarly vocations, as well as careers, are unappealing and unreliable to many (Griffiths, 2014). In the meantime, innovations, swarm financing, and natural science offer good choices and alternatives for pioneers (Johnson, 2008).

Access to traditional research funding proves to be challenging for new associations and DIYers. Funding institutions such as the 'UK Research Council' may offer their funds just to enormous and well-qualified autonomous research associations (Nascimento et al., 2014). However, all things considered, being compelled to move far from customary research financing models can offer incredibly favorable circumstances. This may lead to quicker access to assets and more opportunity to seek research that may be regarded 'unfindable' by a hazard-averse research board (Delfanti, 2014). Crowdfunding has been used by DIYbio members to raise funds to cover some of the costs of community laboratories and the making of cheap laboratory instruments (Tocchetti, 2014). For example, funded via Kickstarter for $35,319, BioCurious, an association founded in 2009 by DIYbio, has leased and turned a 220-square-meter office into a laboratory (Meyer, 2012). Crowdfunding is expanding and offers an excellent option with real alternative (Griffiths, 2014). In contrast to open meetings by research committee gatherings, crowdfunding offers groups the opportunity to cast a ballot with their wallets, implying that science that is of interest to a significant number of people is probably going to be the most straightforward to finance (Ireland, 2014). Thus, this model offers readiness unparalleled by institutions (universities/colleges), permitting quick and adaptable local scale of purpose-driven research by residents (Revill and Jefferson, 2013). Producing such direct connections among society and science may be advantageous. Colleges, universities, and research boards have progressively been making stressed endeavors to improve community network relations, yet an ongoing review demonstrated that half of individuals still think researchers are shrouded, and a majority state that researchers ought to listen more to customary individuals (Revill and Jefferson, 2013).

On the other hand, DIY science projects could have access to public funding from the government. For instance, in the European context, DIY laboratories have received funding from European, national, or regional programs and organizations (Nascimento et al., 2014).

In the US, some DIY laboratories have received funding from military organizations (e.g. Defense Advanced Research Projects Agency (DARPA)) (O'Leary, 2012). On the other hand, DIY laboratories have also received funding from industry, such as private companies and industrial foundations. For instance, Chevron partnered with the Fab Foundation to bring its Fab Labs to areas where Chevron operates across the US (Chevron, 2015). In Europe, the Danish Industry Foundation granted DKK 3 million to the FabLab@School.dk research program (Søndergaard, 2014). As for academia, many universities in different countries across the globe have launched Fab Labs, some of which are exclusively owned by the university (e.g. Fab Lab Westminster owned by University of Westminster), while others are joint ventures between the local government and universities (e.g. Fab Lab Coventry, which is a joint venture between Coventry University, Coventry City Council, and University of Warwick).

Due to the nature of DIY laboratories, besides funding from the traditional sources of government, university, and industry, there are many instances where scientists who engage with DIY laboratories keep their main jobs (Ravetz et al., 2015) and fund their own experiments. The arrangement of personal funding for DIY laboratories could also be through the form of donation. For instance, as one of the largest communities relating to DIY science, DIYbio.org is a charitable organization and welcomes donation from the public (DIYbio.org, 2020b). Furthermore, many DIY laboratories create crowdfunding campaigns in Kickstarter and Indiegogo that sponsor new alternative forms of funding and legitimacy for scientific and technological projects (Nascimento et al., 2014). A third funding model for DIY laboratories is through paid membership. For example, Genspace, the first community biolab in the US, operates as a nonprofit organization with a model of three-tier membership through application, in addition to the funding models of donation and sponsorship. With USD 100 per month, community members can attend member events, receive free lectures, biosafety, and lab equipment training, have access to basic scientific consultation, participate in community projects, and have access to Genspace lab and equipment for group projects (Genspace, 2020). Individual members that pay USD 250 per month have more bonuses. They receive community membership benefits, receive complete intellectual property rights to any discovery, have full access for individual projects, receive individual project consultation, occupy a dedicated storage space, use common consumables, and can order reagents / supplies (Genspace, 2020). The premium membership tier, starting at USD 800 per month, provides members with dedicated desk and freezer space, in addition to all other individual membership benefits. Furthermore, premium members could also have lab interns, and bring in their own equipment and up to two people to the lab (Genspace, 2020).

Based on the Triple Helix model proposed by Etzkowitz and Zhou (2017) and relevant literature on funding for DIY laboratories, the funding sources for DIY laboratories are summarized and presented in Table 2.

Table 2. Funding sources for DIY laboratories based on the Triple Helix Model (adapted from Etzkowitz and Zhou, 2017)

Funding sources	**Purpose**
University (U)	Generating innovative ideas and providing education and training
Industry (I)	Making a profit and improving efficiency
Government (G)	Creating cutting-edge technology and facilitating leading research projects
Personal (P)	Fulfilling personal interests and achieving one's potential
Hybrid (All combinations of the above)	Dependent on the specific funding sources and laboratories

In terms of funding for DIY laboratories, a DIY laboratory could be funded via governmental, industrial, academic, or personal sources, or it could receive funding from a combination of multiple sources at the same time.

2.2 Business model and business model canvases

Although the concept of business model as a "theory of a business" is not entirely new (Drucker, 1955), it is not until recent years that business model research has gained the attention of academic scholars (Joyce and Paquin, 2016). Despite the recent development around business models in academic literature, however, scholars still "do not agree on what a business model is" (Zott et al., 2011, p.1020). In this particular study, the definition of business model is adopted from Osterwalder and Pigneur (2010, p.14), which regards business model as "the rationale of how an organization creates, delivers, and captures value". Proposed by Osterwalder and Pigneur (2010), the business model canvas displays the business model of an organization in nine interconnected components, which include key partners, key activities, key resources, value propositions, customer relationships, channels, cost structure, and revenue streams. However, as the business model canvas emphasizes the economic value created, delivered, and captured by an organization, the environmental and social value is implicitly deemphasized (Joyce and Paquin, 2016). In response to this criticism, drawing upon the triple bottom line, a triple-layered business model canvas

(TLBMC) is developed by Joyce and Paquin (2016), which integrates economic, environmental, and social value that is created, delivered, and captured by an organization into a holistic view. Similar to the original business model canvas developed by Osterwalder and Pigneur (2010), the environmental life cycle layer of the TLBMC also contains nine components, which include supplies and outsourcing, production, materials, functional value, end-of-life, distribution, use phase, environmental impacts, and environmental benefits. In the same vein, the social stakeholder layer of the TLBMC contains nine components as well, namely local communities, governance, employees, social value, societal culture, scale of outreach, end-user, social impacts, and social benefits. The TLBMC can complement and extend the original economically-oriented business model canvas concept with two new canvas layers that explore environmental and social value creation of an organization. As the original business model canvas and the TLBMC have been treated at length by the authors in their respective works, we will not review each of the components in the different layers in this section.

