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PROVIDING A CONDUCIVE ENVIRONMENT TO INTEGRATE DESIGN AND PRODUCTION: ASSESSING THE POTENTIALS OF UNIVERSITY-BASED FABLABS (UB-FABLABS)

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Abstract

While design plays an important role in economic growth, the unanticipated high output of wastes during a product's lifecycle puts to question the current practice of design and production. According to Siefried Dais (Tscheiesner & Loffler 2016 Interview), the current design and manufacturing sectors operate in isolation. The design sectors formulate product solutions and design specifications while the manufacturing sectors produce for the customers. This gap needs to be bridged so that, not only will customers be empowered to design and produce, but also responsiveness to resource conservation and sustainability. This paper discusses findings into a potential platform that can integrate design and production- the Digital Fabrication Laboratories. A mixed method of participant observation and online content analysis was carried out on 53 university-based fablabs. Results revealed the following strengths of four criteria: i) digital technological infrastructures – 97%, ii) constructionist pedagogical approach – 84%, iii) collaboration through networking – 58%, iv) sustainability- 41%. This proposes a potential platform for the integration of design and production.

Keywords: University-based fablabs, Sustainability, Ecodesign, Circular economy, Constructionist pedagogical approach

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1 INTRODUCTION

Design plays a critical and important role in economic growth in the western world and elsewhere through history, however, the unanticipated high output of wastes during the lifecycle of a product and the unexpected market crashes of 2001 and 2008 (Bono and Pilsbury, 2016) puts to question the current practices of design and production. According to Siefried Dais (Tscheiesner and Loffler, 2016 Interview), the current design and manufacturing sectors/companies operate in isolation. The design companies create product solutions and design specifications for customers while manufacturing companies/industries produce for the customers by the mass production processes. This approach, not only has it concentrated skills to only the 'experts' in the fields of design and production, but responsive attitudes towards resource conservation and sustainability (inclusive of eco-design and circular economy aspects) may not have been incubated or nurtured within these sectors. This gap therefore needs to be bridged. This calls for a platform that has the capacity to integrate design and production in an environment where not only skills and knowledge of high-tech production machines are gained but also an environment where collaboration through digital networking, educational and responsive attitudes towards resource conservation and sustainability could be incubated. One of a promising design and production platform is the digital fabrication laboratories (commonly known as Fablabs). For the purpose of this paper, the capacities of fablabs established in universities (particularly in science and engineering faculties within the university) and will be evaluated. The term University-based Fablabs or Ub-Fablabs for short will be used throughout this paper to distinguish these fablabs from industry or entrepreneurship-oriented Fablabs.

These science and engineering faculties in universities have to train students who will influence design and production industries in the future. Therefore the Ub-Fablabs that these students spend most of their time designing, producing and testing their prototypes and products in need to have an environment that is conducive to incubating and nurturing proactive minds for the integration of design and production in the future. This paper therefore assesses the capacities of these Ub-Fablabs in playing this important role in facilitating the future integration of design and production industries.

This paper will firstly discuss the concepts of fablabs, sustainability (inclusive of eco-design and circular economy), emerging technologies and constructionist pedagogical approach in section two. The sections that follow include the methodology, data analysis and discussions, limitations of the study and the conclusion.

2 THEORETICAL BACKGROUND

2.1 The Fablab Concept

The concept of Fablabs was founded by Professor Neil Gershenfeld and his team in the Massachusetts Institute of Technology Center for Bits and Atoms (MIT CBA) in Boston in 2003. Fablabs are physical spaces equipped with specific low-cost technological infrastructures for digital fabrication where people meet face-to-face to invent and make (almost) anything together (Gershenfeld, 2005). In less than two decades, the concept spread throughout Europe and other regions of the world like wildfire. Europe leads in hosting 57% of these fablabs followed by the North American region (27%), Latin America and the Caribbean (10%), Asia (9%), Africa and the Sub-Saharan (4%), the Middle East (3%) and Oceania (1%) (Figure 1).

