

Open Source Hardware for Human Development

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Abstract

Human Development is not a term used in casual conversation, it describes the current approach used by large aid international development organizations like the United Nations; but most people are familiar with the terms “emergency relief” and “humanitarian intervention”. Emergency relief focuses on providing assistance to save lives, alleviate suffering, or protect populations; while human development uses various societal levers to improve living conditions. The United Nation has been publishing an annual report on human development since 1990 (UNDP 1990), and it is widely recognized as a consistent measure of global living conditions. Development strategies revolve around a transfer of something valuable to an aided population: education, vaccination, fertilizers, etc. In technology-based human development projects, technology artefacts (a medical record computer system, solar electrification systems, irrigation) and related knowledge (education, operation and maintenance instruction) are those valuables being transferred.

The benefits of technology are specific to each economy, and dependant on how quickly technology is adapted and integrated in the local economy (Cypher & Dietz 2008). The value of ideas increases to the degree they can be shared with and used by others (Houghton & Sheehan 2000): the more knowledge is diffused and adopted, the greater its value. The success of free and open-source software exemplifies this principle, and a growing number of scholars agree that the model also applies to hardware (Balka et al. 2009; Thompson 2008).

This thesis presents research on open source hardware and its knowledge-sharing approach as a means to human development. It presents a model that leverages the collaborative design methodology of open hardware for adoption of artefacts that address pressing “humanitarian technology” needs, for example, in health or education. To achieve

this, critical literature reviews on open source and on technology-based human development are first done; the findings from literature are then complemented with the findings from interviews and case studies to model a sustainable deployment strategy for open source use in human development projects. Adopting the human development paradigm defined in the first *Human Development Report* (“HDR1990”), which aims at three people-centered aspirations: to live a long and healthy life, to be educated and to have access to resources needed for a decent standard of living (UNDP 1990).

This thesis research models its deployment strategy using the Soft Systems Methodology (SSM), showing that: (a) open source hardware, like any technology used in development, can magnify effective development programs when used appropriately; (b) Dr. E.F. Schumacher’s appropriate technology principles, and P. Polak’s reinstatement, mesh very well with the open source methodology, as long as required constituents in the aided communities are taken care of (availability of electricity, internet access, technical know-how, etc.); (c) extreme affordability is particularly important for open source hardware, because a sustainable strategy is based on the belief that aided population would want to procure these artifacts if they improve their earning potential; (d) participatory human development practices work well with the open source methodology, but “solutions” must be fully verified before deployment.

This document is structured in 5 chapters: introduction, literature review, research strategies, case studies and interviews, and conclusion. The appendix include three articles published on parallel work for the Institute of Electrical and Electronic Engineers (IEEE) on defining a strategy for the IEEE’s use of opens source technology in their humanitarian activities. This research provides insight into the new topic of open source hardware and its proposed use in the mission critical context of international development; because

entrepreneurship is a key enabler to the strategy it describes, I hope the research can support future work on that aspect.

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1 Introduction

“No society can surely be flourishing and happy, of which the far greater part of the members are poor and miserable.” - Adam Smith, Scottish moral philosopher, pioneer of political economy.

The advancement of the human condition through history follows a parallel path to technological progress. Technology surrounds our lives in its different forms: from simple levers, the wheel and paper; to today's smart phones, electric cars and biomaterial for regenerative medicine. Globalization coupled to technological progress in transportation and communications have made us more aware of the dire conditions faced by a large portion of the world's population, and the persistence of poverty. As humanitarianism has evolved over time, so has the technology used to get the work done. Today, Information and Communications Technologies (ICT), energy generation, irrigation technology, health diagnosis equipment, and computing are tools counted upon to effectively conduct humanitarian tasks. Humanitarian intervention through emergency relief or human development are two strategies used to alleviate the effects of these conditions.

The significance of technology and knowledge to the economy is not obvious in Adam Smith's model (the father of modern economics), which reason in terms of *factors of production*: land, labour and capital (Butler 2012); but the benefit of technology, through knowledge generation and accumulation, becomes more evident when considered from an endogenous growth point of view (Cypher & Dietz 2008, p248-249). From this perspective, the benefits of technology are specific to each economy, and dependant on how quickly technology is adapted and integrated in the local economy (Cypher & Dietz 2008, p423-425); while the benefits of knowledge can be generated and accumulated through investment in R&D, education and learning by doing (Rensman 1996). Unfortunately, extreme poverty, recurring natural disasters and armed conflict keep large populations from improving their conditions despite progress in knowledge and technology, unless specific efforts to break

through these obstacles are made. Two well documented examples of technology-based development are the UN Millennium Villages Project¹ (MVP) and the One Laptop Per Child project (OLPC). The Millennium Villages Project is a 10 year joint venture between the Earth Institute of Columbia University, the United Nations Development Programme (UNDP) and various partners to work with 14 sites in 10 countries under the direction of the United Nations governance in Sub-Saharan Africa. The MVP is a well-documented implementation of the Millennium Development Goals, and serves as a reference in contemporary development and a reliable case to study technology use in development, for example: its mobile connectivity project in partnership with Ericsson, MTN and Zain (Tole 2013). This project started in 2007, and by the end of 2009 83% of the focus villages had mobile communication capabilities. These results show that the introduction of mobile networks has the potential to influence economic growth in remote villages by an average of 1.2% growth in GDP for every 10% increase in mobile penetration rate. In the health sector, mobile phones enable health workers to better respond to emergencies, gives more resources to health workers while providing a means to health organization to monitor accountability, and reduce isolation for those who work in rural areas. This is particularly relevant in contexts where health care delivery is limited by the lack of resources, large distances and poor infrastructure. The MVP is an exceptional case of technology-based development, which is the topic of this thesis. To focus the thesis research on open source hardware (OSH) it asks the following question:

Can open source hardware be a means to improve living conditions in technology-based human development initiatives?

Three elements comprise the research question, and they will be identified and their focus specified in the research objectives. The first element of the research question, open source

¹ Millennium Villages: A New Approach to Fighting Poverty. <http://www.unmillenniumproject.org/mv/>

hardware (OSH), is an adaptation of the free and open source software (F/OSS) model to physical items. The release of Linux in the early 1990's clearly defined the open source model (Raymond 2001): original designs made available to a community (a.k.a. commons), and thereon relying on peer-review and reputation to ensure constructive collaboration. Open source rests on the freedoms advocated by the Free Software Foundation (FSF)² to run, copy, distribute, study, change and improve the software shared under its "copyleft" license (Rosen 2005). It is important to note open source's use of licensing to define the terms to share and use intellectual property (technology and knowledge). A License often includes elements other than copyright, such as patents, trademarks, implied warranty, and liability (Rosen 2005). This thesis focuses on hardware that uses the open source model for technology-based human development projects. Borrowing from F/OSS, it does not differentiate between "free" and "open source", since all "free" software is effectively "open source" even if the inverse is not the case (Rosen 2005, p2); and also because the FSF stopped short of endorsing the notion of free hardware (Stallman 2015). This research includes recognized methods specific to OSH. Because of its longevity and commercial success, this thesis will also include prevailing practices from F/OSS applicable to hardware, instead of limiting the research to OSH. By broadening its scope this way, it will be highlighting elements that contributed to the success of the free and open source movement, differentiating between "free" and "open source" only where necessary or warranted.

The second element of the research question, human development, can be traced back to humanitarian intervention: an international community practice going back to ancient Greece and Rome (Knudsen 2009) intended to prevent massacres, persecution and destruction of living conditions. This practice took a different form when president Truman, in his second inaugural address (Truman 1949), announced four major foreign policy points; Truman

² The Free Software Foundation (FSF): <http://www.fsf.org/about/what-is-free-software>

referred to the fourth as a “bold new program” that would draw on American science and resources to aid underdeveloped nations. This marked a new era in economic development and cooperation, defining humanitarianism in foreign policy (Cypher & Dietz 2008, p. 99). Truman’s second inaugural speech has been praised for signifying the rebuilding of post-war Europe and criticized for disguising a new form of imperialism. One notable difference is that the historic form of humanitarian intervention is protected by international law while the second (Truman’s) is not. Humanitarian intervention has historically been carried out collectively by powerful states, and now by organizations like the United Nations. It has grown into a significant sector of economic activity, reaching \$6 billion in 2000 (Barnett 2005), evolving from aid and relief work to global development programs. As it grew, humanitarianism structured as a field and a humanitarian profession emerged. Humanitarian intervention, including emergency response, has a different scope than development; humanitarian intervention focuses on providing assistance to save lives, alleviate suffering, or protect populations and is entrenched in international law (Barnett 2005; Knudsen 2009). While development uses various societal levers to improve the living conditions of served populations, often along ideological boundaries (Cypher & Dietz 2008; Easterly 2010; Nederveen Pieterse 2009; Sen 2000; World Bank 2008). These distinctions between humanitarianism and development can be traced back to the negotiations leading the creation of the Geneva Conventions (Slim 2000). One notable example of development is the United Nation's Millennium Development Goals program (Binagwaho & Sachs 2005).

Human Development is defined in the first *Human Development Report* (HDR1990) as “a *process of enlarging people's choices.*” It stresses three people-centered constituents as critical: to live a long and healthy life, to be educated and to have access to resources needed for a decent standard of living (UNDP 1990). The Human Development process contains three central concepts: (i) functionings, which are defined as being or doing what

people value and have reason to value; (ii) capability³, which is a person's freedom to enjoy being or doing things ("functionings") that contribute to their well-being; (iii) and agency, which is a person's ability to pursue and realize goals she values and has reason to value (Deneulin & Shahani 2009). The HDR1990 introduces a more balanced measurement of development and wellbeing and provides a contemporary reference that can be used to measure impacts of OSH on a humanitarian intervention context. Being able to use the annual Human Development Reports as a baseline was one of the reasons for selecting the Human Development paradigm among others. Human Development is a marked departure from traditional development paradigms that centered on income growth and wealth redistribution, i.e.: economic growth, human capital formation, human resource development, human welfare or basic human needs (UNDP 1990). This thesis analyses what opportunities open source hardware may bring to technology-based human development (TBHD). It is expressed in the research questions as to "improve living conditions"; and in Human Development terms it is measured in terms of being/doing (functioning), capability and agency. They are referred to as "living conditions" in this thesis, and their improvement through OSH will be studied.

Finally, the last element of the research question is the putting the two concepts together by asking if OSH is a means to TBHD. The elements of the research question are examined from an applied economics perspective. Today, science, technology and knowledge are broadly recognized as significant contributors to economic growth. "In an agricultural economy land is the key resource. In an industrial economy, natural resources such as coal, iron ore, and labour are the main resources. A knowledge economy is one in which knowledge is the key resource" (Houghton & Sheehan, 2000, p1). The economic properties of knowledge coupled to the open source methodology (increase value by sharing) are key in

³ The Capability approach : <http://plato.stanford.edu/entries/capability-approach/>

this thesis' research question, and it is the reason why there is such focus on what determines success for open source hardware.

The motivation for this thesis traces back to an objective of the Institute of Electrical and Electronic Engineers (IEEE) Humanitarian Technology Challenge (HTC). It had two goals: (1) "To provide concrete artifacts that address pressing humanitarian technological needs," (2) "and to develop a repeatable methodology for collaboration on a large scale that can be used in future HTC projects" (Perusich et al. 2009). One of its objectives was that the results of volunteer work would be broadly available to anyone for their use in providing humanitarian products or services. This thesis seeks to substantiate this claim of the IEEE HTC, and the overall aim is to review technology-based development projects, like the MVP and the HTC, in order to introduce the concept of open source hardware as a means to human development to formulate a sustainable deployment strategy based on the findings.

Focusing the research on open source and human development facilitates a literature review approach for the first two focus areas, and a case study approach when applying the findings to projects like the MVP and the HTC. The objectives of this research can now be defined to:

1. Determine prominent methods and strategies from open source projects applicable to open source hardware;
2. Determine experiences from technology-based human development projects that are relevant to open source hardware; and
3. Formulate a sustainable deployment strategy model based on the findings from (1) and (2) and applicable to projects like the MVP and the HTC.

1.1 Originality and value of research

Through the duration of this research work, it was interesting to witness the growing availability of publications on OSH; it is a significant new area of activity for technological advancement and economic growth. Open source in general (hardware, software, cultural

works, standards, etc.) is well understood and documented, but despite the growth in publications on OSH, its use in human development projects is hard to find in literature.

For example, use of free and open source software (F/OSS) in technology-based development initiatives like the Millennium Villages project is found in examples like the Open Medical Records System (OpenMRS) (Kanter et al. 2012; Seebregts et al. 2009); but the same cannot be said for open source hardware (OSH): at least not in Binagwaho & Sachs (2005), Sanchez et al. (2007) and Tole (2013). Given the contribution of OpenMRS to the MVP in Kanter et al. (2012) raises the question on the extent to which OSH may be able to contribute to projects similar to the MVP. Some authors have looked at the potential socio-economic benefits of OSH (Thomson & Jakubowski 2012), (Atkinson 2006), (Blikstein & Krannich 2013) and (Lindtner 2014); but they do not extend their enquiry to the human development field which is now mainstream. This thesis aims to address this gap by answering the research question, with the assumption that this gap spans mainly two disciplines: Engineering and Economics.

This initial assumption helps to focus the research activities, notably by narrowing the research methodology choices. Understanding the particularities of research methodology in these two disciplines is important to be able to answer the research question and formulate a model that roots itself on knowledge. It was challenging to establish links between engineering and economics knowledge because they do not share a philosophical understanding of knowledge (Pitt 2001); a significant dichotomy explored in detail by Mitcham (1994). This undesirable situation is best represented by the model shown in Figure 1, based on the article by Sousa-Poza (2013). Reality can be comprehended differently depending on the paradigm adopted; paradigms are proper to a domain of study where knowledge is created and shared from its particular perspective.

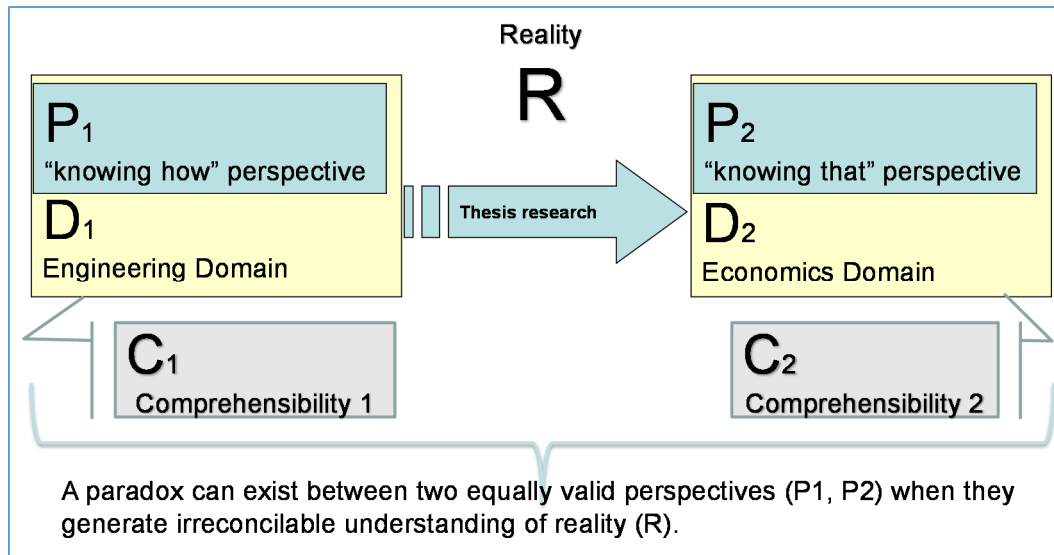


Figure 1: research disciplines epistemic perspectives, based on Sousa-Poza (2013).

The research for this thesis starts by establishing what is known about open source hardware (OSH) and technology-based human development (TBHD). Understanding how knowledge is established, critiqued and compared is key to enable the formulation of a sustainable deployment strategy. The thesis research finishes with a sustainable deployment strategy. Sustainability, and in particular sustainable development, is referred to as a “wicked problem”, characterized by: *“a lack of clarity, uncertainty, ambiguity, high risk, and limited understanding. Among other challenges, these characteristics make establishing appropriate analytical boundaries problematic.”* (Pryshlakivsky & Searcy 2013).

Pitt (2001) presented the differences between what “knowing” means in the engineering domain versus the sciences: “knowing how” (technology) versus “knowing that” (science). Expanding on “knowing how”, Pitt (2001) characterizes engineering knowledge as more universal by being engaged in *“the design, construction, and operation of artifices for the purpose of manipulating the human environment.”* This is in contrast to scientific knowledge, which is defined as explicit by being deliberately bound by theory in its effort to explain. This contrast can be observed in how engineering knowledge can be re-purposed across fields

and contexts, while economic (scientific) knowledge is bound by its concepts. And as Tongia & Subrahmanian (2006) so clearly articulate when referencing von Hippel 2005: traditional R&D's development is organised around the sequential pursuit of ideas from "large scale and expensive fundamental research that is detached from end uses" (Tongia & Subrahmanian 2006); the adaptation of this fundamental research to identified market needs seeks to attract adoption by early adopters and diffusion through marketing efforts. Tongia & Subrahmanian (2006) also note that innovation is user-lead since the end-users have intimate knowledge of their particular needs: inclusion of user in product development reduces the gap between developer's perception and end-users reality. That divide between the designer and the end-user is amplified in the context of development, and for that reason this thesis research sought research strategies and methods to bridge this gap.

2 Literature reviews: what is known

“Perfection is achieved, not when there is nothing more to add, but when there is nothing left to take away.” – Antoine de Saint-Exupéry.

This thesis’ objectives span across two disciplines with different research practices. This is important to acknowledge when selecting a strategy among research methodologies; for example, the way engineering literature presents the benefits of using a specific hardware system differs from the way economics sources report benefits of the adoption of this same technology. Differences in research approaches, or paradigms, affect how relevant literature is selected and how knowledge from these sources is sorted, reviewed and presented. And for this reason the decision was made to do separate literature reviews: one for the first objective, OSH; and one for the second objective, technology-based human development (HD). The third objective, drafting a sustainable deployment strategy, is a topic of operations research for which a normativistic approach will be used based on guidance in Ethridge (2004). The conceptual framework for the research strategies used can be seen in Figure 2.

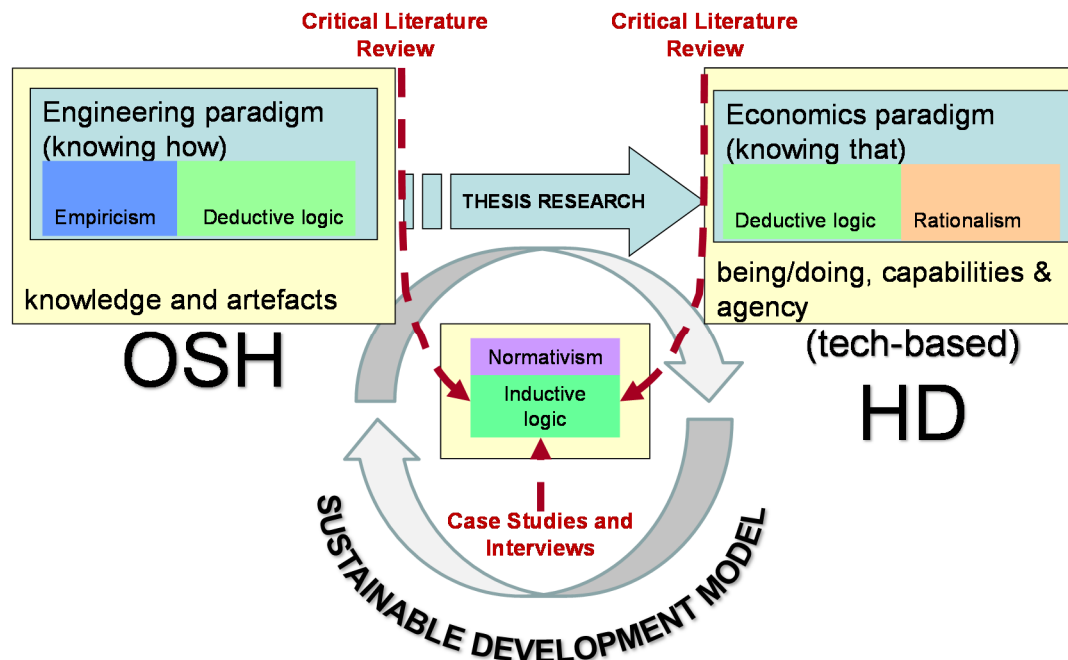


Figure 2: Research philosophies and conceptual framework.

This thesis will make use of a number of literature sources, including reference to pertinent books, journals, reports, conference proceedings, and intergovernmental organization publications. Examples of these include: the United Nations publications; the Yale Law Journal; *Economica*; the First Monday open access journal; the IEEE Technology and Society magazine; and proceedings from the R&D Management Conference. The research in this thesis is applied research in both engineering and economics disciplines and it is composed of multiple steps, starting with the literature reviews. The process of selecting appropriate research strategies, methods and procedures was difficult due to the differences in disciplinary knowledge across the engineering and economics domains and that is discussed in more detail in chapter 3; but using the conceptual framework shown in Figure 2, the research was able to move forward. There were two levels of literature reviews, a more “general” literature review and a more in-depth “critical” literature review based on the paper by Armitage & Keeble-Allen (2008) about research in business and management studies. Their paper presents the Rapid Structured Literature Review (RSLR) research strategy which they deem more appropriate for the type of research in a master’s thesis than the Structured Literature Review (SLR) which is too cumbersome. An adapted (identified with *) version of the RSLR is described in more detail in chapter 3, but here are its main steps:

1 Stage 1: Conceptualization

- 1.1 Introduction.
- 1.2 Scope and range using conceptual map.

2 Stage 2: Operational aspects

- 2.1 Research design and methods with details of evaluation framework.
- 2.2 (*) Literature add/trim.
- 2.3 (*) Main theories, method, scope and results from study.
- 2.4 (*) Tables using matrix method (Klopper et al. 2007).

3 Stage 3: Sense making

- 3.1 Discussions and interpretations.
- 3.2 Conclusions.

To limit the critical literature review to the most relevant while still retaining the ability to identify gaps, a matrix method has been adopted (Klopper et al. 2007). It provides a structured way to execute the review, especially at the beginning of the research. The modification to step 2.2 in the RSLR highlights the need to manage adding and trimming documents in the research repository. The matrix method used in step 2.4 of the RSLR consists in creating a matrix, shown in Table 1, listing the sources critically reviewed on the leftmost column (APA citation style). The heading of each column displays, across the top of the matrix, concepts derived from the problem statement of the thesis research or findings from the review. For each row (source material), there will be a check mark in the appropriate cell corresponding to the concepts it matches.

Source reference	human capital/	growth capability	social influence	entrepreneurial ability	system design & sizing	requirements quality	financing available	participatory adoption	change management	risk of new technology
Barnes, 2011					x	x	x	x		
Dewulf, et al., 2005					x	x	x	x		
Feder, Just & Zilberman, 1985	x	x						x		x
Monge, Hartwich & Halgin 2008			x	x					x	

Table 1: example of critical literature review matrix: technology-based development

This critical literature reviews examine open source hardware (OSH) and technology-based human development (TBHD) using the modified RSLR method (Armitage & Keeble-Allen 2008) and the matrix method (Klopper et al. 2007). It will evaluate critically prevalent practices and elements contributing to the success of both OSH and TBHD. These findings will be used as the input to chapter 4, which will model a sustainable strategy. The analysis focuses on two of the objectives established in chapter 1, and re-formulated as logic propositions here in chapter 2:

- (A) Open Source Hardware improves living conditions.
- (B) Technology-based Human Development projects improve living conditions.

By defining the literature review in accordance with the thesis objectives, the nuances of “knowing-how” OSH can be effectively used in TBHD efforts can be better interpreted. In a similar way, this know-how can be put to better use “knowing-that” OSH in TBHD will have certain effects, limitations and requirements. This, way, chapter 4 will show how a bridge is built (Figure 3) which can bring OSH into the TBHD realm.

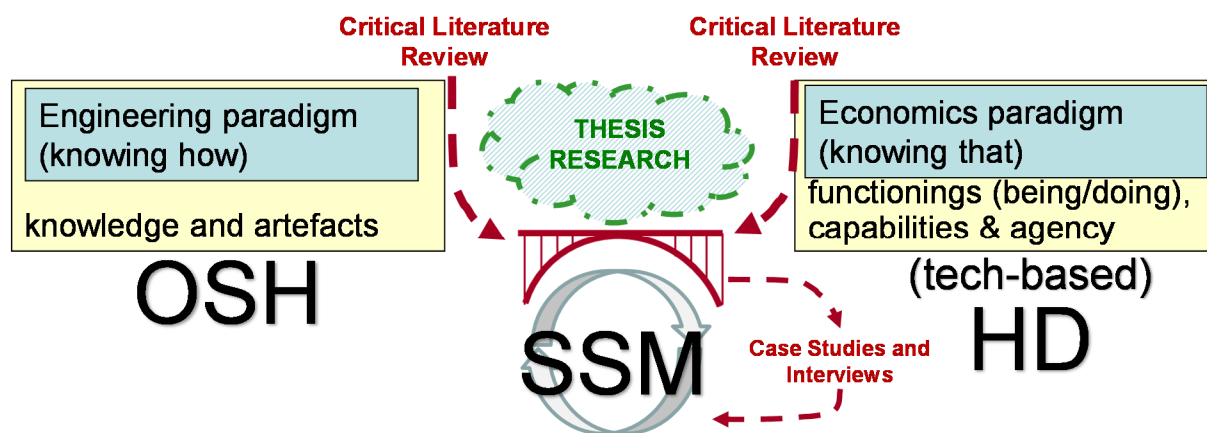


Figure 3: Building a "bridge"⁴ from thesis research.

2.1 Open Source Hardware: foundations and prevalent practices

The thesis research on OSH starts with open source software in the 1960's & 1970's when UNIX source-code was made available for free by hardware manufacturers to users, so they could compile it and run it on their machines. A well-known early contributor of academic software was the University of California at Berkeley, after Ken Thompson of Bell Labs taught there during a 1975-76 sabbatical (Raymond 2003). Berkeley's computer science research group created a very popular version of UNIX under the Berkeley Software Distribution banner (BSD)⁵, this UNIX version turned-up free from copyrights in the mid-1990s; enabling the emergence of a “bazaar model” for UNIX's development: open distribution, and contributions from many (Raymond 2003, p. 85). At the other end of the spectrum, gained understanding of

⁴ Pechristener, via Wikimedia Commons, CC BY-SA 4.0: <http://creativecommons.org/licenses/by-sa/4.0>

⁵ Berkeley Software Distribution: <http://www.bsd.org/>

software licensing allowed a “cathedral model” to emerge at companies like Microsoft (Wong & Sayo 2004). The appropriation of software rights for commercial purposes provoked the creation of the Free Software Foundation (FSF) in 1983, followed in 1985 with the publication of *The GNU Manifesto* (Raymond 2003, p. 89) on the abolishment of the intellectual property rights stranglehold on software: hence the term “free software”. The FSF defined it as a matter of the users' freedom to run, copy, distribute, study, change and improve this software. More precisely, the program's users have four essential freedoms⁶ (Rosen 2005):

- The freedom to run the program, for any purpose (freedom 0).
- The freedom to study how the program works, and adapt it as you wish (freedom 1). Access to the source code is a precondition for this.
- The freedom to redistribute copies (freedom 2) so you can help your neighbour.
- The freedom to improve the software and distribute your improvements to others (freedom 3) to give the whole community a chance to benefit from your changes. Access to the source code is a precondition for this.

There are ideological differences between Free Software and Open Source Software. In the early 1990's, open-source software and free software were terms used interchangeably, although they are based on fundamentally different values. Stallman (2012), the originator of the free software movement describes this difference as follows: “Open source is a development methodology; free software is a social movement”. For software, the term “Free and Open Source Software” (F/OSS) is used to englobe both ideals; but not for hardware. The concept of “free hardware” is not fully endorsed by Stallman (2015) yet because fabrication technology is not as widespread as computing is to run/use software. This thesis research takes advantage of the fact that all free software has been compatible with open source since BSD, the precursor to open source (Rosen 2005, p2); and this way it can rely on Rosen's (2005) definition of shared principles between both variants. The thesis

⁶ Free Software Foundation – Philosophy of the GNU project:
<https://www.gnu.org/philosophy/philosophy.html>

research spans best prevalent practices from OSH and from F/OSS that are applicable to hardware, now that the range of designs to which the open source model is applied has expanded to content, data and beyond. This expanded amalgamation can be divided into tangible and intangible objects. Intangible objects include: Software, Wikis (Black 2008); open educational materials (Atkins et al. 2007); geographic maps of the world (Haklay & Weber 2008); open standards (West et al. 2007); and “open access” to scientific publications (Björk 2004). These technologies rely on the internet as an essential enabler.

2.1.1 Free and open source software licensing

Intellectual property (IP) law applies to trade secrets, trademarks, patents, and copyrights. It defines the rights over products of human creative activities in a similar way to rights over tangible objects like land, services or goods. It grants to owners exclusive rights, including the right to copy, distribute and adapt the work. Trade secrets are protected by secrecy; trade secrets are shared under non-disclosure agreements. Trademarks identify and distinguish the source of a good or a service; they can be a word, phrase, symbol, a design, or their combination, and are shared under licenses. Patents protect the exclusive rights of the inventor over a novel, useful and non-obvious invention for a period of time in exchange for its disclosure; patents are shared under licenses. Copyrights cover creative works like literary, music, paintings and software; they are also shared under licenses. Copyrights are different from other types of IP in the fact that they apply to a work upon its creation, regardless of its novelty; but they only protect the expression of an idea not the idea itself: copyright only prevents others from copying the copyright holder’s particular way of expressing those ideas. Licensing is used to define the terms to share and use trademarks, patents and copyrights. It expresses the terms owners may use to sell or gift intellectual property, including disposing of it after death by will or trust, or have it taken from by bankruptcy court. A License often includes elements other than copyright, such as patents, trademarks, implied warranty, and liability. Weber (2004) in Lock (2013) and Bruijn (2010)

remind us that open source licensing defines terms for sharing not for excluding others from using like patents. But a creative work that is not explicitly licensed doesn't become a public good. Creative works are copyrightable upon their creation, and in the absence of a license, they have an "implied license" with terms and conditions left for interpretation for the licensor and the licensee. The notion of public domain has existed since the Statute of Anne, the act of the British parliament that instituted copyright in 1710. A work is in the Public domain if: it is not covered by intellectual property rights at all, if the intellectual property rights have expired, and/or if the intellectual property rights are forfeited. Rosen (2005) emphasises that under the copyright law there is no mechanism to put an original work on the public domain: "A license is the only recognized way to authorize others to undertake the authors' exclusive copyright rights." Ochoa (2002) describes the nuances in types of public domains which historically referred originally to public land. In its modern use for tangible and conceptual entities, ownership of public land versus private land (and all "hardware") has an exclusivity characteristic; while ownership of ideas (intellectual property) can be had by many without depriving anyone else of its use. This duality affects how OSH use differs from how F/OSS has been used: OSH has an exclusivity characteristic.

Free software is shared under a "copyleft" license. It requires that the four essential freedoms be preserved in modified versions of the work; and it prevents the release of a modified version of the software under a different license. According to Stallman, these software freedoms are essential to preserve society's freedom in general (Rosen 2005). Bruce Perens created the open source definition to differentiate open source from free software. This definition by Perens & others (1999) is now maintained by the Open Source Initiative (OSI); software that complies with these criteria is considered to be open source, criterion summarized by Rosen (2005, pp. 9-11) in the following five principles:

- Licensees are free to use open-source software for any purpose whatsoever.

- Licensees are free to make copies of the open-source software and to distribute them without payment of royalties to a licensor.
- Licensees are free to create derivative works of open-source software and to distribute them without payment of royalties to a licensor.
- Licensees are free to access and use the source code of open-source software.
- Licensees are free to combine open-source and other software.

Not all software is licensed. Before the rise of the free software movement a great deal of software written in academic circles was released into the public domain for peer-review. Public disclosure of an idea can reduce or eliminate "proprietary rights" and some or all options for patent protection, but "implied copyright" still applies. Like public-domain works, software that is in the public domain is not restricted by copyright or licenses, and therefore can be used for any purpose. While open-source and Free Software require protection under IP law as expressed in a license.

2.1.2 Determinants of free and open source software success

The first thesis objective's literature to be critically reviewed is on open source hardware; but free and open source software literature must first be examined, because it is within this movement that the mechanism to freely share design sources was born. Using the Rapid Structured Literature Review (RSLR) method, a conceptual map of the F/OSS is created and shown in Figure 4.

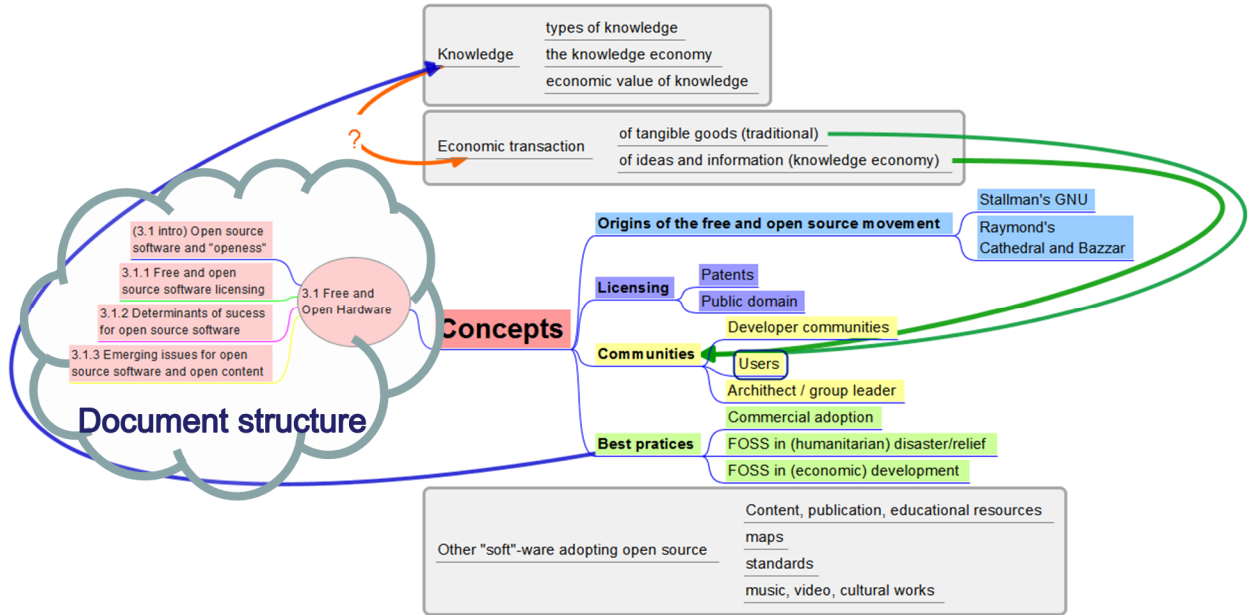


Figure 4: RSLR conceptual map for F/OSS critical literature review.