2.2.1 Business model of DIY laboratories

Whether a DIY laboratory starts from within an existing institution, either public or private, that funds its functioning, or it starts independently, as long as there are rents, expenses, wages, fees, external suppliers, and partners, and "everything has to be developed at least to reach the break-even point", it is a business and it must be financially sustainable in order to last (Menichinelli, 2013). Although there is no preceding research that explicitly examines the business model of DIY laboratories, there are some extant studies that have investigated business models of related phenomena, such as citizen science (DITOS Consortium, 2018), Fab Labs (Menichinelli, 2011; Troxler, 2010; Troxler and Wolf, 2010), and makerspaces (Galaleldin et al., 2016). Specifically, DITOS Consortium (2018) has developed five broad archetypes of business models in citizen science: Motivated Individual; Small Crowdsourcing; Outreach; Research and Innovation; and Long-Term NGO. In addition to the development of these five broad archetypes of business models in citizen science, DITO Consortium (2018) also suggests that these five archetypes are not straightforward, and that the actual business model might depend on the unique nature of the formation and aims of each project. As for Fab Labs, Troxler (2010) discovered that there are two main business models, 1) Fab Labs that provide facilities; and 2) Fab Labs that provide innovation support. In another study, by drawing upon the business model canvas, Troxler and Wolf (2010) found that Fab Labs mainly portray themselves as providers of fabrication facilities, while some Fab Labs also market the possibility of low-cost fabrication to business customers who previously conceived making things as not viable. They also identified four business models for Fab Labs, as shown in Table 3.

Table 3**.** Four business models for Fab Labs (adapted from Troxler and Wolf, 2000)

	Lab as facility	**Innovation Lab**
Open Intellectual Property	Typical Fab Lab approach	Fab Lab innovation ecology
Closed Intellectual Property	Traditional machine shop	Typical innovation consultancy

Furthermore, Menichinelli (2011) describes four business models for Fab Labs that are reported by Fab Lab Iceland: 1) The Enabler business model: to launch new labs or provide maintenance, supply chain, or similar service for existing labs. 2) The Education business model: to provide a global distributed form of education through Fab Labs with the help of the Fab Academy, where global experts in particular topics can deliver training from local Fab Labs or universities/businesses via the Fab Lab video conference network. Peer-to-peer learning among users is an integral part of this business model. 3) The Incubator business model: to provide infrastructure for entrepreneurs to turn their Fab Lab creations into sustainable businesses. The incubator would provide back-office infrastructure, promotion, marketing, seed capital, the leverage of the Fab Lab network, and other venture infrastructure to enable the entrepreneur to focus on his/her areas of expertise. 4) The Replicated/Network business model: to provide a product, service, or curriculum that operates by utilizing the infrastructure, staff, and expertise of a local Fab Lab. Such a business model can be replicated, sold by, and executed at local labs, which can generate a sustainable revenue at each location. The leverage of all labs in the network simultaneously promoting and delivering the business creates strength and reach for the brand. As for the business model of makerspaces, Galaleldin et al. (2016) suggest that makerspaces provide areas that are equipped with state-of-the-art tools and equipment that are difficult for students or individuals to access. Additionally, makerspaces also offer training and workshops, and provide support to users with their projects by either helping them with accomplish/make the project, or by connecting makers together to collaborate on projects together. Despite the fact that the DIY laboratory emerged as a phenomenon with profound environmental and social influences, all of the extant literature that examines the business model of DIY laboratories mainly focuses on the economic perspective. The environmental and social aspects of the business model of DIY laboratories are under researched. All three layers of the TLBMC are important to consider when examining the business model of DIY labs, as they extend previous research on the business model of DIY labs by providing better understanding of how they operate in the current economic, social, and natural environment. In response to this identified research gap, our empirical study investigates the business model of DIY laboratories specifically from a triple-layered perspective addressing the economic, environmental, and social values created by DIY laboratories.

3. Research Methods

Our study aims to develop the triple-layered business model for DIY laboratories. As there is relatively limited preceding research regarding DIY laboratories and their business models, this study adopts an explorative approach of building theory from multiple case studies (Eisenhardt and Graebner, 2007). Although exploratory case study research suffers from low external validity (Bryman, 2016), it could nevertheless enable us to understand the research question and help construct theories from an in-depth analysis of the complex phenomenon related to the business model of DIY laboratories. Qualitative case research is a well-established method for conducting exploratory and theory-building research, and particularly the design of multiple-case studies could provide a stronger base for theory building (Yin, 2017) and more robust findings (Eisenhardt and Graebner, 2007), as it could reduce vulnerability to unexpected circumstances in the chosen cases and increases analytical benefits by providing multiple cases for cross-case analysis (Yin, 2017).

3.1 Case selection

A theoretical sampling approach was adopted, as it ensures that the cases were selected because they were suitable for illuminating the research phenomenon, so that a better grounded and more generalizable theory can be provided (Eisenhardt and Graebner, 2007). As the aim of the research is to understand the financial viability of DIY laboratories, and analyze the selected cases with the TLBMC to achieve the necessary descriptive nature of data, given that the phenomenon of DIY laboratories is relatively new and the aim to have descriptive data implies that a smaller sample of cases is justified. There are three prominent communities within the DIY laboratory phenomenon: DIYbio.org with a focus on biology/biotechnology, Fab Foundation Network with a focus on digital fabrication, and Hackerspaces.org with a focus on electronics and programming. Thus, choosing a single case from each community will render a more descriptive data set to be analyzed. In addition, as the phenomenon of DIY laboratories is in its infancy, in order to ensure mature enough financial experience, the researchers selected cases that were either the first of their kind, or those that founded shortly after the community was formed. The researchers focused their selection also only on those possible cases that were still active, not considering past non-active cases that may have been older. Therefore, the case selection includes Genspace associated with DIYbio.org, Vigyan Ashram Fab Lab associated with Fab Foundation Network, and c-base associated with Hackerspaces.org. Each selected case has an history of more than 10 years, they have a variety of financial models and operate in different regions of the world. Thus, the researchers aim to achieve a broad enough view of the phenomenon while maintain the rich descriptive manner of the small sample base. The objective is to capture the circumstances and conditions of a representative DIY lab within its community. Figure 5 displays the selection process of the cases.

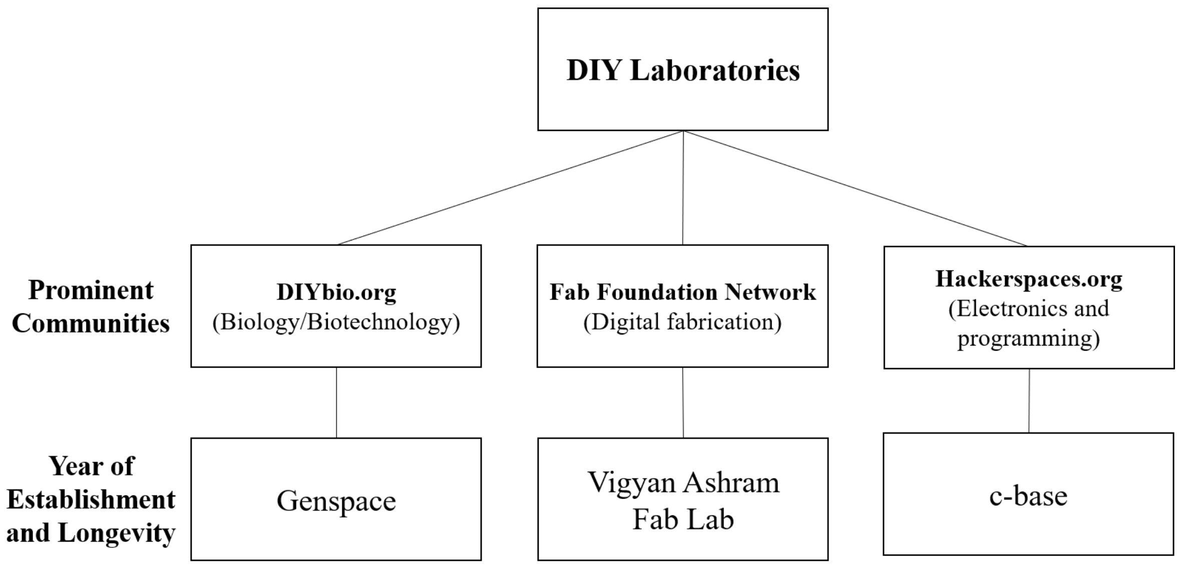

Figure 5. The case selection process

Table 4 provides basic data on the selected cases which represent DIY laboratories with different focuses.