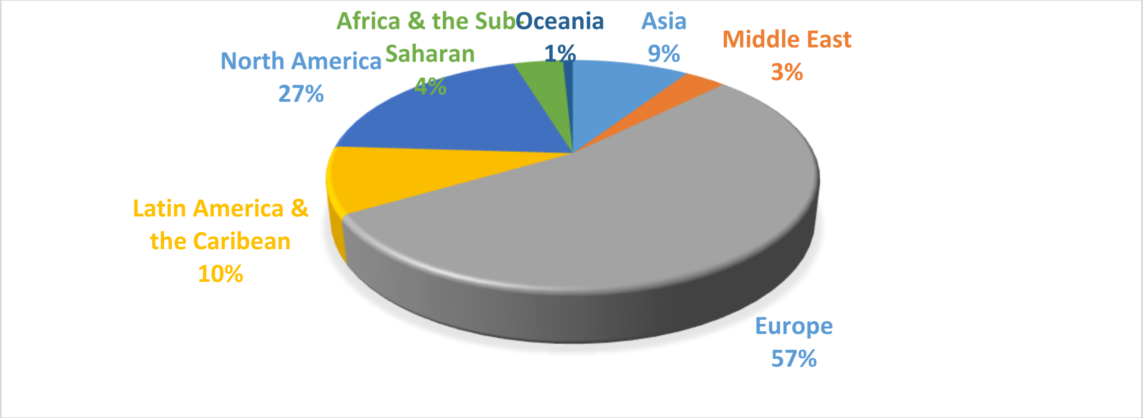

Figure 1. Distribution of Fablabs in the major regions [Source: Botleng, Brunel and Girard, 2016]

The emergence of makerspaces such as the fablabs at the turn of this century has generated many novel approaches to augment traditional manufacturing processes and encouraged a series of shifts: from ‘centralized’ mass production towards ‘distributed’ mass production; from ‘dictated’ technology towards ‘democratized’ technology; from ‘specialized engineers’ towards ‘ordinary people’; and from ‘uniformed’ products towards more customized or personalized products (Gordon, 2011).

Out of the total number of more than 1,123 Fablabs worldwide (Fablab website, n.d.), 13% of these Fablabs are established in educational settings while 87% are established in communities for entrepreneurship. In the educational setting 58% of these are established in the Universities, while 38% are established in high schools and 4% are established in the elementary schools (Figure 2).

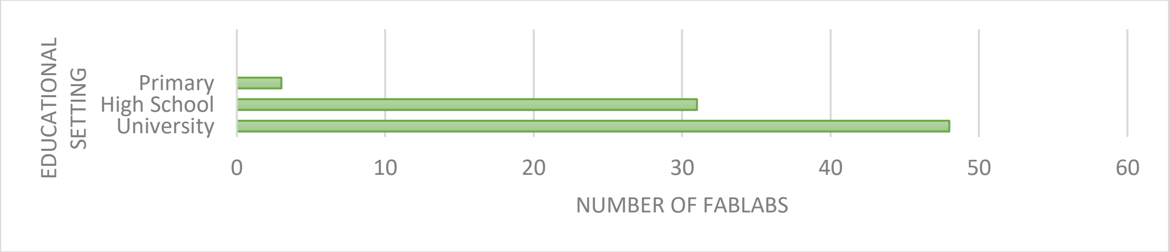

Figure 2. Distribution of fablabs in educational settings

These Ub-Fablabs are being used as platforms for learning and innovations. With the need to bridge the gap in the current practices between design and production industries, these Ub-Fablabs can also serve as ‘support platforms’ to contribute to incubating proactive minds for the future integration of design and production industries.

2.2 Keeping within the realm of a sustainable development approach (inclusive of eco-design and circular economy) to design and production while embracing new and emerging technologies and utilising effective pedagogical approaches in Ub-Fablabs

The terms ‘sustainable’ and ‘sustainability’ have no universally accepted definitions. Different people have differing views on these terms. It has often been used in the past in ecology to refer to the biological systems and how they endure and remain diverse and productive. The term was extended to refer to ‘sustainable development’ by the Brundtland Commission Report in 1987, which, five years later, laid the groundwork for the convening of the Earth Summit in Rio de Janeiro in 1992 (HEC Global Learning, n.d.). Applying this term to design and production, it refers to eco-design approaches in manufacturing industries that utilise renewable energy sources and eco-design materials thus contributing to a circular economy (Ellen MacArthur Foundation, n.d; Girling, 2005).