Another reason why F/OSS is examined is because at the beginning of the thesis research, few academic sources existed on OSH. Free and open source software was studied because: (a) it was the precursor of OSH; (b) understanding F/OSS’s licensing and distinctions in levels of openness would help understand similar peculiarities in OSH. In the later stages of the thesis research, sufficient academic material had become available on OSH to be able to decrease the reliance on F/OSS literature. But some key elements from the F/OSS research were kept and they are presented here because they provide insight into OSH. From the beginning, the research sought to understand the incentives for the different communities to participate in the design process. Table 2 summarises the theories in the selected paper’s including Raymond’s seminal work.

Source	#cited	Relation to thesis	Main theories
raymond2001	2060	Criteria for OSH success	Postulate 1: Linux was first project with conscious and successful effort to use the entire world as its talent pool; Postulate 2: Linus was first to learn how to play by the new rules that pervasive Internet access made possible; Hypothesis 1: the “cathedral” model of commercial SW is not as efficient as the “bazaar” model of Linux; Hypothesis 2: “cathedral” and “bazaar” models have opposing assumptions of sw-debugging; captured in list of 19 lessons, observed from experimentation.
subramaniam2009	117	Criteria for OSH success	Postulate 1: (F)OSS approach is more efficient than traditional software development because: (a) it avoids inefficiencies of a strong intellectual

			property regime and (b) it implements concurrent design and testing of software modules; Hypothesis 1: traditional software success measures (system quality, information quality, use, user satisfaction, individual impact and organizational impact) are not sufficient to measure success factors for F/OSS projects; Hypothesis 2: (F)OSS success can be measured empirically using time-dependent and time-invariant characteristics of development projects.
senyard2004	78	Criteria for OSH success	Hypothesis 1: initial modular design is more important than “bazaar” model for success of F/OSS projects; Hypothesis 2: the transition period from the initial group to the larger community based development is crucial.
atkins2007	611	Emergence of OSH	Hypothesis 1: universal access-to and use-of high-quality academic content on a global scale, through the internet, will expand people’s substantive Human Development freedoms.

Table 2: RSLR's step 2.2 for F/OSS

Raymond's 1996 case study demonstrated the differences between traditional software and open-source software, by evaluating the contribution of the software-debugging methodology used for Linux: “the 'cathedral' model of most of the commercial world versus the 'bazaar' model of the Linux world” (Raymond 2001). The release of Linux in the early 1990’s clearly defined the open source model. It was the first project to make a deliberate and successful use the open-source development model, which builds on an initial design made available to a community (a.k.a. commons). Senyard & Michlmayr (2004) revisited Raymond’s lessons and attributed the success of free and open source software to: (1) a successful transition from the traditional software cathedral-phase to the free software bazaar-phase; (2) and a successful hand-over from the initial group to a larger community of developers. In their view, this transition’s success depends on determinants found in the cathedral, transition and bazaar phases. Below, these determinants are grouped per phase:

Determinants of success according to Senyard & Michlmayr (2004)	Cathedral phase			Transition phase			Bazaar phase		
	Critical	Important	Desirable	Critical	Important	Desirable	Critical	Important	Desirable
1. A prototype with “plausible promise” to meet requirements found, or design from scratch commitment warranted.	X								
2. The design of the prototype must be modular.	X								
3. The source code of the prototype must be available and workable				X					

4. A community of initial developers must be attracted to the project (*).	X								
5. A community of beta-testers and infrastructure resources must be attracted to the project (*).				X					
6. A community of users must be attracted to the project (*).							X		
7. Project author motivated to manage project or find replacement: interest and requirements align	X								
8. Project communication and contribution mechanisms must be in place					X				
9. Scope of the project must be well defined: requirements, architecture, interfaces and interoperability		X							
10. A coding standard or style must be established.								X	
11. Development must have short release cycle between stable user versions								X	
12. License must be attractive to developers: making requirements “open”, source code accessible and enabling peer-review					X				
13. Suitable management style must be selected. Clear ground rules defined.					X				
14. Appropriate amount of project documentation must exist									X

Table 3: modified list of determinants of F/OSS success, Senyard & Michlmayr 2004

Senyard & Michlmayr (2004) do not give an indication of the number of cases behind their claims; but based on their references it can be assumed that their observations are based on those sources. To extend number of cases on which this thesis research is based, the work by Subramaniam et al. (2009) was looked at; they analysed success factors for open-source software over time and the relationship between these factors. Their data shows clearly how open-source projects do not share the success indicators of commercial software: i.e. being on time, being on budget, and meeting specification. Their research looked at data of more than 100,000 projects in the sourceforge.com repository collected each month between January 1999 and December 2005. Finally, another perspective of F/OSS this thesis research wanted to capture in the critical literature review was that of open content. The study by Atkins et al. (2007) on Open Educational Resources (OER) provided that analysis; their study follows the Hewlett Foundation program (2002) promoting global internet access for academic content. The program adopted Amartya Sen’s Human Development paradigm: “to expand people’s substantive freedoms through the removal of “unfreedoms”: poverty, limited economic opportunity, inadequate education and access to knowledge, deficient health care,

and oppression” (Atkins et al. 2007). OER are scientific resources freely available to the public for their use or re-purposing, including: course materials, actual full courses or individual modules, textbooks, multimedia, tests, software, and other didactic resources supporting learning. These resources are predominantly available from: electronic scientific periodicals; subject-specific on-line repositories; institutional repositories; and self-posting by authors. The impact of the Hewlett Foundation program was measured between 2002 and 2006; it looked for evidence, from 134 of the grant recipients, on how they had met the program’s goal components: providing high-quality open content, removing barriers, and understanding and stimulating use. A measure that showed the program to be very successful. Table 4 shows some descriptive characteristics of the papers analyzed.

Source	Methods & Scope	Research variables	Results
raymond2001	Single-case study, sendmail	Number of beta testers; quality and quantity of bug reports from beta testers; length of debug time; number of users.	19 lessons, summarized here: quality of initial source; short development cycles & user versions stable; quality of design data; community built on merit and reputation; recognize good ideas from all; commitment of beta-testers; user interest; project activity; delegate features; be excessively open; license enabling OS peer-review
subramaniam2009	Longitudinal study, designs in <i>source forge</i> on-line repository, monthly over 6 years.	Time-invariant: OSS license type; operating system; programming Language. Time-dependant: development status of the OSS project; developer interest: user interest; and project activity until the previous time period	R1: project status has a positive impact on all three measures of success; R2: in any given time period, project activity and developer-interest are positively associated with user-interest; R3: also, in any given time period, project activity and developer-interest positively impact developer-interest and project activity in the following period; R4: choice of platform (operating system) positively impacts developers, but data shows disconnect of preferences between developer platform vs user platform; R5: restrictive licenses have positive impact on user adoption but negative impact on developer activity.

senyard2004	Literature review	Success or failure of projects in reference material (not visible).	Importance of activities (Table 3) in corresponding design phase.
atkins2007	Longitudinal study	Removal of “unfreedoms” by providing high-quality open content; removing barriers that limit economic opportunity; and understanding and stimulating use educational resources to improve inadequate education and access to knowledge.	134 of the grant recipients. Program achieved goals to address the production, access, use, and evaluation of high-quality education content.

Table 4: RSLR's step 2.3 for F/OSS

Raymond's (2001) community, or commons, relies on peer-review and reputation for their collaboration; and adopt the following principles from the creator of Linux, Linus Torvalds:

- Do not start a project from scratch in bazaar mode, but use an existing design.
- Make sure the initial design runs and that it can be debugged before its initial release. Then, release early and often, delegating openly to as much as can be.
- Build community by presenting the “plausible promise [...] that it can be evolved into something really neat” (Raymond 2001); make it a priority to recognize good design ideas from all.
- Encourage people to participate, and grow the beta-tester list by adding anyone interested in the project.
- Listen to beta-testers, celebrate their contributions, acknowledge their feedback, and include them in design decisions.
- Be excessively open about design feature and requirements; but establish stringent release control and gatekeeping.

By the end of his experiment, Raymond observed that the type of communication the open-source model requires is egalitarian: avoiding problems seen in hierarchical organizations where subordinates are rewarded for telling their superiors what they want to hear. In his epilogue, Raymond commented on the incredible changes open-source brought to the software industry, notably: the decision by Netscape Communications to make the source of its flagship software product open. Raymond helped design Netscape's open source release strategy and open source license, a development of what was later named Mozilla. This was done to bring the attention of industry to the F/OSS development process, a goal

accomplished with the commercial success of Red Hat's initial public offering (IPO), a Linux distributor, and other successful IPOs in 1999 and beyond (Wong & Sayo 2004, p. 9).

Raymond's book (Raymond 2001) is pivotal in the history of the open source movement, key to those seeking to understand what it is all about; but it does little to validate the thesis first objective, and logic proposition, that OSH improves living conditions. Also, Raymond (2001) does not provide much data or arguments for commercial software since it focuses on the merits of open source software. The longitudinal study from Subramaniam et al. (2009) shows clearly how open-source projects do not share the success indicators of commercial software: i.e. being on time, being on budget, and meeting specification. Their analysis shows that development of open-source is more efficient than traditional software because it avoids the inefficiencies of a strong intellectual property regime and it implements concurrent design and testing of software modules. They arrived at this conclusion by looking at: time-invariant factors related to the project (license type, operating system, programming language); time-dependent factors related to features (development status, developer interest, user interest, and project activity). To measure the success of F/OSS projects, they measured developer interest, user interest and project activity over time. They discover that:

- project status has a positive impact on all three measures of success;
- project activity and developer-interest positively associated with user-interest;
- project activity and developer-interest positively impact developer-interest and project activity in the following period;
- choice of platform (operating system) positively impacts developers, but disconnect between developer platform vs user platform;
- restrictive licenses have positive impact on user adoption but negative impact on developer activity.

Last, this thesis research looks at the findings from Atkins et al. (2007) which is an example of applying the concept of open source to open content; a type of design outside of the traditional software domain. They identify the following enablers that made the projects they

sponsored successful: adoption of an appropriate intellectual property policy (including licensing); adopting virtual distributed collaboration; the community governance models; having an appropriate participatory computing system architecture (WWW) that enabled open content use, adoption and collaboration; improvement in performance and access to the underlying ICT; use of rich media, virtual environments, and gaming; and finally, the emerging deeper understanding of human learning using open content. All these findings from the selected documents allow us to gain knowledge of free and open source software and similar “soft” designs like open content.

Continuing with the RSLR method, Figure 5 shows the linkages between the selected literature sources and the time-spans they cover. These do not cover a time period that overlaps OSH because the growing availability of publications on open source hardware meant that relying on software and content was not necessary. The selected F/OSS literature is considered to be sufficient for the goals of this thesis research.

1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007

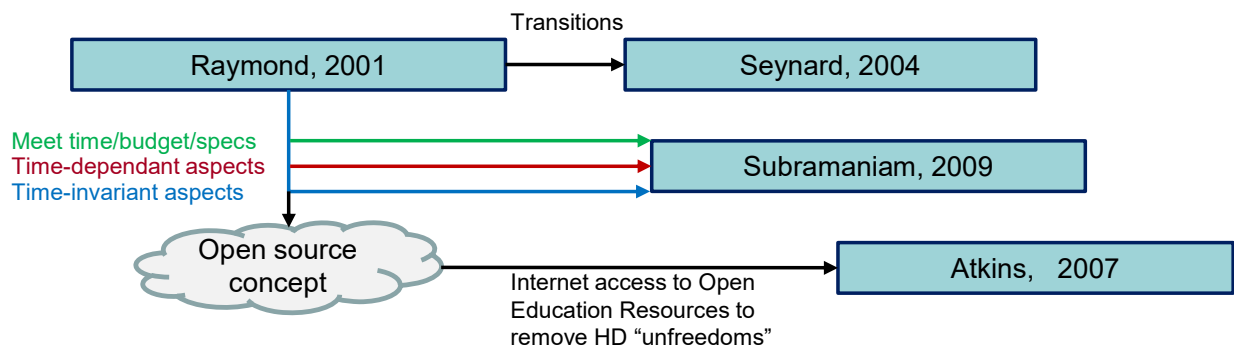


Figure 5: RSLR's step 2.4 for F/OSS

Table 5 completes the critical review of the papers using our modified RSLR method. It summarises the document's strengths, weaknesses and a short assessment to see if the arguments and hypothesis advanced in the papers were properly addressed.

Source	Strengths & Weaknesses	Arguments	Cross analysis
raymond2001	Seminal work, describing the open source methodology. But discourse lacks statistically significant number of cases; it also limits itself to showing the open source software case, no data or argument is presented for/against commercial software.	The list of 19 lessons collected during from case study record the particularities of the “bazaar” models, but the same is not done for the “cathedral” model. The author assumes the reader is familiar with commercial development to conclude for Hypothesis 1 that the “cathedral” model is not as efficient as the “bazaar” model.	senyard2004, and its references, support the claims of raymond2001.
subramaniam2009	Longitudinal study, linking customary time-dependent measures of success to time-invariant variables and relations.	The statistical analysis validates the correlation between traditional software success measures and variables used in this paper. Correlation confirms importance of time-invariant and time-dependent metrics, and affirms both Hypothesis.	Some of the findings from seynard2009 support the findings here. But not all of them, there are gaps in the overlaps between papers.
senyard2004	Process oriented view, instead of before/after static view.	Seynard2004’s argues the point that the “closed” phase of the initial “bazaar” development is more critical to the project’s success than literature had established.	Raymond2001 doesn’t spend much time discussing transition steps between project stages. But there is no incompatibility between raymond2001 and senyard2005.
atkins2007	Extensive study of open content; but weak on reported details.	The reported review shows that Hewlett’s program has been successful, and respects a human development point of view.	---

Table 5: RSLR’s step 3.1 for F/OSS

Common in all the articles were the importance of: the level of project activity; and selecting an appropriate licensing strategy. The F/OSS critical review yielded the critical elements identified by Senyard & Michlmayr (2004) of version release, gatekeeping/management, beta-testers and choice of participatory platform, as well as user interest/satisfaction to include them as success factors that are relevant to OSH use to improve living conditions.

2.1.3 Emerging issues for open source software and open content

One of the issues raised by Senyard & Michlmayr (2004), but without offering a solution, is the ownership and location of the design repositories: using public hosting sites versus owning and managing the hosting servers. These repositories are the platform used by the project groups to create a community, and the issue is in finding the best vehicle to facilitate

the task of distinguishing between active and dormant projects. This is important because active projects have a higher probability of success. Benkler (2002) compares the open source methodology against Coase's 1930's depiction of *the Nature of the Firm*. On the one hand firms emerge when production transaction are more profitable than market forces; while on the other hand sustainable and productive open source communities emerge in digitally networked environments apart from markets or managerial hierarchy: a design repository is essential. One benefit from the open source model is reducing uncertainty of participants by using decentralized information gathering to allocate resources that self-identify tasks and perform required work. Misidentifying tasks and misallocating human creativity in F/OSS communities may lead to failed projects. Dueñas et al. (2007) address the problems leading to dormant or failed new projects indirectly by discussing incubation programs at Apache⁷ and Eclipse⁸. They start by stating that F/OSS projects will likely fail unless the kick-off phase is successful in yielding a community of 5 to 15 developers, an observation that resonates with Senyard & Michlmayr (2004). The Apache Software Foundation uses a project management committee in their incubation process to accept projects, provide technical/administrative support, reviews incubated projects and proposes their termination, continuation, or escalation. In a similar way, the Eclipse Foundation's incubation process is a milestone in their first validation phase within the project life cycle to signal the start of development and the establishment the project's community; decision to continue or terminate a project are done at each checkpoint review to see if the projects continues to the next phase. Dueñas et al. (2007) observed that: it is significant for both approaches to differentiate between top-level projects and subprojects because of the implications of community support and integration/interoperability; clear and focused objectives are a must; a viable number of developers/committer is critical and for that reason monitored; an iterative development

⁷ The Apache software foundation: <http://www.apache.org/>

⁸ The Eclipse foundation: <http://www.eclipse.org/>

approach during the incubation phase helps reduce risk to delivering a stable first release. This concern was also part of the elements that need to be actively managed in Raymond (2001) and Senyard & Michlmayr (2004); this is identified under the heading “Gatekeeping: Cathedral-Transition-Bazaar progress; ground rules “ in table 6. To our knowledge, similar incubation programs have not formally emerged for OSH; but distributors, publishers and suppliers in this new ecosystem fuel a vibrant community of self-starters and self-taught producers of OSH. The incubation models described by Dueñas et al. (2007) do not address the issue of volunteer motivation raised by Benkler (2002), but Lakhani & Wolf (2003) looked at this and they identify four types of motivation that can be attributed to F/OSS project success: (1) a personal sense of creativity; (2) being paid to write code; (3) having a positive bond to the project team; and (4) caring about reputation in the F/OSS community. In the critical review of OSH, the volunteer motivation issues raised by Benkler (2002) were looked at for the different types of community members (user, beta-tester, developers and architects) without gaining any significant insight.

Source	Success determinants for Open Source Software and Open Content													
	Development version short-cycle, user version stable	Quality of initial source: available, workable; modular	Quality of information: requirements, architecture, interfaces, interoperability	Gatekeeping: Cathedral-Transition-Bazaar progress; ground rules	Build on merit and reputation; recognize good design ideas from all	Core team motivated; developer's interest/requirements align	User interest/satisfaction	Project activity/status; delegate features; be excessively open	Operating system; platform;	Programming language; coding style	License attractive to developers; enabling OS peer-review	Beta-testers and key resources commitment	Accessible participatory platform; clear communication/contribution mechanism	deeper understanding of human learning (end-users needs)
raymond2001	x	x	x	x	x		x	x			x	x		
subramaniam2009						x	x	x	x	x			x	
senyard2004	x	X	x	X		x	x	x		x	X	X	X	
atkins2007					x			x			x		x	x

Table 6: determinants of success for open source and open content

Table 6 shows that certain elements are only deemed important by individual studies; in the limited selection of articles, there is no consensus that choice of operating system, infrastructure, sharing platform and learning understanding are important factors. Prevalent items coloured green in Table 6 will be considered for the next section which evaluates critically open-source hardware practices and elements contributing to their success.

2.1.4 Open source hardware

In his article, Thompson (2008) interviews Massimo Banzi, one of the founders of Arduino⁹, an Italian firm that makes this open source micro-controller electronic kit with an inestimable number of configurations for its hardware and the flexibility of software programming. Arduino users share the characteristics of hobbyists, computer hackers and radio amateurs: interest in a specific technology; and a passion to tinker, learn and share their learnings (Coile 1997; Gotkin 2014; Literat 2013; Swalwell 2012). As with traditional electronic kits, users can purchase the parts from Arduino or order a fully assembled unit; in either form, users can modify the software running on their Arduino because it is F/OSS, but also the hardware design files and configuration because it is OSH. Thompson (2008) reports that, at the time of writing, 50,000 Arduino boards had been sold since the beginning of their operations. This is significant given Arduino's unreserved adoption of the free software ideals and use of modern open source licensing to release their system's details; this means for a puzzling business model: all the design details of their product are freely available on their website for anyone to take, including schematics, design files, and software. This allows anyone to manufacture an Arduino without patents or royalties preventing it. Banzi admits in Thompson (2008) that the business model seems insane in terms of traditional commercial practice, because: "If you publish all your files, in one sense, you're inviting the competition to come and kill you." The sequence of events that lead to this success is as follows: (1) Banzi, Cuartielles, and Mellis

⁹ Arduino: <https://www.arduino.cc/>

created an initial working design; (2) they invested to make the first batch and sell to their first customer; (3) word spread, and a few months later there were orders for hundreds more Arduinos, which confirmed there was a market for their design; (4) they adopted an open-source model, using the GPL license for their F/OSS, the Creative Commons open content license for their hardware design files, and the trademark for the “Arduino” name.

Unfortunately for the Arduino pioneers, the vulnerability of the open source hardware model made them victims of usurpation of copyrights by their original manufacturing partner (Banzi 2015). But despite this setback, the success of Arduino and projects alike marked a rebirth of the hardware hobbyist and the spread of the open source hardware model to: vehicles (Müller-Seitz & Reger 2010); 3D printing (Anzalone et al. 2013; Pearce et al. 2010); desktop manufacturing (Malone & Lipson 2007); small animal medical devices (Prajapati et al. 2014); farm machinery (Thomson & Jakubowski 2012); bioengineered regenerative materials (Modulevsky 2015); and pharmaceuticals (Maurer 2007). Open Source Hardware is a term for tangible artefacts, and defined by the Open Source Hardware Association (OSHW) in its “Statement of Principles 1.0”:

“Open source hardware is hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design. The hardware’s source, the design from which it is made, is available in the preferred format for making modifications to it. Ideally, open source hardware uses readily-available components and materials, standard processes, open infrastructure, unrestricted content, and open-source design tools to maximize the ability of individuals to make and use hardware. Open source hardware gives people the freedom to control their technology while sharing knowledge and encouraging commerce through the open exchange of designs.” (OSHW 2011)

These principles follow the open source software commercial aspirations sought by Perens & others (1999), but for artefacts that include machines, computer devices, or other physical things. We need to keep in mind that hardware is different from software in that resources are seized in each manufactured item, while software resources are not monopolized with each use. Capturing hardware sources physically affects how manufacturers sustain warranties, liability and trademarks owned by the original designer. This difference between software (ideas) and hardware (things) is understood in economic terms (Romer 1996): software (ideas) are nonrival goods that can be owned at the same time by many people, and they are not seized or destroyed in consumption; hardware (things) are rival goods with mass or energy that cannot be owned by many at the same time. And technology in both (hard, soft) camps is nonrival and at least partially excludable (e.g. licensed). Stallman (2015) recently ventured a concept for free hardware based on the availability of “free digital designs” that enable the freedom for users to examine, fabricate hardware (physical representations) from it, copy and redistribute using available free design(s) (source files); but he also identifies the significant hurdle to adapt and understand even moderately complex hardware designs from CAD hardware source files. His recent comment on the topic and call for “hardware freedom” (Stallman 2015), shows the emergence of the concept of “hardware freedom”. A notions also articulated by Jakubowski (Thomson & Jakubowski 2012).

2.1.5 Open source hardware licensing

For the Arduino example and the references above, you can see that ownership and copyright for hardware is different than for software. Ackerman (2008) was the first to address these differences in copyright terms, when he drafted his open source license: up-to that point, open source hardware designers had adopted one of the open source software licenses already in existence. Like Arduino, many current hardware designs are continuing the trend and adopting a Creative Commons or free software (GPL) license; and OSH licenses are continuing to evolve, for example the CERN source hardware license (Ayass &

Serrano 2012) and the Open Source Ecology (OSE) license for Distributive Economics (Thomson & Jakubowski 2012). The CERN licensing strategy starts from the premises that licencing the design documentation is a suitable basis to establish a contractual relationship between the licensor and the recipient wishing to study, modify or manufacture products based on them; this point agrees with Stallman's (2015) "free hardware" concept. The CERN OSH licensing strategy recognizes that open source tangible goods are fundamentally different from open source software which can be distributed virtually cost-free: hardware electronic designs files share F/OSS' low-transaction cost characteristics, but open source physical hardware embodiments requires capital investments for manufacture and distribution of the physical products. Another example is the OSE licensing strategy for their Distributive Economics (Thomson & Jakubowski 2012). It is based on the Creative Commons CC-BY-SA 3.0 license, which was defined for documentation and creative works (art, books, etc). They adopted the Creative Commons copyleft ShareAlike license feature to require contributors to make available their modifications under the same terms. Their Distributive Enterprise model is built on an open source freely shared set of designs, as well as the sharing of their entire business plan and procurement strategy. Distributed manufacturing and commons-based peer production is a significant new model as explained by Benkler (2002), and it will be interesting to learn how OSE's model resembles or differs from traditional firms and markets.

Intellectual property regime	Technology blueprints	Participatory development	Firm/Enterprise blueprints
Proprietary	No	No	No
Open source	Yes	Yes	No
Open business model	No	Yes	Yes
OSE's Distributive Enterprise	Yes	Yes	Yes

Table 7: Levels of openness according to OSE.

A less known and not broadly adopted license , the Solderpad Hardware License¹⁰ (Katz et al. 2012), needs to be mentioned as a critique of existing copyleft open hardware licenses. It

¹⁰ The Solderpad Hardware License: <http://solderpad.org/licenses/>

captures the limits of reciprocal copyleft licenses for OSH in this sentence: “Running a software program like a spreadsheet requires a software licence. Using a hardware device like an abacus (or a difference engine) does not” (Katz et al. 2012). Tangible or physical goods require the exclusivity protection described by Ochoa’s (2002): giving the inventor/author a time-limited exclusive right; but the underlying technology of inventions and creative works are nonrival and at least partially excludable according to Romer (1990): technology can be shared by many and it’s not destroyed or seized in consumption, but it can be managed for a period of time to exclude others from using it. Using an abacus does not require a license, but the design details to a specific abacus model are exclusive/excludable; furthermore, knowledge to use or build the abacus is non-rival because it can be held by many at the same time although access to that knowledge can be reserved using intellectual property rights. OSH’s electronic design details are protected by copyright law, licensing is the means to ease its sharing and reuse (Bruijn 2010); but because this sharing/reuse practice is rooted in a shared understanding of fairness and reciprocity, it comes with significant risks as seen in the Arduino example.

2.1.6 Determinants of success for open source hardware

Following the RSLR method, a conceptual map of open source hardware is created and shown in Figure 6 on how to approach the application of the open source software model to hardware. This figure shows a desire to seek to understand OSH markets, firms and commons-based peer production. This thesis research also seeks to understand how the prevalent practices from OSH lead to economic transactions that may generate socio-economic benefits that improve human conditions (in technology-based human development terms).

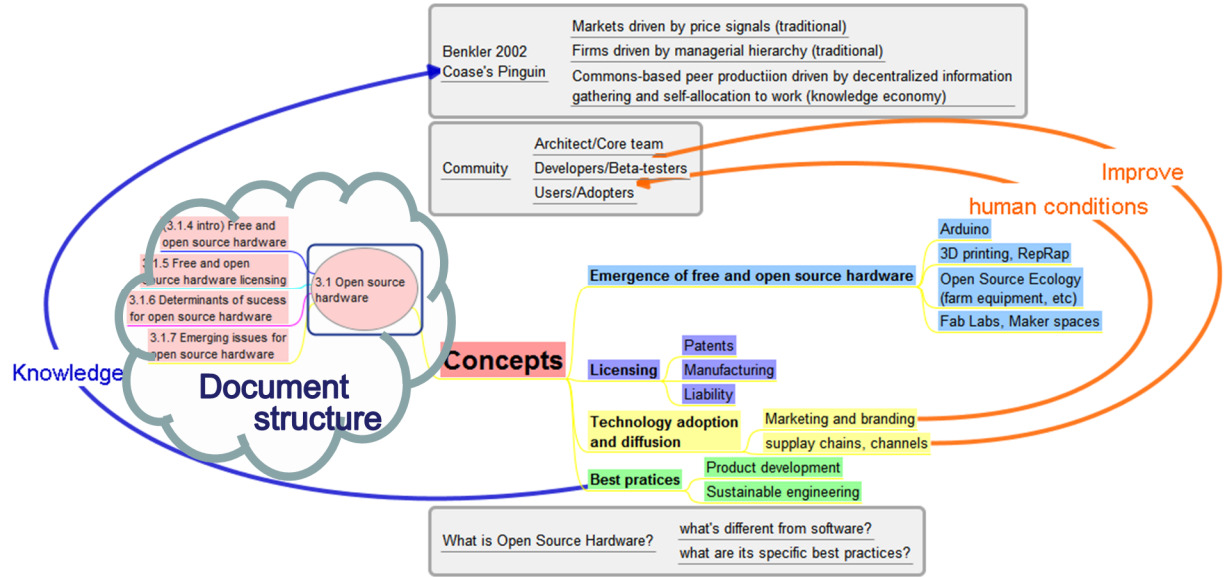


Figure 6: RSLR conceptual map of open source hardware.

Finally, the thesis research sought to learn more about technology adoption and diffusion, a well-known concept that Rogers (1976) traces back to the 1940s, and that he identifies as the dominant paradigm for development in the 1960s. Rogers (1976) defines the "classical diffusion model" as comprising: (1) the innovative idea, practice, or artefacts offered for adoption; (2) the communication channels for its marketing; (3) the time span of this campaign; and (4) the targeted members in the system. The thesis research started from this model for diffusion, and focused on its first element by seeking to understand how these ideas, practices and know-how are created for OSH designs; it left the three other elements (channel, time span, targets) to be addressed from a human development perspective later in our research. Balka et al. (2009) use the term "Open Source Innovation" (OSI) for the creation of open source designs outside of software. Their study covered 107 projects and it took place between August 2008 and February 2009; which they classified in two categories: "open content" (described in section 2.1.2); and "open design" (in this section), i.e. open hardware and other physical goods. OSI includes four critical elements: (1) "non-market, non-contractual transfer of knowledge", alike Benkler (2002); (2) contribution of ideas specifically for a joint development; (3) mutual understanding that contribution is within collaborative

development of larger design; and (4) understanding that exploitation of OSI includes production, sale, combination with other products, and any other private or commercial use. The OSI elements are also seen in Thomson & Jakubowski's (2012) recounting of the journey that started when Marcin's tractor broke when starting a new life as a farmer. Out of need, Marcin designed a new tractor from scratch, and made the design available on the internet: shared as open source hardware for the Do-It-Yourself community (DIY). He founded the Open Source Ecology (OSE) group with the objective of democratizing the industrial tools that help to self-determine subsistence and human wellbeing, 50 simple modular open source tools, called the Global Village Construction Set (GVCS), created and shared to provide "modern comforts and basic material autonomy", "hardware freedoms" in Stallman (2015). The OSE designs include tractors, bread ovens, and circuit makers. OSE wants to communicate their model for a "Distributive Enterprise" so that it can be adopted and become the foundation for an economic system, similar to the F/OSS ecosystem. In their view, the globalisation of the production supply chains and foreign policy dependencies artificially create material scarcity; this artificial scarcity leads to procurement uncertainty that OSE believes their Distributed Enterprise model can overcome. Their ideal is to work in the interest of "environmental regeneration and social justice" by joining the open software methodology, the distributed fabrication paradigm and the basic human needs development approach (a precursor to Human Development). Thomson & Jakubowski's (2012) search for a sustainable model is also central in Lock's (2013) Master's research, although for a different community of developers, users, organizations, companies, and governments. Lock seeks to answer the question: "*can embedded electronics companies thrive through the use and/or development of open source hardware?*" His research assumes that OSH can successfully adopt a business model very similar to that of F/OSS. They identified the following options:

- **Support, service, or customization:** model to sell an open source product for which consulting, support or customization services are offered. Successful for F/OSS, but risky for Arduino, and OSH in general, as reported by Banzi (2015).
- **Loss leaders, or Hardware versioning:** a reduced open source product version is released, hoping for upgrades to a more advanced or customized proprietary version.
- **Integrated OSH modules:** difficult/costly to manufacture OSH modules sold and released to community lacking manufacturing capability, openly sharing intimate knowledge of item to study and understand functionality.

Lock's (2013) Master's research shows how an OSH-centered business model can be successful, based on the success of companies like Sparkfun¹¹, Adafruit¹², Evil Mad Scientist¹³, Arduino¹⁴, Make magazine¹⁵, Instructables¹⁶ and Raspberry Pi¹⁷. Another master's thesis, by Bruijn's (2010), explores the extent to which the open source model is viable, by looking at the "RepRap" 3-D printer's community, name that stands for Replicating Rapid Prototyper. He describes open source development as the sharing of the design workload between a multitude of individuals and/or organizations in a way that preserves the public good properties of what is produced. The 3-D printer community rally around an automated machine that adds layers of a material that solidifies to form a 3-D objects of arbitrary shape, including its own parts; this is done from computer files freely distributed on the internet. For this "additive manufacturing" process, design details are shared under an open source license, as well as objects that can be printed with them. The RepRap is one of these open source 3-D printer projects, with the ambitious goal to be able to produce a physical copy of itself. Bruijn's (2010) thesis looks at the RepRap globally-distributed low-cost additive fabrication community of users, to research this question: "*To what extent is the open source*

¹¹ Sparkfun Electronics: <https://www.sparkfun.com/>

¹² Adafruit Industries: <https://www.adafruit.com/>

¹³ Evil Mad Scientist LLC: <http://www.evilmadscientist.com/>

¹⁴ Arduino: <https://www.arduino.cc/>

¹⁵ Make Magazine: <http://makezine.com/>

¹⁶ Instructables: <http://www.instructables.com/>

¹⁷ Raspberry Pi: <https://www.raspberrypi.org/>

development model also viable for the design of physical objects?” Which is similar to Lock’s (2013) research question and Thomson & Jakubowski’s (2012) OSE group, they are all concerned with sustainability of an OSI (Balka et al. 2009) community and shall yield information that can be used in our own thesis to define determinants of success for OSH projects. The RepRap is particularly interesting because: (a) it is a successful application of open source software and hardware beyond the traditional F/OSS context; (b) of the physical nature of the OSH engine (RepRap), its OSH products (3-D artefacts) and their shared innovations; (c) the characteristics of the interactions within its community (frequency, actors, etc.); (d) the rapid growth of the RepRap community; and (e) the access to specialized resources individuals enjoy, resources that are often inaccessible to traditional firms.

Finally, the demographic study by Buechley & Hill (2010), looked at differences between adoption of Arduino and one of its variants called “LilyPad Arduino”. The LilyPad is an open source kit for to experiment with wearable devices; an “integrated OSH module” business model described by Lock (2013). Their study tracks the gender, location and uses of this kit since it was commercially introduced in October 2007, until November of 2009. This study is constructed on the idea that once a media (or “thing”) is easily created and published, its production and consumption is decentralized (Anderson, 2004, via Buechley & Hill, 2010). Once they establish that the Arduino has reached that state, they detail the steps used in their study. They pay special attention to gender to validate the hypothesis that LilyPad enables a new and unique engineering community attracting a growing numbers of women.