Table 4. Basic data on the selected DIY laboratory cases

	Genspace	**Vigyan Ashram Fab Lab**	**c-base**
Associated group	DIYbio.org	Fab Foundation Network	Hackerspaces.org
Organization type	Nonprofit organization	Affiliation with an educational institution	Nonprofit organization

Focus of the DIY Laboratory	Biotechnology	Digital Fabrication	Computer software, hardware, and data networks
Founding year	2009	2002	1995
Location	New York, USA	Pabal, India	Berlin, Germany
Funding sources	Membership fee; Donation; Sponsorship	Governmental funding; Industry; University; Donation	Membership fee; Donation

3.2 Data collection and analysis

While the usage of primary data for case studies in particular has been regarded as beneficial in obtaining in-depth evidence, there are nevertheless several advantages to using secondary data, even as the main source of data (Ritala et al., 2014). Our study builds upon secondary data collected from multiple sources. Using a broad range of publicly available secondary data, such as newspapers, policy papers, and archival documents, has been established as a valid practice for conducting case studies (see, for example, Kshetri, 2018; Ranta et al., 2018; Ritala et al., 2014; Rusko, 2011). On the other hand, the use of an extensive set of various types of secondary data collected from different sources to cast light upon the same topic could constitute data triangulation and help in validating the findings (Olsen, 2004). The main data sources of this study include: 1) websites, 2) discussion groups and online forums, 3) books and reports, 4) academic journal articles, and 5) news articles (e.g. newspapers, magazines, newsletters, and news websites), which focus on Genspace, Vigyan Ashram Fab Lab and c-base, as well as the relevant communities, such as the Fab Foundation, the Fab Academy, the Fab Charter, and Hackerspaces.org, etc. The qualitative content analysis of the secondary data was conducted in a structured manner, first with within-case analysis and then cross-case analysis, as suggested by Yin (2017) and Bell et al. (2018). In the within-case analysis, each case is considered and analyzed as a separated data unit; it supplies reliability of the data at the case site, as well as a thorough picture of the particular context (Coates and McDermott, 2002). Once every case has been understood on its own terms, we followed up with cross-case analysis to compare and contrast the patterns in terms of business model that emerged from the detailed within-case write-ups (Bell et al., 2018).

4. Results

4.1 Case summaries

4.1.1 Genspace (DIYbio.org)

Genspace is a nonprofit organization that is dedicated to promoting science literacy through citizen access to biotechnology, by providing STEM educational outreach, cultural events, and a platform for science innovation at the grassroots level. In 2009, a group of hobbyists, entrepreneurs, artists and scientists met in a living room to explore their interests and enthusiasm in biology and biotechnology. Within a year of the meeting, co-founders Nurit Bar-Shai, Ellen Jorgensen, Daniel Grushkin, Russell Durrett, and Oliver Medvedik founded Genspace, the first-ever community biotechnology laboratory in downtown Brooklyn, New York. The purpose of Genspace is to allow the general public to pursue individual and group projects in the area of biotechnology. For the past decade, the Genspace community has expanded, and in 2017, Genspace moved to its new home in Sunset Park, Brooklyn. Currently, Genspace provides a lab for biotech entrepreneurs and explorers, support to high school education as well as collaborative higher education and outreach. It provides education in bio-art and bio-design, as well as science education at the high school and college level. At the moment, Genspace provides New York High School and University students with hands-on science education, its Community Research Projects research across the phylogenetic tree, and its arts and design program, the Biodesign Challenge, spans the world. Additionally, Genspace provides a forum for dialogue about the social and ethical dimensions of biotech. Genspace continues to be a platform for curious people to follow their imaginations, and some individual member projects have grown into million-dollar companies and revolutionary art pieces.

The analysis was conducted by filling out the TLBMC for Genspace. For the economic layer of Genspace, the most important factors are the resources, costs and revenues they have. The resources they have are the laboratory workspace, equipment they own, knowledge of the people involved and relevant processes. The costs they have are in relation to their workspace in terms of the location, laboratory equipment and materials, maintenance of their website and server as well as human resource costs. Their revenues streams are made up from membership fees for those wishing to use the laboratory as well as other external grants and funding options they apply for. On the environmental layer, the most important factors are the benefits and impacts they have on the environment. The impacts are in the form of the equipment and their life-cycle, the raw materials used in the lab, website maintenance and server carbon emissions as well as the utilities from the facility itself. The benefits on the environment are from the shared use of the laboratory to anyone, this enables the possibilities to solve modern environmental issues. In addition, the laboratory enables knowledge sharing which supports positive action towards the environment. Similarly, the social layer looks at the impacts and benefits of the laboratory on the society around them. The impacts include the issues with the possible loss of intellectual property rights and potential disputes related to this. The benefits include the ability to share more knowledge for those that do not have access to an institutional laboratory as well as personal development of people and their research topics that may be too controversial for traditional laboratory settings.

4.1.2 Vigyan Ashram Fab Lab (Fab Foundation Network)

Vigyan Ashram is a center of Indian Institute of Education (IIE) Pune, founded in 1983 by the late scientist-turned-educationalist Dr S. S. Kalbag with the aim of finding out solutions to problems in education. Vigyan Ashram is located in the village of Pabal, which is approximately 70 km from Pune. The idea of establishing Vigyan Ashram in Pabal, a drought-prone village with 10,000 inhabitants, is that whatever is done at Ashram can be replicated in any part of the country. "Vigyan" means "Search of Truth" and "Ashram" symbolizes "simple living and high thinking for us, an organization where all are equal, a modern version of old Gurukul system". There are many programs and projects that are organized at Vigyan Ashram, and Vigyan Ashram Fab Lab is one of them. Vigyan Ashram Fab Lab was established in 2002 through an interaction between Dr Kalbag and Dr Neil Greshenfeld, director of the Centre of Bits and Atoms at MIT, who created the Fab Lab concept. Vigyan Ashram was the first Fab Lab to be set up outside MIT, and it was described by Dr Greshenfeld as "Fab Lab – 0". Furthermore, Vigyan Ashram has also started a satellite lab in Pune city which is named Do-It-Yourself (DIY) Lab, which provides a workplace and relevant digital fabrication tools, and hosts Makers meet-ups in Pune. In addition to a Fab Lab and the satellite DIY Lab, Vigyan Ashram is also home to a Fab Academy, where users can complete hands-on training on digital fabrication and earn a diploma.