The concepts of circular economy and eco-design are closely related in the sense that to gain a truly circular economy, products have to be eco-designed. The concept of circular economy (consisting of four building blocks namely Circular economy Design, New business models, Reverse cycles, Enablers and favourable system conditions) was first touted by environmentalists John T Lyle and Walter Stahel in 1970s and re-emerged in 2010 by the Ellen MacArthur Foundation and advocated by celebrities like Arnold Schwarzenegger (Ellen MacArthur Foundation, n.d.). Circular economy calls for an industrial economy that produces no waste and pollution, by design or intension and in which materials flows are of two types: biological nutrients, designed to enter the biosphere safely, and the technical nutrients, which are designed to circulate at high quality in the production system without entering the biosphere as well as being restorative and regenerative by design (ibid).

According to Girling (2005), 90% of the raw materials used in manufacturing become a waste before the product leaves the factory while 80% of the products are thrown away within the first six months of their life. Although recycling materials to produce secondary materials has been adopted by the current manufacturing industries, the recycling process to regenerate secondary materials involves a high energy consumption and downgrades materials for productions. To achieve circular economic targets, the platform's goal would not be to meet a better end-of-life recovery but to minimise energy use. McKinsey's analysis of business profits applying circular economy projects an astonishing figure of a $1 trillion addition to the global economy and that 100,000 new jobs could be created within the next five years. Several governments have started to implement these concepts, for example, the CACE association in China, the circular economy blueprint in Scotland and the European Commission's Circular Economy Framework (Perella in Guardian Sustainable Business, n.d). In France, there are discussions on the need for its education system to be geared towards preparing future engineers in sustainable development and eco-design (Catherine, Robin and Girard, 2017). The introduction of these concepts into the curriculum would make physical spaces like the Ub-Fablabs a practical venue for implementation. This practice would undoubtedly place more responsibilities on the users thus a shift in minds could go from users seeing themselves as just consumers of products to designers, producers as well as users of products. A more responsible attitude could be incubated by this approach.

Eco-design is an approach to designing products with special consideration for the environmental impacts of the product during procurement, manufacture, use and disposal stages of the product (Girling, 2005). The fundamental rational for this approach is to design products that are environmentally friendly which would lead to a reduction in the consumption of materials and energy thus the concept of sustainability is upheld.

The new and emerging technologies (Bono and Pilsbury, 2016; Barlex, Given, Hardy and Steeg, 2016) could facilitate the integration of design and production industries in the future. The new and emerging technologies are impacting the design and production industries and the general society in a way that has not been in the past (ibid). The McKinsey Global Institute used the term 'disruptive technologies' to refer to these new and emerging technologies. Four features were suggested to mark out a technology as having the potential to be disruptive (see Barlex et al 2016, p. 77 for the description of the four features by Manyika et al, 2013). Barlex et al (2016) identified nine technologies that meet McKinsey criteria (see list of the nine technologies in Barlex et al 2015, p. 77-78). Out of these nine technologies, Bono and Pillsbury (2016) signalled out four technologies that can directly influence design and production. These four technologies are: i) Internet of Things (IoT); ii) Robotics; iii) Augmented Reality (AR) and iv) 3D printing (or Additive manufacturing). Pilsbury and Bono (2016) have stressed that these new technologies need to be embraced by industries in order to improve productivity, complete against rivals and maintain an edge with customers. In line with the need to embrace new technologies, a concept that is starting to appear in literatures is the concept of '*Industries 4.0'*. Originating from a German Governmental working group, the concept refers to the current trend of automation and data exchange in manufacturing technologies (Hermann, Otto and Pentek, 2016). The IoT and cloud computing is transforming '*…the physical world into a type of information system through sensors and actuators embedded in physical objects and linked through wired or wireless networks via the Internet Protocol'* (Tschiesner and Loffler 2016: 1). In manufacturing, this IoT could pave way for machines, work pieces and systems to be connected and business intelligent networks could be created along the entire value chain to control each other autonomously (ibid). With the invention of CAD and CAM computer software programs and computerized production machines, like the ones found in Ub-fablabs, it has finally come to a stage when it is possible to integrate design and production.