Source	#cited	Relation to thesis	Main theories
balka2009	13	Emergence of OSHW	Hypothesis 1: size of community is positively correlated with project advancement; Hypothesis 2: participation of commercial contributors is positively correlated with project advancement; Hypothesis 3: Highly restrictive licenses is negatively correlated with project advancement; Hypothesis 4: Activity is positively correlated with project advancement; Hypothesis 5: Addressing an advanced audience is positively correlated with project advancement.
thomson2012	5	Criteria for Open Source Hardware	Abstract (What was this about?): Postulate 1: creation of “ <i>Distributed Enterprise</i> ” share-alike open source license maximises total innovation

			and replication by including enterprise blueprints in distribution; Hypothesis 1: making available set of 50 open source machines to anyone (from the remote villages in Third World to small enterprises developed world) can improve global wellbeing; Hypothesis 2: application of existing software development paradigms to the physical world (i.e. open source hardware) is a means to improve global wellbeing; Hypothesis 3: adoption of existing innovations and other open source communities democratizes the process in crucial ways; Hypothesis 4: technology improvements can fuel increased innovation, leading to a more equitable distribution of wealth, and improved material well-being;
lock2013	nill	Criteria for Open Source Hardware	Hypothesis 1: The future success of OSH largely depends on its adoption among developers and users, individuals, organizations, companies, and governments; Hypothesis 2: Adopting an OSH-centered business model can be successful; Hypothesis 3: OSH business models are nearly identical to those for F/OSS: support sellers, loss leaders, and widget frosting.
debruijn2010	22	Criteria for Open Source Hardware	Postulate 1: Non-exclusiveness general open source development process has spill-over effects and enables organizations and individuals to innovate faster and at a lower cost; Postulate 2: open source development methodology important with regards to creation of public goods and has shown to be sustainable in terms of continuity; Hypothesis 1: findings from RepRap instrumental case study can be generalized; Hypothesis 2: Bowyer (2004) in De Bruijn (2010) number of RepRaps and wealth they create could grow exponentially, becomes subject to evolution by artificial selection, and it creates wealth with minimal dependence on industrial manufacturing;
buechley2010	72	Criteria for Open Source Hardware	The "Long Tail" Postulate 1: when media is easy to create, publish and distribute, production and consumption decentralize; Hypothesis 1: LilyPad made possible by internet and hardware focused technologies, in particular, online storefronts, media sharing sites, open source hardware and software, and rapid prototyping; Hypothesis 2: LilyPad in turn enabled new and unique engineering community to develop and grow, engaging large numbers of women; Assumption 1: studied retailer data assumed to be indicative of larger Arduino communities;

Table 8: RSLR's step 2.2 for OSH

In their research on the generalized definition of open source innovation transcending software, Balka et al. (2009) denote the following factors as indicators of success: (a) the size of the community of developers; (b) the participation of commercial contributors; (c) intensity of project activity; (d) addressing an advanced audience; and (e) development tool/environment. They also observed that highly restrictive licenses have a negative impact on project advancement. This was observed when finding out how the designs of the global communities coordinated their efforts to create an innovative physical object(s). In this way, they gathered information of actors, object being designs, governance structure, development

process, design environment, and innovative outcome. This allowed them to conclude that OSH can be developed in very similar fashion to F/OSS. Thomson & Jakubowski's (2012) chronicle what lead them to create their Distributed Enterprise model; it spans Marcin's beginning in 2009 until the article's publication in 2012. Their initial work was done in Wisconsin then Missouri, but the continued growth of their development effort will be put to the test when they conduct their first large-scale "replication" in Guatemala. Although their altruistic goals are not shared by other researchers in the critical literature review, it is clear that a sustainable or viable open source hardware model is sought by all. For example, Lock (2013) shows OSH of embedded electronics is less risky than new development, in part because it is flexible and can evolve with the refinement of requirements through the iterations of the development process. His research also showed that users valued OSH when adequately documented and supported; but the risk of third parties cloning or reverse engineering OSH was identified as a significant risk due to the poor Intellectual Property (IP) protection available. Bruijn's (2010) research goes back to RepRap's beginning at the University of Bath by Dr. Bowyer. The RepRap grew to an official core team with people contributing from "the periphery" but with the possibility to gain a place in the core team. These volunteers were driven to participate in the project by a desire for: greater autonomy, gaining competence, relatedness/kinship, and a sense of meaningful contribution. Using a web survey between February 25, 2010 and March 18, 2010; he collected responses from 386 participants (estimated 20%-25% response rate). This survey revealed a substantial user community, comparable to established vendors in the industry; with an innovation investment estimated at between US\$382,000 and US\$478,000. These levels of adoption and innovation are estimated to exceed that of the incumbent industry; and industry where user innovation is significant. To continue to flourish and be viable, the RepRap community must sustain its commitment to innovations and the pace at which it is generating this. This may help lower one of the barriers for wide-adoption of RepRap: the capital-intensive large-scale physical

tools used by the incumbents. The research by Bruijn (2010) identifies the following reasons for RepRap's adoption success: (1) availability of a wide range of applications; (2) the low switching costs between build jobs; (3) the benefits of using digital designs as input; (4) that there are only a few restrictions on shapes that can be fabricated; and (5) the ease to share RepRap designs. Finally, Buechley & Hill (2010) used a feminist research method to study the demographics of adoption of Arduino and Arduino LilyPad boards. They compared the records of a major distributor of both boards, including: (a) sales data for both Arduino and Arduino LilyPad boards; (b) project documentation shared by adopters back to community; and (c) information of uses of these boards by costumers and builders. The results confirm that the Arduino LilyPad enables a new and unique engineering community attracting a growing numbers of women, as reflected by the significant larger proportion of women in the Arduino LilyPad community versus Arduino's. This new strategy, using a customized microcontroller board shows to successfully broaden women's participation in computing. Their work also shows that it is now feasible for a small team to design, manufacture, and distribute new technology (including hardware); and that the open source model allows to gain marketing insight into adopter's and user's "real-world" issues.

Table 9 shows some descriptive characteristics of the OSH literature reviewed. Note that it tries to capture the elements of Thomson & Jakubowski's (2012) narrative analysis and, some of that research method's practice where the narrative orientations (who, what, when, where) are used to guide the recounting.

Source	Methods & Scope	Research variables	Results
balka2009	Method: Quantitative, focus on modes of development of tangible objects; Scope: actors involved, the objects being developed, and the question of how the ideas and solutions of a group of dislocated volunteers can be coordinated to create an innovative physical object.	Constituents: (1) actors; (2) object; (3) governance structure; (4) development process; (5) environment; and (6) innovative outcome.	Finding 1: progress related to: size of developer community; commercial participants; intensity of project activity; "advanced audience"; development tool/environment; Finding 2: tangible objects can be developed in very similar fashion to software.

thomson2012	Scope: the Open Source Ecology group ; Method: narrative analysis ¹⁸	Orientations: Who? Open Source Ecology group, M. Jakubowski; What? 50 OSH machines, and Distributed Enterprise model; When? 2003 to 2012; Where? Wisconsin, Missouri, Guatemala, USA and growing globally.	Evaluation (So what?): first large-scale replication of OSE's equipment in Guatemala, the design library and communities continues to grow, reinforces the validity of their claims.
lock2013	Scope: embedded electronic companies developing, selling, or supporting OSH; Methods: on-line survey, interviews and literature reviews	Survey variables: Type of respondent; Use & Development attributes for OSH; OSH compared to proprietary equivalents; attributes of OSH; participant demographics;	Finding 1: OSH less risky than new development; Finding 2: OSH development able to evolve with requirements; Finding 3: users valued OSH if adequately documented and supported;
debruijn2010	Scope: builders and/or operators of open source or open source derived RepRap 3-D printer project(s), including its F/OSS and OSH; Method: instrumental case study of RepRap, literature review of open source software and hardware, survey on differences of creation, transfer and diffusion of F/OSS & OSH, study of drawbacks of open source of physical objects.	Survey variables: type of user; adopting machine; innovating software; innovating hardware; Thingiverse; demography and general questions	Finding 1: user innovation is significant in 3-D printer industry; Finding 2: capital-intensive large-scale tools barrier for wide adoption of RepRap, but peer production advantageous; Finding 3: reasons for adopting RepRap result from: wide range of applications, low switching costs between build jobs, benefits of using digital designs as input, few restrictions on shape of fabricated object, ease to share designs; Finding 4: ability to sustain radical and incremental innovations key for viability of RepRap community
buechley2010	Scope: Lilyypad adopters; Method: feminist research Arduino adoption by Lilyypad users and builders	Method: Comparative study between Arduino and Lilyypad communities, using: sales records, project documentation shared back to community; demographics of costumers and builders;	Finding 1: new strategies for broadening participation in computing; Finding 2: now feasible for a small team to design, manufacture, and distribute new technology- including hardware-gaining real-world issue insight;

Table 9: RSLR's step 2.3 for OSH

The research and data in Balka et al. (2009) show that the open source model can be successfully extended beyond software when the size of the developer community is significant, especially if there is participation of commercial contributors, when the project is active and the adopted licenses are not restrictive. Thomson & Jakubowski (2012) are also positive about the potential for success of OSH. Having access to specifications of designs and interfaces enables adaptation-by and participation-in commons based distributed

¹⁸ Narrative Analysis: https://en.wikipedia.org/wiki/Narrative_inquiry

production communities. As long as adequate documentation is available to support OSH's adaptation. Large-scale distributed customization and innovation open new markets including market niches previously not addressed. Buechley & Hill (2010) took advantage of widespread accessibility since the Arduino LilyPad kit is made available via the internet (online storefronts, media sharing sites, open source hardware and software, and rapid prototyping/manufacturing technologies).

Following the RSLR method, Figure 7 shows a few linkages between the selected OSH literature sources and the time-spans they cover. The figure is misleading because there are more connections between items than shown, especially between both theses. But the overlap of the Thomson & Jakubowki's OSE with the F/OSS critical literature review (sect. 2.2.2) and DeBruijn's thesis gives us some confidence that there are not too many gaps in time.

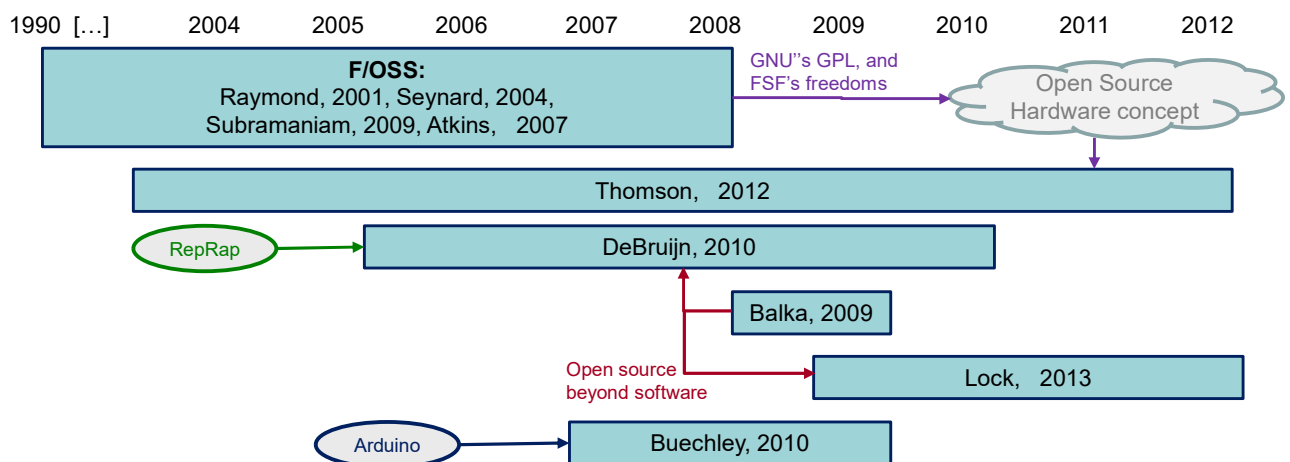


Figure 7: RSLR's step 2.4 for OSH

Table 10 completes the critical review of the OSH literature reviewed. The topics for these documents were chosen to cover a wide variety of topics to yield different perspectives. The choice of literature for OSH was more eclectic than the choice for the F/OSS critical literature review in section 2.1.2; that earlier review was focused on measures of success for

“prevalent” or “common” open source/content projects. The choice of literature for both studies is not comprehensive, but it is adequate to sustain this thesis research.

Source	Strengths & Weaknesses	Arguments	Cross analysis
balka2009	Quantitative proof that open source model can successfully be extended beyond software	In extending the open source model beyond software, balka2009 validates all hypothesis.	Hypothesis 1 to 4 are supported by subramaniam2009 and seynard2004.
thomson2012	Passionate narrative, representative of most of the literature on open source hardware. Academic/scientific publications on the topic just becoming available. Enthusiasm of acceptance by general public show affinity to people’s beliefs	Open source hardware, when matched with needs based development (in their paper), and by extension Human Development (our interpretation) can be an important accelerator positive change	Resonates with buechley2010. Supported by balka2009, but claims societal and geopolitical benefits remain unsupported. Provides counterpoint to debruijn2010 on necessity of proprietary/exclusive specialized equipment.
lock2013	Brings out most common issues of OSH. Good review of literature on open source hardware and provides work to validate sources and theories in our thesis research.	Demonstrates very well that F/OSS and existing OSH business models can be viable. Good analysis of issues, and implication of vulnerability of OHS licensing	Licensing ell supported by Rosen, Stallman, Perens, etc. Model supported by
debruijn2010	Very good analysis of 3-D printer community and RepRap’s context, issues and qualities.	Arguments from RepRap, may have benefitted with short reference at least to RakerBot.	Interesting references to Brenkler’s paper that are also selected for this thesis research.
buechley2010	Assumptions on statistical validity of data is not reliable; but good description of open source hardware movement and commercial growth potential.	An open source Arduino variant for wearable applications may appeal more to women than regular Arduino boards.	No other feminist analysis included in thesis research, this

Table 10: RSLR’s step 3.1 for OSH

The thesis research could not substantiate OSH specific characteristics of the motivations of the individual types of community members (user, beta-tester, developers and architects).

These types of community members share characteristics seen in the F/OSS literature. Also, there was not sufficient analysis of how OSH design information is managed, and how beta-testers’ developers and architects self-allocate to task within the implementer’s community.

This will need to be done in future research.

2.1.7 Emerging issues for open source hardware

Lock (2013) research provides a comprehensive list of issues related to OSH; for example, he mentions four persistent issues hindering OSH’s growth: (1) poor documentation, which

hampers community growth; (2) inadequate support, limiting support for industrial and mission-critical applications; (3) uneven quality of OSH devices, affecting the ability to supply consumer-level supply chains; and (4) dishonest cloning due to lacks in current open source licensing mechanisms. This last issue highlights the limitations of the hardware open source model as seen in the misappropriation of production rights by the Arduino manufacturer (Banzi 2015). Also brought up by Lock (2013) is the fact that physical characteristics of embedded electronics, like circuit topology and component choice, is not covered by copyright. Copyright in open source hardware licenses is limited to the digital source files, not the items manufactured from them.

Also, there are operational issues affecting OSH include: (a) distribution and storage costs of OSH; (b) upgrading and retrofitting fabricated OSH; (c) Specialized resources or manufacturing capabilities generally not available. This last point is, again, particularity to OSH and different from F/OSS which only requires access to a compatible computing device. As stated earlier, examples of hardware that can now be developed using the open source method include: vehicles (Müller-Seitz & Reger 2010); 3-D printing (Anzalone et al. 2013; Pearce et al. 2010); desktop manufacturing (Malone & Lipson 2007); small animal medical devices (Prajapati et al. 2014); farm machinery (Thomson & Jakubowski 2012); bioengineered regenerative materials (Modulevsky 2015); and pharmaceuticals (Maurer 2007). It can easily be observed that these examples require some specialized resources or manufacturing capability; although the RepPap, and similar technologies, are making this issue manageable.

Two last operational issues affecting OSH are: (1) regulatory requirements, for example: medical device regulations (e.g. World Health Organization's guidelines¹⁹), environmental

¹⁹ The World Health Organization's guidelines for medical devices:
http://www.who.int/medical_devices/safety/en/

restriction (e.g. European Union's RoHS in EEE²⁰), and electromagnetic compatibility (e.g. United States' Federal Communications Commission guidelines²¹); and (2) supplier dependence and obsolescence management, especially when manufacturing and selling OSH products. Out of the five documents critically reviewed in this section, Thomson & Jakubowski (2012) are the only ones mentioning improvement to living conditions using OSH, but their account does not attempt to demonstrate achieving any improvement. Living conditions will be addressed in chapter 4.

Success determinants	OBJECT				COMMUNITY				PROCESS/ENVIRONMENT			
	Quality of initial source: available, workable; modular	Commons-based, non-market, non-contractual transfer of knowledge	Free to study, modify, fabricate, copy, redistribute, and sell without royalties; be free of dependencies	Specialized resources or manufacturing capabilities generally not available	Build on merit and reputation; recognize good design ideas from all	Core team motivated; developer's interest/requirements align; commercial contributors	Beta-testers and key resources commitment; advanced audience	User interest/satisfaction; Community size; insight into real-world issues.	Project activity/status; delegate features; be excessively open	Gatekeeping: Cathedral-Transition-Bazaar progress; ground rules	License attractive to developers; enabling OS peer-review	Accessible participatory platform; design tools; clear contribution mechanism
Source												
(*) Inherited from software	X				x	x	X	x	x	X	X	X
balka2009		x	x			x	x	x	x		x	x
thompson2012			x							x	x	x
lock2013	x		x	x		x				x		
debrujn2010	x	x	x	X		X		x	x			X
buechley2010					x			x				

Table 11: determinants of success for open source hardware

Table 11 (OSH) is difference from Table 6 (F/OSS) in how findings have been grouped under: object, community, or process/environment. Note that the most common factors are marked.

²⁰ Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS in EEE): http://ec.europa.eu/environment/waste/rohs_eee/legis_en.htm

²¹ USA's Federal Communications Commission, Equipment authorization – measurement procedures: <https://www.fcc.gov/oet/ea/eameasurements.html>

2.2 Technology-based projects in Human Development

Human development is an evolution of the aid and cooperation model from the mid-1900's. Since the inception of development, there has existed a distinction between human rights, humanitarianism, and development; this distinction is attributed according to Best in Slim (2000) to negotiations leading the creation of the Geneva Conventions: this distinction never really existed in the minds of those who produced the Universal Declaration of Human Rights (1948) or the Geneva Conventions²² (1949) which govern respectively development and humanitarianism. With the evolution of humanitarianism and development, the technologies used to get the work done have also evolved. Today, Information and Communications Technologies (ICT), energy generation, and computing are tools counted upon to effectively intervene. Technology is defined as “knowledge applied to the production process [...] a way of doing things and a way of thinking” (Cypher & Dietz, 2009, p423). In development, the use, adaptation and adoption of technology for the aided populations is key to success. The more rapidly technological knowledge is able to be adapted and put to work in an economy, the more rapid will be the pace of economic growth; and in this view, technologies are specific to each economy (Cypher & Dietz, 2009, p425). Understanding how to tailor technology to specific population needs, to poverty challenges and to development issues is key. Two important figures in these aspect of development are E.F. Schumacher and Paul Polak, their legacy as analyzed by Nelson (2012). Schumacher introduced the notion of appropriate or intermediate technologies as: “technology that recognises the economic boundaries and limitations of poverty” (Schumacher 1973, p 159), and founded the Intermediate Technology Development Group in 1965 (renamed Practical Action in 2005). While Polak started from Schumacher's vision but emphasized affordability and scale (Polak 2009) in the venture he founded in 1981: International Development Enterprises (IDE). Nelson (2012) describes how

²² 1949 Geneva conventions and protocols: <https://www.icrc.org/applic/ihl/ihl.nsf/vwTreaties1949.xsp>

the appropriate technology movement grew out of interest in Schumacher's vision, contrasting with Polak's more pragmatic income growth through the development of "radically affordable technologies" (Polak in Nelson 2012), which rely on market demand to create sustainable technologies. Both IDE and Practical Action harness the energy of designers to solve problems that affect people living in poverty. But while Schumacher's approach was to better adapt existing technologies, Polak's approach views people in poverty as consumers for whom an extremely affordable technological solution needs to be created. Their approach to address poverty marks a shift from traditional economic strategies propose. As Cypher & Dietz (2008) point out, the great economists of the past three centuries pursued the understanding of "the roots of economic wealth and the reasons for poverty" and what are the mechanisms to increase socio-economic gains and to share them among members of society. Because poverty reduction and development use economic means to achieve their goals, it is also important to understand key elements of economic thought.

2.2.1 Brief history of economics

Classic economic theory focused for a long time in the interaction between the factors of production (land, labour, capital) and their equilibrium (Butler 2012). For example, in Adam Smith's model, gains in knowledge and skill increase economic gains without requiring additional investment in the factors of production: this is known as the principle of *increasing returns*, it is the intended results of the *division of labour* and it is governed by the "relation between the invisible hand of the markets and the visible hand of the state" (Cypher & Dietz 2008, p. 112). While in David Ricardo's model, successive increases to any of the factors of production have decreasing economic benefits over time as they become scarce: this is known as the principle of *diminishing returns* and it limits growth (Cypher & Dietz 2008, p. 118). Because of a stated desire for economic steadiness, classic economist laboured to design policies to attain a balance, and scrambled whenever the economy would adjust (Schumpeter 1927; Schumpeter 1950).

Going back to the first 200 years after the British industrial revolution (1760-1830), the economy was characterized by sequences of growth (booms) and depression (busts), or business cycles. Schumpeter (1927) elucidates how the economic model at the time (Marshallian) could not explain these cycles. In his view, business cycles are caused by external impulses, and its booms are the result of innovation in the combination of the factors of production. Schumpeter argued that the external impulses affect the economic systems by instigating innovators and entrepreneurs to willingly react. To the level of their capability, they amplify the impact of these external impulses on the economic systems from within. In Schumpeter's view capitalism is "by nature [...] an evolutionary process that can never be stationary" (Schumpeter 1950, p. 82). Its boom cycles are set and kept going by the fundamental impulses created within the system. Mokyr's makes similar observations in his recount of the British industrial revolution. For him, technological change, or innovation, was "the only dynamic element that seems thus far to be exempt from diminishing returns" (Mokyr 1993). In some views, technological change is thought to be primary to the changes observed by Smith: a delicate balance between innovation and inventiveness. Innovation cannot be sustained without a stream of new inventions; while inventions need to be adopted, adapted and applied to yield economic benefits. When open source hardware is considered in-view of these particular economic elements, a path starts to open where the inventiveness of the open source communities, if nurtured in the entrepreneurial spirit identified by Schumpeter, may be an agent of positive change with appropriate or extremely affordable technology that improves living conditions. Figure 8 shows this model, but that unfortunately lacks a clear anchor to the human development socio-economic context.

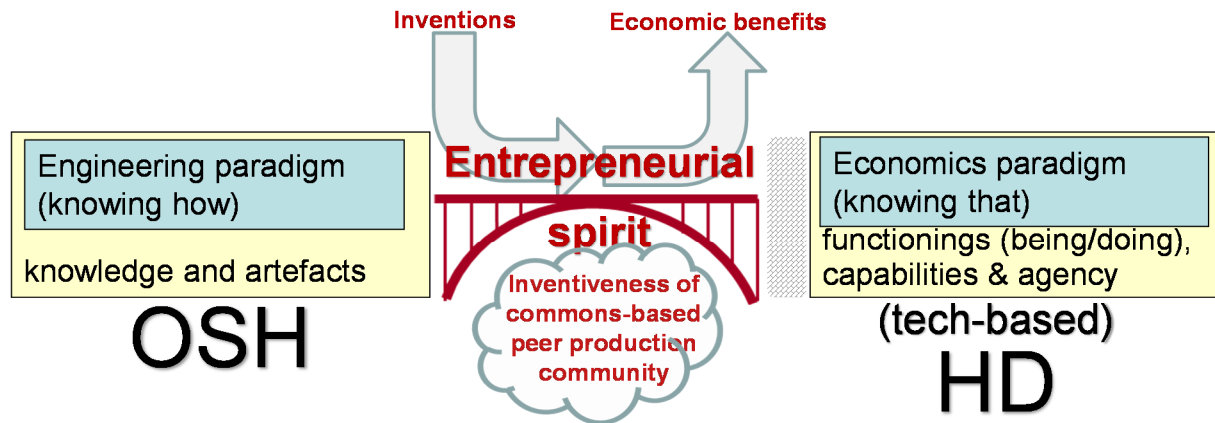


Figure 8: Partial OSH-HD Bridge on inventiveness and entrepreneurial spirit

The industrial revolution took place between 1760 and 1830 and it coincided with the publication of Adam Smith's "Inquiry into the Nature and Causes of the Wealth of Nations" (published in 1776). Smith observed that the gains from trade and specialization were the main sources of economic growth. There are different interpretations to what Smith describes: for example, economist of the Industrial Organization school define the change observed by Smith as a change from an economy in which capital was primarily of the circulating kind (i.e. mercantilism, exchange of raw materials in domestic industry) to one in which the main form which capital took was fixed capital (i.e. machines, railways, and structures); while economics of the Social Change school attribute it to the a change in the way economic transactions where done, replacing the medieval regulations with a formal, competitive, and impersonal market competition for goods and factors of production (Mokyr 1993, p5). Traditional economic schools reason in terms of factors of production:

- Land: productive capacities and natural resources
- Labour: the talents and motives of working men and women
- Capital: financial and infrastructure assets enabling production of goods and services.

But in modern times, science, technology and knowledge have become broadly recognized as significant contributors to economic growth. "In an agricultural economy land is the key

resource. In an industrial economy natural resources, such as coal and iron ore, and labour are the main resources. A knowledge economy is one in which knowledge is the key resource” (Houghton & Sheehan 2000, p4), as exemplified by how sharing of knowledge in the open source movement creates economic activity. Romer (1996) makes the connection between ideas and things in this way: ideas are “nonrival goods” that can be owned at the same time by many people, and they are not destroyed in consumption; while things are “rival goods” with mass or energy that cannot be owned by many at the same time. In his view, economic growth comes from the discovery of new ideas and the accumulation of wealth through knowledge of how-to rearrange these ideas from a low to a high value configuration. The knowledge economy is very different from the traditional industrial economy. The value of ideas and information increases to the degree they can be shared with and used by others (Houghton & Sheehan, 2000, p13). And as Mokyr (1999, p11) writes, knowledge is exempt from diminishing returns: the more knowledge is diffused and adopted, the greater its value.

2.2.2 Criteria for Technology based Human development (TBHD)

Armed with basic relevant economic principles and a general understanding of the evolving meanings of development, the thesis research can continue with a critical literature review of human development. Using the Rapid Structured Literature Review (RSLR) method, the conceptual map of TBHD is created and shown in Figure 9. It shows the search to understand what human development is, what notable publications teach us and what is meant by the “wicked problem” of sustainability. It also shows desire to identify prevalent economic tools and interventions used in TBHD that improve living conditions.

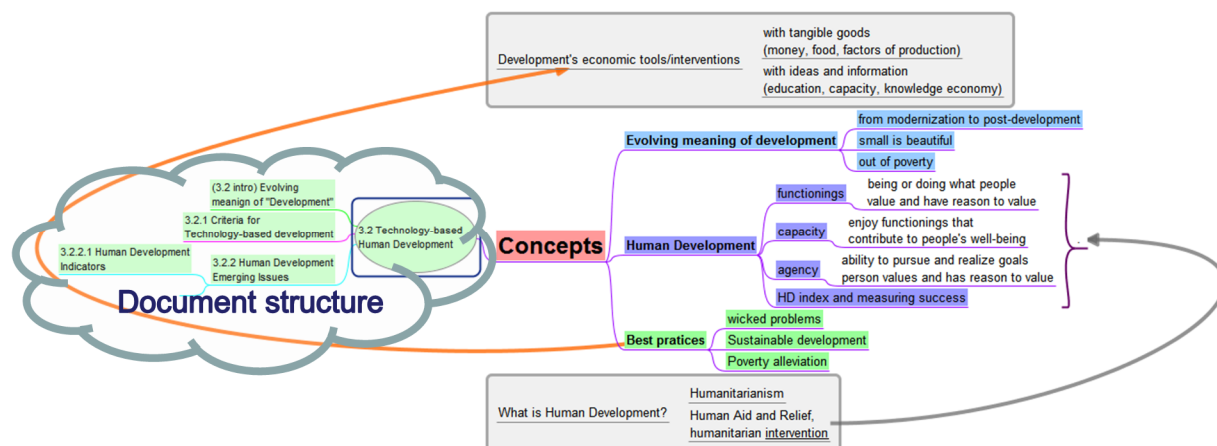


Figure 9: RSLR conceptual map of human development (HD).

The One Laptop Per Child (OLPC) project and the Millennium Villages Project (MVP) are two examples of TBHD that will be analysed as case studies in chapter 4; these two cases provide theoretical replication examples for technology based human development: the former being a counterexample and the latter being an exceptional example (Eisenhardt 1989; Yin 1998). To have a broad set of cases for our critical literature review, technology-based projects on ICT, electrification, health and farming were selected. The first study reviewed is the thesis research by Tole (2013) on the Kenyan government's 2007 initiative, led by the ICT Board of Kenya²³. The Kenyan government, in collaboration with private organisations, created set-up "Digital Villages" in selected rural communities with the expectation that it would increase growth and interest in Information and Communications Technologies (ICT) and electronic commerce (e-commerce); the project later adopted the name "Pasha", which comes from Kiswahili word "Kupasha" meaning to "inform". Tole (2013) mentions different goals for the ICT Board of Kenya, the Digital Village project and the This initiative's main goals were to:

- Build a telecommunications infrastructure to bridge the digital divide between developed and developing countries.
- Enable access to information in rural areas whenever required by the user.

²³ Kenya's Digital Villages - "Pasha" centres: <http://www.icta.go.ke/digital-villages-pasha-centres/>

- Encourage communication outside their local settings, with others in different parts of the world.
- Leverage ICT knowledge to encourage creation of new economic opportunities such as software development, local content and E-commerce.
- Support and enhance local economic activities such as agriculture and tourism through information growth.
- Introduce the Kenyan government's concept of "Business Process Outsourcing" to allow decentralization of government functions and remote access to information.

Tole (2013) includes a literature review of other Digital Village projects by private organizations and agencies; but his main research is on the Pasha initiative. The project started in 2007, asking for entrepreneurs to apply to the program; the government invested in the creation of five centres, each with an estimated set-up cost of US \$5,000 and a satellite 128/256kbps data link costing an additional US\$ 1,350 month. The Pasha project brought private sector partners to collaborate with the ICT Board of Kenya, the Ministry of Youth Affairs and the Ministry of Information and Technology. Tole's (2013) thesis hypothesis is that Digital Villages are yet to reach their full potential in rural ICT community development in Kenya due to lack of adequate support by participating organisations.

From an electrification perspective, the results of a large study in Brazil offer insight into the impact of this technology on the reduction of energy poverty presented by Pereira et al. (2010). Their study sought to find out if household electricity consumption can show the economic benefit of rural electrification because they believe that electricity is vital to support education and health programs and fundamental for the eradication of poverty and reduction of social inequality. To validate this hypothesis, they conducted a four year study (2000-2004) of 23,000 rural domiciles and rural properties; their work seeks to influence public policies to include the expansion of access to electricity and thus mitigate, and hopefully eradicate, the effects of a lack of this resource on impoverished populations.

From a health perspective, the OpenMRS community is described in two documents review together (Seebregts et al. 2009; Seebregts et al. 2010). OpenMRS²⁴ is a highly configurable F/OSS client-server implementation of a Medical Records System (MRS); such systems are built around a database structure to collect, manage and share medical information, diagnosis, tests, procedures, drugs and other general questions and potential answers. OpenMRS is used mainly for information management in developing countries for HIV/AIDS and Tuberculosis patient treatment. The open source approach enabled the OpenMRS Implementers Network (OIN) to grow between 2008 and 2010 to: (a) over 50 internships; (b) 384 individual implementers and developers; (c) over 200 students in Rwanda; (d) 3 centers of excellence; and over 10,500 downloads of the software. The growth of the OIN community is based on the belief that the use of properly structured electronic medical record can improve patient care and public health management through better decisions. A belief (or hypothesis) corroborated through the success of OpenMRS and the momentum it gained by adopting the open source model. OpenMRS was first implemented for HIV and TB patient management in 2006 in Kenya, followed by Rwanda, South Africa, Malawi, Mozambique, Lesotho, Tanzania, Uganda and Haiti. And more recently, it has been deployed through the Millennium Global Village Network in eleven African countries. The maturity and reliability of this software suite can be seen by the adoption by the World Health Organization (WHO). The WHO has a customized version (OpenMRS Express) that includes the forms they use for HIV patient treatment and their monitoring guidelines.

The last document to be critically reviewed in this section is the book written by Polak (2009): "Out of Poverty: What Works When Traditional Approaches Fail". This book re-estates some of the ideas Schumacher (1974) pioneered in his seminal book: "Small is beautiful: : economics as if people mattered," but with more recent economic data and new insight into

²⁴ OpenMRS: <http://openmrs.org/>

small-scale entrepreneurial development: the bridge between technology/knowledge and economic development uncovered to by Mokyr (1993), Romer (1996) and Schumpeter (1950). Polak’s book is a critique of traditional top-down economic paradigms, a view that must be included in our research.

Source	#cited	Relation to thesis	Main theories
tole2013	nill	Criteria for Technology-Based Development	Hypothesis: Digital Villages have not yet reached full potential in rural ICT community development in Kenya due to lack of adequate support by participating organisations.
pereira2009	53	Criteria for Technology-Based Development	Postulate 1: Electricity is one of the pillars on which education and health lean and fundamental for the eradication of poverty and reduction of social inequality; Hypothesis 1: household electricity consumption can show economic benefit of rural electrification.
seebregts2010 seebregts2009	10	Criteria for Technology-Based Development	Postulate 1: appropriate structured electronic medical record use can improved patient care and public health management through better decisions; Hypothesis 1: open source medical record system (OpenMRS) can help deliver benefits of Postulate 1.
polak2009	145	Criteria for Technology-Based Development	Abstract (What was this about?): Postulate 1: practical solutions require going to where they live, to learn about; their lives, why they do what they do, and present/future opportunities they pursue; Hypothesis 1: finding ways to help increase income is the most direct and cost-effective first step out of poverty.

Table 12: RSLR's step 2.2 for HD

The research by Tole (2013) points to studies by the government and international development agencies that supported investment in ICT. For example: the estimate by Kenya’s ICT board of a 128% growth rate in the ICT market, following the strong growth (20%) between 2000 and 2009 reported by the World Bank; and also the recommendation by the International Monetary Fund to implement a Digital Villages program to strengthen the emerging Kenyan knowledge economy. The Digital Villages “Pasha” programme studied by Tole (2013) is part of the Kenyan government’s initiatives to support ICT literacy, other examples are the Kenya Transparency Communication Infrastructure Programme (KTCIP), the Rural ICT Enterprise programme, and a requirement instituted in 2009 requiring the mobile operators to create at least 5 Digital Villages per constituency. For his study, Tole (2013) used qualitative data collection, from 37 questionnaires and interviews (ICT Board of Kenya representative, senior manager Safaricom Ltd and business manager from Ericsson), and quantitative data collection, from secondary data obtained by representatives of different

private organisations involved in the setting up of Digital Villages within Kenya. The research also uses case studies of five Digital Village projects: (1) Safaricom Digital Villages; (2) the Ugunja Community Digital Centre, from Kentel Telecenters; (3) Ericsson's Millennium Villages Project; (4) the Digital Villages Project from the Cisco/Clinton Global Initiative; and (5) the work by the ICT Board of Kenya. The factors of success cited by Tole (2013) include: active community participation in set-up and operation; increased community training; periodic monitoring and reporting of progress; user interest in ICT growth and development; end user costs and infrastructure; and high interest and involvement by participating organizations.