The analysis was conducted by filling out the TLBMC for Vigyan Ashram Fab Lab. For the economic layer of Vigyan Ashram Fab Lab, the most important factors in relation to financial aspects are from the resources, costs, and revenues they have. Their resources are camp and certificates, academy program, technology available in the laboratory, and the laboratory itself. The costs were identified as costs related to the laboratory, human resources costs in regard to staff, technology development costs, and costs related to their facility. Their revenue streams include donation that they promote on their website, funding from different sources, and sponsorship programs. While considering the environmental layer, Vigyan Ashram Fab Lab's environmental impacts and benefits are discussed. The environmental impacts discuss the materials (virgin materials/recycled) used within the laboratory and possible outcomes and their life-cycles, the materials used in the facilities they reside in, the impacts of the equipment used and their post-use life, utilities and their effects, and finally website related impacts from maintenance and server usage. Environmental benefits were identified as the promotion of environmental solutions and innovations, sharing economy logic, promotion of local solutions that can be implemented within rural India, and the focus on Third Industrial Revolution solutions. Finally, the social layer, focusing similarly on the impacts and benefits of Vigyan Ashram Fab Lab. The social impacts include disputes of intellectual property, community response, and disagreements. The social benefits include localized solutions focused on India and environmentally positive solutions that benefit the entire world.

4.1.3 c-base (Hackerspaces.org)

Founded in the fall of 1995 by 17 people, c-base is a nonprofit association of about 550 members located in Berlin, Germany, with the purpose of increasing knowledge and skills pertaining to computer software, hardware, and data networks. The organization provides training, lectures, workshops, and cultural events of various nature for its paying members as well as non-member participants. It is widely recognized as one of the first hackerspaces in the world, and together with Metalab in Vienna, Austria, they have a direct and profound influence on the creation of hackerspaces in the US (Tweney, 2009). At the moment, c-base is funded by its paying members, donations, and sponsorships. Apart from the main purpose of c-base, members also engage in many other activities, and the premises of c-base also host a series of different events, including parties, presentations, theatrical performances, concerts, and exhibitions. In 2003, c-base began staging weekly meetings of musicians, named Cosmic Open Stage, to provide a platform for well-known or unknown musicians to hold jam sessions or to give concerts. In the same year, members of c-base also participated in World Children's Day, and introduced robotics and 3D design to young visitors. The premises of c-base are also used in cooperation by other initiatives and groups in and around Berlin as an event location or as function rooms. Any groups that identify themselves with the purpose of c-base are also welcome to use the premises for meetings and events, with wireless LAN available to all guests (Markham, 2015).

The analysis for c-base followed the process of filling in the TLBMC. From the economic layer, the resources, costs, and revenues are discussed in more detail. The resources are the physical location, the technology they offer their users, and their website. c-base's costs include location costs (e.g. rent and utilities), Internet fees and server costs, and equipment acquisition, maintenance, depreciation, and disposal. The revenues include donations, company memberships, membership fees for community members, seminar fees, venue rent, and sponsorship in the form of materials or equipment. For the environmental layer, the impacts and benefits are discussed. The environmental impacts of c-base include utility usage, server and technology maintenance, and facility materials. On the other hand, the environmental benefits consist of the solutions and new innovations enabled and the idea of sharing economy. The social layer focused on the impacts and benefits of c-base. The social impacts are limited to the possible enabling of cyber bullying and exclusion of individuals. Contrarily, the social benefits encompass social inclusion, allowing individuals to learn and realize their own potential through meaningful jobs, enabling start-ups, connectedness to others via the location and online, and allowing for open access to different projects.

4.2. Cross-case analysis

Table 5 presents a summary of the business models of the selected cases of DIY laboratories, and highlights the similarities and differences in business models among the cases from the economic, environmental, and social perspectives.

Table 5. Economic, environmental, and social business model analysis of DIY laboratories

Business model components	**Genspace**	**Vigyan Ashram Fab Lab**	**c-base**
		Economic layer	
Partners	High schools; Higher education institutions; Corporate clients; Funders	Companies – e.g. Tata; Fab Lab Networks; Communities in India; Universities	Member companies – e.g. Archimedes, Google; Sponsor companies; Individual members
Activities	Laboratory; Classes; Outreach events; Website maintenance	Teaching and training; Support for companies; Website maintenance	Facility usage; Event organization; Website maintenance; Introducing robotics to children
Resources	Laboratory workspace; Equipment; Knowledge and processes	Laboratory workspace; Equipment and tools; Knowledge and processes; Camp and certificates; Academy	Laboratory workspace; Equipment and facilities; Web presence
Value Proposition	Providing a lab for biotech entrepreneurs and explorers; Providing support to high school education, collaborative higher education, and outreach; Providing education in bio-art, bio-design, and science	Providing a workplace, relevant digital fabrication tools, and hosting Makers meet-ups; Providing training on digital fabrication and relevant certificates.	Providing training, lectures, and workshops relating to computer software, hardware, and data networks; Providing a space for cultural events of various nature
Customer	Membership events	Workshops and camps	Membership events

Relationship			
Channels	Laboratory workspace; Website; Event outreach	Laboratory workspace; Website; Reports; Documentaries	Laboratory workspace; Website; Online communication
Customer Segments	Students; Hobbyists; Professionals; Companies	Students; Hobbyists; Entrepreneurs; Companies; Start-ups	Hobbyists
Costs	Facility costs; Laboratory costs; Equipment and material costs; Website maintenance and server; Human resources	Laboratory costs; Equipment and material costs; Building costs; Human resources	Laboratory costs; Facility costs; Internet and utilities
Revenues	Membership fees; External grants and funding	Donation; Funding; Sponsorship	Donation; Company membership; Sponsorship; Membership fees
Environmental life cycle layer			
Supplies and Out-sourcing	Laboratory equipment; Laboratory materials; Utilities	Laboratory equipment and materials supplies; Utilities	Utility; Internet service; Equipment
Production	Knowledge; Project prototypes and samples	Reports; Documentaries; Knowledge; Project prototypes and samples	Knowledge; Project prototypes and samples
Materials	Raw materials for biotechnology experiments	Raw materials for fabrication	Office supplies; Materials for robotics
Functional Value	Laboratory use for anyone, possibility to solve major environmental issues; Education and knowledge for all	Laboratory use and training for students in rural India to solve environmental issues	Enable computer technology and engineering development by all to all
End-of-life	Laboratory equipment and materials	Laboratory equipment and materials	Computers and related hardware
Distribution	Personnel traveling	Personnel traveling	Personnel traveling
Use Phase	Laboratory workspace and equipment usage	Laboratory workspace and equipment usage	Laboratory workspace and facility usage; Computer hardware and software usage
Environmental Impacts	Laboratory equipment usage and raw materials; Website maintenance and server usage; Utility usage	Materials used; Building built; Website maintenance and servers; Utility usage	Utility usage; Website and server maintenance
Environmental Benefits	Laboratory open for anyone, possibilities to solve major environmental issues; Knowledge sharing - more beneficial actions towards the environment	Individuals learning and sharing information; solving issues within rural India; Focus on environmental-friend solutions	Computer and internet sharing thus creating less waste; Centralized location ease of access via public transport; Software and technical innovations with less harm to environment
Social stakeholder layer			
Local Communities	Access to science laboratory, possibilities for new companies and research	Educate local villagers with limited access to education within local communities; Access to digital fabrication laboratories, equipment, and tools	Facilitating learning and experiencing of computer technology to those who are interested; Local children