To nurture the responsive attitudes towards resource conservation and sustainability during design and production, the environment in these Ub-Fablabs must also be inviting and be gender-neutral. It has to have an environment where a user feels free to design and produce anything he/she wants while at the same time learns and collaborates with others. The open-access status, digital networking and Seymour

Papert's Constructionism approach to learning using *'manipulative materials' aided by technology'* (Martinez and Stager 2013, p. 72) can offer for that environment.

2.3 Assessing the capacities of Ub-Fablabs

Drawing from a whole wide range of proposals and discussions in the literatures on best forecast mechanisms and infrastructures in integrating design and production, this study proposes a requirement matrix (Figure 3) and an analytic scoring rubric (Table 1) to use to assess the capacities of these Ub-Fablabs. To be able to integrate design and production, Ub-Fablabs should:

1. provide a sustainable digital technological infrastructure
2. enhance collaborations through digital networking
3. cater for a Constructionist pedagogical approach
4. be responsive to resource conservation and sustainability (inclusive of eco-design and circular economy)

1.

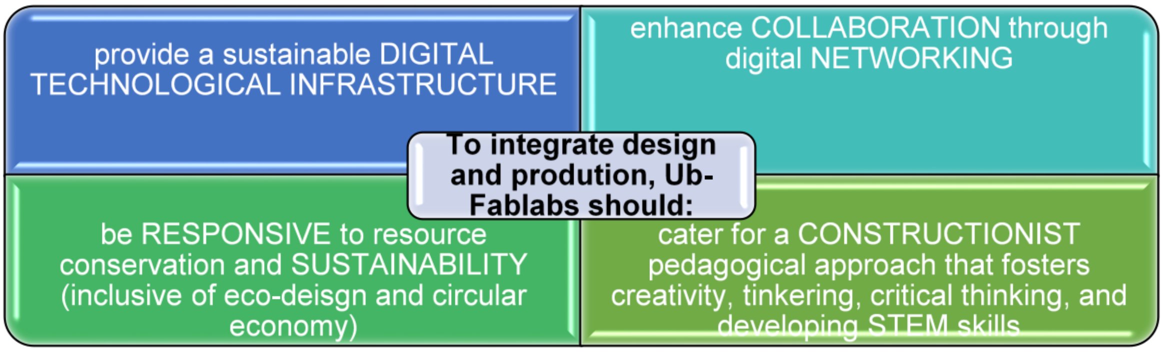

Figure 3. Ub-Fablabs proposed requirement matrix

This study proposes a three-level criteria for assessing the capacities of these Ub-Fablabs (see Table 1). Each level describes the indicators and a numerical score is assigned to each level, for example Level 3 = 3 points; Level 2= 2 points and Level 1= 1 point.

Table 1. An adapted Analytic scoring rubric used to score on Ub-Fablab potentials in integrating design and production.

	The indicators of Ub-Fablab capacities		
Aspects	**Level 3: Outstanding mechanisms/systems and technological infrastructures**	**Level 2: Substantial mechanism/systems and technological infrastructures**	**Level 1: Yet to provide mechanism/system and technological infrastructures**
Digital Technological Infrastructures	Fully equipped with the latest digital fabrication machines /tools for production: Additive machines (3D printers), subtractive machines: (CNC Milling, Laser cutters and Etchers, Precision Milling, Vinyl Cutter), Circuit Production, CAD and CAM software programs; Conventional machines/tools also used to complement digital machines/tools; Information easily accesses through internet use via the Fablab website.	Equipped with only a computer with internet connectivity ; only digital subtractive and conventional machines and tools	A computer and internet connectivity without any digital fabrication machines
Constructionist Pedagogical approach	Fablab environment conducive to rigorous approach to hands-on constructions and an environment where users collaborate to design and produce using digital fabrication machines; CAD and CAM software programs allowing iterations between each stage of design to enhance Science, Technology, Engineering and Mathematics (STEM) knowledge and skills; Open access status to allow a gender-neutral environment to promote female participation in STEM fields.	The Fablab environment is not too conducive for collaborative designs; iterations using CAD and CAM software programs restricted.	There is very little hands-on activities in the fablabs; only use conventional machines and tools.
Collaboration through digital Networking	Internet connectivity and in-dept. information accessed via the Fablab network website; Indication of active participation in fablab network forums, sharing of information and designs with other Ub-Fablabs	Access to internet connectivity and information accessed via fablab network website; sharing of designs/projects with other Ub-Fablabs, but no active participation in fablab network forums.	Access to internet connectivity and information accessed via Fablab website; no active participation in forums and sharing of designs/projects.
Sustainability (inclusive of eco-design and circular economy)	Well ventilated, spacious and attractive fablab building; some use of renewable energy sources e.g. solar; use of eco-design materials (biodegradable or compostable); additive manufacturing process that reduces waste (indicator: use of 3D printer).	Well ventilated building, but does not use any form of renewable source of energy; use mainly subtractive machines/tools (contributes to wastes)	Crowded and dull looking building /room with a lot of waste produced from subtractive and conventional machines/tools.