Pereira et al. (2010) used random sampling with a structured interview, and calibrated their data gathering by determining level of energy consumption that would represent "energy poverty" in the context of rural Brazil. The statistical results from Pereira et al. (2010) indicate a reduction of energy poverty; although little details are given on the actual electrification program. Also, there is little discussion on the factors to which the success of the electrification program can be attributed.

Seebregts et al. (2010) describe the four pillars of the OpenMRS Implementers Network (OIN) strategy: (a) face-to-face meetings and workshops; (b) online collaboration tools and communities; (c) capacity and community development programs; and (d) outreach programs. By proactively working on building the open source OpenMRS community, the OIN has flourished; this success has been measured in terms of: attendance numbers to the annual OpenMRS Implementers meetings; number of implementations and on-line activity; number of on-line collaboration participants; number of participants in OpenMRS internship programme; number of participants in training programmes; growth and maturity level of centers of excellence. Between 2008 and 2010, the OpenMRS community grew to: over 50 internships; 384 individual implementers and developers; over 200 students in Rwanda; over

10500 downloads; and 3 centers of excellence. Seebregts et al. (2009) highlight the decision, in early deployments, to rely on an open source communities of volunteers (ONI) to help maintain OpenMRS. Their focus is to: (1) implement collaboration tools for implementers in developing countries and thus free developers from this task; (2) organize regular meetings and training courses; and (3) to seek economies of scale and collaboration with other developer/implementer communities to develop interoperability between applications.

In its narrative analysis, Polak (2009) shares his findings from his conversations with more than 3,000 small-acreage farmers in developing countries; gained knowledge at the core of International Development Enterprises (IDE), the venture he founded in 1981 and that has helped more than 17 million people move out of poverty and leave behind extreme poverty (surviving on less than a dollar a day). His early observations from talking to many extremely poor people, earning less than a dollar a day, forged the premises on which he built his organization. These principles are simple and obvious, but the results from adopting them show their relevance and liberating potential. Polak (2009) intertwines the story of Krishna Bahadur Thapa and his family with his experience in other projects and in contrast with traditional top-down development paradigms. IDE uses treadle pumps for drip irrigation to help small-acreage farmers; and the book describes how that technology made an impact through their work between 1981 and 2006. IDE has a global impact, but is more focused in Bangladesh, India, Nepal, Cambodia, Vietnam, Myanmar, Zambia, Zimbabwe, and Ethiopia

Source	Methods & Scope	Research variables	Results
tole2013	<p>Scope: focus on rural communities in Kenya, exclusively ICT impact within these communities with a focus on Digital Villages.</p> <p>Method: interviews, questionnaires, and case studies</p>	Age; % use of digital villages among older population; most used services; opinion on impact of digital villages; frequency of use; mobile usage	<p>Finding 1: active local community participation in set-up and operation;</p> <p>Finding 2: increased community training;</p> <p>Finding 3: periodic monitoring and reporting of progress; Finding 4: user interest in ICT growth and development;</p> <p>Finding 5: end-user costs and infrastructure; Finding 6: high interest and involvement by participating organizations.</p>

pereira2009	Scope: Brazil, but start by establishes comparison with similar countries; Method: Case study, structured questionnaires; interviews, random sampling;	Energy consumption; demographic, geographic, social, environmental, economic and energy characteristics.	Finding 1: based on energy consumption per household, the rural electrification program in Brazil has had a significant impact.
seebregtsa2010 seebregts2009	Scope: OpenMRS implementers network; Methods: experiment	Attendance numbers to the annual OpenMRS Implementers meetings; number of implementations and on-line activity; number of on-line collaboration participants; number of participants in OpenMRS internship programme; number of participants in training programmes; growth and maturity level of centers of excellence.	Finding 1: strong communities are fundamental to success, growth, sustainability and fostering learning; Finding 2: personal enjoyment, interpersonal relationships, leadership effectiveness, and quality of open source project community are important in attracting developers; Finding 3: mentoring and training users from low income countries is key; Finding 4: community-driven approaches more effective for: greater code functionality, higher code quality, sustainability, and improves enterprise-readiness.
polak2009	Scope: the work of IDE with one-acre farmer earning a dollar-a-day; Method: narrative analysis ²⁵	Orientations: Who? Paul Polak, Krishna Bahadur Thapa and his family; What? Treadle pumps for drip irrigation; When? 1981 to 2006; Where? Globally, but focused in: Bangladesh, India, Nepal, Cambodia, Vietnam, Myanmar, Zambia, Zimbabwe, and Ethiopia.	Evaluation (So what?): model has positively impacted 3.5 million dollar-a-day small-farm families (17.5 million individuals); working on reaching 30 million families by 2020. Principle 1: the biggest reason most poor people are poor is because they don't have enough money.; Principle 2: most of the extremely poor people in the world earn their living now from one-acre farms; Principle 3: they can earn much more money by finding ways to grow and sell high-value labor-intensive crops such as off-season fruits and vegetables; Principle 4: with access to very cheap small-farm irrigation, good seeds and fertilizer, and markets where they can sell their crops at a profit.

Table 13: RSLR's step 2.3 for HD

The research by Tole (2013) indicates issues encountered during the set-up and the lack of follow up procedures on already established Digital Villages; these factors have contributed to a failure of the Pasha Digital Villages. These issues, found in the case studies, surveys and interviews, validate the thesis hypothesis that the potential of Digital Villages in Kenya is not being fully met in Kenya. Support needs to be sustained by both the government and private

²⁵ Narrative Analysis: https://en.wikipedia.org/wiki/Narrative_inquiry

sector, and attaining self-sufficiency must be emphasized. By leveraging access to government services, the support of the Digital Villages and the feedback mechanisms can lead to a better monitoring of the benefits of the programme.

The study by Pereira et al. (2010) provides details of comparable electrification levels of other countries, in a way that eases the understanding of the Brazilian electrification goals. The explanation on energy poverty thresholds for Brazilian households is also well presented, easing the understanding and meaning of the Brazilian data provided, which shows a change in behavior in the amount and profile of consumption among the families analyzed. The study lacks details on strategies used to improve electrification and achieve the results which would have helped our analysis, but the measuring strategy is valuable to our research.

The study by Seebregts et al. (2010) provides information on what was measured and some indication on the multi-pronged approach to achieving the growth observed. Additional details are found in Seebregts et al. (2009), for example: a list of the OpenMRS Internship Programme projects, and projects identified during OpenMRS implementers face-to-face meetings. Figure 10 shows the elements contributing to the project's success.

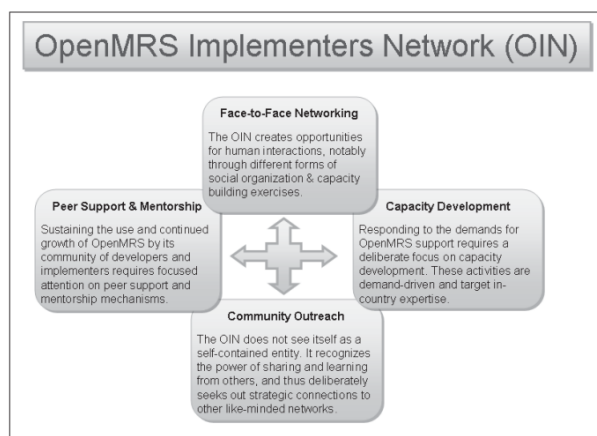


Figure 10: OIN constituents, educational use permitted (Seebregts et al., 2010).

The OpenMRS is the only study on our critical literature review that focuses on open source use for international development. It contrasts to the Digital Villages and electrification

program which are top-down governmental initiatives. Polak's IDE work is critical of prescribed programs but does not share the open source approach. OpenMRS is interesting to our research because of its link to the MVP and how it used open source (software) in Human Development.

Polak (2009) provides design principles that he has proven in the work done through IDE with many dollar-a-day small-acreage farmers. These are: (a) think of poor people as customers instead of as recipients of charity; (b) complete these three minimum feasibility steps of visiting/talking to at least 25 poor people before starting design, result must at least pay for itself in the first year, and sales must reach at least a million units at an unsubsidized price to poor customers; (c) adopt the Small is Beautiful principles (Schumacher 1974) by scaling to poor-people's needs; and (d) design for extreme affordability. These principles have been validated by IDE in different communities around the world with very positive results, showing that they work. The lack of intellectual property protection is a hurdle identified in this book; but one that can more easily be cleared with an open source approach than with traditional product development methods. By focusing on people, Polak's approach relates to the Human Development paradigm: enlarging people's choices and improving living conditions. By treating poor-people as customers, Polak provides them with the freedom to choose what they value and have reason to value (which cash crops), the capability to enjoy these (water harvesting and management) and means to pursue and realize these goals (treadle pumps).

Source	Strengths & Weaknesses	Arguments	Cross analysis
tole2013	The literature review and secondary data analysis provided a clear picture of Digital Villages relevant to Kenya's context. The interviews and surveys provided significant information to form an opinion of the status of the Pasha Digital Villages and potential improvements for the programme. But the reliance on vendor-led initiatives shows a bias towards more equipment investment and less on	Although only few secondary data samples are given, it is sufficient to make arguments but not enough to validate or invalidate the conclusions with certitude. This is indicated in the "future work" section of the conclusion. Overall, the hypothesis is confirmed since government and industry-lead studies confirm that the goals of	Tole mentions participatory development and community engagement, but does not describe these to the extent of Seebegtsa's OpenMRS study of Polak's recount of his conversations with farmers. Also, Tole's data collection is not linked to the ICT Board's set goals assumed that what is shown isn't the full potential of the initiative.

	social issues and economic development.	Digital Villages program are still not met.	
pereira2009	Paper provides significant quantitative information on what the comparable global electrification level is and what the Brazilian level is; making it easier to understand the methodology and impact.	The study makes an effort to explain how the impact of rural electrification was measured before presenting their analysis. The description and arguments are coherent and clear.	In our critical literature review, Tole's research is the only other national government-lead programme using technology for development. And Pereira's study is more statistically sound.
seebregtsa2010 seebregts2009	Study provides information on what was measured and some indication on the multi-pronged approach to achieving the growth observed. A more detailed presentation of the strategy, lessons learnt from these efforts, and the effect on the beneficiaries of OpenMRS would have helped our research.	The story told by both papers demonstrates how OpenMRS improved patient care and public health management. They present public health service improvements and refer to efficiency and financial benefits of adopting this open source solution.	No other study in our critical literature review was on open source projects. The Digital Villages and electrification programmes where top-down governmental initiatives and Polak's IDE work was critical of prescribed programs without being open source. But OpenMRS is interesting to our research because of its link to the MVP and its successful use of open source (software) in Human Development.
polak2009	Very compelling case for small-acreage farmers; provided statistics on success shows favorably IDE's strategy versus traditional top-down programmes. But not obvious to make link to open source, despite being technology-based solutions.	Treating dollar-a-day people as customers instead of treating them as charity recipients is illustrated by referring to many examples. Using Bahadur's and other stories, the point is clearly made.	The paradigm proposed by Polak share some of the principles of Human Development: treating poor-people as customers to provide freedom to choose what they value and have reason to value, the capability to enjoy these and means to pursue and realize these goals.

Table 14: RSLR's step 3.1 for HD.

2.2.2.1 Emerging issues for technology-based Human Development

One element that is common to all documents in the critical review is poverty. The technology solutions and activities in the critical literature review aim to help impoverished Kenyan communities (Tole 2013), positively impact Brazilian poor rural populations (Pereira et al. 2010), provide better healthcare to populations affect by HIV/AIDS and Tuberculosis (Seebregts et al. 2009; Seebregts et al. 2010) and help dollar-a-day small-acreage farmers get out of poverty (Polak 2009). But these present a different approach than mainstream development which has been mostly focused on economic growth. The benefits of economic growth are significant to 21st century economists and important to development practitioners of all doctrines. For example, in *The Growth Report* the World Bank presents its analysis of

13 economies with sustained inclusive growth over at least 25 years since WWII (World Bank 2008). The World Bank and the International Monetary Fund have been the main western providers of development funds since WWII; this aid has allowed sovereign nations to extend their production capabilities with foreign resources; but these funds have historically been marked by attempts to influence the course of events and the economic dynamics of the less-developed nations (Cypher & Dietz 2008, pp. 555-591). Mainstream development has counted on “the World Bank Imperative form” (Easterly 2010): where the developed world imposes a long list of actions for developing country governments to follow. Delegated authority to the Bretton Woods institutions have also brought its lot of criticism; some of which are overstated, as (Vetterlein 2012) claims. In Vetterlein’s (2012) view, it is clear the difference it makes whether poverty is defined as a purely economic problem or a multi-dimensional holistic problem. But despite any criticism, it is important to understand how these global institutions define poverty to understand the thread that strings discourse, policy, operations and organisation of modern development efforts: for example, when modernization was prevalent during the capitalism versus communism tug-of-war of the 1950s because technology-based development is part of the modernization paradigm. The nuance between views is on how technology-based development would be implemented differently depending on the period and political inclination of the aiding institutions. Modernization is easily identifiable in Pereira et al. (2010), Polak (2009), Seebregts et al. (2010), Seebregts et al. (2009) and Tole (2013); and it is a type of development criticized for being a form of “digital capitalism” (Nederveen Pieterse 2009). Despite *The Growth Report’s* success stories, extreme poverty still affects millions; for example, over 30,000 children, under the age of five in the less-developed countries, die daily²⁶ and this from preventable illnesses (Cypher & Dietz 2008, p. 4).

²⁶ World Health Organization, child mortality fact sheet:
<http://www.who.int/mediacentre/factsheets/fs178/en/>

Vetterlein's (2012) analysis shows that the World Bank's understanding of poverty has changed over time, but kept on turning abstract concepts into *actionable knowledge*: from an independent objective of development in the 1970s; to an outcome of economic growth in the 1980s; and then, to the centre of discourse and policies in the 1990s. By the time of the Bank's publication of the *2000 World Development Report*, it is evident that poverty had become an overall underlying theme of development including both concepts: (a) "low income and consumption"; and (b) "low achievement in education, health, nutrition, and other areas of human development" (Vetterlein 2012). Cammack's (2004) attributes a hidden agenda to that the Bank's commitment to poverty reduction. He interprets the evolution of the Bank's strategy on poverty as using knowledge to support capitalist development and to influence aided countries to this end, a concerted means to "lock the poor into the market [and] present this 'locking in' as liberation": a position akin to alternative development narratives (Nederveen Pieterse 2009). A more positive stance is found in Lok-Dessallien's (1999) claims that understanding the main concepts of poverty aids the selection of methods to measure, assess and derive development policies/programs for it. For example, a poverty concept based on human capabilities differs from one based on income growth. She identifies the following poverty concepts (Lok-Dessallien 1999):

- Absolute and relative poverty: subsistence below minimum, socially acceptable living conditions (i.e. indigence, extreme poverty), versus income compared between lowest and upper segments of a population.
- Objective and subjective poverty: normative value judgements (traditional economists model), versus individual preferences/value of goods and services (individual utility).
- Physiological and sociological deprivations: lack of income, food, clothing and shelter versus (basic needs), versus lack of opportunities to lead valuable and valued lives (human capability).
- Poverty and inequity: deprivation/dispossession, versus distribution of wealth.
- Poverty and vulnerability: deprivation/dispossession, versus external risks, shocks, stresses and internal defencelessness.

- Poverty and exclusion: deprivation/dispossession, versus social deprivation impeding full participation in society and its development.
- Poverty and underdevelopment, as distinguished in the *Human Development Report*²⁷: individual deprivation/dispossession, versus an aggregate perspective.

Poverty reduction requires action along the concepts seen above. It has historically been carried out collectively by powerful states, and now by organizations like the United Nations.

Depending on the definition of poverty observed, technology-based efforts would adopt: either, economic growth levers like trade and foreign investment; or a social transformation strategy involving Human Development concepts like local knowledge and social capital.

Nederveen Pieterse's (2009, p. 84-85) comparison of alternative development to mainstream development is a good way to understand development paradigms:

1. "It is now generally accepted that development efforts are more successful if the community participates".
2. "It is now widely accepted that development is not simply a matter of GDP growth".
3. It is now widely accepted that "human development is a more appropriate goal and measure of development".
4. "[D]evelopment funds being channelled through NGOs [...] well exceed the total annual disbursements through the IMF and World Bank"

Critics of mainstream development models are proponents of people-centred development as an alternative. Alternative development emphasizes agency, in the sense of people's capacity to achieve social change. Forms of alternative development have become institutionalized, and under some circumstances have become or overtaken mainstream development (Pieterse 2002). Some examples of alternative development include: Basic Needs, Capability, and Human Development. Increasingly, emphasis is shifting to the notion that it is ideas, not objects, which poor countries lack. But measuring the success of such endeavours is complex, and depends on many socioeconomic factors. The method to measure

²⁷ The Human Development Report: <http://hdr.undp.org/en>

development has followed the evolution of the meaning of development. From a traditional growth perspective, development progress is measured by improvements in income (a conceptualization of poverty). However, growth is not a reliable measure even when adjustments for currency fluctuations, purchasing power, and other factors are done. The Human Development Index (HDI), first proposed 1990, has gained wide acceptance. It includes education, life expectancy, standard of living, and Gross-National-Income per-capita to represent a normalized picture of development (Cypher & Dietz 2008). It has been published annually since its introduction in the Human Development Report by the United Nations. It is interesting to see the time span that the literature in the Human Development Critical review covered and some of the development paradigms adopted. Two of the cases studies were governmental programmes, with the electrification program in Pereira et al. (2010) not acknowledging relying on beneficiary's input while Tole (2013) describes the importance of such input for the success of the programme. The OpenMRS project goes a step further, and build on its implementer community: fully adopting open source's participatory development model. The concepts of Schumacher's (1974)"Small is beautiful" are explicitly identified as being part of Polak (2009) development paradigm; but this literature source is the only one expressly espousing these ideals. Tole (2013) points out how the lack of consideration for the end-users in the solution development process strengthens Polak's position in adopting it.

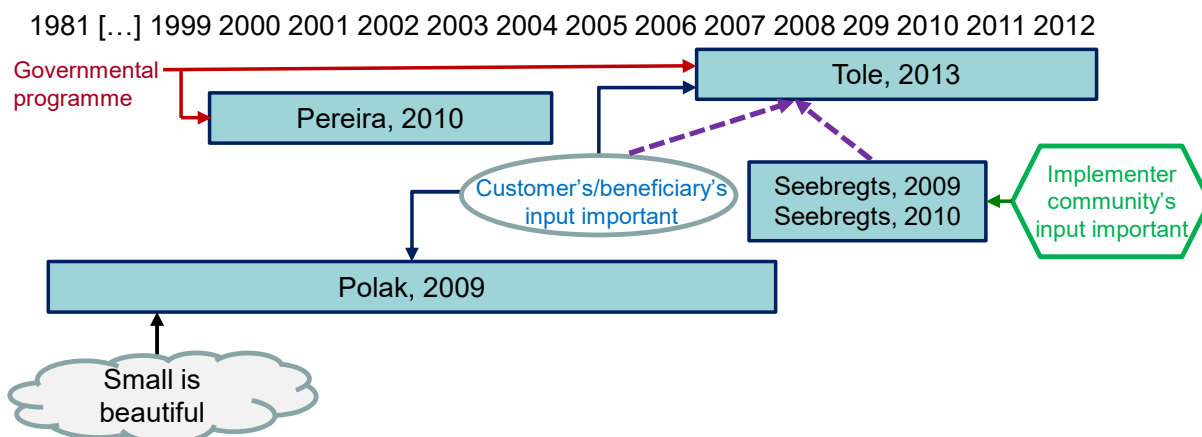


Figure 11: RSLR's step 2.4 for HD

With the gained understanding of poverty and technology-based human development, this thesis research shows in Table 15 the salient success determinants that resulted from our critical literature review.

Success determinants	OBJECT/SOLUTION				COMMUNITY				PROCESS/ENVIRONMENT			
	Solution is open source: study, share, modify, fabricate or sell.	End-user costs and effect in improving infrastructure	Based on end-user input, participatory development, and appropriate use of technology in context of deployment	Solutions improves earning potential of beneficiaries	User interest/satisfaction; Community size; insight into community issues.	Core team motivated; developer's interest/requirements align; commercial contributors	Community training, proficiency on technology/solution	High interest and involvement by participating organizations, partners.	Accessible participatory platform/design tools; clear contribution mechanism	Increased support during implementation and regular monitoring of progress	Clear definition of measures of success and process to collect that data	Talk/visit customer, ROI in 1st year, 1M sales, scale to needs, ultra-affordable
Source												
Salient OSH characteristic	X				X	X			X			
tole2013		x	x	x	x	x	x	x		x		
pereira2009		x		x							x	
seebregtsa2010	x		x		x	x	x	x	x			
polak2009			x	x	x							x

Table 15: determinants of success for human development

The TBHD determinants of success from Table 15 are combined with the conceptual framework in Figure 8 to create an updated conceptual shown in Figure 12. This new model shows links between the OSH domain and the TBHD domain. Based in this new understanding found in the critical literature reviews, the thesis research can now proceeding to model a sustainable deployment strategy in chapter 4.

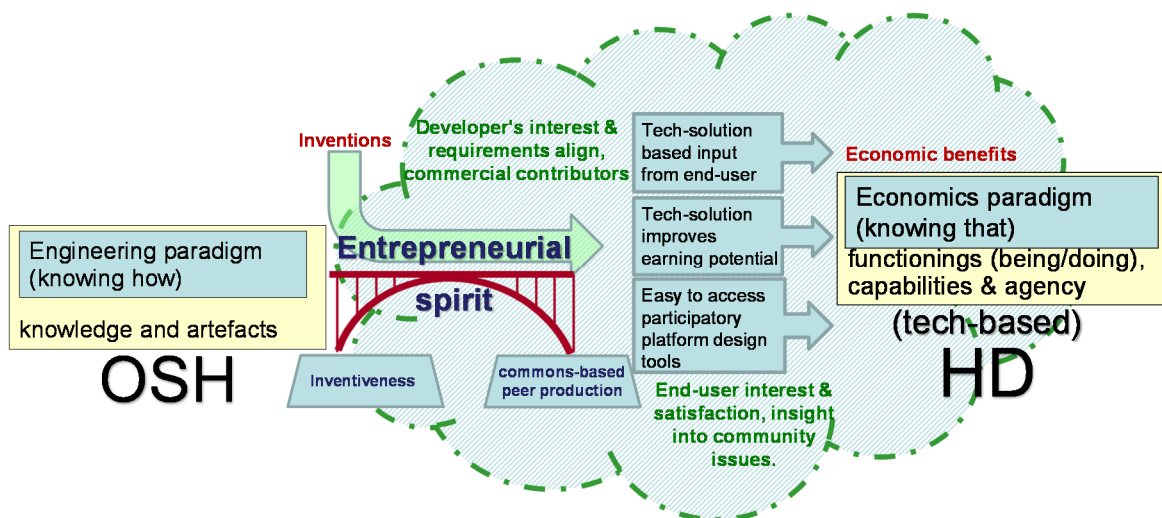


Figure 12: Linking a "bridge" between OSH and HD

But before doing that, the research strategies, methods and procedures that will be used need to be defined and clarified. This will be done in chapter 3.

3 Research strategies, methods and procedures

“As to methods, there may be a million and then some, but principles are few. The man who grasps principles can successfully select his own methods. The man who tries methods, ignoring principles, is sure to have trouble.” – Harrington Emerson, American efficiency engineer and business theorist.

As stated in previous chapters, this thesis research span two disciplines with different research practices. The general differences between disciplines have been studied and grouped, for example in Biglan’s classification which grouped academic disciplines into eight categories depending of the degree of their belonging to: life or non-life areas; tangible (“hard”) or conceptual (“soft”) study paradigms; and pure (theoretical) or applied research (Creswell & Roskens 1981). Biglan’s classification (see Table 16) measured the social behavior within different academic faculties and clearly showed commonalities within groups, characteristics that have been verified in various studies (Creswell & Roskens 1981; Smart & Elton 1982). In our case, the two disciplines of our research question relate to Biglan’s nonlife systems: open source hardware is a hard-applied discipline, while human development is a soft-applied discipline. Biglan’s classification does not consider research strategies, despite this the classification is used as a starting point to select from the research methodologies related to our research question. In this way it is determined that open source hardware would naturally benefit from empiricist research approach because it is an engineering topic (Pitt 2001) and hard disciplines generate knowledge under controlled conditions to test their theories (postulated relationships between physical forces , verified through experimental design and data generation) (Ethridge 2004). On the other hand, human development would naturally benefit from a rationalist research approach because it is an economics research topic (Pitt 2001; Walliman 2011) and soft disciplines tend to address complex individual and

group phenomenon where motivation, behavior, and effects on societal institutions are studied (not directly observed or quantified under controlled conditions) (Ethridge 2004).

Task area	Hard (study of tangible elements)		Soft (study of concepts)	
	Nonlife system	Life system	Nonlife system	Life system
Pure (theory)	Astronomy, Chemistry, Geology, Mathematics, Physics	Botany, Entomology, Microbiology, Physiology, Zoology	English, German, History, Philosophy, Russian, Communications	Anthropology Political science Psychology Sociology
Applied (practice)	Ceramic engineering, Civil engineering, Computer science, Mechanical engineering	Agronomy, Dairy science, Horticulture, Agricultural economics	Accounting, Finance, Economics	Educational administration and supervision, Secondary & continuing education, Special education, Vocational and technical education

Table 16: Biglan's classification (Creswell & Roskens 1981), *emphasis added*.

Using propositional logic²⁸ instead of the research question, each element can be expressed in relation to improving living conditions (i.e. being/doing, capability and agency):

- (A) Open Source Hardware improves living conditions.
- (B) Technology-based Human Development projects improve living conditions.
- (C) Technology-based Human Development projects using Open Source Hardware improve living conditions.
- (D) Open source hardware is a means to improve living conditions in technology-based human development initiatives:

If A and B and C then D

Each proposition can be used to select appropriate research strategies, methods and procedures that take into consideration their nature. The first two propositions (A and B) refer to the first two research objectives. Validating "A" uses an empiricist research approach which will be significantly different from validating "B" with its rationalist research approach, for this reason two separate critical literature reviews are done in the previous chapter. Differences in research approaches, or paradigms, affect how relevant literature is selected and how knowledge from these sources is sorted, reviewed and presented. As seen in the critical literature review (chapter 2), there is sufficient secondary and tertiary research data to limit

²⁸ Propositional Logic: <http://www.iep.utm.edu/prop-log/>

the study to this critical literature reviews for the first two research objectives and related propositions; but the difference in their research strategies directed the research to treat them separately: one for OSH and one for HD. For the third objective/proposition, drafting a sustainable deployment strategy, which is a topic of operations research for which a normativistic approach is adopted (Ethridge 2004). The conceptual framework in Figure 13 has been updated from figures 2 and 12 to include the findings from the literature review in chapter 2; it represents better the alignment of developer interests in an open source project with project requirements on the OSH. It also shows the alignment of the insight into the end-user and community issues with end-user interest and satisfaction. Because of the underlying economic principles, these two linkages must align with the entrepreneurial spirit fuelled by inventions and sustained by inventiveness as identified earlier (Mokyr 1993; Rensman 1996; Romer 1996; Romer 1990; Schumpeter 1927; Schumpeter 1950). In this way, a “bridge” can be described which is rooted in OSH’s commons-based peer production described by Benkler (2002); note how literature review findings are integrated, for example, a “conveyor belt” represents how industry participation contributes, and bridge footings represent the relation of inventiveness and commons-based peer production to the entrepreneurial spirit.

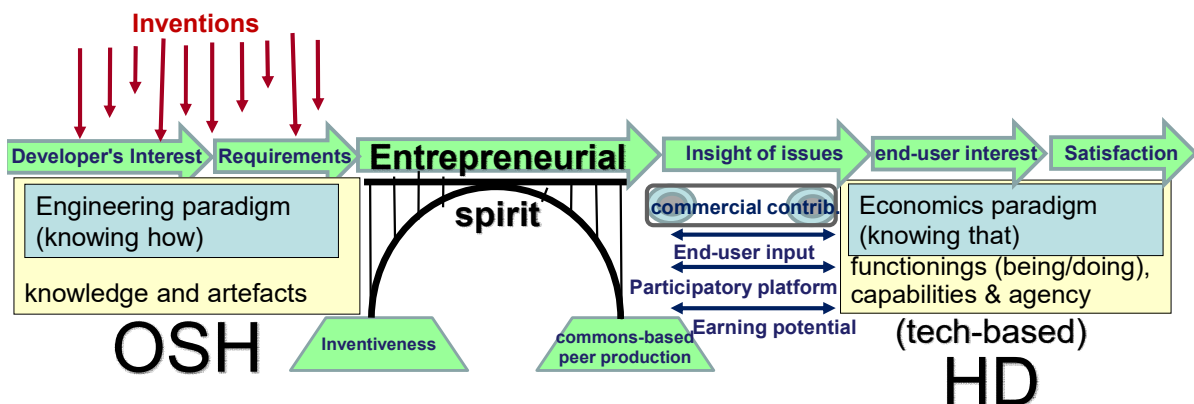


Figure 13: Updated conceptual framework, including Critical Literature Review findings.

The normativistic approach used to research the third objective is concerned with what “ought” to be done. It emphasizes people’s values: efficiency, welfare, income, standard of

living, quality of life. This prescriptive knowledge considers intrinsic values to be "knowable", and is in-line with the Human Development's people-centered constituents: to live a long and healthy life, to be educated and to have access to resources needed for a decent standard (UNDP 1990). It is important to note, as Ethridge (2004) does, that normativism in economics is mainly concerned with what is good or bad instead of moral questions of right and wrong: prescribed economic choice may include "bad" or unfavorable alternatives. Starting from the findings in the literature reviews (Figure 13), the thesis research will iterate through an inductive process using case studies and interviews to validate the applicability of OSH to human development.

This case study research method for the third objective, takes the knowledge gained from the literature reviews and iterates through refined versions of a model based on the Soft Systems Methodology (SSM). As a starting point, the thesis research uses case studies (Yin 2009) with semi-structured interviews (Gubrium & Holstein 2002) to guide the iterations of the sustainable deployment strategy. Interviews are used as the data sampling method because, as Ethridge (2004) indicated, applied economic research cannot be directly observed or quantified under controlled conditions. The thesis research did not have the resources to conduct experiments and deploy controlled versions of TBHD projects using OSH. Empirical data collection was impractical due to the time constraints and scope of this research and the prohibitive cost of designing and deploying such systems in numbers that would generate reliable data. Also, complex systems modeling was not a reliable alternative because the gap between the disciplines in the research is not sufficiently understood to produce reliable results: too many assumptions would have been needed.

The rest of this chapter includes sub-sections on the two research methods selected: (a) critical literature review, and (b) case studies leveraging interviews and the soft systems methodology (SSM); but these sub-sections will only follow after some time is taken to

describe the preliminary work done prior to formally starting the formal research for this thesis. Ethridge (2004) identifies six ways of gaining knowledge: the senses, intuition, revelation, measurement, reasoning, and experience. The experience described in the next sub-section helped me gain knowledge that enabled the thesis work.

3.1 Knowledge through experience during preliminary research

As mentioned earlier, the research in this thesis traces back to IEEE's HTC where I was a member of HTC's Reliable Electricity working group from 2009 onwards. In this manner, I completed one iteration of the solution process described in Perusich et al. (2009). The work in IEEE's humanitarian activities was one strong motivation to pursue this thesis research; and my involvement in this type of IEEE activities continues to this day. This subsection is a parenthesis summarizing some of my IEEE involvement and its link to the thesis research; this subsection is meant to show how volunteering for the IEEE advanced the thesis goals while still staying a distinct activity from the thesis research work.

For starters, it is significant to mention that my initial involvement in the HTC closely followed completing a course on the design of economic systems at the University of Ottawa. This course introduced the theory of complex systems (Bar-Yam 1997; Beinhocker 2007), economic implications of policy and the Nash equilibrium (Bowles 2009). The course was a study of leading theories and debates concerning the meaning, challenges and possibilities of development. The main learning activities included analysis and discussion of the different aspects of development, including its cultural, political, economic, security, legal and territorial implications. The course introduced key concepts, theories, and methods of what is called development, to provide a framework for the analysis of structural changes experienced in third world countries in recent centuries to understand contemporary issues of development, for example: expansion of European capitalism; transitions from agrarian to industrial

societies; globalisation; the rise of a post-industrial, knowledge-based economic model; the eventual decline of liberalism; and the emergence of structural crises brought by the peaking of oil production and climate change.

The volunteer work in IEEE's HTC, started in 2009, provided the motivation to follow up on a personal interest in collaborative development of a technical solution for humanitarian problems. The HTC project ended in mid-2010, but the desire to continue working in this area of research did not end there; the end of the HTC left me wanting to learn more, and it led me to take a course on understanding development at the faculty of social sciences. This craving for understanding and some exploratory searches culminated in the registration in the spring of 2011 of this thesis' research topic, originally titled: open source hardware in impoverished communities. Because of the order of events that led me to take this path, I started my research with a sizable quantity of unorganized information of varying relevance. Some of the information was on licensing of open source hardware designs, due to my work for IEEE's HTC; some other information was on development theory, due to my course work; and some other work was on random topics loosely related to my interests: operational research on humanitarian supply chains, innovation, economic policy, education, marketing, 3D printing, orphan disease research, appropriate technology, etc. It must be stated that all this effort was not a complete waste. For example, Warsh's (2007) book on the history of economic thought eased the effort when later reading economic publications from authors with divergent views; also, having taken the understanding development course made me aware of the conflicting views of what "ought to be done" when looking for thesis research material; and also the benefit of having read Rosen's (2005) book on open source licensing and Raymond's (2001) book on the open source methodology because they provided the base of knowledge for the research on open source hardware.