Governance	Autonomous non-profit organization; Knowledge-sharing; Affiliation with DIYbio.org	Donation based nonprofit organization with a focus on autonomy; Affiliation with Fab Lab networks	Autonomous; Nonprofit organization; Affiliation with hackerspaces.org
Employees	Staff; Volunteers	Staff, Volunteers; Interns	Staff; Volunteers
Social Values	Knowledge-sharing, education for high schools and higher education; Access to laboratory to encourage biotechnology research and business	Education for everyone; Knowledge sharing and transfer	Providing access to computers, internet, gadgets, and workspaces for those interested with a minimum fee; Lectures and teaching for those in need
Societal Culture	Culture of open knowledge; Transparency; Promoting science	Culture of sharing knowledge; Open source philosophy; Promoting science	Culture of open knowledge and creativity; Open source philosophy; Promoting computer science
Scale of Outreach	New York and USA: Schools and events Worldwide: websites and TED talks	Rural India: schools Worldwide: websites; reports; documentaries	Influence on hackerspaces in Europe and the US
End-User	Knowledge; skills; innovation; creation	Learning; Possibility to realize one's ideas; Meaningful contribution to society	Possibility to use computers, Internet, and experience the technical world; Knowledge sharing
Social Impacts	Potential loss of intellectual property rights	Potential loss of intellectual property rights; Potential community disagreement	Potential loss of intellectual property rights; Potential conflicts with different societal groups
Social Benefits	More knowledge for those unable to access an institutional laboratory; Personal development to research topics previously out of bounds	Local solutions to better the community in India; Possible solutions that benefit the rural areas in other parts of the world; Personal development of participants	For users to realize own potential; Possibility to start companies; Partaking in projects; Connectedness among similar-minded individuals in a community

Despite the three cases operating in different types of fields, they share the common logic of open source, freedom of knowledge, and sharing economy. They all aim to offer interested parties easily accessible training and knowledge, necessary workspaces, tools, and equipment. Thus, they share similarities in the cost structures of their nonprofit organizations, in the form of equipment, materials, utilities, and staffing. All cases have a similar focus on the environment, as they hope to facilitate innovation and research with the sharing of knowledge and accessibility of laboratory equipment and workspaces while considering the impact on environment. In addition, the environmental impacts of the case organizations are fairly similar as they have similar needs for materials, utilities, and equipment maintenance. The major social impacts that all of the case organizations strive for is the betterment of their local community's social standing and the enhancement of their specific research field's global community. Pushing towards accessible knowledge and science, the DIY laboratory movement *en masse* seeks a development of research untethered to any specific institution.

In terms of the differences among the business models of the case organizations, one of the main differences is how they acquire funds for their operations. Genspace and C-base operate with a membership model, while at the same time accepts donations and possible funding options. Both have adopted different types of membership fees for different categories of possible users, from individuals to corporations. On the other hand, as Vigyan Ashram Fab Lab is affiliated with an established education institution, it functions solely on donation and funding. Not only does it receive governmental funding, but it also partners with companies. Although the Fab Lab in Vigyan Ashram may not specifically be the recipient of any given fund or partnership, they may access funds from the main Vigyan Ashram organization. In regard to environmental impacts of the case organizations, as the focus of c-base is on computer software, hardware, and data networks, it requires far more electricity and usage of different servers (and relevant Co2 emissions) compared to the other two cases. On the other hand, in the cases of Genspace and Vigyan Ashram Fab Lab, the consumption of raw materials for the laboratory experiments are higher. The differences in social impacts among the business models of the case organizations lie in the focus of the case organizations. While Vigyan Ashram Fab Lab has more of a particular focus on the local villages in rural India, the social impacts of Genspace and c-base are extended to a much wider audience.

5. Discussion

5.1 Business models of DIY laboratories

A triple-layered business model of DIY laboratories has been informed and developed from our research findings based upon the identified cases and comprehensive literature review. Figure 6 below presents our summary of the analysis of DIY laboratories business model canvas from the economic, environmental, and social values perspectives. Our analysis shows that DIY laboratories share a common logic of shared knowledge and easy access to equipment and physical and social spaces from not only the economic perspective, which is in line with the findings of Van Holm (2014), but also environmental and social perspectives. The business models of DIY laboratories share similarities in their revenue logic, as seen from Menichinelli (2011), but they also share similar environmental impacts and benefits, as well as similar desires for local community empowerment.

Partners

- Education institutions
- Companies
- Local communities

Activities

- Workshops, classes, lectures, seminars, events, reports

Resources

- Laboratory workspace
- Equipment and tools
- Knowledge and know-how

Value Proposition

- Providing a workspace
- Providing equipment and tools
- Providing training, knowledge and processes

Customer Relationships

- Workshops and camps
- Membership events

Channels

- Laboratory workspace
- Events and workshops
- Website and reports

Customer Segments

- Hobbyists
- Students

Costs

- Rents and utilities
- Laboratory equipment and tools
- Personnel wages

Revenues

- Membership fees
- Funding
- Donation
- Sponsorship

Economic Business Model Canvas

Supplies and Out-sourcing

- Laboratory equipment
- Utilities

Production

- Knowledge
- Project prototypes and sample
- Documentation

Materials

- Knowledge
- Project prototypes and sample
- Documentation

Functional Value

- Laboratory use and training for everyone

End-of-life

- Laboratory equipment and materials

Distribution

- Personnel traveling

Use Phase

- Laboratory workspace and equipment usage

Environmental Impacts

- Laboratory equipment and raw materials usage
- Utilities
- Website maintenance and server usage

Environmental Benefits

- Workspace and equipment sharing creating less waste
- Innovative projects with less harm to environment

Environmental Life Cycle Business Model Canvas

<table>
<tr>
<td rowspan="2">Local Communities
• Local educational institutions
• Local children</td>
<td>Governance
• Nonprofit organisation
• Autonomous
• Affliction with a DIY laboratory group</td>
<td rowspan="2">Social Values
• Education for everyone interested
• Access to laboratory workspace, equipment, knowledge and processes</td>
<td>Societal Culture
• Culture of open knowledge
• Promotion of science</td>
<td rowspan="2">End-User
• Knowledge
• Skills
• Creation
• Experience</td>
</tr>
<tr>
<td>Employees
• Staff
• Volunteers</td>
<td>Scale of Outreach
• Local
• Regional
• National
• International
• Worldwide</td>
</tr>
<tr>
<td colspan="2">Social Impacts
• Potential loss of intellectual property rights
• Potential conflicts with different societal groups</td>
<td colspan="3">Social Benefits
• Personal development
• Realization of one’s own potential
• Connectedness among similar-minded individuals in a community</td>
</tr>
</table>

Social Stakeholder Business Model Canvas

Figure 6. A triple-layered business model of DIY laboratories

5.2 DIY laboratories and technology incubation

DIY laboratories provide technology entrepreneurs with physical and social spaces and incubation to help them survive and thrive (Sarpong and Rawal, 2020). At the early stage of the entrepreneur journey, most technology entrepreneurs face risks and challenges to survive due to reasons such as limited access to resources financially and materially, and a lack of sufficient marketing knowledge and project management skills (Ferretti, 2019; Sarpong and Rawal, 2020). DIY laboratories are technology incubators that enable the process of technology transfer which provide laboratories, office space, equipment, legal advice and networking, mentoring services, and other administrative supports. Our findings from the cases of Genspace, Vigyan Ashram Fab Lab and c-base have shown that DIY laboratories offer technology entrepreneurs accessible support, training and knowledge, workspaces, and tools and equipment.