3 METHODOLOGY

This study used a mixed (quantitative and qualitative) approach to research and a mixed research methods of participant observation and online content analysis (Krippendorff and Klaus, 2012; Selm, Martine and Jankowski and Nick, 2005). Online Content analysis follows a basic research procedure indistinguishable from the traditional content analysis using offline sources (McMillan, 2000). Participation observation was also done in ‘Fablab for Education’ in Bordeaux University in France to ensure that triangulation of methods is served and thus the credibility of this study. To abide with cyberspace privacy (Murphy, 2011) the researcher, being a registered member of the Fablab, solely has the access to internal information of fablabs and online projects from the Fablab network website and thus no mention of specific Ub-Fablabs through the internet searches will be made. Codes were used instead to refer to these Ub-Fablabs, for example, UbF20 refers to Ub-Fablab number 20. A total of 53 Ub-Fablabs were used for this study (see Table 2). This represents 90% of the total Ub-Fablabs worldwide.

Table 2. The sample of Ub-Fablabs used in this research.

Major Region	Number of Ub-Fablabs surveyed	Fablab assigned Codes
Western Europe	17	UbF1, UbF2, UbF3, UbF4, UbF5, UbF18, UbF19, UbF21, UbF22, UbF23, UbF24, UbF25, UbF26, UbF27, UbF28,UbF33, UbF37,
Eastern Europe	5	UbF16, UbF29, UbF30, UbF31, UbF32
Southern Europe	5	UbF42, UbF43, UbF44, UbF45, UbF46
Northern Europe	5	UbF17, UbF20, UbF34, UbF38, UbF47
Northern America	8	UbF9, UbF10, UbF48, UbF49, UbF50, UbF51, UbF52, UbF53
Latin America	9	UbF6, UbF7, UbF8, UbF11, UbF12, UbF15, UbF35, UbF36, UbF39
Asia	4	UbF13, UbF14, UbF40, UbF41
Total	53	

Data was collected using a scoring sheet and an adapted analytic type of scoring rubric (see Table 1 above) was used to analyse the capacity of the Ub-Fablabs. A numerical score is assigned to each level, for example Level 3 = 3 points; Level 2= 2 points and Level 1= 1 point. The results are depicted in both a table and a radar graph in the results section.

4 RESULTS AND DISCUSSIONS

This paper proposed a criteria to assess the potentials of Ub-Fablab (Table 1). Data collected from the 53 Ub-Fablabs using a scoring rubric was analysed. Due to space limitations, Table 2 shows only scores from the first 10 Ub-Fablabs. Note that Ub-Fablabs scoring 3 points meet Level 3 standard; 2 points = Level 2 standard and 1 point = Level 1 stand (refer to Table 1 for the standards).