Docear definitively helped, but it was no replacement for the effort that still needed to be done to read all the accumulated material, classify it, annotate it and write the findings from them in the thesis. This helped to use interesting references like Dr. Junjei Wu's tutorial³⁰ on critical literature review: it stresses the need to take a critical look at the literature (facts and views) that already exists in the area of research; it makes the point that a literature review is not "a *shopping list of everything that exists*", but a critical analysis; finally, it proposes a simple strategy to conduct the critical literature review. Using Docear, I added to each document in the database a note to build this critique of literature. This research procedure is in accordance with Biggam (2011) who stresses the adoption of a critical evaluation of literature. In addition, I started using Ethridge's (2004) stated logical tests: are the propositions/outcomes free of logical contradiction, errors and fallacies (logical coherence test); are the outcomes/statement consistent with what is already 'known' (correspondence test); are the outcomes/statements free of ambiguity or vagueness (clarity test); and do the results must work, are they relevant, and are they reliable (pragmatic test). These research procedures and tools allowed us to dive into the research activity with confidence.

3.1.1 Published papers related to thesis work

In closing this parenthesis about the additional research activities, I need to describe three articles successfully submitted to three different conferences for publication. As I made progress in our thesis research, it became manifest that the IEEE volunteer work did not perfectly align with the focus of the thesis research, but it is connected. These three works are the deliverables to IEEE on seeking a mechanism to support their volunteer's work on humanitarian technology. The HTC work was concerned with artefacts, systems and methods that used technology to address specific humanitarian problems; while this thesis' research is

³⁰ Critical Literature Review: <http://www.resourcesvalley.com/critical-literature-review/>

concerned with finding out if one specific embodiment of technology (OSH) is an approach suitable to a specific development concept (human development).

3.1.1.1 *Open Source and Product Lifecycle Management*

The first article was successfully published in the International Technology Management Conference 2014 proceedings (ITMC2014). The objective of this paper, titled *Open Source and Product Lifecycle Management* (Herrera et al. 2014), was to describe a Product Lifecycle Management process for IEEE's Humanitarian Technology (HT) "Solutions". The paper claims that a process that leverages IEEE's peer-review would be beneficial to the open source hardware release process. This first paper uses as a case study the student design competition that the Humanitarian Initiatives Committee (HIC) of IEEE Region 7 organized in 2011. This competition's main objective was to understand the design process of making HT "Solutions" available as open source. Other objectives of this competition included understanding open source licensing, open source hardware and the open source development model. The paper also presents the HIC student paper competition in 2013 as a second case study. The main goal of the 2013 competition was to nurture the growing interest in Humanitarian Technology in IEEE's region 7 (Canada) and to address one of the concerns raised during its 2011 competition: to put more effort in the paper review process, standard IEEE peer-review tools and processes were used. The ITMC2014 paper presents lessons learned during HIC's competitions to present the Product Lifecycle Management (PLM) framework in Figure 15. This framework is extended to Open Source Innovation (OSI), a term defined by Balka et al. (2009). Finally, the paper briefly presents Intellectual Property Rights (IPR) models that IEEE could adopt in IEEE-lead humanitarian activities in a way that leverages IEEE's peer-review process. The paper focused on operationalization of a process that would take innovation from an IEEE engineering domain to an open source market. The paper is successful in describing a release mechanism, even if it does not address issues from the human development perspective.

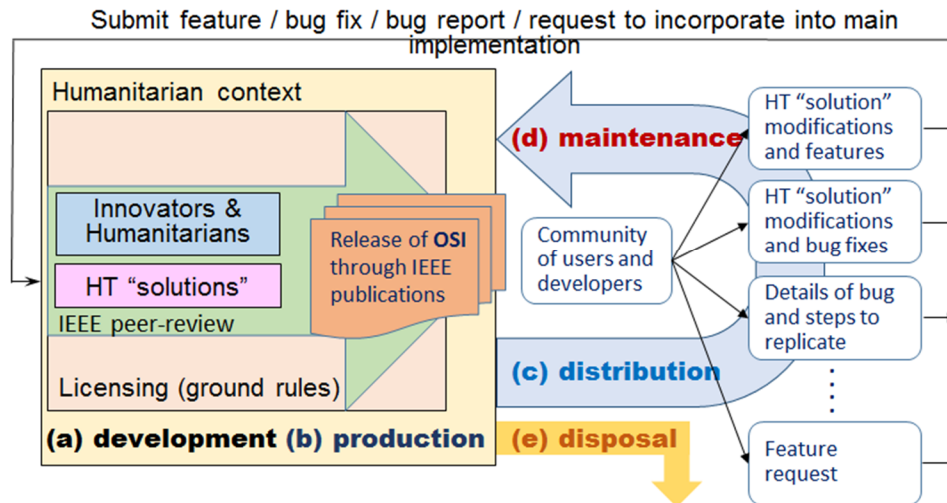


Figure 15: Product Lifecycle Management of IEEE IPR (Herrera et al. 2014).

Unfortunately for the thesis research, the paper's coverage of the open source methodology did not go into details, mostly relying on Balka et al. (2009); but it made the links between the peer review processes of open source and paper publishing to support a PLM model.

3.1.1.2 *Open source licensing of commercial product*

The second article was successfully published in the International Conference on Consumer Electronics 2015 proceedings (ICCE2015). This paper, titled *Open source licensing of commercial product* (DelCore & Herrera 2015), described the adoption of an open source hardware release process for a wearable headlamp: a LED light worn on one's forehead. The headlamp is described briefly in the paper, but most of the focus is on how it was developed to satisfy an end-user requirement of hands-free, directional lighting for use in remote areas that lack reliable electricity. The description of the design of the headlamp emphasizes the importance of "*built-in resilience*" and durability; and the open source methodology is referred to as a way to improve prototyping and promote regionally-appropriate technology. Because of the endorsement of the open source design methodology, the paper claims that releasing the product under an open source license fosters product adaptation for the design, manufacture, and use of the headlamp in various locations. The paper concludes with a statement on the availability of working prototypes and the impending release of do-it-yourself

kits under an IEEE open-source hardware license. The paper did mostly focus on the technical design choices made to add durability and to build-in resilience, with local maintenance and repair claimed as a significant enabler. The distribution enabled by the adoption of open source licensing is also claimed as beneficial to ease distribution and low-cost. Unfortunately, the paper's claims are not demonstrated in a way that can be used for the thesis research. And there are not links to human development concerns, despite mentioning the adoption of appropriate technology principles. But despite this, the paper is successful in introducing how IEEE's open source licensing can be used.

3.1.1.3 IEEE's Humanitarian Open Source

The last publication has been accepted at the International IEEE conference on Standardization and Innovation in Information Technology (SIIT2015). This paper, titled *IEEE's Humanitarian Open Source: A path to Open Standards and Interoperability* (Herrera & Prowse 2015), will present IEEE's development of an organizational capability to create open source innovations for humanitarian needs since the 2004 Tsunami. The poster recounts briefly IEEE's Humanitarian Technology Challenge (HTC) held in 2009 where one of the stated objectives was that Humanitarian Technology "Solutions" developed under that initiative results would be broadly available to anyone for their use in providing humanitarian products or services. Since then, various Humanitarian Open Source activities have been sponsored by the IEEE, notably under the Special Interest Group on Humanitarian Technology (SIGHT) program. These activities will be presented, as well as their accomplishments with regards to the global open source movement. Finally the newly drafted IEEE open source licenses are presented, with emphasis on the need to protect IPR developed by IEEE volunteers under the humanitarian activities it sponsors. In the closing section of this third article, open standards and interoperability are discussed in relation to IEEE's stated humanitarian goals. Unfortunately for the thesis research, the poster presentation will take place after the thesis is submitted to the faculty. Feedback from the

poster sessions and learning from the interaction with IEEE's Standards Association members will not benefit the research in this thesis. But the poster presentation, and related work, is significant to IEEE and to the thesis research because of the practical implications from applying the experience gained during the IEEE projects.

Publication of these three papers is significant for IEEE's effort on Humanitarian Technology, not because of what they report as having been done but because of what they put forward and get validated in three separate peer-reviews. An effort was made to seek conferences from which the peer-review process would validate a specific aspect of the solution being developed for the IEEE: the technical committee of the ITMC2014 conference peer-reviewed the proposed knowledge management process; the technical committee of the ICCCE2015 peer-reviewed the proposed distribution model of a medical open source consumer electronic device; lastly, the technical committee of the SIIT2015 conference peer-reviewed how the licensing strategy can enable development and use of open standards for HT solutions for IEEE-sponsored HT designs. These articles benefited from using Docear to manage the reference material and structure the concepts communicated. Research for these three papers helped learn about some aspects of technology use in humanitarian work, but it only contributed with basic knowledge, through experience. These learnings will be revisited in the conclusion section of this thesis. In summary, the preliminary work helped to:

- (1) Gain a basic knowledge on economics, human development and the open source methodology.
- (2) Find and use Docear to manage the large amount of research material accumulated, to try to avoid falling into "special pleading" and bias.
- (3) Validate certain concepts on how to develop, review and release open source hardware that could be used in humanitarian or development projects; this was done while searching for a suitable licensing strategy to support such projects.

3.2 Knowledge through critical literature reviews

There are many ways to create knowledge through research. The paradigm adopted will influence how that knowledge is built. Two research strategies underpin this thesis research, one of which is discussed in this sub-section: the critical literature review. As Ethridge (2004) points out, literature reviews may not always be necessary: for example in “problem-solving research for industry”; but he makes the point that “research should never be undertaken without a literature review (Ethridge, 2004, pp 115). Following his guidance and other references, a sound literature review shall:

- Lay out existing research by others that is relevant to our defined research objectives; but without superfluous duplication.
- Present the work of others in a clear, interesting and progressive manner.
- Provide evidence of in-depth critical evaluation, helping provide insight about what has (and has not) worked.
- Highlight pertinent/emerging issues, and it may help to identify new areas where research is needed.

From Ethridge (2004) it is clearly understood that literature reviews on topics of the thesis research are necessary. It has been established that critical review of existing literature on OSH and on TBHD is needed to address objectives one and two. Ethridge (2004) also clearly shows that a literature review is necessary for key knowledge necessary to evaluate, classify and fully benefit from the outcomes of the research in this thesis, notably: economic development theory, the open source methodology, sustainable development, soft-systems methodology, and complex system modeling. But these more “general” topics do not require the extra rigor of the critical literature review. A critical literature review is an accepted research strategy to accomplish the first two thesis goals, and a suitable research strategy according to Biggam (2011). Ethridge (2004) makes the point that the main point of a thesis literature review is to provide an understanding of literature about the proposed research including strengths and weaknesses. And this is true not only to answer the thesis objectives,

but also to identify gaps and to build the necessary knowledge on the topics of the thesis research. Ethridge (2004) is categorical about critically evaluating literature, instead of merely describing what has been read; but warns about overdoing the critical evaluation: for example in critiquing every piece of literature quoted. The justification to use critical literature reviews for the first objectives is as follows:

- although there are many publications on open source and on human development, there is a lack of substantial literature that puts them in relation with each other as defined in the research question (objectives 1 and 2);
- F/OSS and OSH are well documented with ample secondary/tertiary data available;
- TBHD is well documented and with sufficient secondary/tertiary data available; and
- a critical literature review of these sources provides a solid base for our research.

Because of how preliminary research was done, there was a concern with “special pleading”; Armitage & Keeble-Allen (2008) literature review method was adopted to address this concern. It helped harvest key knowledge needed for the later steps of this thesis research; but this method was only partially adopted for the “general” literature review (up-to item 2.2) because the extra work was unnecessary. The Rapid Structured Literature Review (RSLR) research strategy presented by Armitage & Keeble-Allen (2008) is well suited for the type of research in this master’s thesis, but it was adapted (identified with *) as follows:

1 Stage 1: Conceptualization

- 1.1 Introduction: research topic; research question and objectives; use (*) Docear for conceptual mapping of topic areas and issues.
- 1.2 Define scope and range using conceptual map, including: time frames covered; research approach and paradigm; and inclusion of seminal articles and authors

2 Stage 2: Operational aspects

- 2.1 Research design and methods, including: critical literature review; case studies; semi-structured interviews (data collection); and the soft-systems methodology. It is important to define details of evaluation framework for each item under review.
- 2.2 (*) Initial adding and trimming of irrelevant literature with three simple steps: (a) read the abstracts & conclusions to determine if worth to read; (b) quick-read to

identify document's link to research topic; (3) check number of citations reported by Google Scholar to have a figure of merit (although not fully reliable).

- 2.3 (*) Findings from accumulated literature: create tables of descriptive information, for example: thematic relationships and connections; emergent system characteristics; prominent methods and strategies; and experiences. Requires careful reading of document to identify: main theories; method & scope of research in paper; research variables; and results from study.
- 2.4 (*) Use matrix method (Klopper et al. 2007), instead of RSLR's literature map, to group literature by thesis topic: identifying author(s) and timeframe of study.

3 Stage 3: Sense making

- 3.1 Discussions and interpretations, including for our thesis: critique of document's strengths & weaknesses; assessment if conclusions are supported by claims; cross-analysis or test of positions in each paper.
- 3.2 Conclusions: (*) The findings of the critical literature reviews will be evaluated following the criteria set by Saunders & Rojon (2011) and Ethridge (2004): Rhetoric/Clarity; Objectivity/Coherence; Tradition/Correspondence; and Authority/Workability.

Significant time was initially invested in collecting information on topics related to the thesis research; as can be seen in Figure 16, over 450 files in the main directory (shown left in Figure 5), about 20 books, and more than 200 files (not shown) in another repository for methodology-related data, make for a very large amount of data to review. Before using Docear, a manual method was tried using short code words in the file and folder names (OpnSrc, HD, etc); the idea was to sorting the file names to navigate/progress through the reading, but that became impractical very quickly. Many of these documents were collected during the preliminary research; they were quickly reviewed using the method above leading to trimming of one third of them from the detailed review and inclusion in the thesis.

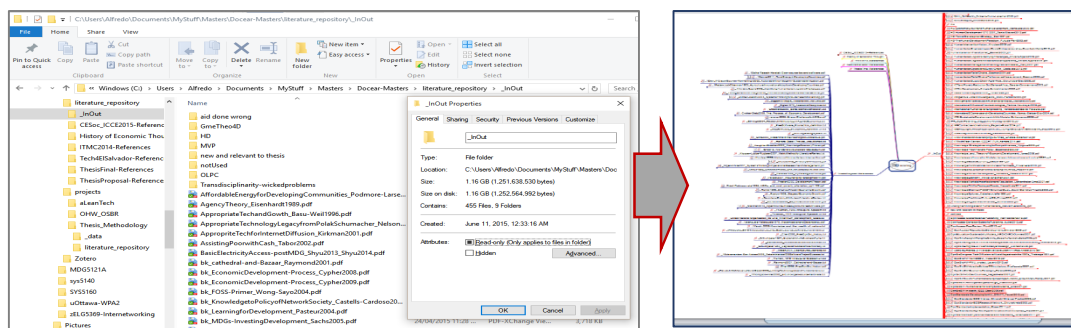


Figure 16: partial snapshots of repository: Windows view (left), Docear view (right).

Once the Docear tool started being used to apply the RLSR, the research work became more efficient. Figure 16 shows sorting for document review using plain old windows (left), versus using Docear (right). After importing this large number of files into Docear, they appear connected to a central node called “Imported”, in its mind map view. Docear’s built-in tools made management of the literature possible; it’s mind mapping tool helped structure the documents by themes/ideas; and other built-in tools allowed for annotations to be made and references to be managed (Beel et al. 2011). Other software tools were evaluated for academic literature management: Zotero and Mendeley³¹; these were mentioned in a training workshop by the librarians of the university of Ottawa. Although Zotero was tried for some time, practice showed that Docear was better suited for the research needs.

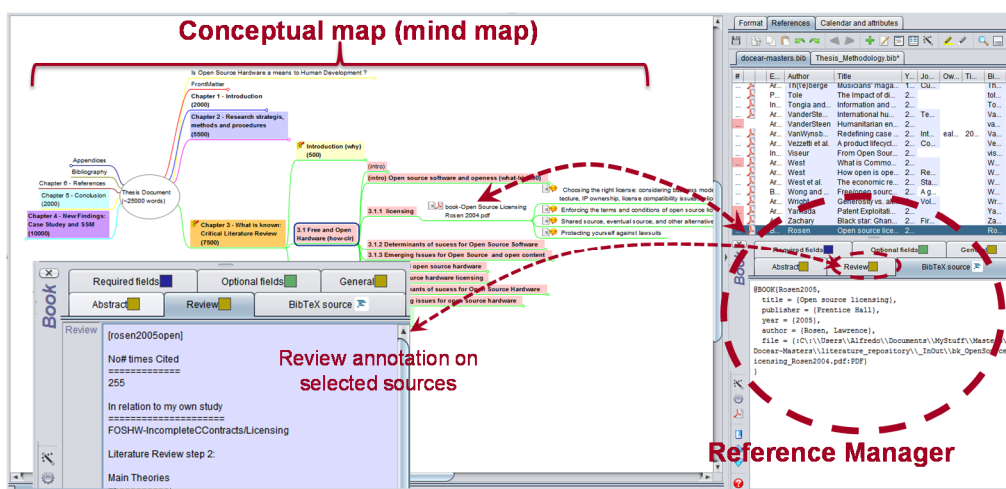


Figure 17: RSLR critical literature review using Docear.

³¹ Comparison of Docear, Zotero and Mendeley: <http://www.docear.org/2014/01/15/comprehensive-comparison-of-reference-managers-mendeley-vs-zotero-vs-docear/>

As already mentioned in chapter 2 the matrix method (Klopper et al. 2007) was adopted to compile the critical literature findings. Creating a matrix method table for each of the critical literature reviews (OSH and TBHD) will help create a knowledge basis that will be examined using the criteria set by Saunders & Rojon (2011) and Ethridge (2004) in Table 17. Using these methods for the literature reviews shall improve significantly the reliability of the research in this thesis. Finally, in concluding the literature review, during the “Sense making” stage of the RSLR, the findings of the critical literature reviews will be: interpreted, critiqued, and their conclusions checked against their paper’s claims; during this exercise, they will be evaluated following the criteria set by Saunders & Rojon (2011) and Ethridge (2004):

Saunders & Rojon (2011)	Ethridge (2004)	Criteria for evaluating critical literature review findings
Rhetoric	Clarity	Language used effectively for reasoned judgements and argument in writing, and outcomes/statements are free of ambiguity or vagueness.
Objectivity	Coherence	Bias in the knowledge and information being discussed is recognized, and they are free of logical contradiction, errors and fallacies.
Tradition	Correspondence	Evidence and ideas in the literature is used to question the conventional wisdom, while keeping consistent with what is already ‘known’.
Authority	Workability	Evidence and ideas in the literature used to question the dominant view, but aims to evaluate that the results work, are relevant and reliable.

Table 17; Criteria for evaluating critical literature review findings.

3.3 Soft Systems Methodology modeling of case study

Case studies are a qualitative research method that can use surveys, individual interviews and group interviews to collect data for the research (Biggam 2011; Yin 2009). This research method will be used to formulate a sustainable deployment strategy for technology-based human development projects using open source hardware, which is the third objective. The process will be iterative, starting with the results from the critical literature reviews and going through multiple loops through refined versions of our model using the Soft Systems Methodology (SSM). These iterations will consider the suggestions in Palmer et al. (2009) and Pryshlakivsky & Searcy (2013) because of their approach for tackling sustainability and human development “wicked problems”, a term attributed to Rittel in Mingers (2011).

According to Voss et al. (2002), case studies are suitable for exploration, theory building, theory testing and theory extension/refinement. As Voss et al. (2002) affirm that case studies have been particularly suitable in operations research in the development of new ideas and in developing theories, despite the efforts needed to effectively use them. Case studies tends to require: significant time investment; skilled interviewers; significant effort to generalize conclusions; and significant effort to show “rigorous research”. The starting point for case research is the research framework and the research question. In this thesis research, the critical literature review was added between the research question and the case studies to provide a sound starting point, because there is a need “to have a priori view of the general constructs or theories we intend to study, and their relationships” according to Voss et al. (2002). From this starting point, a model will be built using case studies and interviews. When building theory from case studies, Voss et al. (2002) stress that case selection using replication logic rather than sampling logic should be used, or expressed in another way: use a few meaningful cases instead of seeking probabilistically significant quantities of cases. This means that each case should be selected so that it either: (a) predicts similar results (a literal replication); or (b) produces contrary results but for predictable reasons (a theoretical replication). For the thesis research, selected cases were about technology claiming to be specifically used for human development. The results to be replicated in these cases (literal replication) was “to improve living conditions”. For the interviews, the effort was to find representative cases of technology-based human development projects. But to respect the guidance from Voss et al. (2002), the negative or disconfirming case were sought (theoretical replication), for example the critique of the One Laptop Per Child (OLPC) project in Toyama (2010). Also, an exceptional case (theoretical replication) was found in the Millennium Villages Project (MVP) where a top-down neo-modernization development model has shown positive results (Sanchez et al. 2007). The interviews are exploratory case studies, as described in Yin (1998); these are particularly useful when the available literature is poor or

inexistent or when the topic is not well understood: this is the case for the thesis research. And following Yin's (1998) recommendation, the interview questionnaire was designed to seek the validity of the propositions made at the beginning of this chapter, namely: (A) open Source Hardware improves living conditions; (B) technology-based Human Development projects improve living conditions; (C) technology-based Human Development projects using Open Source Hardware improve living conditions. These propositions define what is explored by the thesis research (propositions A and B), the purpose of the exploration (proposition C). In this assessment, "improving living conditions" is defined in terms of the central concepts of human development and use it to judge if the thesis is successful; these concepts are: functionings (being/doing), capability, and agency.

To formulate the sustainable deployment model of the third objective of this thesis, it was decided to choose a Soft Systems Methodology (SSM) instead of adopting the analysis methods in Voss et al. (2002). The SSM approach belongs to the systems thinking field of research, and the choice is based on the desire to keep a holistic view of stakeholders and context; this would have been difficult with traditional reductionist approaches. Morgan (2005) summarizes the four schools of systems thinking, which are summarized and present here to elucidate the choice:

- 1 Chaos and complexity theory: rooted in the idea that hidden order exists within chaotic situations. It focuses on rapid, nonlinear and unpredictability patterns of relationships amongst system constituents that generate rhythms, cycles and disorder. It values the ability of small events to have large systemic effects and the ability of systems to shift rapidly into new forms and processes, thus giving greater importance to individual human agency and to the system initial conditions which challenges current assumptions about how change takes place and the input-output-results methodology that is a central tenet of aid thinking.
- 2 Complex adaptive systems: focuses on change and adaptation and it incorporates many of the ideas of chaos theory while paying attention to the nature of control and creativity as well as consideration to network structure and functioning.

- 3 System Dynamics: methodology for the study and management of complex feedback systems. It assumes that events are part of patterns generated by structures, focusing on understanding systems basic patterns, dynamics system characteristics, and stocks and flows within systems. Lends itself to computer modeling, but struggles in capturing emerging properties, all system components, and setting system boundaries.
- 4 Soft systems methodology: it is mainly concerned with finding out what might work, not what is optimal from a technical perspective, by focusing on facilitating the design of interventions in contexts of conflicting interests. It tries to combine logic-based approaches with social and political analysis; being primarily a learning system that can be used by a range of actors to create a shared understanding and hence improve performance.

Mingers (2011) argues in favour of SSM by using examples with: very dissimilar stakeholders, lack of reliable data, incomplete definition of the “problem”, diverging and even conflicting concerns, etc. SSM is the original “soft” Operational Research methodology that goes beyond purely mathematical methods to tackle these problematic situations:

“social problems which are ill-formulated, where the information is confusing, where there are many clients and decision-makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing”. (Churchman 1967 in Mingers 2011)

These types of examples have long been identified as problematic situations. Mingers (2011) list their different appellations: Ackoff called them messes instead of problems; Rittel called them wicked as opposed to tame; Schon used swamp versus high ground; Ravetz used practical instead of technical; and Checkland used soft as opposed to hard. SSM uses “rich pictures”, starting from a root definition where the systems purpose is formulated using the form: “To do P by Q to achieve R”. In this thesis’s case P is TBHD, and Q is the OSH that the research seeks to validate as a means to realise R and improve human conditions (being/doing, capability and agency). In the early 1980s, SSM used seven steps (Checkland 2000): (1) it starts by appreciating the problem situation, the research question and the

conceptual framework in our case; (2) based on the description of the situation, choices are made on the elements to be studied, the three research goals; (3) root definitions of relevant activity systems are created, the research methods in our case; (4) the root definitions are modelled to examine the problem situation, this SSM; (5) comparison, and (6) analysis use the models to structure the further questioning of the situation; (7) the SSM approach encourages iterations through the process, in step seven the decision is made to stop the iterations or to take any action to improve the problem situation (1) and go through steps (2) to (6) again. Step 4 is illustrated in Figure 18.

o- Root definition (PQR):

(P) -> To do Human Development (HD)

(Q) -> By using Open Source Hardware (OSH)

(R) -> In order to contribute to improve human conditions (IHC)

C -> aided individual,
aided community
A -> OSH architect,
coders/testers,
OSH admins,
field aid workers



W -> that an appropriate
OSH exists and that
it can be obtained to
meet HD needs

O -> funders, government,
aided communities

E -> geography, ethics,
disasters, poverty,
lack of capacity

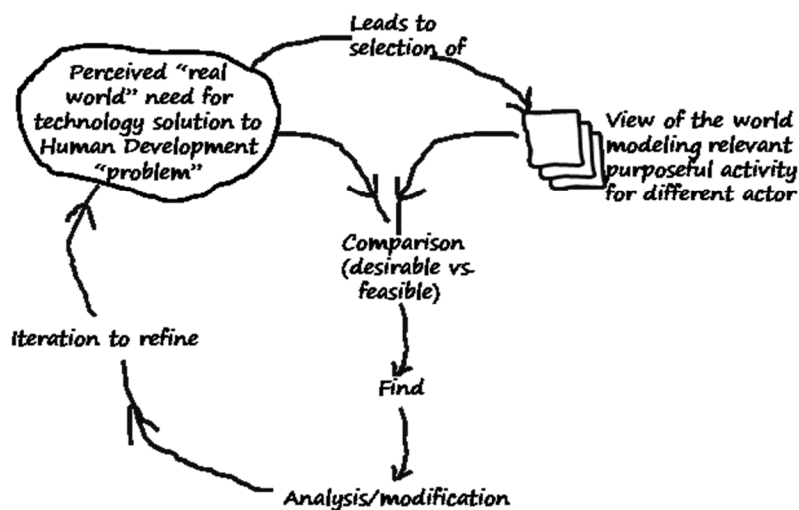


Figure 18: Initial SSM model for thesis research, based on Checkland (2000).

In chapter 4 of this thesis, the findings from the critical literature review (Figure 13) will be added to the SSM model in Figure 18 to iterate to a new model. A new iteration will also be triggered when adding the data from the interviews and the case studies until a final refined model is obtained for a sustainable deployment model for TBHD projects that use OSH. In this manner, convergence towards a formulation that matches the third objective of the thesis research shall be achieved. To validate the propositions related to the objectives in the thesis research, the SSM criteria of efficacy (were living conditions improved?), efficiency (were

improvements achieved using the least resources?), and effectiveness (is the strategy executed in a sustainable way for all stakeholders and the community at large?) are used.

This SSM has successfully been used in international development. For example, Hjortsø et al. (2005) uses SSM to model a management and planning decision support system for a mangrove in Vietnam. Also Palmer et al. (2009) uses SSM in his analysis of the complexity in modeling sustainability. He relies on the ease with which SSM includes multiple of stakeholders to produce a dependable model that accommodates their points of view. Finally, Brewer (2013) refers to SSM in his review of paradigms and philosophical foundations of systems and complex situations. SSM is an established methodology to study complex systems, including those seen in Human Development.

3.3.1 Framework for data analysis

Semi-structured interviews are the methods used to collect data for the iterations of the sustainable deployment strategy model. The interview questionnaire and transcribed interviews are appended to this thesis. To prepare for these interviews, the case study guidelines from Yin (2009) were followed: ask good questions and interpret the answers; be a good "listener" avoiding own bias; be adaptive and flexible to recognize new situations as opportunities; have a firm grasp of the issues being studied; be sensitive and responsive to contradictory evidence, specially avoiding bias derived from theory. For the interviews, the coding scheme recommended in Voss et al. (2002) was adopted; this coding scheme includes three steps: (1) open coding, where individual observations, sentences, ideas and events are categorized into basic building blocks of theory; (2) axial coding, where categories are regrouped and linked in a rational manner; (3) and selective coding, where a core category is selected and related to other categories. For these three steps, the case study tactics suggested by Yin are used (2009), shown in Table 18, to ensure the validity of the

findings from the interviews and their correspondent critical literature reviews (archival analysis in case study terminology).

TESTS	Case Study Tactic	Tactic's research phase
Construct validity	<ul style="list-style-type: none"> • Use multiple sources of evidence • Establish chain of evidence • Have key informants review draft case study report 	<ul style="list-style-type: none"> • Data collection • Data collection • Composition
Internal validity	<ul style="list-style-type: none"> • Do pattern matching • Do explanation building • Address rival explanations • Use logic models 	<ul style="list-style-type: none"> • Data analysis • Data analysis • Data analysis • Data analysis
External validity	<ul style="list-style-type: none"> • Use theory in single-case studies • Use replication logic in multiple-case study 	<ul style="list-style-type: none"> • Research design • Research design
Reliability	<ul style="list-style-type: none"> • Use case study protocol • Develop case study database 	<ul style="list-style-type: none"> • Data collection • Data collection

Table 18: Case study tactics to ensure validity (Yin, 2009, pp 41)

For the first iteration of the SSM model, the interview questionnaire (Appendix 1) was designed to harvest data on the following units of analysis (Yin 1998): (1) the knowledge and experience of the interviewees on tech-based HD; (2) the disposition of the interviewees to use technology in human development projects; (3) factors deemed significant contributors by the interviewees to the success or failure of TBHD projects; (4) the knowledge and experience of the interviewees on OSH; (5) the disposition of the interviewees to use OSH in human development projects; and (6) any additional insight the interviewees have on the topic. Once the SSM model incorporates the findings from the interviews, the MVP and OLPC case studies are analyzed to see if these exceptional (MVP) and disconfirming (OLPC) cases also validate the model. Given all these methods and based on the guidelines from literature, convergence towards a suitable model that validates the objectives of the thesis research shall be achieved, if such convergence is possible.

3.4 Limitations and potential problems

This thesis research work was very challenging for a few reasons: it spans multiple disciplines which complicates all aspects; it seeks to model a soft, messy and wicked problem using a mixed research methodology; the research material on the question topic is uncommon and hard to replicate through experiments and field trials; and the interviews

where hard to do because there are very few people using open source hardware for development with a human development framework. This means that extra effort had to be put in conducting the research to unveil reliable sources of data that could be processed to unveil new knowledge and thus be able to put it through the formal process of the SSM and create a reliable model. But the chosen research strategy produced satisfactory results.

4 Case study and interviews: findings

“A rock pile ceases to be a rock pile the moment a single man contemplates it, bearing within him the image of a cathedral.” – Antoine de Saint-Exupery

This chapter builds on the knowledge of open source hardware (OSH) and technology-based human development (TBHD) achieved through the critical literature review in chapter 2.

These are the first and second objectives in this thesis research:

1. Determine prominent methods and strategies from open source projects applicable to open source hardware,
2. Determine experiences from technology-based development projects that are relevant to open source hardware.
3. Formulate a sustainable deployment strategy model based on the findings from (1) and (2) and applicable to projects like the HTC and the MVP.

In this chapter, interview data and two case studies using literature will be analysed to model a sustainable deployment strategy for TBHD projects using OSH (the third objective).

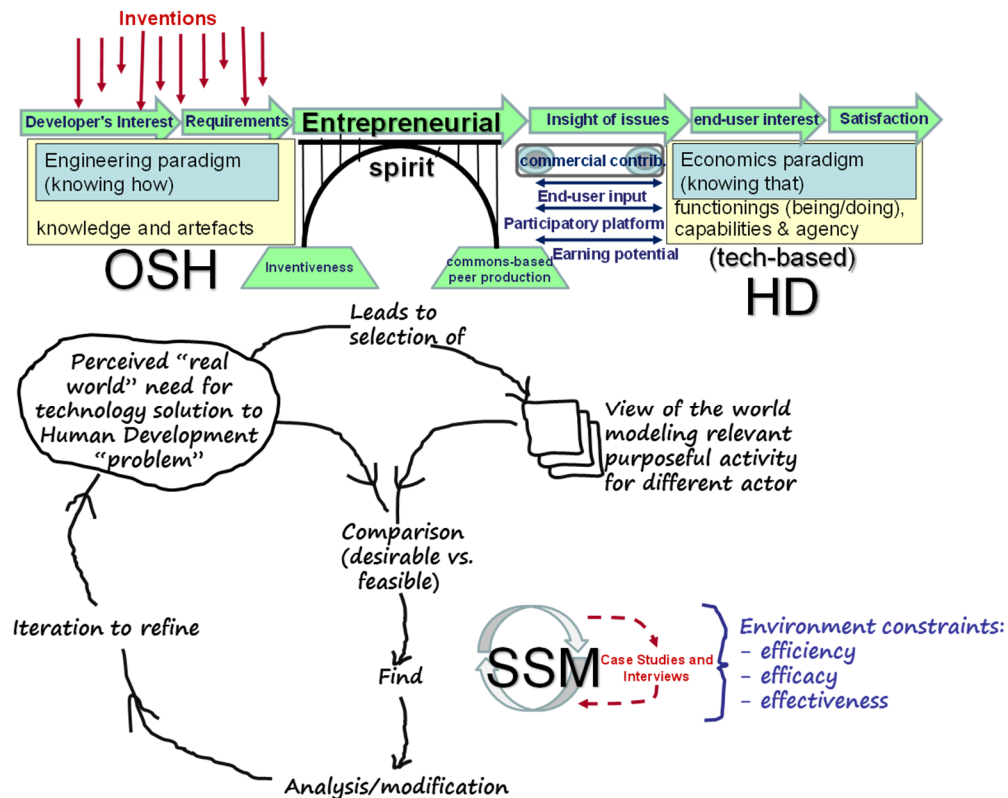


Figure 19: mapping literature review results into an SSM model.

An initial analysis framework will be based on the findings from the critical literature review and represented in Figure 13, but mapped onto a rich pictures representation to leverage the Soft-Systems Methodology and thus iterate through versions of that model based on our interview data and case studies. The transcripts from the interviews are in Appendices 2 to 4, and based on the questionnaire in Appendix 1. For the interviews, the thesis research used the coding scheme recommended by Voss et al. (2002), and first coding sections of the transcript following the structure of questionnaire (Appendix 1). Across the three interviews, a second coding of the transcripts was based on categories regrouped and linked across the transcripts. Finally, core categories were selected and related to other categories. The data focusses on the developer's world view because interviews or surveys for end-user and implementers were not done due to time and resource limitations. The findings from the interviews, with the developer's world view, are compared to the initial model in Figure 13 which represents our perceived real-world problem situation. Following the guidance from Voss et al. (2002), the cases of the One Laptop Per Child (OLPC) project (disconfirming case) and the Millennium Villages Project (MVP) (exceptional case) were used; both provide theoretical replication and will help iterate the updated SSM model to a final representation.