Our triple-layered business model analysis reveals that the classical Triple Helix interactions (university-industry-government relations) model is useful to understand and explain the role of DIY laboratories to engage all the Triple Helix parties to collaboratively support and promote technology entrepreneurs. This is seen from the case organizations in the form of collaborative actions; in Genspace they offer different levels of education institutions workshops for a fee, similarly as for corporations, for Vigyan Ashram Fab Lab they are connected to the education sector, not only in hopes of funding options but also possible necessary projects, while c-base offers industry-related companies membership fees that enable companies to be connected to and arrange events for the community of c-base. According to our business model analysis, DIY laboratories offer a platform of technology incubation for technology entrepreneurs to engage with and benefit from all the Triple Helix parties economically, socially, and sustainably.

5.3 DIY laboratories funding source and future impact

For economic-related issues of DIY laboratories, the main forms of revenue are through funding, membership fees, sponsorships (money or materials), laboratory knowledge as a product, and donations. Extant literature identified funding branches of government, industry, university, and personal sources (Nascimento et al., 2014; Ravetz et al., 2015), yet academic literature fails to mention different types of membership fees, laboratory knowledge as a product as well as material-based sponsorships. For Genspace, the revenues come from membership fees for those wishing to use the laboratory, workshops held for education institutions and private sector organizations at hire, lectures given outside of the laboratory and donations to the community. In the case of Vigyan Ashram Fab Lab, the DIY laboratory was established as a subsidy of an already existing organization and, as such, receives financial support from the parent organization or directly to the DIY laboratory. C-base, on the other hand, is its own entity with no affiliation with other organizations. Some DIY laboratories will utilize open calls to funding, varying from private foundation level, to country level, to EU level.

Another financial route is to be affiliated with an established education institution to attract donation and funding, just as Vigyan Ashram Fab Lab has done. It not only receives funding from the government but also partners with various companies in order to tackle its financial constraints. Although the Fab Lab in Vigyan Ashram may not specifically be the recipient of any given fund or partnership, they are able to access funds from the main Vigyan Ashram organization. In a similar fashion, c-base has separate memberships to companies and accepts sponsorships from companies in the form of materials or equipment.

The evolution of education and innovation can be dynamically impacted on by the activities of DIY laboratories within communities (Keulartz and van den Belt, 2016). With equipment becoming more affordable and accessible (Million-Perez, 2016), DIY laboratories can run workshops and education for the general public that would otherwise be accessed only by those in higher education institutions and those working in the research and technology industry. This promotes creativity and innovation and democratizes research, allowing for transparency and responsibility within research (Eitzel et al., 2017; Nosek et al., 2015; Berkes, 2005) in the economic, social, and environmental contexts. Therefore, the significance of DIY laboratories in education cannot be underestimated. DIY laboratories could be useful as teaching and learning resources for underfunded education systems in many countries, not only in developing countries but also in regions where access to education depends on social and economic status (Ferretti, 2019). Furthermore, fully-fledged community-based laboratories can become a learning platform for new researchers and experienced researchers to educate and train learners of any age and field. The future of DIY laboratories seems bright, as they are answering a need within communities where discrepancy of education and access to research is existing. In addition, DIY laboratories answer the desire within research to have more transdisciplinary research (Gray, 2008), which further enable an ideal setting for innovations, specifically radical innovations (Chesbrough et al., 2006). With the emergence of the sharing economy logic, (Frenken and Schor, 2019), it is only logical that DIY laboratories with the same logic are the way of the future.

5.4 DIY laboratories: environmental and social responsibility

The environment is currently one of the most topical issues within media and research. It is not surprising that it is an important aspect of DIY laboratories, as they are seen as the breeding ground of future sustainable solutions (Bergvall-Kåreborn, 2009). The benefits of DIY laboratories to the environment may be self-explanatory, yet this research identified specifically these factors: enabler for environmental solutions and innovations, sharing economy logic (Frenken and Schor, 2019), promotion of localized solutions that are applicable elsewhere, shared materials, and life-cycle thinking. Yet a less-discussed factor, but of substantial importance due to the ease of neglect, is the environmental impacts of DIY laboratories: material usage (virgin materials) in research and facilities, solution life-cycle and recycling, utility usage and their larger impact, website management and server impacts, and equipment acquisition, depreciation, maintenance, and disposal (Landrain et al., 2013).

From the social perspective of DIY laboratories, these communities believe and push forward open knowledge and sharing of physical products as well as ideas (Cloutier et al., 2018). They envision a world where all individuals are entitled to quality education, resources, technology, and sense of community. In their essence is a belief that all humans are created equal and have equal rights to pursue research and create meaningful jobs and lives. In addition, DIY laboratories hope to spark start-up companies and support them, as such providing economic growth and prosperity to spread well-being to individuals, economies, and communities. There are some social problems related to DIY laboratories. As laboratory equipment continues to become more affordable, easily accessible, and user-friendly, concerns of laboratory security and safety also rise (Tocchetti and Aguiton, 2015). This phenomenon is not only to the benefit of DIY laboratory communities, but may result in individuals acquiring equipment in private homes. With DIY laboratory spaces and their lack of formal structures, the problems of leadership arise. With the DIY movement, scientific discoveries shift from the top-bottom view to bottom-top, specifically so that discoveries and knowledge are transferred to the general public rather than a closed scientific community. As such, the development of a code of ethics is probably the most obvious example of the communities' desire to achieve a safe and secure environment in an otherwise flexible community. As such, different fields and communities may choose to follow existing guidelines, accreditation, or standards laid out by official entities. In addition to safety issues, other social impacts include questions of intellectual property and recognizing those who input work and those who are credited for no input (Cloutier et al., 2018). Further, allowing for shared use equipment brings questions of liability, the danger of supporting negative impacts (e.g. cyber-bullying), and possible resistance from local communities.

6. Conclusion

From a theoretical perspective, this research found that DIY laboratories do not have a well-established definition, and thus a definition for DIY laboratory has been proposed. In addition, we have attempted to map out some of the terms related to the DIY movement and how they affect the theoretical development of different research streams and disciplines. Further, our research is one of the first that attempts to observe and understand DIY laboratories from business model and management perspective. Our triple-layered business model of DIY laboratories contributes to the literature on laboratories management. Our research enriches the Triple Helix Model literature related to DIY laboratories from technology entrepreneur's perspective.

On a more practical level, especially focusing on the economic, environmental, and social value creation perspectives, we developed a triple-layered business model for DIY laboratories. DIY laboratories are technology incubators providing technology entrepreneurs with physical and social spaces and support to help them survive and thrive, providing laboratories, office space, equipment, legal advice and networking, mentoring services, and other administrative supports. This paper argues that DIY laboratories offer a platform of science innovation and technology incubation at the grassroots level for technology entrepreneurs to grow economically and socially, and to sustainably engage with all the Triple Helix parties. Practically, the paper aims to support the DIY laboratory movement, not as a competitor of traditional laboratories but as a less formal means to connect business and science to promote innovation and better solutions to solve modern day problems and thereby to create new business opportunities. In addition, the paper discusses the role of DIY laboratories within the educational field as a supportive tool.

Our study focuses on the financial sustainability aspects of DIY laboratories and specifically their business models; this has limited our ability to examine all relevant actions of the DIY laboratory cases selected as we focus on a more general view of the laboratories. We recommend future research to investigate the connections between DIY laboratories and Living Labs interfaces and the incubation services provided by the labs in relation to other incubation forms, ranging from business to high-tech, as well as how incubation relates to the broader scope of the start-up movement. Finally, we recommend studies into the possible connections between policy to enable DIY laboratories in their pursuit of open knowledge that leads to economic growth.