Table 3. Summary of tally for Level 3, Level 2 and Level 1 Ub-Fablabs

	Ub-Fablabs meeting requirements at each level		
Aspect	**LEVEL 3**	**LEVEL 2**	**LEVEL 1**
Digital Technological Infrastructures	UbF1- UbF3, UbF6 - UbF10, UbF12 - UbF32, UbF35-UbF53 (Total = 48)	UbF4 - UbF5, UbF11, UbF33, UbF34 (Total =5).	None
Constructionist Pedagogical approach	UbF1 – UbF3, UbF7-UbF10, UbF13-UbF14, UbF16 -UbF19, UbF21-F23, UbF25-UbF28, UbF30, UbF32, UbF35, UbF36,UbF39, UbF41-UbF42, UbF44, UbF48, UbF51 (total = 30)	UbF4- UbF6, UbF11 - UbF12, UbF15, UbF24, UbF29, UbF31, UbF37- UbF38, UbF40, UbF43, UbF45-UbF46, UbF47, UbF49-UbF50, UbF52- UbF53 (total = 20)	UbF20, UbF33- UbF34 (total = 3).
Collaboration through digital Networking	UbF17, UbF48, UbF52- UbF53 (total = 4)	UbF1, UbF3, UbF6- UbF11, UbF13 -UbF16, UbF18 - UbF19, UbF21- UbF22, UbF23- UbF28, UbF30, UbF32, UbF35 - UbF37, UbF39-UbF42, UbF44 -UbF46, UbF52 (total = 35)	Ub2, UbF4- UbF5, UbF12, UbF20, UbF29, UbF31, UbF33- UbF34, UbF38, UbF43, UbF47, UbF49- UbF50 (total=14)
Sustainability (inclusive of eco-design and circular economy)	UbF3, UbF7, UbF13, UbF17, UbF19, UbF25, UbF27, UbF51 (total = 8)	UbF1, UbF8-UbF11, UbF14 - UbF16, UbF18, UbF22 -UbF24, UbF26, UbF28, UbF30 - UbF32, UbF35-UbF37, UbF39-UbF42, UbF44, UbF48, UbF52(total = 27)	UbF2, UbF4- UbF6, UbF12, UbF20 - UbF21, UbF29, UbF33 - UbF34, UbF38, UbF43, UbF45-UbF47, UbF49- UbF50, UbF53 (total = 18)

Calculating the percentages of each aspect, the radar graph (Figure 4) indicates the strengths for each aspect.

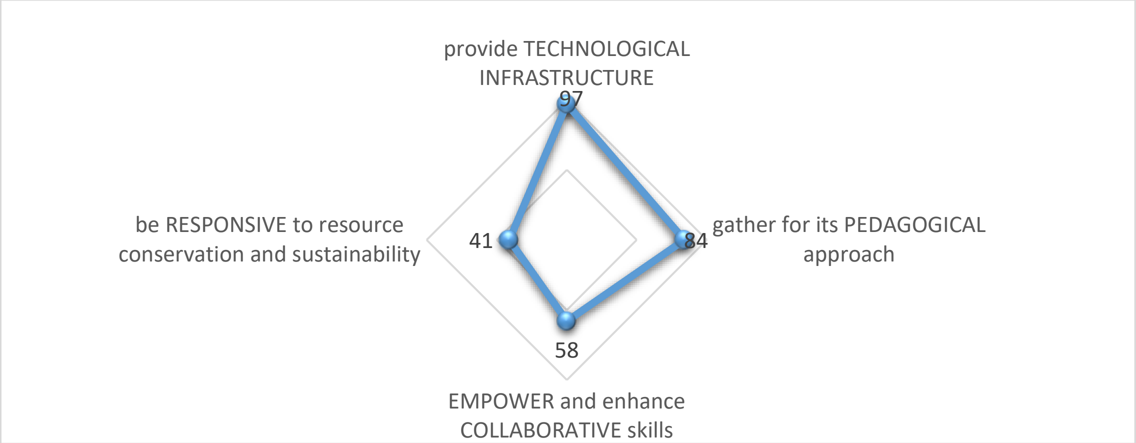

Figure 4. Graph showing strengths in the aspects of Ub-Fablabs

The Ub-Fablabs reveal a 97% strength in the provision of a technological infrastructure that can integrate design and production. The latest high-tech digital production machines in these Ub-Fablabs include standardised machines produced by the MIT CBA. These machines include the 3D printers (Additive manufacturing machine), CNC Millers, Laser cutters and etchers, Vinyl cutters, precision milling (subtractive manufacturing machines) and Circuit Productions. These machines are able to print, cut or mill objects from CAD files (data files).The standardised computers are the IBM-compatible computers supported by Computer –Aided Engineering (CAE) software such as the Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) software. These production machines and software being standardised enhance Fablab collaborations and avoids the problems of compatibility of machines between the Fablabs. The software used in Fablabs are also available under the Open-source (or comparable) licenses therefore are adaptable and developable (Walter-Herrmann and Buching, 2013, p.2).