4.1 SSM model of critical literature review findings

The SSM uses "rich pictures" and has evolved since its emergence in the early 1980s, in its earlier expression it had seven steps. Checkland (2000) combined those 7 steps into the following 4 activities: (1) finding out about a problem situation, including culturally/politically, a step done through the critical literature review; (2) formulating some relevant purposeful activity models, shown at the top of Figure 19; (3) using these models of purposeful activity to debate and find (3a) changes which would improve the situation in a desirable and (culturally) feasible way, and (3b) accommodations between divergent interests which enable/support improvement; and (4) action to realize this improvement. The initial "root definition", defined in

terms of “PQR” is: To do Human Development (P), by using open source hardware (Q) in order to improve human conditions (R). Figure 20 shows this initial model.

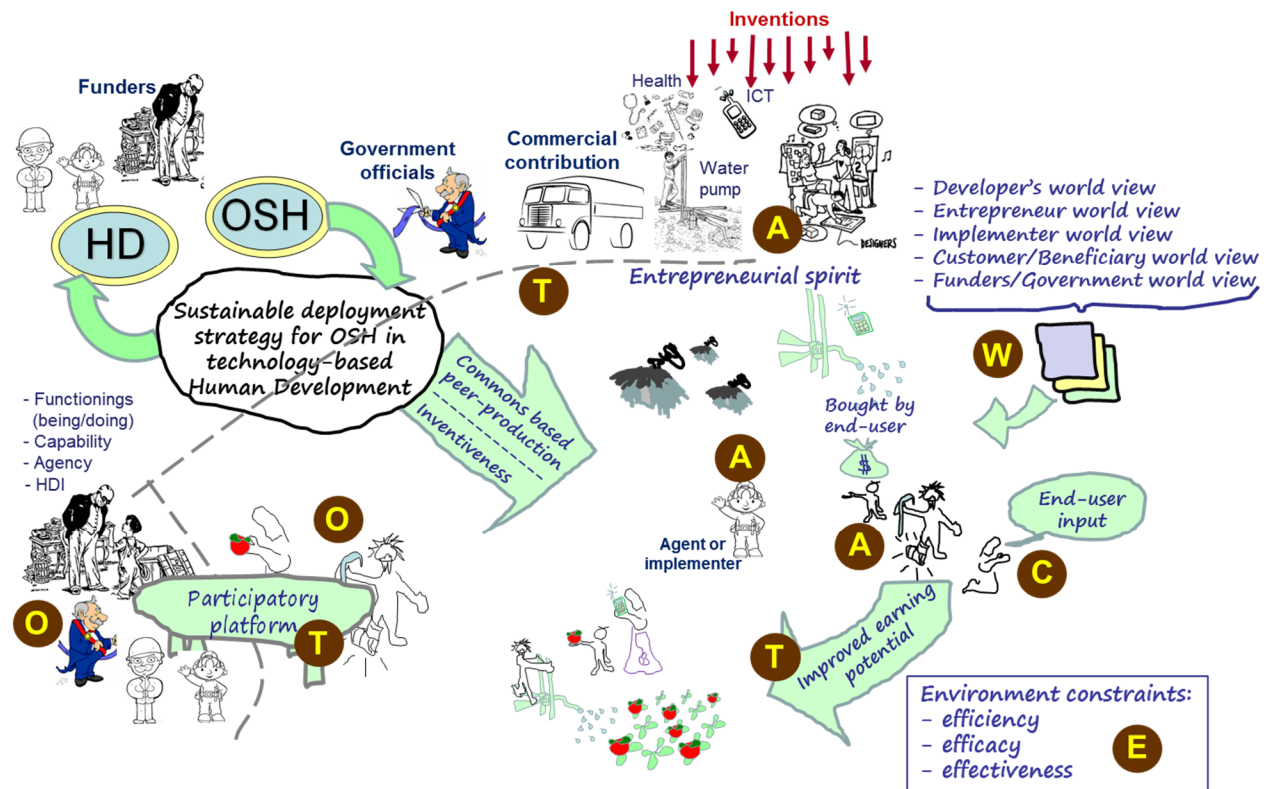


Figure 20: initial SSM model of a sustainable deployment strategy

Some of the characteristics of the SSM must be given now to ease the interpretation of the model in Figure 20. First note the implicit identification in CATWOE terms of: (C) customers, in our case the aided individuals or communities; (A) actors, in our case the OSH architects, coders, testers, administrators, as well as the “customers” and NGO/Agency field workers; (T) transformation, in our case is the entrepreneurial spirit that seeks to integrating OSH in a way that improves the “customers” earning potential; (W) world view, the perspective that an appropriate OSH “solution” exists and that it can be obtained to meet needs based on end-user (customer) input; (O) owners, in our case the funders, the government and the aided communities; and finally (E) environment, in our case these are geographic, ethical, often in the midst of disasters, chronically stricken by poverty and lacking the capacity to integrate OSH (or technology in general). Secondly, observe how at the top and left of the dashed line,

you will find most of the elements establish through the Critical Literature Review. This brings us to the focus of this chapter which is the drafting of a sustainable deployment strategy; an initial model is shown at the bottom of that dashed line in Figure 20. As stated before, a bridge was established between OSH and technology-based HD supported by the inventiveness of commons based peer review. The main thrust of change is provided by the economic concept of entrepreneurial spirit which is applied in a coordinated manner that leverages the multiple world views of the actors and owners in our model first case study. Third, care was taken to create free form figures for elements on the SSM that is part of the sustainable deployment strategy, using standard figures, arrows and symbols. In the next sub-section data collected during the interviews will be used to validate the findings and to refine the model.

4.2 SSM model iteration based on interviews

Checkland's (2000) SSM is used to model purposeful activity, in observing Figure 20, it can clearly be seen that it models the strategies identified in the study of OSH and TBHD, but that research stems from traditional applied academic disciplines with traditional empiricist and rationalist research approaches. To fully benefit from the SSM, the purposeful action elements in the selected test cases ought to be examined to bring that collected data into the strategy. The first data used is that of the interviews transcribed in Appendices 2 to 4. It is important to note that the questionnaire was designed to include self-assessment questions on the level of success of the interviewee's projects; the numeric answers is not given too much importance, these questions were meant to allow the interviewees a few minutes to reflect and organize their thought before being asked about specific elements on which they base their judgements, what they value. This insight is key to this thesis research and consistent with qualitative research methods.

Participant #	Background, roles, motivation	Disposition to use technology in HD	Tech-based HD success/failure factors
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Participant 1	<p>Who: senior university professor, very active with global development organizations; What: collaborative work with international organizations, international development, teaching/mentoring; When: 2009 to present; Where: in developing country; Why: alignment with professional goals and employer's mission; to use teaching/technology know-how; inspired by altruistic work of others.</p>	<p>Unequivocal endorsement: <i>"Of course, absolutely. Ahhm, you know, you look at electrical systems, ahhm, water sanitation, ahh, communications technologies. You know, the, they have been revolutionary in terms of supporting development."</i></p>	<p>Detriments: One challenge mentioned was the difficulty to integrate "solutions" with local authorities: <i>"with regards to its success, the challenge it's been to trying to get this linked up with the, the ministry of health to become a program that's incorporated into their normal suite of the programs that they offer. So trying to build that into the ministry of health's program."</i></p> <p>Success factors: community enthusiasm, community needs, community impact; affordability, holistic approach (commercial contributions are key enablers).</p>
Participant 2	<p>Who: university professor, 20+ years industry experience, very active in promotion of new technology; What: student competition, robotics & automation, unmanned aerial vehicles (UAVs) and research in humanitarian applications of R&A technology; When: 1995 to present day; Where: research in developed world, but deployed in developing countries; Why: ideal of compassionate & kind applications of technology, for pure good"; to inspire others to use technology for good; to use technology to foster understanding & appreciation for all, to positively contribute to civilian society, instead of destructive (military) uses.</p>	<p>Rooted in personal beliefs, motivated leaving industrial and military application in favour of Human Development: <i>"people are surviving at best on a day-to-day basis, and I saw robotics can make a fundamental difference in, in alleviating suffering for these people. So that is sort of ahm, my motivation and why I got attracted, from going from one side to the other."</i></p>	<p>Because interviewee was very critical of his work, success factors expressed in how they have only partially achieved a certain feature/goal: <i>"we are also going to have to change some of the ways we are doing it based in the unexpected or un-thought of needs that will come up and how the local agents and local communities want to respond it [sic]. So, we need to be able to change our solution a little bit"</i>.</p> <p>Success factors: high level of completeness, and validation; "solution" adaptability, ease to iterate and field repair; partnership to facilitate deployment (NGO).</p> <p>Detriments: poor dissemination of technology solution is detrimental; need of actual disaster for validation of "solution" is a significant hurdle for development: <i>"in many ways we have been doing a proof of concept type of demonstrate [sic] based on previous disasters. So we really haven't tested in- on- on the aftermath of a disaster. It may sound mean when I say this, we are waiting for a disaster. Ahh, but we really haven't field tested it."</i></p>
Participant 3	<p>Who: Young professional; What: community development, social enterprises, alternative energy and makerspaces; When: 2013 to present day; Where: in developing country; Why: to give back to community; to use technology know-how, responding to project challenges; desire to find opportunity/job for skilled new university graduates.</p>	<p>Question skipped (interviewer mistake). Support of significance of technology for human development can be inferred from overall interview.</p>	<p>Interviewee #3's area of activity is community based, success factors reflect this.</p> <p>Success factors: community enthusiasm; finding required resources; finding the right partner/mentor.</p>

Table 19: RSLR's step 2.2 for HD

On the last part of the interview, the strategy was to qualify the familiarity of the interviewees with open source technology in general and open source hardware in particular. One of the ways was to get them to express their level of agreement this definition: "Open Source technology is technology that has been developed collaboratively in a way that promotes free

redistribution and access to the design, implementation details and documentation available at no cost.” All interviewees agreed with the definition, but not without needing to affirm their personal interpretation of an aspect of the definition. They all clearly indicated having used open source in their project, and showed a significant level of understanding and expertise.

Participant #	Knowledge, experience of OSH	Disposition to use OSH in HD	Additional insight
Participant 1	Self-declared expertise: 9; Open source use: Linux, MySQL, RapidSMS, etc. in telehealth project; also, new development of OSH project in [C7]; Success factors: use of stable F/OSS solutions; Detriments: patent infringement; poor documentation; poor tech support; poor copyright protection; difficult to choose and scale OSH “solutions”.	Yes, but under favorable conditions: <i>“yes, where you can develop something that isn’t patents protected, or patents have expired and that you can go to an open source model. I can certainly advocate that.”</i>	Uncertainty during development process, is especially difficult to manage for open source: <i>“I am not sure what challenges we’re going to come up with, but it’s progressing along very nicely.”</i>
Participant 2	Self-declared expertise: 9; Open source use: Robot Operating System (ROS); open sourcing student competition winner’s code for next competition; Success factors: peer-production’s sustainability; extreme affordability: <i>“costs are going to be really- really low so they’re affordable by these communities.”</i> Detriments: none provided.	Point made on how its extreme affordability makes it a compelling solution: <i>“to sustain development, human [...] other than the foundational investment as I called it, other than that I do not see any other way. The only way is open source.”</i>	In this case study, the technology has a direct benefit of removing landmines (harm reduction), but the second benefit is making available land for agriculture. This validates the important of increasing the earning potential of aided communities. Two topics discussed in more detail: the importance of realistic verification environments and the fact that there is an inherent cost to open source hardware: the design files can be “freely shared” but not their embodiments (Stallman 2015).
Participant 3	Self-declared expertise: 7; Open source use: Arduino, Open Office, 3D-printing, Linux, Raspberry Pi. Success factors: affordability; minimal governmental control (accessibility); interoperability; free of unnecessary regulations Detriments: none provided.	Yes, due to affordability and accessibility (context of interventionist government): <i>“basically because it’s- it’s more affordable [...] And also it- it’s, the open source devices, [...] they’re [sic] not been banned or they’re [sic] not controlled in their use by any kind of a government.”</i>	One point retained from the additional data from Interviewee #3 was the importance of “learning by doing” in contexts using OSH: <i>“creating and learning how to do prototyping, and ideally, they can actually ahm, try to educate [sic] and pass this information to other- to other people, and also develop their own start-up or their own innovative ahm, social enterprise”</i>

Table 20: RSLR’s step 2.2 for HD

Based on this analysis, the SSM model in Figure 20 has been updated to integrate the observations, insight and apprehensions seen in the interviews.

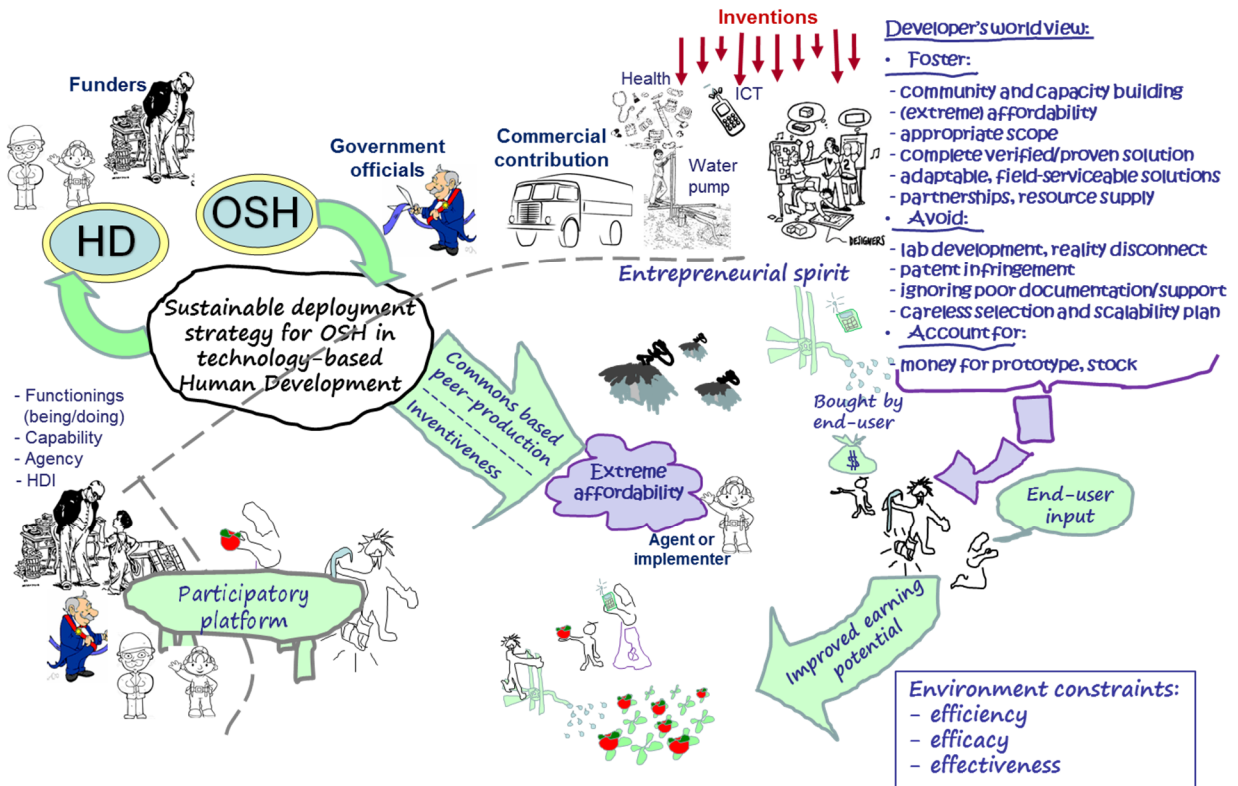


Figure 21: updated SSM model with findings from interviews

Note that the updates to the SSM model, in Figure 21, are to clarify the world view from the interviewees whom are all developers. The research will now look at exceptional case studies to validate the thesis's objectives and related logic propositions.

4.3 SSM model iteration based on exceptional cases

To try to expand or study and generalize our findings, two exceptional test cases are used: the One Laptop Per Child (OLPC) project and the Millennium Villages Project (MVP). The intention is to use articles about these two projects because they are examples of technology-based human development. The goal is to analyze this literature in relation to the SSM model and provide theoretical replication examples (Voss et al. 2002; Yin 1998); because of this, the analysis will not use all the criteria of the RSLR but a subset to help establish the relevance of the document to this thesis. A first table captures this RSLS subset. An interpretation of the case study sources' world views aims to collect how they would perform in the context of the

SMS model; a second table captures the following elements: (a) the SSM criteria of efficacy (living conditions improved?), efficiency (improvements achieved using the least resources?), and effectiveness (strategy executed in sustainable way for all?); (b) indications of use of participatory strategies; and (c) any success and failure factors presented. Table 21 shows the RSLR subset for the MVP case study, based on Carr (2008), Denning et al. (2009), Kanter et al. (2012) and Puri et al. (2010).

Source	#cited	Arguments	Main theories
carr2008	30	MVP's strategy at odds with development literature and problematic for policy makers, it includes Modernization theory, World Bank's Poverty Reduction strategy, and Dependency theory.	Postulate 1: MVP is "bottom up" effort of UN's Millennium Project to develop village-level means to meet MDGs, based on: (a) proof of concept for "integrated, community-based, low-cost interventions"; (b) identified means to scale-up interventions to support regional/national MDG development strategies; (c) 10 year effort in Africa and other parts of the Global South. Hypothesis 1: MDG and MVP focus may result in conflict of interest for project implementers if local concerns do not align with MDG; Hypothesis 2: MVP's needs assessment method may have structural bias towards the powerful vs. larger population; Hypothesis 3: MVP's "known packages of effective interventions" sectoral focus fails to capture interlinkages, trade-offs and synergies; Hypothesis 4: MVP's "known packages of effective interventions" budgeting overlooks, is not sustainable development promotes aid dependency.
denning2009	219	Study of Malawi's circumstances, results, and implications behind success with input subsidies for maize productivity improvement (2005 to 2007) and Malawi MVP experience. Technology and knowledge to improve maize yields in Malawi have existed for at least three decades.	Postulate 1: Agricultural productivity improvements viewed as the foundation for economic prosperity and social development, stifled in Africa by: poor infrastructure and related high transport costs, inadequate institutional support, political instability, agro-ecological complexities, low fertilizer use, and limited availability of suitable high-yielding crops; Hypothesis 1: improvement to smallholder maize productivity will alleviate socio-economic problems; Hypothesis 2: turning knowledge into practice are first steps out of chronic poverty.
kanter2012	4	MVP eHealth architecture built on F/OSS platform for health, open and international standards, to facilitate collaboration across: countries, languages, and governmental systems.	Postulate 1: country-specific requirements and existing solutions can inform a more generalizable architecture which can then lead to common platforms and tools, which then lead to country-specific technology solutions; Hypothesis 1: Open source allow full control over process permitting iterations on local requirements, creation of the general (MVG-Net) architecture, local adaptation and country specific implementations.
puri2010,	4	MVP villages can transform themselves and meet the MDGs if they empowered with affordable science-based solutions. Partners: Millennium Promise (MP); United Nations Development Programme (UNDP); Earth Institute at Columbia U. (EI); aided communities- local,	Postulate 1: ICTs are critical catalysts for accelerating economic development: Hypothesis 1: ICT create a cadre of well supported and accountable health workers; Hypothesis 2: access to instant communication because it saves lives; Hypothesis 3: ICT improves quality of education and increases enrolment; Hypothesis 4: ICT increases income; Hypothesis 5: ICT affecting Social & Safety networks.

	district, and national government agencies.	
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Table 21: RSLR subset for MVP case study

Table 22 shows the “performance” of the MVP case study in this thesis’ SSM model.

Source	Efficacy, efficiency, effectiveness	Participatory?	Tech-based HD success/failure factors
carr2008	Efficacy: no sufficient data, only partial Sauri (Kenya) results; Efficiency: poor, based on unsubstantiated itemized “requirements” inflating costs; Effectiveness: questioned because of doctrinaire/directing approach.	Not, according to carr2008 because of how (end-users) villagers encouraged to express concerns in terms of MDGs, to understand program’s efficacy between villages and achieve a shared set of goals, theoretically making concerns intelligible to national-level policy makers.	Success factors: recommended “critical grassroots approach; Find out: (a) who gains/losses from MVP’s definitions-of/solutions-to problems; (b) how definitions/solutions are validated and reproduced by both project staff and villagers alike; (c) develop critical understandings of local capacity to assess efficacy before implementation; (d) use biophysical and economic data relevant local problems to build-on critically appropriate solutions. Detriments: current prescriptive approach
denning2009	Efficacy: results from government seed/fertilizer input subsidies prompted establishment of MPV in Malawi; Efficiency: different from national program: (1) enough seed provided for 0.4 ha maize, and (2) farmers not required to pay up front for fertilizer but required to repay portion of input cost (~30%) in kind to a school meal program instead; Effectiveness: yes, MVP data complements national input subsidy program data.	Several rounds of consultation held August-October2005 with Mwandama community: “farmers expressed an urgent need for seed and fertilizer over food aid”	Success factors: Political will and action; national-scale program; know-how to increase smallholder maize productivity and reduces food insecurity; understanding economic bases for input subsidies vs. output subsidies; food security program cost is manageable & responsible; Detriments: absence of private agro-dealers in remote rural areas; limit of human/financial capacity of government agencies to meet the operational demands of the program; need for irrigation infrastructure; unpredictable rainfall, climate change and associated risks; fertilizer prices fluctuations; post-harvest losses, due to pest, vermin.
kanter2012	Efficacy: yes, cost savings, resource sharing and de-risking goals achieved; Efficiency: yes, to the extent of the open source methodology; Effectiveness: not outside MVP	Yes, for developers because of F/OSS culture: “Working with partners in a collaborative manner to create the underlying platform in which tools are built helps greatly to reduce risk and costs.”	Success factors: cost, flexibility, ownership, and the benefit of a large passionate, and involved developer and implementer community; source code sharing which saves time/money resulting in culture of sharing and proper attribution to promote open innovation; Detriments: higher levels of developer support, need to build own support capability; need to validate “solutions” in a few sites before wide distribution; lack of adequate human resources; poor interoperability to bridge information systems; development teams in multiple locations; need to incorporate analyses into a monitoring and evaluation framework for eHealth projects: health economist
puri2010	Efficacy: 3 of 4 end-users benefited socially and/or financially; Efficiency: current network does not meet needs (lack of 3G, broadband); Effectiveness: affordability	Not obvious from post-deployment interviews.	Success factors: not stated. Detriments: high investment, operational costs, lack of electricity are main barriers to rural deployment by operators; lack of “universal” availability of ICT is barrier to generate benefits.

	questionable, 3 of 4 communities stated making sacrifices to get service		
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Table 22: interpretation of MVP case study “performance” SSM model

Table 23 shows the RSLR subset for the OLPC case study, based on Buchele & Owusu-Aning (2007), Camfield et al. (2007), Toyama (2010) and Warschauer & Ames (2010).

Source	#cited	Arguments	Main theories
buchele2007	33	Summary and synthesis of accurate information relevant to expansion of OLPC project to Ghana. Ghana Poverty Reduction Strategy goals may be addressed by OLPC program in Ghana: literacy, educational quality improvement, increased use of ICT might.	Hypothesis 1: providing laptops to children in poorer and more remote areas of the globe allows them to use these laptops to access knowledge and to engage their own capacity for learning regardless of geographic location or financial limitations; Hypothesis 1: size of community is positively correlated with project advancement; Hypothesis 2: participation of commercial contributors is positively correlated with project advancement; Hypothesis 3: Highly restrictive licenses is negatively correlated with project advancement;
camfield2007	6	OLPC’s top-down requirement (large orders by governments) to reap manufacturing economies of scale is at odds with bottom-up sustained development and standard diffusion and mediation by early adopters.	Postulate 1: knowledge-based global economy is dependent on skilled individuals using ICTs rather than exploiting natural resources: learning ICT in academic setting is valid strategy to bridge “digital divide”; Hypothesis 1: (Schumpeterian) innovation-based economy is based on human capital development. Science, engineering, and math are fundamental to national economic growth through innovation and ICT-based education becomes critical for long-term gains; Hypothesis 2: OLPC is “Trojan Horse” pushing constructionist pedagogy without regard for education minister’s existing programs in recipient countries.
toyama2010	64	Technologies themselves are not causal to poverty alleviation, effects are wholly dependent on the intention and capacity of the people handling it: <i>“technology—no matter how well designed—is only a magnifier of human intent and capacity. It is not a substitute.”</i> Seek out and understand institutions yielding positive outcomes to then design technologies that magnify their force. Between technology and human capital, invest first in the most lacking factor: <i>“Technology is just a tool; its impact depends on how it’s wielded. If tool after fancy tool doesn’t build a better house, maybe we should invest more in the carpenter.”</i>	Hypothesis 1: Despite widespread optimism on potential successes of ICT4D are few, fleeting, and very far between: underperforming, unprofitable and unsustainable; Hypothesis 2: Idealist view that large-scale dissemination of appropriately designed technology, per se, can provide “solutions” to poverty and other social problems is flawed; Hypothesis 3: the greater one’s capacity, the more technology delivers; the lesser one’s capacity, the less value technology has: technology widens the gap between haves and have-nots; Hypothesis 4: unsubstantiated, Fung in Toyama: <i>“recognizing that technology can be biased by design to benefit some socioeconomic groups over others leads to a constructive possibility. Redoubled efforts to create technology that will be of special value to the least advantaged might help to offset technology’s tendency to heighten inequality. Think of this approach as affirmative action engineering.”</i>
warschauer2010	78	The OLPC program is the latest in a long line of technologically	Postulate 1: Activity; Hypothesis 1: poorest countries targeted by OLPC cannot afford laptop computers for all their children;

	Utopian development schemes that have unsuccessfully attempted to solve complex social problems with overly simplistic solutions: OLPC premises and approach are flawed.	<p>Hypothesis 2: it would be better to invest in building schools, training teachers, developing curricula, providing books and subsidizing attendance;</p> <p>Hypothesis 3: ICT is sociotechnical network: implementations are ongoing, effects are often indirect and involve multiple timescales, politics are central and even enabling, social repercussions are unpredictable, contexts are highly complex, knowledge and expertise are inherently tacit or implicit and much additional skill and work is needed to make infrastructures function appropriately.</p>
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Table 23: RSLR subset for OLPC case study

Table 24 shows the “performance” of the OLPC case study in this thesis’ SSM model.

Source	Efficacy, efficiency, effectiveness	Participatory?	Tech-based HD success/failure factors
buchele2007	Efficacy: no deployment yet, no data reported; Efficiency: uncertain: “ <i>are laptops the best use for such an investment? And, a related question, who exactly would pay?</i> ”; Effectiveness: questioned because of doctrinaire/ directing approach	None reported, only theoretical study of potential adoption of technology.	Success factors: Only theoretical, none reported in context of paper (Ghana). Detriments: low level of alphabetization;
camfield2007	Efficacy: questioned in this paper; Efficiency: OLPC techno-positivism criticized for taking focus away from implementation challenges, for example, target price excludes other logistic expenses; Effectiveness: questioned because of doctrinaire/ directing approach	None reported, critique of OLPC program and strategy points to its top-down prescriptive approach, requiring blanket acceptance of “solution”.	Success factors: adoption of set of metrics to quantify success without undercutting programme approach; management of implementation and diffusion in a locally sustainable way with: (a) pilot projects using metrics; (b) localization entailing local-language content, curricula, and teacher involvement and training; and (c) industry demand creation.; Detriments: (in other computer in schools programs) not as successful as possible because teachers are not included in deployment; competing similar laptops may undercut program; lot size pricing for economies of scale
toyama2010	Efficacy: questioned in this paper: “ <i>ICT4D assumes knowledge it aims to generate must already be in place for its technology “solutions” to work [...] if developing economies had this capacity, there would be no need for an external technology push</i> ”; Fung in Toyama: “ <i>ICT is less useful in societies where human well-being depends more upon moving and making things than upon manipulating data.</i> ” Efficiency: questioned in this paper, inefficiency not disputed by OLPC foundation chairman; Effectiveness: questioned in this paper,	None reported, critique of OLPC program	Success factors: mitigating: disproportionate access to technology between rich/poor, e.g. with universal access; unequal capacity in terms of education, social skills, or social connections; mitigate lack of motivation purposely use technology for improving (own) living condition instead of misuse/waste; technologies must be designed appropriately; Detriments: lack of context-appropriate technology; ignoring local sociocultural norms; poor electrical supply; absence of relationships with local governments; negligence of community participation; overlook meeting local needs; bad transportation infrastructure; inadequate financial model; disregarding stakeholders incentives.

	rebutted by OLPC foundation chairman: “OLPC triggers communitywide capacity building. Laptops arrive, and generators-for-hire appear, or suddenly, as in Rwanda, the school is electrified. In Peru and Paraguay, local, independent software developers and repair shops start popping up [...]”		
warschauer2010	<p>Efficacy: OLPC program has flawed expectations about the effects of implementation;</p> <p>Efficiency: OLPC laptop is not affordable for countries targeted; Effectiveness: problems stem from utopianism about how rushed laptop to perform in the real world, how children can learn from a machine that through its design, makes teacher-student interaction difficult. Design problems of OLPC laptop (XO) and false perception of student use hinder program broadening.</p>	Poor, no intention by OLPC to nurture XO user community, user groups, implementer networks or nurture development.	<p>Success factors: if laptops viewed as component of overall educational strategy based on: broader technological infrastructure, provision of technical support, professional development, curriculum development, assessment reform and a carefully planned implementation process with staged distribution and ongoing evaluation; provide repair services, close to end-users; Detriments: naïve and technologically determinist views: ICT is a tool to be passed out, implementations are one-shot, technological effects are direct & immediate, politics are irrelevant, social effects are benign, contexts are simple, knowledge and expertise are easily made explicit and ICT infrastructures are fully supportive.</p>

Table 24: interpretation of OLPC case study “performance” SSM model

Some of the points found in these two case studies resonate with the previous findings from the critical literature review and the interviews. In Figure 21, the findings originating in the former is coloured in light green with blue lettering; while the latter is shown with purple colouring and a different typeset. The MVP and OLPC case studies yielded additional characteristics to add to the SMS model, notably: the influence of political will to enable the adoption or diffusion of technology in development; also, the agricultural example showed how subsidies could be beneficial; the importance of having appropriate technology and to enable local adaptation of the solutions and field repairs; finally, Toyama 2010 makes the point that there has to be some level of motivation by the beneficiaries. Motivation was noted in the literature review as an element of Schumpeter’s entrepreneurial spirit, but Toyama makes it clear that this is also part of the overall “recipe” for success.

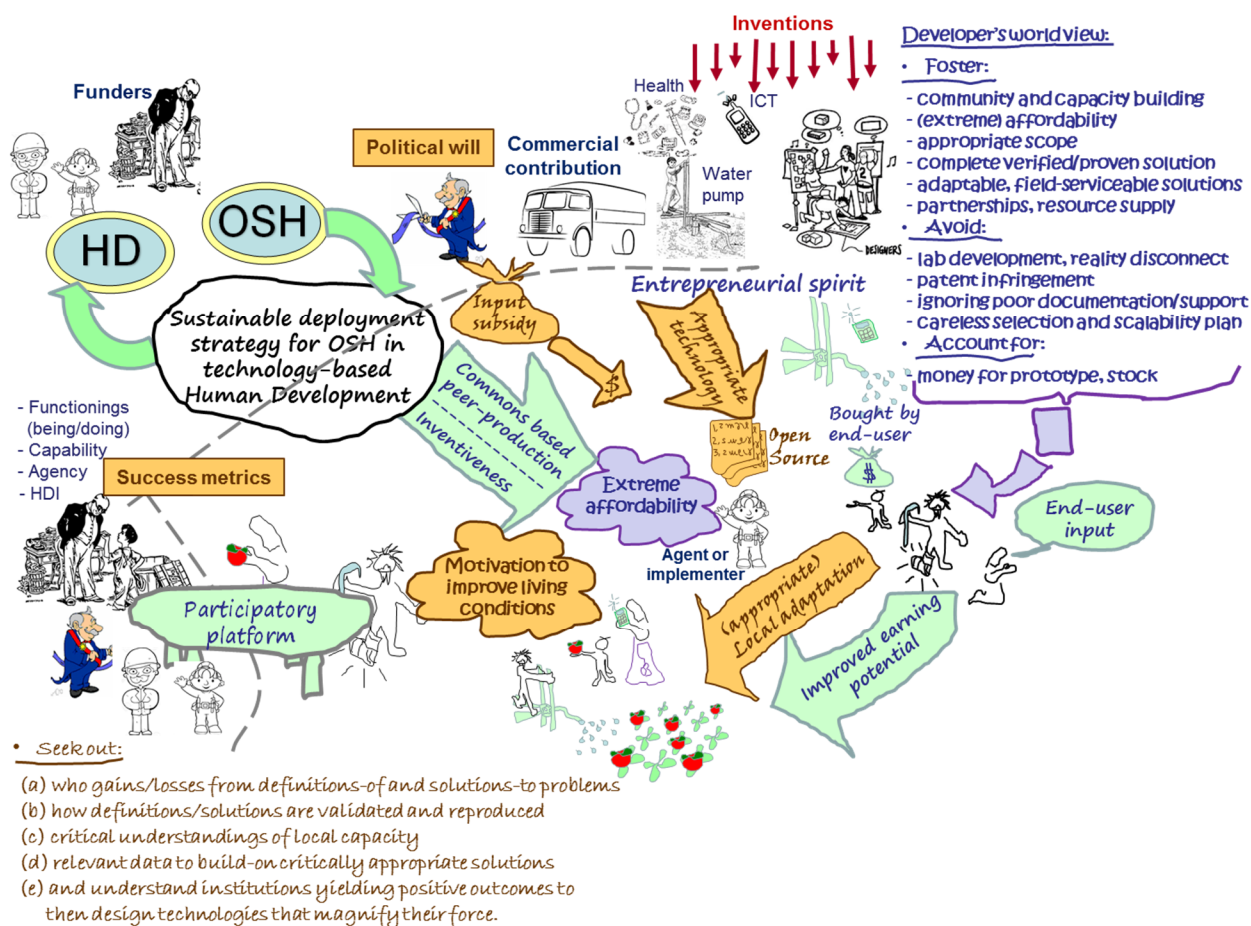


Figure 22: final SSM model with findings from exceptional case studies

4.4 Synthesis and evaluation

Adoption and diffusion theory (Rogers 1976) has 4 elements, one of which is the artefact to be adopted. In this thesis research, we covered that element when describing open source hardware (section 2.1.6). This section focuses on two of the three other elements: channel and targets. Although time span (the 4th element) was not touched in the research, the findings for the characteristics of the diffusion “channel” and the “targets” are interesting. In SSM terms, the purposive human activity of the deployment strategy has for “target” to improve living conditions of poor communities and individuals. Also, in SSM terminology the transformation “channel” is the entrepreneurial spirit of both the open source developing community and the aided communities. It is the intersection of their interest and the pursuit of

their common interests that carries the elements of the strategy. And the characteristics of open source hardware gives this strategy a lot of potential. Going back to the four critical elements of the definition of open source innovation , it is particularly interesting to be reminded that open source hardware is a “non-market, non-contractual transfer of knowledge” (Balka et al. 2009) where ideas/knowledge is shared specifically for a joint development with mutual understanding that contributions are within collaborative development of larger design. All these elements can be identified in the deployment strategy in Figure 22. Furthermore, because of the shared common interest of the developer community and the aided communities, there exists an explicit understanding that exploitation of OSH includes production, sale, combination with other products, and any other private or commercial use: this is the fourth critical element of the definition from Balka et al. (2009). This clearly addresses the thesis’s objectives and is a condition to affirm the logic propositions from chapter 3:

- (A)** Open Source Hardware improves living conditions.
- (B)** Technology-based Human Development projects improve living conditions.
- (C)** Technology-based Human Development projects using Open Source Hardware improve living conditions.
- (D)** Open source hardware is a means to improve living conditions in technology-based human development initiatives:

Propositions (A) and (B) were addressed in the critical literature review of chapter 2, and this chapter has addressed proposition (C): based on a mutual understanding between the developer community and the aided population, and with the support of the SSM identified owners, open source hardware can be a means to improve living conditions in technology-based human development projects. Figure 22 represents the sustainable deployment strategy for this. The model only shows elements for the developer’s world view, but it is solidly rooted in theory. It also has integrated the SSM environment constraints of efficiency, efficacy and effectiveness. These three elements were evaluated in the MVP and OLPC

case studies, and the findings align with what was already known. Some key elements were found throughout the three research steps (critical literature review, interviews, and case studies), like the need for: an extremely affordable solution, appropriate technology that can be adapted locally and serviced in the field. The commons-based peer-production model of OSH meshes well with the need of a participatory platform. Some other elements emerged from the research, for example: the realization that extremely poor people can afford a solution if it improves their earning potential.