Reference

Bell, E., Bryman, A., Harley, B., 2018. Business research methods. Oxford University Press.

Bergvall-Kåreborn, B., Eriksson, C. I., Ståhlbröst, A., Svensson, J., 2009. A milieu for innovation: defining living labs. In ISPIM Innovation Symposium: 06/12/2009-09/12/2009.

Berkes, F., 2005. Commons theory for marine resource management in a complex world. Senri Ethnological Stud. 67, 13-31.

Bloom, P. N., Dees, G., 2008. Cultivate your ecosystem. Stanf. Soc. Innov. Rev. 6(1), 47-53.

Bolton, R., Thomas, R., 2014. Biohackers: the science, politics, and economics of synthetic biology. Innovations: Technol., Gov., Globalization 9(1-2), 213-219.

Bryman, A., 2016. Social research methods. Oxford university press.

Cavalcanti, G., 2013. Is it a Hackerspace, Makerspace, TechShop, or FabLab. Make, May, 22. Available from https://makezine.com/2013/05/22/the-difference-between-hackerspaces-makerspaces-techshops-and-fablabs/ (accessed on 18 October 2019).

Chesbrough, H., Vanhaverbeke, W., West, J., (Eds.) 2006. Open innovation: Researching a new paradigm. Oxford, UK: Oxford University Press.

Chevron., 2015. Partnering with the fab foundation. Available from https://www.chevron.com/stories/fab-foundation (accessed on 10 September 2019)

Cloutier, G., Papin, M., Bizier, C., 2018. Do-it-yourself (DIY) adaptation: Civic initiatives as drivers to address climate change at the urban scale. Cities, 74, 284-291.

Coates, T. T., McDermott, C. M., 2002. An exploratory analysis of new competencies: a resource based view perspective. J. Operations Manag. 20(5), 435-450.

Colegrove, T., 2013. Editorial board thoughts: libraries as makerspace?. Infor. Technol. and Libraries (Online), 32(1), 2.

Davies, S. R., 2017. Hackerspaces: making the maker movement. John Wiley & Sons.

Delfanti, A., 2014. Is do-it-yourself biology being co-opted by institutions? In Meta Life. Biotechnologies, Synthetic Biology, Alife and the Arts. UC Davis. Available from https://escholarship.org/uc/item/4nz3p0hf (accessed on 10 September 2019).

DITOS Consortium., 2018. Doing It Together Science: D6. 6 Innovation Management Plan:" Making citizen science work". DITOS Consortium: London, UK.

DIYbio.org., 2020a. Local groups. Available from https://diybio.org/local/ (accessed on 14 April 2020)

DIYbio.org., 2020b. An Institution for the Do-It-Yourself Biologist. Available from https://diybio.org/ (accessed on 14 April 2020).

Drucker, P., 1955. The Practice of Management. Allied Publisher.

Fab Foundation., 2020. What is the Fab Lab network?. Available from https://www.fabfoundation.org/getting-started/#fablabs-full (accessed on 14 April 2020).

Eisenhardt, K., Graebner, M., 2007. Theory building from cases: Opportunities and challenges. Acad. Manag. J. 50(1), 25-32.

Eitzel, M., Cappadonna, J., Santos-Lang, C., Duerr, R., West, S. E., Virapongse, A., West, S., Kyba, C., Bowser, A., Cooper, C., Sforzi, A., Metcalfe, A., Harris, E., Thiel, M., Hakley, M., Ponciano, L., Roche, J., Ceccaroni, L., Shilling, F., Dorler, D., Heigl, F., Kiessling, T., Davis, B., Jiang, Q., 2017. Citizen science terminology matters: Exploring key terms. Citizen Science: Theory and Practice, 2(1), 1-20.

Etzkowitz, H., Zhou, C., 2017. The triple helix: University–industry–government innovation and entrepreneurship. Routledge.

Ferretti, F., 2019. Mapping do-it-yourself science. Life Sci., Society and Policy, 15(1), 1.

Frenken, K., Schor, J., 2019. Putting the sharing economy into perspective. In A Research Agenda for Sustainable Consumption Governance. Edward Elgar Publishing.

Galaleldin, M., Bouchard, F., Anis, H., Lague, C., 2016. The impact of makerspaces on engineering education. Proceedings of the Canadian Engineering Education Association (CEEA).

Genspace., 2020. Join the lab. Available from https://www.genspace.org/join-the-lab (accessed on 14 April 2020)

Gobel, C., 2019. Participatory Research: Extending Open Science beyond the ivory tower - Open Science Barcamp 2019. Available from https://zenodo.org/record/2654994#.XXD5PJhKhPY. (accessed on 5 September 2019).

Goma, H. C., Rahim, K., Nangendo, G., Riley, J., Stein, A., 2001. Participatory studies for agro-ecosystem evaluation. Agriculture, ecosystems & environ. 87(2), 179-190.

Gray, B., 2008. Enhancing transdisciplinary research through collaborative leadership. Am. J. of Preventive Med., 35(2), S124-S132.

Grey, T., Dyer, M., Gleeson, D., 2017. Using big and small urban data for collaborative urbanism. In Citizen empowerment and innovation in the data-rich city (pp. 31-54). Springer, Cham.

Griffiths, A., 2014. DIY labs offer an agile alternative to university---based research, The Guardian, 16 June, Available from https://www.theguardian.com/higher-education-network/blog/2014/jun/16/diy-labs-exciting-alternative-university-science-research (accessed on 6 September 2019).

Guthrie, C., 2014. Empowering the hacker in us: a comparison of fab lab and hackerspace ecosystems. In 5th LAEMOS (Latin American and European Meeting on Organization Studies) Colloquium, Havana Cuba (Vol. 2, No. 5).
Hackerspaces.org., 2020. List of Hacker Spaces. Available from https://wiki.hackerspaces.org/List_of_hackerspaces (accessed on 14 April 2020).
Ireland, T., 2014. Do It Yourself. The Biologist, 61(3), 12-15.
Johnson, C., 2008. Accessible Science. Hackers Aim to Make Biology Household Practice. The Boston Globe, September 15. Available from http://archive.boston.com/news/science/articles/2008/09/15/accessible_science/ (accessed on 10 September 2019).
Joyce, A., Paquin, R., 2016. The triple layered business model canvas: A tool to design more sustainable business models. J. Clean. Prod. 135, 1474-1486.
Keulartz, J., van den Belt, H., 2016. DIY-Bio–economic, epistemological and ethical implications and ambivalences. Life Sci., Society and Policy, 12(1), 7.
Kshetri, N., 2018. Blockchain's roles in meeting key supply chain management objectives. Int. J. Info. Manag., 39, 80-89.
Landrain, T., Meyer, M., Perez, A. M., Sussan, R., 2013. Do-it-yourself biology: challenges and promises for an open science and technology movement. Systems and Synthetic Biol., 7(3), 115-126.
Ledford, H., 2010. Life hackers: amateur hobbyists are creating home-brew molecular-biology labs, but can they ferment a revolution?. Nat. 467(7316), 650-653.
Maker Faire., 2020. What is maker faire. Available from https://2019.makerfairerome.eu/en/what-is-maker-faire/ (accessed on 14 April 2020).
Markham, D., 2015. C-base. Digital in Berlin. Available from https://www.digitalinberlin.de/c-base/ (accessed on 13 November 2019).
Maxigas, P., 2012. Hacklabs and hackerspaces: Tracing two genealogies. J. Peer Prod. (2).
Menichinelli, M., 2011. Business Models for Fab Labs. Available from http://www.openp2pdesign.org/2011/fabbing/business-models-for-fab-labs/ (accessed on 24 October 2019).
Menichinelli, M., 2013. What is a FabLab? Available from http://www.openp2pdesign.org/2013/spaces/what-is-a-fablab/ (accessed on 24 October 2019).
Meyer, M., 2012. Build your own lab: Do-it-yourself Biology and the Rise of citizen biotech-economies – Invited Comment. J. Peer Prod. 4(3), pp. 173-174.