Aided by technology, the constructionist approach to learning by the process of tinkering, meddling and experimenting using the Ub-Fablab digital fabrication machines shows a strength of 84%. The use of computers, CAD and CAM software programs allows an iterative approach to design and production. Unlike traditional approaches to the design process, for example the Waterfall Model (Martinez and Stager 2013) where each stage of the design process is completed before one proceeds to the next stage, the iteration approach allows one to iterate between the stages of the design process thus enhances cognitive processes and reinforces and improve engineering skills.

Empowering and enhancing collaboration skills through networking shows a low strength rating of 58%. One reason for this that due to the '…*'the rapidly growing size of the network (the fablab network) …impeding the development of interconnections between the Fablabs as there were more people with different backgrounds and for the time it takes to know each other'* (Troxler, Wolf et al 2014, p. 16). However, these Ub-Fablabs are interconnected via the Fablab network website therefore the users can upload and access projects and designs from other fablabs readily. The wonder of this capacity is described by Gershenfeld (2012) by this success story:

> From the Boston lab, a project was started to make antennas, radios and terminals for wireless networks. The design was refined in a fablab in Norway, was tested at one in South Africa, was deployed from one in Afghanistan, and is now running on a self-sustaining commercial basis in Kenya. None of these sites had the critical mass of knowledge to design and produce the networks on its own. But by sharing design files and producing the components locally, they could do so together (p. 11).

Being responsive to the environment has shown the least weighting here of a 41% strength. While there are rooms for improvement by Ub-Fablabs in this aspects in the future, these fablabs are already taking some lead in ecodesign and showing some promising signs of contributing to a circular economy in the future. All the Ub-Fablabs surveyed use a 3D printer. The 3D printers, using additive manufacturing processes only adds materials needed based on a digital file. This therefore uses up to 98% of raw materials for the finished part/product and saves up to 50% of energy compared to subtractive manufacturing processes which could waste up to 30 pounds of materials for every 1 pound of useful material in some parts (Greene and Matulka, n.d.). The 3D printers in these Ub-Fablabs use mainly Polylactide (PLA) plastic filaments for Fused Deposit Modelling method of production (Martinez and Stager, 2013). The PLA filaments, being made out of corn-starch or sugar are potentially biodegradable if not composting.

5 LIMITATIONS OF THIS STUDY

While all steps in the research design are thoroughly planned and revised before investigating the capacities of Ub-Fablabs in this study, there are limitations worth mentioning. The concept of Fablabs, only emerged in 2001, is still a new concept to many. There is therefore very little or no prior research into the capacities of Ub-Fablabs in integrating design and production. There are also no data collection and analysis instruments from prior researches therefore the instruments used to collect and analyse data in this study are adapted from various sources from related fields (see Krippendorff and Klaus, 2012; Selm, Martine and Jankowski and Nick, 2005; McMillan 2000; Murphy, 2011). This study therefore may serve as an exploratory research study to lay some groundwork for future researches into Ub-Fablabs. The adapted instruments used in this study would also make a good starting point in developing research tools for future researches in this field.

6 CONCLUSION

This paper has highlighted the capacities of Ub-Fablabs as a support platform to incubate and nurture proactive minds for the future integration of design and production industries. The findings revealed that Ub-Fablabs have a 97% strength in providing a digital technological infrastructure and an 84% strength in enabling a constructionist pedagogical approach that will enhance STEM knowledge and skills, which are required for the future integration of design and production. The other two aspects: collaboration through digital networking and sustainability (inclusive of eco-design and circular economy) shows a 58% strength and 41% strength respectively, which, needs more attention to by the universities.

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