It is difficult to see from the SSM model what step shall come first, and in what sequence to read the model if implementing a project based on this thesis research. One way that can be used is as a template to help fill blanks of an initial deployment plan. For example, in the case of a developer that would like to deploy lighting for rural clinics that lack electricity, the model may be followed by first looking at the end-user needs. Interviews, surveys and literature reviews would yield information for a first prototype. The model in Figure 22 shows that solutions shall: (a) be extremely affordable; (b) address the needs at the right level (appropriate scope); (c) be complete and verified; (d) be adaptable, field-repairable; (e) be free of patents infringements. To be considered an open source hardware solution, the requirements and initial prototype would need to be shared with a community of developers for peer-production; upon completing the iterations leading to a product that is suitable for initial deployment, commercial contributions, input subsidies or seed grants may be sought for a field trial. At this stage, a participatory approach would be used to clearly define: (i) who may gain or lose from the definition of lack of lighting as a problem in rural clinics and the definition of head lamps as a solutions for it; (ii) how these definition/solutions are validated in the field and how the solution is replicated for wide adoption; (iii) what is the capacity of the targeted communities to reproduce this solution and sustain/maintain it; (iv) what is the relevant data that can substantiate the adoption of this solution; (v) what effective institutions

may gain new productivity from adopting this solution (magnify their force). In this manner, a TBHD project may continue through the elements of the SSM model until all elements are identified and acted upon. It must be stressed that the model is iterative, a learning methodology that gains in value with each refinement.

The model drafted in this section is very different from the model resulting from the literature review in Figure 13. Figure 22 is mainly focused on the gap that is only partially identified in Figure 13; it expands from merely considering commercial contributions, end-user input, a participatory platform and end-user earning potential. The SSM model expands on these characteristics found in the literature review and builds on the bridge established between the two domains by adding policy, political and logistic elements. Also, the CATWOE constituents from the SSM added new insight not obvious from the literature review.

5 Conclusion

“Failures, repeated failures, are finger posts on the road to achievement. One fails forward toward success.” – C. S. Lewis

Knowing-how to fabricate an artefact to fulfil a purpose, function or requirement is behind most artisan’s or engineer’s activities. Purposely human activity is not exclusive to engineering or craftsmanship, the critical literature reviews showed that it is a fairly universal undertaking. The desire to conquer new frontiers and set new paths has inspired many perilous journeys: space exploration, science-based crop central planning, railroad building... there are many endeavors where the knowing-how was sometimes sufficient to achieve a worthwhile goal. But in development, this approach has sometimes given catastrophic results. Good intentions have sometimes brought more suffering to populations already in dire situation, than good. Humanitarian intervention’s history is filled with cases like these; but among those, lay also success stories, discoveries and significant breakthroughs. Malaria has been eradicated from most parts of the world, the standard of living of whole populations has improved dramatically in others, and discrimination seems to be decreasing in industrialized societies. Without the thesis research, it was easy to dismiss open source hardware as a means to human development, even for those projects that are based on technology. Naysayers may be inclined to say that open source hardware is a means to human development as much as a screwdriver is a means to space exploration!

But the findings from this thesis research show clearly that naysayers are wrong and that open source hardware is a human purposely activity that can have a positive impact in technology-based human development projects. This last chapter summarizes the findings and conclusions before closing with some recommendations for future research.

5.1 Summary of findings and conclusions

After considering the thesis findings and the sustainable deployment strategy, it can be said that the research supports use of open source hardware as a means to do human development in technology-based projects, but under specific conditions. Let's consider the initial objectives:

1. Determine prominent methods and strategies from open source projects applicable to open source hardware.
2. Determine experiences from technology-based human development projects that are relevant to open source hardware.
3. Formulate a sustainable deployment strategy model based on the findings from (1) and (2) and applicable to projects like the MVP and the HTC.

The first half of the critical literature review in chapter 2 was successful in determining prominent methods and strategies to create open source hardware; and the second half was also successful in determining experiences from technology-based human development projects. Although none of the case studies clamoured to be human development projects, it was clear from the literature that they could be criticized and analyzed based on the definition of human development. Chapter 4 addressed the third objective of this thesis research, and was the last element needed to answer the research question: Can open source hardware be a means to improve living conditions in technology-based human development initiatives?

The short answer is “yes”, but with some limitations required by the delicate nature of assisting communities and individuals devastated by poverty, natural disasters and military conflict. Some of the critical limitations are part of the deployment strategy's SSM model; that model shows that: (a) open source hardware, like any technology used in development, can magnify effective development programs when used appropriately; (b) Dr. E.F. Schumacher's appropriate technology principles, and P. Polak's reinstatement, mesh very well with the open source methodology, but attention must be paid to other elements required in the aided

communities to enable this potential (availability of electricity, internet access, technical know-how, etc.); (c) extreme affordability is particularly important for open source hardware, because a sustainable strategy is based on the belief that aided population would want to procure these artifacts if they improve their earning potential; (d) participatory human development practices work well with the open source methodology, but “solutions” must be fully verified before deployment; (e) entrepreneurship underpins this strategy.

But this thesis research’s strategy must be evaluated using the human development three central questions/concepts (Deneulin & Shahani 2009):

- Does the strategy enable being or doing what people value and have reason to value?
- Do the developer community members and the aided-community members have the freedom to enjoy being or doing things that contribute to their well-being?
- Do the actors in the strategy model have the ability to pursue and realize goals they value and have reason to value?

The first question is answered for the aided populations by the findings from the MVP and OLPC case studies: these need to be motivated to improve their living conditions. This first question is also answered for the open source hardware community in the critical literature review by Lakhani & Wolf (2003) who identify four types of motivations for this community members: a personal sense of creativity; being paid to write code; having a positive bond to the project team; and caring about reputation in the F/OSS community. These are the two actors concerned with the first question. The second questions is answered by the shared common interest of the developer community and the aided communities that was the fourth critical element of the definition of open source innovation from Balka et al. (2009). The last question was raised in the interviews, and is captured in the developer’s word view of the SSM model: to foster community and capacity building. To clarify, the actors in this model perform to the level of their technical capacity (OSH developers) or are helped by the process to develop an increasing capacity (aided community) for self-sufficiency.

All these elements are a result of the literature review, interviews, and case studies that constitute the research activities of the thesis. They all support the use of open source hardware in human development projects not because of the function the hardware may perform, like the screwdriver in the space exploration example. Because of the participatory nature of open source development, and the pursuit of affordability and freedom inherent to its activities: open source has the potential to magnify to a greater degree the work of those already using technology in human development projects. The potential is significant.

5.2 Recommendations.

The findings of this thesis are modest, by plucking knowledge of how to do OSH and organizing it into purposeful activity in accordance to knowledge of how to do human development: the research demonstrates that the sustainable deployment model has significant potential. But regardless how well researched this model is, it remains theoretical exercise yet to be demonstrated in the field. Also, the research identifies certain elements as critical or essential, for example details of participatory platforms or individuals motivations, but it does not have data to quantify them.

Future research shall seek to conduct field-trials of open source hardware to further test the findings in this research and refine its model. One possibility is establishing a laboratory to continue this work. In the three papers in Appendix 5, 6 and 7 (IEEE publications), a model is proposed where a library of verified open source designs would be curated and maintained for such field trials. Standards certification and regulatory approval of these designs would add value to this library of “Humanitarian Technology Solutions” as first envisioned during IEEE’s Humanitarian Technology Challenge. Other possibilities exists, for example in supporting the work of institutions and organizations that are already effectively delivering Humanitarian Technology; for example, UNICEF’s Innovation Labs, the MVP open source

community, Open Street Map, etc. Validating the findings in this thesis in partnership with these organizations would also help advance this new type of research.

6 References

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Appendix 1: Interview script

Before commencing the interview the interviewer should take the time to explain again the reason for the interview including the aim of the research project and what will happen to the interview data. He/she should check whether the interviewee has any questions. Questions should be asked in a relaxed informal manner so that the interview appears more like a discussion or conversation. The interviewer must be aware of the effect of body language in indicating interest, encouraging the interviewee to talk and maintaining a non-threatening atmosphere.

Opening statement: “Hello *«respondent name»*, my name is Alfredo Herrera and as you know, I would like to t interview you as part of the research for my master’s thesis. Thank you for making yourself available.

<Respondent>

Before we proceed, we need to go through the following questions, please answer by yes or know:

- 1 First, may you state your name for the record?
<Respondent>
- 2 Thank you *«respondent name»*, as you know I contacted you because of your work in *«respondent organization or project»*, did I get that right?
<Respondent>
- 3 Ok. For this interview, are you speaking on behalf of *«respondent’s organization»*? Or are you answering on a personal basis?
<Respondent>
- 4 (if on behalf of *«respondent’s organization or project »*) are you authorized by *«respondent’s organization»* to do this interview? (if no, terminate interview)
<Respondent>
- 5 Thank you *«respondent name»*, have read the information I shared about my research?
<Respondent>
- 6 Have you signed the consent form to willingly participate in this interview?
<Respondent>
- 7 (if no) please sign ASAP and send back to me; for now, can you please confirm by yes/no if you accept to willingly participate in this interview?
<Respondent> (if no, terminate)
- 8 Thank you *«respondent name»*, we are almost done with these formalities. I just need to let you know that this interview will be recorded, and the transcript will be sent to you for your review and comments prior to the submission of the final version of the thesis”. Is that ok with you?
- 9 Good, thank you. Do you have any questions before we begin the actual interview?
<Respondent>

Listen to respondent, but decline to answer any detailed questions until after the interview is done to avoid biasing. Answer any yes/no questions right away.

1. Can you briefly describe your < organization or project >?
2. What is your role, and how long have you been in this role?
3. How would you describe your work in this role?
4. What attracted you to this < organization or project >?
5. Can you name the top three reasons that attract you to this < organization or project >?

6. As you know, I am researching the relevance of open source technology in the context of human development. Based on your experience, would you consider technology to be a significant factor in this context?
7. Now, let's get back to your project: in a range from 1 to 10, How successful do you consider your <i><organization or project></i> ?
8. Could you name three factors to which you attribute that value?
Thank you <i><Respondent></i> , we are more than half way done.
9. Has <i><organization or project></i> deployed implemented outside of your group?
10. (If yes) If you were to deploy/implement the current latest and greatest version, how do you suppose the "beneficiaries" would rate the success of your <i><organization or project></i> ? On a scale from 1 to 10. What would that rate be in one year from now? 10. (if no) Consider the situation where a remote community contacts you to get a the latest and greatest copy <i><organization or project></i> . how do you suppose the "beneficiaries" would rate the success of your <i><organization or project></i> ? On a scale from 1 to 10. What would that rate be in one year from now?
11. On a scale from 1 to 10. How familiar with open source technology? Have you used it in your projects? (if yes) How? (if no) Why?
12. Do you agree with this definition: Open Source technology is technology that has been developed collaboratively in a way that promotes free redistribution and access to the design, implementation details and documentation available at no cost?
13. Would you recommend the use of open source technologies for human development needs? For example, energy generation, communications, software, etc.
14. Any final thoughts on using open source technology for use in emergency response, aid and human development?

Closing statement: "Thank you *«respondent name»* for your time today; that is the end of the interview. Do you have any questions of additional comments?"

Appendix 2: Interview – Participant #1

Corresponding Materials: Recruitment letter, consent form, research summary

Interviewed By: Alfredo Herrera

Location of Interview: Skype call

Date: 30/Jun/2015

Interview Summary:

00:00:00 Start of recording

00:03:20 Projects overview

00:04:56 Role

00:09:06 Motivation

00:11:12 Top 3 reasons to join this work

00:13:31 Rate your work (1 to 10)

00:19:17 Training, the big differentiator

00:24:15 Open source hardware

00:28:44 End of recording

Transcribed By: Alfredo Herrera

Edited By: Alfredo Herrera

Date: 24/Aug/2015

Number of Pages: 7

Acronyms, pseudonyms and non-verbal:

C1 – Country where most of work done

C2 – Origin of researchers that visited C1

C7 – Country for new project deployment

I-triple-E – the Institute of Electrical and Electronic Engineers

N1 – NGO partner #1

PL1 – project location #1

PL2 – project location #2

PL3 – project location #3

U1 –University #1 in developing country

U2 –University #2, where P1 works

UNAM – Universidad Nacional Autonoma de Mexico

MySQL database – pronounced My-Sequel
[pause] – Pause

(sic) – Mispronounced/grammatically wrong

[inaudible] – inaudible material

emphasis – italics for spoken emphasis

Word– – long dash to end unfinished words

Underlined, highlighted, yellow codes
replace text for confidentiality.

Interviewer: [I] = Alfredo Herrera

Participant #: [P1] = “Participant 1”, name withheld

[I]: so here we go again, ahhp- hello professor [P1]. My name is Alfredo Herrera and as you know I am... ahhm- doing a masters in, at [sic] university of Ottawa and I would like to interview you for that research that I need to complete. Thank you for making yourself available tonight

[P1]: Sure, you are welcome

[I]: So before we proceed, we need to go through the following questions and can you please answer them by yes or no... ahhm, first may you state your name for the record please.

[P1]: ahhm, my full name is [P1] but I go by [P1].

[I]: OK, may I call you [P1] [inaudible-00:41] the interview?... yes Oh, thank you professor [P1], can you know- as you know, I contacted you before [sic] of your work with, in [C1] with the United Nat-, with the UNICEF program and ah- at the universit- [U1] and also whe- because of your work with the I-triple-E. Ahhm, is, is, is that ahh, is that the eh... the projects mhh of [sic] which you have been working lately. Is that all of them or did I miss some?

[P1]: hello [sic], that’s correct

[I]: ok... so, I need to ask you this question: for this interview, are you answering on behalf of your university or is it at- on a personal basis.

[P1]: ahh... I would say on a personal basis

[I]: ok... ahh, have you had a chance to read the information I sent you via email before this week- ah that includes the ahh- the consent form, a short description of my research.

[P1]: I, yes, I did

[I]: ah, did you get a chance to sign the consent form and to ehh, send it back to me saying that you accept to be a willing participant

[P1]: I believe I did but I don't remember because I think it's around the time ahh, the I-H-T-C and I thought I did it at that time but I am not sure [inaudible]

[I]: ok, I, I don-, I checked earl- just before the call today and I, I didn't find the signed form so if, I'll, what I'll do I'll send it again right after the call so that you get a chance to sign it and send it back to me

[P1]: OK, I will get that back to ahh... probably later on this week because I'm not planning to go to work tomorrow but may be on Thursday [inaudible] back

[I]: Or later this week it's fine

[P1]: OK

[I]: oh, we're almost done with the formalities. I just need you to know that this interview will be recorded and that the transcript will be sent to you for review and comments prior to submission of the final version for the thesis. Is that ok with you

[P1]: that [inaudible] fine

[I]: good, thank you. Oh, do you have any question before we begin the actual interview

[P1]: no

[I]: OK, can briefly describe your eh-, your work at the university, especially the projects, the humanitarian projects that you have been doing recently

[P1]: So, ahhm... the major project it's been around the telehealth system... where we provided community health workers with cellphones [inaudible] cellphones. And we trained them to make very basic ehh, vital sign measurements. We also trained them to input that ehh, information ahh, into a cellphone, text that information by the cellphone to the computer server and then that information is stored in an electronic health record there.

Ahhh, the ahh, healthcare professional then will use that data to provide feedback to the community health worker with recommendation for follow up if needed. I also have a group that's working on bringing a wireless communications link to provide internet to a school in [PL1] ahh, we also have the students who working [sic] on ehh some other projects and then I've also worked with the UNICEF on some entrepreneurship related workshops in [PL2]. This is a summary of the span of things that I am working on.

[I]: Than you, and, and can you please expand on your role ehh, for these projects and how long you have been in the

[P1]: yes, so I was the one who basically started the telehealth project and brought together the team of people that I know over at the nursing school, business school and then I've also been ahhm... collaborating with the, the, ehh, students and professors at [U1] as well as the N-G-O partner that we're working with in country in [C1] and also the ehh, companies like Claro and Technosol [sounds like] have been getting [sic] some support from, as well as

UNAM in [PL3] where the nursing program director and students have been supporting the program. So, a lot of project coordination in terms of the health, telehealth project, and then with some of the other projects I've been ahhm, more the mentor and guide for the students project designs.

[I]: So, the next question I'll paraphrase what it says here is can you describe work in, in these roles, but I, you partially answered that but I mmm, just wanna clarify so, would you describe yourself mostly as a meh- coordinator, a project manager, a manager, is it a managerial level or is it also on the technical side.

[P1]: technical, ahh, so, so for example in terms of the telehealth project than involves coordinating marketing for that project, fundraising, program coordination, making sure that the funding is, you know, appropriately dispersed and spent, and then on the project design work then I'm more of a technical mentor.

[I]: ok, the... next question is ehh: what attracted you to this work? Ehh, ehh, you were already very, very busy at the university with your heading the department and then this came along, this opportunity, what was the motivating factor to get involved?

[P1]: Ahh, so, [phone ring] I guess the humanitarian technology challenge [phone ring] excuse me just one second [recording interrupted – 30 seconds]

[P1]: OK, so, in terms of ehh, what motivated me. You know I made my first trip down to [CI] in mid 2009. We had been working fairly extensively with the parish there in the town of [recording interrupted – 60 seconds]

[P1]: OK, sorry about that. Everything is under control again.

[I]: ok

[P1]: Alright, so, back in 2009 I made my first trip down to [CI], and the, my colleagues there had been working for several years on water distribution systems and the, finding sources of water to wa- clean waters to build gravity fed water distribution systems from there. And the, they were starting to get into small scale hydroelectric generation, and so they're mostly mechanical and civil engineers and so they needed help on the electrical engineering side.

And so I went down, ahhm, I think, it was the third week in May directly after graduation and spent some time looking at the project work down there. And the, when I ahhm, got to ehh, came back ahh, immediately after that the beginning of June was the I-H-T-C [sic, meant HTC] humanitarian technology conference that was organized by I-triple-E. And you know I was invited to that and attended on June first and second, and I just found it, the ehh, the, the project work that people were doing, that Laura [Laura Stachel, WECARE Solar] reported, than, that Chris [Christopher Fabian, UNICEF Innovation] reported, just very inspiring. I had done some sort of outreach work before, ahh, but I saw this as an opportunity for ehhm, doing some new project work in [CI], ehhm. So I found that particular conference to be very inspirational [pause-3 seconds]

[I]: So, so, if I can ask uhh, more, a more focused question about the, the reasons for joining. Say, the top three reasons why, that attracted you to this type of work: is it the technical challenge? Is it the, the ahhh, philanthropist side of you know, helping out? What are the, can you name three, three elements that attracted you to this work.

[P1]: I, I think one of the things I saw ahm, is, you know, we work for a catholic university and part of the mission is to serve the poor. And I saw opportunities for civil and mechanical engineers to use their technical skills ahh, to be able to do project work in developing countries. And I was exploring the opportunity for electrical and computer engineering students also to contribute. And so that was part of the motivation, the educational opportunity as well as alignment with the mission of [U2]. But firstly I was, you know, I, I would like to make a contribution to helping in development, in particular using eh, you know, technical skills, the electrical computer engineering skills to support that development [sounds like] [pause – 3 sseconds]. And I think that is why the I-triple-E humanitarian technology conference resonated so much

[I]: yes. Thank you. Now, as you know I am researching the relevance of open source technology in the context of humanitarian and human development. Based on your experience, would you consider technology to be a significant factor in this context of Human Development? Not just open source technology, but technology in general.

[P1]: Of course, absolutely. Ahm, you know, you look at electrical systems, ahm, water sanitation, ahh, communications technologies. You know, the, they have been revolutionary in terms of supporting development.

[I]: Hmm, and now, getting back to the projects you've worked on. Ahhp. can you give me, on a range between 1 and 10, 1 being the lowest and 10 being the highest: how successful do you consider the projects you mentioned eh, eh, at the earliest [sic]. You mentioned three projects, so, how you, would you grade them. How do think you have succeeded with them.

[P1]: ahm, I would say, with the telehealth project, eh, I would rate that maybe an 8. Ahh, the wireless connection, you know that's a little bit a newer project but I would rate that between an 8 and a 9. And then eh, I guess the entrepreneurship one we're doing with UNICEF, you know that's a longer term program that's gonna take some time, ahhm. I, so I'm not really sure how to rate that. I, I think, you know, there's been some more business development coming out of that, but it really only started last year, last October. So it's still early in its development

[I]: OK. That, that's-, you know, you don't need to grade it since it's so new.

[P1]: Right

[I]: But then as a follow up to that question. Ahh, so on the first two you gave a grade or number. Ahh, what are the factors, that eh, you know. Can you name three factors to which you attribute the value? For example, the first, telehealth, you said it was an 8. Can you identify three factors why it is an 8?

[P1]: so, I think that eh, the impact has been significant. It's eh, peoples, ahm, lifes have been impacted specially in emergency situations. Ahm, and I think that there is a good ahm, acceptance of the ahm, approach by the communities. They, they like ahh, the approach and embrace it. Ahm, and I think it's a holistic approach that's very cost effective in the bringing a higher quality of health care or even just health care *access* to communities that eh, are not able to get access any other way, ahm, or very limited access any other way.

But to know with regards to its success, the challenge it's been to trying to get this linked up with the, the ministry of health to become a program that's incorporated into their normal

suite of the programs that they offer. So trying to build that into the ministry of health's program.

[I]: Oh, but the wireless, you gave that a higher grade

[P1]: The wireless one

[I]: yes

[P1]: That's a, you know, small scale project that is very focused on a particular community. And that we are to the point that we are putting out bids for contracts for putting in towers, I see that moving along more rapidly and ahh more likely to be implemented and ehh succeed. The reason why it's not a ten is because it is still developing and being implemented. I am not sure what challenges we're going to come up with, but it's progressing along very nicely.

[I]: So if I ha-, if I, 'cause I just noted two and I guess that's what I'll find in the recording. So you say it's smaller and more focused and now that you're doing the bidding to getting some towers in, and the pace at which it's going it's a good factor. Do you have a third one that would attribute for that, how do you rate the success of that proj-.

[P1]: Ahh, again, I think that the communities are very excited to have this internet access there. Ahhm, many of the children in those communities go to school where there is an expectation for them to do things in the internet, so they need to ahhm, take transportation to a local city, you know, is some distance away in order to get access to the internet. And so it's not necessarily very conducive to their education, they may not always be able to get access. And there's a cost factor as well for the community members.

[I]: Mhh, thank you. Thank you for ahh, ehh, answering the, the questions that's [sic] I have. I know it's not always obvious to ehh answer without much preparation ahead of time. We're almost half way through it, so hang on.

[P1]: [chuckling], OK.

[I]: So, ahh, the next question is ahh: has any of these projects been ehh, deployed or implemented outside of the collaboration you have in [C1]. For example, has anybody taken the wireless solution you know, that was about [sounds like] through your program and taken it outside, somewhere else.

[P1]: Ahhm, I, I think other people may have done this elsewhere. It's not a, you know, a very original approach. Ahhm, in fact I, I know that these Ubiquity networks have been setup elsewhere. So ahhm, yeah, I don't think there is lot of originality necessarily on this particular project.

Ahh, with regards to the telehealth project, there are similar telehealth programs out there. I think the big difference with our program is that we have integrated in the program the ehh, training and education of the health workers wich I think is an integral part to ehh, really developing the *capacity* for ehh, just, just to improve quality healthcare. [pause – 3 seconds] There, there has been interest expressed by other organizations, in fact when I was down in [C1] in May we had a team from Child Fund International ahhm, come to [C1] with us, from [C2] ahh, to see the project and see how we're implementing it.

[I]: and the reason why I, I asked this question in the, it's odd how it's phrased. But it's just to to ahh, to take you outside the known environment, context in which you have been working. So, ahhp- if you, if you can answer this one here. If, if you, based on what you know, similar projects that have been done somewhere else, through literature or conference

proceedings, or work that you have seen in, you know, in your travels. Ahh, how do you think your projects, how do you-, or the work you've done, compares to that. Is it ahh, I do not know if you can, you can use the same scale from 1 to 10; saying, or can you say I am on par, higher, lower, about the same. Just to see where do [sic] you gage that your project's success is, compare to other projects you have seen.

[P1]: So, ahh, yes, I've seen several telehealth projects in other countries. And there is a variety of different models. Some, for example in Kenya use a kiosk like model, In Honduras they're doing, they're basically texting out ehh, messages which are more education oriented. Ahhm, that's that they are also in India and in ahhm, Burundi [sounds like]. Soo, there is a variety of different modalities, I think ehmm, our is a little bit unique in that there is that educational element that I mentioned that's not as widely developed as we've done it. Ahh, but that might be based in the context of different areas.

Ahh, with regards to the internet connection, I would say it's probably on the par with the other locations.

[I]: OK Than you, thank you again for answering the questions. But now, moving out to the open source side of things. On a scale from 1 to 10. How familiar do you consider yourself to be with open source technology?

[P1]: ahhm, 9

[I]: ohh, and, and ahh, have you used it in you projects.

[P1]: yes...

[I]: yes, how?

[P1]: ahh, so the open source for the telehealth project, all of the software ahh, has been open source in that ehh, project. So we're working with the Linux operating system. We're working with the, tha, the, My-Sequel [MySQL] database, what else, [pause 5 seconds] and then the UNICEF RapidSMS software tool is an open source tool. So yes, all the software we've been using is basically open source software in that project.

[pause – 4 seconds]

[I]: OK, based on you experience in, in project and also in use of open source. Would you agree with this definition of open source, ahh, and I quote: "Open Source technology is technology that has been developed collaboratively in a way that promotes free... re-distribution and access to the design, implementation details and documentation available at no cost"...

[P1]: yes... [inaudible]

[I]: So, ahh, and you already answered this, so the next question was: what is the extent of you use of open source technology. Ahh, and I guess we- you already answered that, that's fairly extensive in your projects. You've used software, how- but may I ask you if you have you considered using open source hardware

[P1]: Ahh, we have, and we are in the process of developing some open source hardware for a project in ehh, [C7]. Working with a business there. Ahh, that, that's a little bit more tricky [sic] to develop the hardware open source in the sense that you have to be very careful about violating any patents. Just like, you know, violating copyright for software.

[I]: mhh, so, would you recommend the use of open source technologies for human development needs? For example, in energy generation, communications, software, etc.

[P1]: yes, where you can develop something that isn't patents protected, or patents have expired and that you can go to an open source model. I can certainly advocate that.

[I]: Oh, but thank you. The en- Now the last questions. We are at the end of the interview. Any final thoughts on using open source technologies for emergency response, aid, relief and human development? Any other things you wanted to add or clarify before we end our discussion.

[P1]: Ahhm, [pause – 4 seconds] so, so there is an interesting ahhm, dilemma in this sense that, you know, open source ahhm, and I had this conversation with **[name of person]** from ahh, [inaudible] **[NI]**. So, on the one hand with open source you have relatively limited documentation and ehh, technical support; but at the same time it's free of cost. On the other hand, the- with commercial products, commercial technologies you have a lot of technical support that is offered to you, but of course you know, you have to pay for it. So I think, depending on the particular application and the context one may be more appropriate than the other. Ahh, so I don't think it's a simple answer to say, only open source or only commercial. Ahhm, because sometimes you know, having that technical support can be very bad [sic] project sustainability as well. Ahhm, I think you really need to evaluate project by project what type of licensing or open source versus commercial ahhm, needs to be implemented.

The other thing that happens of course in the developing word is that as soon as you put something out there someone is going to be copy it. And so what is the likelihood that you need to protect your investment there. So that becomes another array of issues that comes up. So then, it really depend on the context, and the, how, how the system is going to be implemented. What scale it's implemented at, and what support is required.

I hope I answered you questions.

[I]: Yes you did, it's very interesting. I am thinking as you are saying those words 'case there are so many, so many things to, that, that can be added, that I could add but that I can't at this moment. Let's close the interview at this moment, nd I wanted to thank you for your time today. This is the official time of the end of the interview. And before I close the recording I wanted to ask if you wanted to add anything before I finish that part of the interview.

[P1]: I think that the, the topic of your thesis is very interesting. And I am very glad that you are exploring this area of open source hardware in particular. And ahh, I wish you well in completing the work and I look forward to seeing your completed work that is a reference that we can reference to for future research to build on.

[I]: OK, thank you.

[end of recording – 28min 44sec]

Appendix 3: Interview – Participant #2

Corresponding Materials: Recruitment letter, consent form, research summary

Interviewed By: Alfredo Herrera

Location of Interview: Skype call

Date: 3/Jul/2015

Interview Summary:

00:00:21 Start of preliminary questions
00:03:14 Overview of work
00:10:44 Specifics aspects of role
00:17:44 Top 3 reasons to join this work
00:27:07 Three top reasons for grades
00:34:19 Grades from customer perspective
00:50:30 End of Interview
Transcribed By: Alfredo Herrera

Edited By: Alfredo Herrera

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Acronyms, pseudonym and non-verbal:

C3 – Country where first project done

C4 – Country where second project done

C5 – Country where third project done

I-triple-E – the Institute of Electrical and Electronic Engineers

U-A-Vs – Unmanned Aerial Vehicles

S1 – group where P2 volunteers

U3 – University #1, where P2 works

[pause] – Pause

(*sic*) – mispronounced/grammatically wrong

[inaudible - timestamp] – inaudible material

emphasis – italics for spoken emphasis

Word– – long dash to end unfinished words

Underlined, highlighted, yellow codes
replace text removed for confidential

Number of Pages: 14

Interviewer: [I] = Alfredo Herrera

Participant #: [P2] = “Participant 2”, name withheld

[P2]: [computer sound effect] [pause – 4 seconds] what is this “please answer my call?”

[I]: That is the ehh, the tool that I use ehh, to record. It’s just ehh, like an add, if you click on that it’s going take you to the webpage of the tool that I’m using to record the call

[P2]: ahh, OK. So I don’t have to do anything.

[I]: You don’t have to do anything

[P2]: Alright.

[Start of Interview – 21 seconds]

[I]: Ssso- So, Hello professor [P2]. My name is Alfredo Herrera and ahh, as you know I would like to interview you as aprt of my research for my master’s thesis. Thank you for making yourself available today.

[P2]: You welcome, my pleasure

[I]: So, before, before we proceed with the questions for the interview I need to ask you the follow. First, may you state your name for the record?

[P2]: OK, [P2].

[I]: Yes, thank you. And tha- I contacted you because of your work on robotics and automation for the different humanitarian ehh, ehh, projects notably on the landmine clearing and other projects. Is that correct? Did I catch everything, or there is something else that you’re working on?

[P2]: Ahh, so the landmine clearance is a competition that I run, but I’m also ahh, involved in a humanitarian projects using robotics and automation on disaster response and recovery.

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I'm also interested in search and rescue ahh, and ah, using robotics for education in places where, for example, English is not a first language. So, we're also involved in such efforts.

[I]: Mhh, and, and, and for this interview can you state clearly if you're answering on behalf of the [U3] or on be- on a personal basis?

[P2]: Ahh, no, I'm ahh, whatever I'm going to say, ahh, everything I'm going to say is purely my opinion and doesn't reflect the I-triple-E, opinions of the [I-triple-E S1] or the [U3]

[I]: OK, thank you, yes. I, I thank you for clarifying that. Ahhm, so, ahh, [pause – 2 seconds] ahhm, eck- have you, have you received the email with the consent form and the, and the, the summary that I sent about the research and the, this, the work that I'm doing.

[P2]: Yes, I have.

[I]: And as I, I, as we know I, I sent that just recently and we haven't have had the chance to sign it. Can you please sign it and send it back to me as soon as possible so that I can have it for my records.

[P2]: OK, will do.

[I]: OK, so, so, we're almost done ehh, before I start the actual ehh, questionnaire for the interview. Ahh, do you have any questions.

[P2]: Not, not at this point.

[I]: OK, perfect. So, here we go!

Can you briefly describe your ehh, ehh, work ehh, more in detail? The kind of work you're doing with robotics. You know, these fields for the-. Disast-, not disast-, the disaster relief part, but also the, the ahh, the humanitarian side of the work you're doing with robot- robo-robotics

[P2]: OK, ahh, so, I'm primarily interested in ahh, applying robotics and automation technologies ahh, for benefiting humanity ahhm, ahhm, more importantly I'm- I'm interested in having robotics and automation technology make a fundamental difference in people's lives in terms of elevating their quality of live.

Ahh, I'm doing currently work in [C3]. I'm also doing some work in [C4] but also within the [S1] we're engaged in a variety of things including the ahh, landmine clearance competition ahh, we're also working on projects that are focused as you said on the disaster response and recovery side of things.

Where primarily the goal is the use of unnamed aerial vehicles to provide ahh, an onsite assessment and- when a disaster happens and using the imagery that is being collected and then having this provided to the first responders.