Meyer, M., 2013. Domesticating and democratizing science: a geography of do-it-yourself biology. J. Mater. Culture, 18(2), 117-134.

Million-Perez, H., 2016. Addressing Duel-Use Technology in an Age of Bioterrorism: Patent Extensions to Inspire Companies Making Duel Use Technology to Create Accompanying Countermeasures. AIPLA QJ, 44, 387.

Minkler, M., Wallerstein, N., 2003. Community-based participatory research for health. San Francisco: Jossey-Bass.

Moilanen, J., 2012. Emerging hackerspaces–peer-production generation. In IFIP International Conference on Open Source Systems (pp. 94-111). Springer, Berlin, Heidelberg.

Nascimento S., Guimarães Pereira Â., Ghezzi A., 2014. From citizen science to do it yourself science: An annotated account of an on-going movement. EUR, Scientific and technical research series: vol. 27095. Luxembourg: Publications Office.

Nosek, B., Alter, G., Banks, G., Borsboom, D., Bowman, S., Breckler, S., Buck, S., Chambers, C., Chin, G., Christensen, G., Contestabile, M., Dafoe, A., Eich, E., Freese, J., Glennerster, R., Goroff, D., Green, D., Hesse, B., Humphreys, M., Ishiyama, J., Karlan, D., Kraut, A., Lupia, A., Mabry, P., Madon, T., Malhotra, N., Mayo-Wilson, E., McNutt, M., Miguel, E., Levy Paluck, E., Simonsohn, U., Soderberg, C., Spellman, B., Turitto, J., VandenBos, G., Vazire, S., Wagenmakers, E., Wilson, R., Yarkoni, T., 2015. Promoting an open research culture. Sci., 348(6242), 1422-1425.

O'Leary, A., 2012. Worries Over Defense Department Money for 'Hackerspaces'. Available from https://www.nytimes.com/2012/10/06/us/worries-over-defense-dept-money-for-hackerspaces.html (accessed on 10 September 2019).

Olsen, W., 2004. Triangulation in social research: qualitative and quantitative methods can really be mixed. Developments in Sociology, 20, 103-118.

Osterwalder, A., Pigneur, Y., 2010. Business model generation: a handbook for visionaries, game changers, and challengers. John Wiley & Sons.

Ranta, V., Aarikka-Stenroos, L., Ritala, P., Mäkinen, S., 2018. Exploring institutional drivers and barriers of the circular economy: A cross-regional comparison of China, the US, and Europe. Resour., Conservation and Recycling, 135, 70-82.

Ravetz, J., Pereira, Â. G., Nascimento, S., 2015. Do It Yourself Science: Issues of Quality. Publications Office of the European Union. Available from http://bookshop.europa. eu/en/do-it-yourself-science-pbLB0415970 (accessed on 10 September 2019).

Revill, J., Jefferson, C., 2013. Tacit knowledge and the biological weapons regime. Sci. Public Policy 41(5), 597-610.

Rip, A., Voß, J., 2013. Umbrella terms as mediators in the governance of emerging science and technology. Sci., Technol. & Innov. Stud. 9(2), 39-59.

Ritala, P., Golnam, A., Wegmann, A., 2014. Coopetition-based business models: The case of Amazon. com. Industrial Market. Manag. 43(2), 236-249.

Rusko, R., 2011. Exploring the concept of coopetition: A typology for the strategic moves of the Finnish forest industry. Industrial Market. Manag. 40(2), 311-320.

Sarpong, D, Rawal, A, 2020. From the open to DiY laboratories: managing innovation within and outside the "rm. In: Fritzsche, A., Fritzsche, A, Jonas, J.M., Roth, A., Möslein, K.M. (Eds.), Innovating in the Open Lab: The New Potential for Interactive Value Creation across Organizational Boundaries, https://doi.org/10.1515/ 9783110633665-023. De Gruyter Studies in Innovation and Entrepreneurship.

Sarpong, D., Ofosu, G., Botchie, D., Clear, F., 2020. Do-it-yourself (DiY) science: The proliferation, relevance and concerns. Technol. Forecast. Soc. Change 158.https://doi.org/10.1016/j.techfore.2020.120127

Sarpong, D., Meissner, D., Botchie, D., 2019. The rise of Do-It-Yourself (DIY) Laboratories: Implication for Science, Technology, and Innovation (STI) Policy. Technol. Forecast. Social Change. Available from https://www.journals.elsevier.com/technological-forecasting-and-social-change/call-for-papers/the-rise-of-do-it-yourself-diy-laboratories (accessed on 11 September 2019).

Stone, Z., 2015. The Maker Movement Taking Over America. Here's How. Available from https://thehustle.co/the-diy-maker-movement-survives-by-doing-the-opposite-of-whats-smart (accessed on 9 March 2020)

Søndergaard, M., 2014. FabLab@School.dk workshop challenges schoolteachers to program LilyPads and robots. Available from http://cavi.au.dk/latest/news/enkelt/artikel/fablabschooldk-workshop-challenges-schoolteachers-to-program-lilypads-and-robots/ (accessed on 10 September 2019).

Tocchetti, S., 2014. How did DNA become hackable and biology personal? Tracing the self-fashioning of the DIYbio network (Doctoral dissertation, The London School of Economics and Political Science (LSE)).

Tocchetti, S., Aguiton, S., 2015. Is an FBI Agent a DIY Biologist Like Any Other? A Cultural Analysis of a Biosecurity Risk, Science, Technology, & Human Values, 40(5), 825–853.

Trabulsi, A., 2015. How DIY engineers are challenging global manufacturing. World Economic Forum. Available from https://www.weforum.org/agenda/2015/04/how-diy-engineers-are-challenging-global-manufacturing/ (accessed on 5 March 2020).

Troxler, P., 2010. Commons-based peer-production of physical goods: Is there room for a hybrid innovation ecology? In 3rd free culture research conference, Berlin.

Troxler, P., Wolf, P., 2010. Bending the rules. The Fab Lab innovation ecology. In 11th International CINet Conference, Zurich, Switzerland (pp. 5-7).

Tweney, D., 2009. DIY freaks flock to 'hacker spaces' worldwide. Wired. Available from https://www.wired.com/2009/03/hackerspaces/ (accessed on 13 November 2019).

Van Holm, E., 2014. What are makerspaces, hackerspaces, and fab labs?. Hackerspaces, and Fab Labs.

Wray, B., 2012. Changes at the lab bench: interdisciplinary art and life's new design (Masters Thesis, OCAD University). Available from http://openresearch.ocadu.ca/id/eprint/102/4/B%20WrayThesis%20FINAL.pdf (accessed on 5 September 2019).

Yin, R., 2017. Case study research and applications: Design and methods. Sage publications.

Zott, C., Amit, R., Massa, L., 2011. The business model: recent developments and future research. J. Manag. 37(4), 1019-1042.