Ahhm, so this is in addition to what may be available ahh, in terms of satellite imagery, but these images are on demand, the ones that are being collected using the U-A-Vs are images that are on demand and that are of high resolution. So we're deploying ahh, these types of technologies to, to assist responders and communities that are affected by disaster, but also in the landmine clearance case, we are also helping communities. Ahh, trying to make a fundamental difference in their lives by removing the landmines but also providing them with the lands. That thing then can be used for agriculture

And also I'm interested in education, side of things: how can we use the robotics technologies for, ahh, enabling a change in the communities in terms of ahh, interval [sounds like]. Was there, is the word eliminating, but rather it's more ahh, empowering and enabling, ahhh, people to, for example, learn English if English is not their first language. But that's just not the aspect I'm interested in education. Education also comes in the form of inform these communities ahh, in term of the solutions that we are proposing. We can train them to maintain the solution that that way the solution continues to live on even after the experts have left. Soo, just to give you tag-line it's ehh, it's it's technology for good and it just so happens in my case it's robotics and automation technology, and we're trying to use

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them for ahh, constructive purposes ahh, of civilial society as opposed to some of the destructive military-type things people immediately think about when you talk about robotics and automation.

[I]: So, than you and if I listened correctly. Ehh, you know you mentioned the work you are doing, and the way you describe it, it's. It seems to me like it's mostly ahh, organizing competitions, and doing ehh, awareness campaigns for work with other organizations. Is that correct?

[P2]: Ahh, that's only true for the landmine clearance. Ahh, the [C5] work, I am collaborating with a local university there. So, we are developing applied systems type technologies and then we are ahh, putting that on a hardware, piece of hardware that U-A-Vs or drones and then were are are also working with the local governments and communities in a trying to understand their needs, but also trying to educate them on how the solutions that we are proposing can be useful in ahh, in the event of a disaster

[I]: So, so, if sec- second question that I have is: ahh, there are two roles that you're, that you have right now. One role is as an organizer, but a second role is a developer. Is that correct?

[P2]: Ahhm, yeah I guess you can say that.

[I]: And, and how long have you been doing these two roles?

[P2]: Ahh, the competition is- we just completed two years. Soo, and also within [S1] I have local group ahh, which is the Special Group on Humanitarian Technology so that's about two and a half years. So I wanna say, the humanitarian type of works I've talked about, maybe I've been involved for about two and a half years now.

[I]: OK. So, how would you describe your work? Ahh, your specific work in this role. For example, ahh, you know we say- you've, we said or we agreed [sounds like] that one of them is as an organized, the second one if you can expand a little bit on the development work you've been doing. Just to stablish you know, the depth of work you've done in for example in [C5] like you mentioned [sounds like].

[P2]: OK. So, ehh, development work comes in terms of developing, for example, algorithms and having them working on robotics platforms. So, the main distinction I would like to make here is: we are not interested- I am not interested in developing new algorithms or new theoretical frameworks and methodologies. I'm more interested in, taking existing technologies, existing methodologies, techniques, frameworks. Whatever you wanna call them. Ahh, and making them, tailor them to our needs.

So, sometimes we see when you want to, let's say, survey an area using U-A-Vs. Ahh, that, that necessitates developing some new techniques, but usually we are not in a the process of technology development, ahh, for the sake of ahh, say, you, know advancing the state of the art in terms of fundamental research. But we, we consider ourselves doing more applied, applied technology type development. So, ahhm, on that front the technology development work has ahh, taken the form of ahh, looking at the literature: what type of technologies exist and then - when I put my organizer or bringing together people hat- ahhm, I look for people who have the necessary skills. And then, I try to pair the technology with the people who can really make the technology work as dictated by the application. So that's ahhm, that's how I would say the [interrupted call 00:09:31 – 28 seconds]

[I]: yes. hello?... oh!

Hello?

[computer sound effect]

Hello, [P2]?

[P2]: [call re-established 00:09:59] Yeah! I think we got disconnected?

[I]: Yes we did [barking noise in background] we did get disconnected. Sorry about that.

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Recording for participant #2

You were answering the question about ahh, what attract- you know the type of work, and you were describing how ahh, your- no, you do some algorithm ehh, work but not re-invent new algorithms, but adapt them and that- and then, the types of works were applied, applying that technology to the different situations and and then you organize, when you back to the organizing the, the, the, these. You know, you apply, you go get the people that have the skills to implement that, and that that's where we were cut off.

[P2]: Right, so there, there are three distinct aspects of what I do. Ahh, first one is identifying or, or finding out about a problem that's worthwhile to be solved. Worthwhile to be solved not just from a technical viewpoint but in the terms of needs of the community. So that's the first very fundamental question is: is there a problem that is worth solving and can robotics automation technology solve the problem. So that's the first question.

The second question I look for is: ahhm, can we partner with people, both tech- technical people but also people who are embedded in the communities or part of the local ahhm, organizations in terms of ahhm, in terms of the communities, in terms of the local agencies so [computer sound effect] partnering up with people is the second one.

And the third thing is, how do we really bring all these people together ahh, in terms of say, funding. Can everybody get paid? Ahh, how is this going to work? There are three distinct aspects that need to be solved for any effort to be successful. So, I focus on this three ahhm, I'm I'm interested in the middle part of it which is the ahhm, or rather the technology development part of it. Ahhm, most- that's where my skills land myself into most. But I wear all these three hats because I ahhm, also do the organizing and bringing together people part.

[I]: uhhm, Thank you for that answer, and thanks for putting up with the technical problems. Ahhm, so if I, if I may have your- you know, your- your answers on these questions... what attracted you to this, this work? Because it seems to me like, it is ahh, very large problem that requires a lot of effort to ahh, to ehh, getting to this field of ehh, ahh, helping people with the skills you have and then attracting other people that may not have the same ehh, links to these topic and then getting them interested to do this work. So, what attracted you to this ehh, what seems to be a very hard job?

[P2]: Ahhm, OK, so ahhm, mainly so I've I have to give you a little background on where I come from, ahhm, in the sense of not geographically but ahhm... so I completed my PhD in 2000. So my PhD thesis was actually on underground mining. So I wrote navigation algorithms for a 40 ton truck that worked on underground mines. Ahhm, so I've- from that time actually even before that, maybe since about 1995 I've been ahhm, involved in the field of robotics, more more from a control perspective initially but then from a mobile robotics perspective. Ahh, truly for my PhD thesis onwards. Ahhm, and then I worked with a government agency- two government agencies actually, and then ahhm I'm- I've also worked with the, the ahh, the academia, the university type setting and a lot of my funding has come from the industry. So, I've worked with government, industry, academia ahhm, in ahhm, I've- I would like to think I know what the issues are and ahh, why people work the way they do.

Now, most of the work in robotics, and this is purely my opinion, ahhm, and I've been around for what? About 25 years now, rather 20 years, since 1995... we're in 2015. Ahhm, so my observation has been ahh, that ahh, robotics most of the robotics work anyway, maybe 90% of it ahh, is squarely focused ahh, at ahh, developing a technologies for the top of the pyramid people if you want. Ahh, there are two terms I talk about, and ahh, you probably have heard me talk about this before. Ahh, there is the standard of living and the quality of life.

Soo, standard of living is, ahh, is using technology for making life better. Soo, it's it's more a matter of convenience. So, things like ahhm, assistive robotics. People who don't have mobility, you build exo-skeletons for them. You you've seen the news of autonomous cars coming, taking us from point A to point B where you can be reading a newspaper and get to work. You don't need to be bothered by the traffic and things of that nature. These are purely matters of convenience. And I'm sad to say, and this is the reasons that propelled me to do the type of work I'm doing these days, is ahh, lot of this work is standard of living improvement and lot of robotics work it happens in this domain.

So, on the other side of the coin. Ahh, where I use the term quality of life. Ahhm, lot of the wo- work I would like to do, and most of my work ah, is in this quality of life domain. These are pockets of the population, not in necesarity, in, in...

[computer sound effect]

In ahh, in underdeveloped, underserved areas. This could be up- urban pockets where you know, people are surrounded by ahh, wealthy neighbourhoods. Soo, these are the so called ghettos if you will, in many of our big cities in the western hemisphere, or rather in the northern hemisphere. Ahhm, lot of these ahh, ahh, ahh, communities, they generally take many of the things we take for granted... ahh, things like health care, things like hot water, things like ahh, an electricity and things of this nature. We don't ven give a second thought to these things, these are... you wake up and it's there kind of thing. Ahh, but these are not, this is not true for a bulk of the population ahh, by some estimates 4 billion people in the world, and we have about 7 billion now. Ahh, more than half the people in world live by, on incomes less than 2 to 3 dollars a day.

Ahhm, so I'm very much interested in using technology for making a difference in people's lives in these communities, so thereby improving the quality of life. So the attraction primarily for me has been, because I have seen one side of the equation where robotics and automation is helping the convenience needs of peoples, as opposed- on the other side- a lot of things cannot be taken for granted, because are people are surviving at best on a day-to-day basis, and I saw robotics can make a fundamental difference in, in alleviating suffering for these people. So that is sort of ahh, my motivation and why I got attracted, from going from one side to the other.

[I]: Mhh, if y- If I, If I can push a bit and ask you what are the top three reasons that attracted you to this fields. And if you can pick three out of four things you mentioned just now.

[P2]: Ahh, top three. OK, ahh, as a practicing Buddhist, compassion and kindness are very important to me. Ahhm, and I felt ahh, technology can also be benign and can be kind to people instead of destruction, we can use it for constructive purposes. So first answer is, first point of the three: using technology for good, good quote-unquote. You know, completely good: *no* ifs and buts, no caveats, purely good, no second interpretation. So that's the very first reason. Ahhm, the, the second reason is also is from a- again from a robotics point of view. Ahhm, I see this as a necessary thing for people ahhm, largely people but also agency, and to a larger extent, governments also should be engaged in this work. And I am not saying they are not doing it: they are doing it, but not as much as they should. So the second motivation comes from the fact that if I do this, and if I'm successful hopefully. ahh, lot of people would see that and then they would jump ship, and that way we would have more robotics and automation humanitarians, trying to make a difference in people's lives. So that is sort of my second motivation.

Ahhm, third- third motivation comes ahh, from the fact that ahh, you know, I'm a human-being, one of the 7 billion in this world and ah, we need to foster understanding and appreciation of each other and technology I believe can purely do that, and this is looking in purely at this world as a, as a shared place that is common for all of us and we need to take

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care of it. So, then again the technology twist here is putting technology for constructive as opposed to destructive purposes thereby we make this world a better place for all of us.

[I]: Mhh, thanks. That's that's those are very good eh, goals and reasons to wait-to [sounds like] this work. Thank you for sharing that. Now, next question: as you know, I am researching the relevance of open source technology in the context of human development. Based on your experience, would you consider technology- not just open source- but technology in general to be a significant factor in doing human development?

[P2]: Yeah, absolutely. I mean ahh, Human Development as I understand it, and as you defined a little bit before. So this is, this squarely goes to this quality of life issue that I was talking about. Can technology, can humanitarian technology help, dev- help human development in the form of ahh, better quality of life, in terms of you know, having education, in terms of having four walls around you, in terms of food, in terms of quality of life and all these things can generally can generally be bunched together under this human development. So I- I- I definitely believe, and I wouldn't be doing as if I didn't believe in it strongly, I do believe technology ahh, can- can make a huge difference in people's lives. In developing the human development ahh, side of things.

[I]: So now that agree on on that, let's get back to the projects you mentioned before.

[P2]: Mhh hum,

[I]: And I'll ask you to grade yourself. In a range from 1 to 10, where 1 is the lowest and 10 is the highest: how successful do you consider your- your projects, or your work to have been? Whe- how would you rate that- the efforts you've been doing?

[P2]: OK, so now I'll give my answer in two parts. First, the first one I will give you the, the ahh, wishful or the wish list kind of thing. Ahhm, so if the efforts I'm trying to do are successful and I'm not claiming by any means they already are. If they were successful, I think I would give myself a 10...

[I]: OK...

[P2]: But, but as I said ahh, it's not completely done. Ahhm, so... to answer your question directly: assessing myself on where we are, I would probably give us a 6 at this point. Ahh, because some of it is making a difference, some of it hasn't made the complete difference that I would like to- I would like to see. Ahh, some of the efforts are just starting, soo, anywhere between 4 and 6 at this point.

[I]: That's very harsh, so if I- I'll just walk you down the projects that I have here. For example, the eh, ahh, on the eh, landmine clearing. How would you rate that? From 1 to 10.

[P2]: OK, so again, if this is, as I mentioned before. This is an effort that's been ongoing for 2 years. So the larger goal, Ahh, I'll talk a little bit about the problem itself: that will help you better understand my scoring. Ahhm, lots of ahh, lot- lot of regions in this world ahm, are are buried under landmines. And this is a direct result of ahh, wars, historically many of the wars, for example south-east Asia: Cambodia, Laos, Vietnam, that type of [sic] these countries have been war-ravaged countries, so they, they have something to show for it and the, those are landmines. So, people live very close to these habitats, or they they habitat the regions that are very close to the mines. So, you don't only see people periodically, regularly getting blown up and loosing arms and in the extreme case people dying. Children thinking they're playing and they walk onto into these fields and they get blown up. So you don't only see that, but there is the other angle which is: these are good agricultural lands and people are not... able to cultivate crops on that becomes a- a- a means of sustenance for them. There, the motivation, I mean, is in very many ways is very noble because you not only saving lives but also you're providing a livelihood for these people by clearing these mines. So what our challenge is doing is ahh, we (a) of course, we are raising the

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awareness, and I think we have done that pretty successfully. Ahh, but we are coming from a technology perspective, we are coming from a robotics and automation perspective, and trying to propose a solution here. The main difference, ahh, between previous efforts- and there's been a lot of efforts- and the current effort we are undertaking, is in terms of producing (a) a very cost-effective solutions and (b) a reliable solution.

So there are solutions, there is a \$100,000 solutions for example, the solution is. You have this huge truck which is armored and it's- the underbody is coated with, you know, thick metallic plates to withstand explosions of any kind. Ahh, grenades to R-P-Gs and things of that nature. They just drive these trucks over the landmine covered areas, and they literally blow them up. Ahh, and the vehicle is not affected but then, ahh, at the end of the day the land is cleared because you've blown every single mine, ahh, there is nothing else to blow up. Technically you have cleared the landmine filled-area, now the problem is twofold: first, it's a \$100,000 solution, it's very expensive and in these communities, this is not sustainable. You cannot really propose this solution. It will not work. And second of all, going back to this ahh, sustenance type of things I was talking about, you blow up an area filled with chemicals with all the explosives and ordinances, the land is pretty much shot. I mean, you are not going to cultivate anything because of all the explosions. So you- you can find this solution, but this not a ahh, quote-unquote "a *green* solution" or even a sustainable solution. So that's what we are trying to solve, so we are trying to do an open source free solution ahh, to- to bring to these communities a very cost effective solution. So, our- our target is \$500.

So we want to be able to develop this solution: which could be just like a black box, it could mount on top of any robot. And then when the robot is driven it could reliably tell... this... place there is a mine and you can put, you can put a marker on a map and then either people can go and clear that mine or you can send another robot or even modify the same robot to do the clearance.

So our- our work has this distinction of looking at an open source, cost-effective solution. Now, going back to the scoring, which I've been trying to answer, ahhm, is, so this work is ongoing. It's not completed. We have tested it in a mock type of a setup...

[I]: So, if I may- may interject. So, if you can answer this question, and- and think of, you know, just because of the way I have my questions here, of three reasons why you gave yourself a 6 on- on this landmine clearing project.

[P2]: OK, a (a) because the main reason is because it's a, it's not a complete solution, not yet. Ahhm, so, that's one. And (b), it's ahh, not completely proven and tested; in the sense that it has not been deployed in the place where we think it would make a big difference. And, three, is the dissemination of the solution; so, right now we're doing it as a challenge where student are coming in and participating; ahh, but really to make [sic] difference, this solution has to be disseminated and be deployed in communities where we will think- it will make a fundamental difference. So that, those would be the three reasons why I gave myself a 60% score.

[I]: OK, how about the U-A-Vs. Would you grade yourself as a 6 on that one too?

[P2]: Ahh, ahhm, probably yes because again that' ongoing work. Ahh, we- I in many ways we have been doing a proof of concept type of demonstrate based on previous disasters. So we really haven't tested in- on- on the aftermath of a disaster. It may sound mean when I say this, we are waiting for a disaster. Ahh, but we really havne't field tested it, ahh, so I gav- I think similar reasons to the landmine, I think this will also apply to this one. Ahhm, when we deploy these of course, I think, we are going to find that some of these solutions we thought "are perfect" "are not perfect". And we are also goinf to have to change some of

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the ways we are doing it based in the unexpected or un-thought of needs that will come up and how the local agents and local communities want to respond it [sic]. So, we need to be able to change our solution a little bit.

So there is a little bit of a feedback loop, that's involved and we- we really have to go back and forth a few iterations before we perfect the solution. So, that's again why I think I gave myself a very low score, because it's again not a complete- not a complete solution in the sense that not a completely demonstrated solution.

[I]: How about the education project?

[P2]: Education project is also ongoing. I mean, this is a project for example, one of the things we are trying to teach ahh, education ahh, teach English for people ahh, education- I, I actually would give this a little higher score because we already have partnered up with a, a local N-G-O and a local foundation in **C5**. Ahh, and there are lesson plans that are currently being developed to be embedded as part of the curriculum. Ahhm, and this is a defined project, meaning at the end of the year we will have some pilot demonstrations. So we are definitively heading in the right direction, but... compared to the two other two things I talked about, where probably the progress is more tractable, and also at the same time, because of the defined time plan, we are hitting the milestones along the way. So, I think we- if you ask me the same question in January of next year the project as opposed to end of December, probable- I'll probably rate it, depending on how it goes, probably more, more than 7 or 8. At this point I will probably give it a 7.

[I]: OK. Wow, that's two answers to two questions at the same time. That's very- you're making it more difficult to your- on yourself that you should. Thank you, thank you. We're more than half way done.

[P2]: OK

[I]: So, next question is ahh, is, it's about the projects you've been working on. Is, is ahh, some of the projects, not yours, other ones have mainly been, you know, like a lab exercise or a proof of concept, you know, by a few people. So the question for you, I think it's- it's more like that. But, have your projects been deployed outside of the competition? Ah, they've been deployed in the field, in some places?

[P2]: Well, that's the- that's the intention, I mean. We certainly I wouldn't classify myself as a pure academic controlled lab-type experiment. Even the competition we run, Ahh, all the, as I mentioned before, there is a mock setup. It's outdoors. It's running on a real robot, it's running real code. Ahhm, so we have to be able to tackle, for example, things like: if we do that- if we use cameras, for example, and if you run the test on a bright sunny day versus a cloudy day, you're going to get two types of results, 'cause they both have advantages, they both have disadvantages. So we have been testing it on different environmental conditions ahh, not just in terms of lighting but also in terms of soil conditions; you know, going up a ramp versus traveling on level ground. Things of that nature, these are the kinds of conditions you are going to encounter in realistic settings. So, I definitely wouldn't call, or rather I would like to distinguish ourselves that we are not a lab-type experiment. We are real experiments running on realistic scenarios. The final test would be to implement these in ahh, environments where it is intended to work for longer periods of time. So these, these going phases, first you have to perfect at least as much as you can. You think you can perfect your technology, and then you have real deployment, and during which time, be it for the platform, be it for the algorithms.

So, that quote-unquote "*testing phase*" type of things, we propose to do them but we really haven't done them yet. So, I don't know if that answers your questions, But I just wanted to draw the distinction that we are not and we will not agree that we are a lab type controlled

setting type of testing environment. We do test with real people, with real requirements, and real environments.

[I]: OK, so, ahh, eh, I understand the wa- the answer as being: you have deployed in a semi-controlled environment but with real challenges and you are working towards being able to deploy in the field with ahh, where you know the stakes are higher in this, an actual deployment. Something along those lines, I think.

[P2]: Yean.

[I]: So- but ahh, let me ask you this ahh, this ahh, you know, theoretical question. For this question if a community somewhere in the world that, you know, reads about your project and contacts you and asks you if they can get, you know, your project to be deployed in their field; because they really wanna get rid of the landmines and they would like to try it out. Ahh, based on the low score you gave yourself, you know, and- and the proj- and where you- you're aiming to go in the understanding you have of what's needed. Ahh, a year after the deployment, let's say you deploy this year and next year and you back go and measure. What do you believe would be the, the ahh, the "beneficiaries", the communities, you know, how do you think they would rate the experience, do you think based on the technology you have now: they'll give you a 6? Or based on the technology you have now they'll give you a 10? Or somewhere in between?

[P2]: Ahh. Hahh, I can tell you it will not be a 10. Ahh, I don't wanna oversell myself here, but I- it will not be a 10 because: (a) technology is not perfect, it has to go through this iterations and refinement. So, we're definitely not there at the 10. I don't think deploying it right now, and even after a year, ahmm, maybe we will get to a 9; but probably not to a 10. There is also another part of this, right, I mean. This is.. this is ahh, probably one of the challenges with robotics and automations types solutions, and that it. Ahhm, you almost always would need somewhat of a technical person to be in the loop, at least in the initial stages when a solution- we are talking about the landmine clearance problem, so let's stick with that as an example.

Ah, let's say somebody from Vietnam calls me, and then says: we read about, just like as you said, we read about your project and you are doing this challenges. We would like to deploy your solution in our community. So, what would have to happen is, we have to send either myself or whoever else, ahhm, and interested technical person, to go and- and ahh, live in the community for- for a while, to understand the layout of their land and also try to test things. But more importantly, I allude to this before, is ahh, we probably also would have to train the local people before the solution can continue to live on.

So at this point that's, that's just not draw back of this problem, this is a draw bac of many of the technology solutions. It's not a, a turnkey project. You know, you cannot send a- a- a packet that arrives by fedex, they open it and then everything is hunky-dory, worlds problems are solved. That's not gonna to happen. It will require some people ahh, some to use an analogy you're familiar with "feet on the ground"...

[I]: ... yes...

[P2]: Ahhm, so we will definitely would need some people to go at least initially to set things up. Try to have them running, but also involve a local community to maintain the solution and give them some- some background information of who thing work. But more importantly what to do when things break. I mean, things will break down. Ahhm, who to do things and how they can fix them, and if they cannot fix them, how can we be contacted, how can the solution can continue to live on. I think that's the biggest challenge, when you do a technology solution. Is sustaining part of it. Ahh, but going back to the scoring, as I said, ahhm, we're running the competition, we ran it for 2 times and we are happy with the progress so far.

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Ah, we think we need to run it at least for another 2 years before we can be really confident of deploying this in a see- in a community.

[I]: aht, that is fine, but if you just, you know, for the question the way I have it. I am trying to get a sense of, you know, I know what you believe and where you thin- you know you are. But if I- I would like to put yourself in the shoes of a community that would want to use it right now and knowing how fragile, not fragile but how much customization and dedication and all the logistics for deployment you tell us. Getting a sense of, you know, a best guess, you know, an educated guess of, you know, how ready this technology may be and some of the challenges you see with that. That's why I'm pushing for a number, because ehh...

[P2]: I probably

[I]: ... across..

[P2]: I'm probably- I'm probably going to surprise you with my answer. So I said 6 for our testing, but now I will give ourselves a 5

[I]: A 5?! Wow!

[P2]: Yeah. But- because, purely because as you said, it's a semi-controlled environment so, we know the environment. We- we control it to an extent even though it's outdoors, there are other variables that we do not control. But when you go to another completely new environment, an environment in which we have not previously and you try to deploy... obviously our solutions is going to suffer, I would need to have to, reluctantly or un-reluctantly, I would have to lower the score to a 5 now, as it stands now.

[I]: OK. Thanks. Ehh, so ahh. Moving away to the projects, and a more, to technology in general. So, on a scale from 1 to 10. How familiar would you consider yourself to be with open source technology?

[P2]: Ahh, let's- well depends on open source hardware, software.

[I]: Either one

[P2]: Ahh, ahh, combined I would give myself, myself about a 7.

[I]: You're a tough marker. I see that.

[P2]: [laughing] Well, I may not- I would like to be a realist. I don't wane. It's better to- you know, have an expectation that lower than then having a higher expectation and fail miserably.

[I]: So, have you used open source technology in your project, either software or hardware?

[P2]: Ahh, yes. Both. So the landmine clearance competition all the software is open source.

[I]: Soo, all the software is open source. Yeah, OK.

So- so, here I have the definition, I= I'll cut and paste in the skype window as you can read it as will read it to you. Just a sec- if I may [pause – 5 seconds.]

So, ahh, do you agree with this definition of open source, ahh, this definition: "Open Source technology is technology that has been developed collaboratively in a way that promotes free redistribution and access to the design, implementation details and documentation available at no cost"?

[P2]: I would agree to that, except for the no cost part. Open source necessarily is not free. So you see, free open source, yes the definition is true. But generally open source doesn't have to be free.

[I]: OK, thank you.

Now, on a scale from 1 to 10, again. What is your- the extent of your uses of open source technology. I think you already answered that, but if you just can, you know if you can grade, you know how much you use it. Not your knowledge of it, but how much you've actually used it.

[P2]: 9

[I]: 9, OK.

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So, in the- ahh, and you already said that in your projects ahh, you have used it like this software is all open source, for the algorithm and- and the ahh, the drones. So that's ... are there any other uses that you have- say for example a compiler or some tools you'r using or some- some other areas you've been looking at.

[P2]: So, one of the things we use. Ahh, it's called the "ROS", R-O-S, robot operating system. So, this is a free robot operating system ahh, developed jointly by the community and the- constantly updated and maintained by the community, based on ahh, based on their use in different ahh, applications.

Ahh, but also the nice thing about the "ROS" is, we also have libraries that do different kinds of task for robotics, from sensor side of things, to control side of things, to mapping and localisation type of things. There is been [sic] extensive input from the community in maintaining this body of ahh, libraries and they're usually tested in some environment. So, it really helps us not to re-invent the wheel, ahh, so we can take some module and just we [sic] plug it into our challenge for example. And also within the challenge, ahh, all the source code that's developed by any team, at least for the finalists, they're really made available for the ahh, next- next cycle... next year when we do the competition. Whatever the finalist used is already available for the new teams.

[I]: OK. Thanks, and now then ehh, second to last question from this survey... in this interview. Based on your experience, your knowledge and the depth of work you are doing: would you recommend the use of open source technologies for human development needs? And the- ahh, as we said. We've been discussing the landmine application, and the U-A-V projects, they're not directly linked to human development projects, like you know: ehh, ehh, child mortality, maternal health, and things like that. But for those projects you see a way or would you recommend that based on your experience in this projects you've been working on.

[P2]: So, I mean, I want to- I don't know ahh, the reason for what I'm going to say but- OK. Let me start over that didn't come out right. So, I'm- I- I do not see, at least based in my experience ahhm, the things you just mentioned: child mortality and things of that nature. How robotics can make a difference. I mean, it can make a difference, in the sense that you can deliver medicines in a remote part of Africa. Drones can deliver the message, yes. That kind of help can be provided, so I wanna preface my comments with the. But, barring somebody... providing a large amount of money, like the Gates Foundation or someone to buy solutions, commercial solutions which can then be implemented free of cost. Barring that type of foundational ahh, ahhm, what do you call, foundational investment: I think open source is the only way to go. Ahh, to sustain development, human development as you mentioned, in many of the communities, and the reason is very simple: ahh, it's because, where is the money come [sic] from, and ahh, it's a community effort and open source is the right way to go. And there is- other than the foundational investment as I called it, other than that I do not see any othr way. The only way is open source.

[I]: So, you've been limiting your answers to the topic you are knowledgeable of and- and not commenting on other technologies. But, you know, based on your limited experience of, let's say energy generation or communications, ahh, would you recommend for the same reasons you gave for robotics, would recommend open source technologies for other areas that would have a stronger link with human development.

[P2]: No, my answer- last answer was for a broader- broader answer. I mean, barring somebody providing a commercial solution free of cost, meaning they buy it and give it away for free: all the, fields that you mentioned, not just robotics and automation, but energy and all the other types of things you mentioned. I think even in those field I think open source is

the way to go because that's the only way you can sustain a new solution that you can deploy in these communities.

[I]: OK, thanks. Thanks for the clarification. And the final question is: "do you have any final thoughts on using open source technology, for example in emergency response, or aid and relief efforts, or human development? And, tha- and tha- no, I'll let you answer that and if you have any final thoughts I will have another question that I would like to ask.

[P2]: Ahh, I think I covered pretty much what I wanted to say in terms of open source. Ahh, hm, as I said we are interested in developing an open source solution for example in the landmine clearance; but most of the projects use ahh, at least that is the point, they are open source in terms of software. But there are also other things we are working on in terms of open source hardware. For example, things like some ahh, I'll give you an example in terms of a flood: can you come up with devices that sound audible alarms, there are devices that can measure water levels, for example. So, there's a lot of work I'm ahh, well, not personally but I know of work my collaborators are involved in [C3] for the floods, and the other types of related scenarios in developing open source hardware where is not necessarily free but the costs are going to be really- really low so they're affordable by these communities that live in a very hand to mouth existence.

[I]: Mhh, and- and in my additional question in just ahh, about these the- the way you've used and myself have used "free". We have used free, both of us, either as ahh, "without monetary compensation" and free as "freely available"; and that always comes back to that definition of free in open source.

So as, when you were making the case for technology in all these areas, you said that's you know, that's the way to go if there is a free solution than, can be implemented. So can you, just elaborate where- for- ehh, I know, you know. For example, you were saying that- earlier with the definition that free doesn't necessarily mean with- without any charge. So, so, can you just clarify, you know, your thought around the- the term free and what you mean and- and why it may be an issue and where you think ahh, you know, the problem and a potential solution, you know, how to go around that. Or...

[P2]: OK, So- so I'll- I'll clarify something here, I did not say free as in ahh, free of ahh, h, you said something which is not what I said. Which is- What I said was "open source as in open source and free", and ahh, free for me always means free of cost not free as in freely available. Yes, it's freely available, if you can buy, yes, anything is freely available... if you can afford it, right?

[I]: OK...

So, when I say open source, I mean ahhm, I'm OK with the distinction having to say every time open source and free. Ahh, open source and I think we agreed on the definition open source just means it's freely available in the sense it's available, maybe for a price, it's freely available in terms of content not being locked down behind some- some- some- firewall or jailbreak kind of thing. It's not locked-in, it's freely available from that point of view, so I'm OK with that open source definition. But when I say free, I do mean free as in no cost.

Ahhm, so I've- I think it's critical, I mean, how else are gonna sustain a solution that you develop on a quote-unquote open source in the traditional definition when it's *not* free.

Ahhm, again, we go back to this human development index that you are talking about and these are probably the communities I earlier mentioned, half the population or more than half the population of the globe live under \$5 a day of \$2 to \$3 a day. Ahh, and it's just not practical and feasible from a sustainability point of view to have these communities pay for these open source solutions and my- I strongly believe ahh, that open source at least from these communities in- from the human development- development point of view: they have to be open source and free, free of cost.

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[I]: oh, thanks ahh, that thus hear now and that concludes the- the interview. So than you again, tha- professor [P2] for your time today. That's the end of the interview, and if you have any additional questions and comments not that we are done. Please do so, if not we will be, may talk later.

[P2]: OK, I take the recording is done now?

[I]: Ahh, I stopping it[...]

[end of recording 00:50:30]

Appendix 4: Interview – Participant #3

Corresponding Materials: Recruitment letter, consent form, research summary

Interviewed By: Alfredo Herrera

Location of Interview: Skype call

Date: 30/Jul/2015

Interview Summary:

00:00:00 Start of recording

00:04:11 Projects overview

00:07:50 Role

00:09:04 what attracted to this work

00:10:57 Top 3 reasons to join this work

00:13:58 Three top reasons for grades

00:26:30 The problems of regulations

00:31:43 End of recording

Transcribed By: Alfredo Herrera

Edited By: Alfredo Herrera

Date: 24/Aug/2015

Number of Pages: 8

Acronyms, pseudonym and non-verbal:

C6 – Country where most of work done

Ct1 – City #1 where work is done

Ct2 – City #2 where work is done

I-triple-E – the Institute of Electrical and Electronic Engineers

U4 –University #1 in developing country

Maker Space – definition

[pause] – Pause

(sic) – Mispronounced/grammatically wrong

[inaudible] – inaudible material

emphasis – italics for spoken emphasis

Word– – long dash to end unfinished words

Underlined, highlighted, yellow codes
replace text for confidentiality

Interviewer: [I] = Alfredo Herrera

Participant #: [P3] = “Participant 3”, name withheld

[P3]: [computer sound effect] *Alfredo, ya estoy por aca*

[I]: *Ok, perfecto* [P3]. I’ll switch to English now...

[P3]: OK...

[I]: for the interview...

[P3]: ... very good

[I]: OK, hello [P3]. My name is Alfredo Herrera and as you know, I would like to interview you as part of my research for my master’s thesis. Thank you for making yourself available.

[P3]: Yes, thanks to you.

[I]: Ohh, may you please state your name for the record?

[P3]: My name is [P3]. And ahh, and I am from [C6].

[I]: Ohh, great. Oh, thank you [P3]. As you know, I contacted you because of your work in [C6] with maker spaces. But also I was interested in, in some of the work previous to ahh, the maker spaces in community development and, and some designs that you did for solar systems and things like that.

Ahh, did I get that right, or did I miss some of the work you’ve been doing in the community?

[P3]: That is, that is actually ahh, quite good. I am- I’m actually sort of been a social entrepreneur since I was a student. I was doing my undergrad in electronic engineering at the [U4] in [Ct1]. And so, I started working and getting involved with a volunteer program in my university ahhm, that basically provided me opportunities to go to the country side and start a community solutions [sic] based on ahh, solar energy and then started working with the, with

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Recording for participant #2

other partnerships with the university of Minnesota having wind energy systems installed in some communities. And later on, with I-triple-E ahhm, started what is right now called the maker space [C6].

[I]: So, great. So, ahh, so for the ehh, this interview are you gonna be speaking on behalf of any of those organizations you work with or on a personal basis?

[P3]: I'm gonna be... *both*, I would say. Everything it's been part of my ahh, of my personal activities that I've been doing. These have been ahh, personal intuition or initiative that I have developed and I've been looking for support and funding actually from different stakeholders and organizations like I-triple-E, also Internet Society and any other organization that I'm, that I'm involved with.

[I]: OK. Thank you. Ahh, so ahh, [P3], have you read the information that I shared with you about my research,

[P3]: I have read ahh, some parts. Yes. I don't, I can't remember exactly everything right now. But I, but I do know that you've been working with open hardware ahh, licensing, and ahh, and actually the ahh, the impact that it has on humanitarian technology projects.

[I]: Oh, thanks [P3]. And thank you also for sending the consent form. Ahh, fo- to willingly participate in this interview.

[P3]: Absolutely. No problem.

[I]: OK. So, ahh, we're almost done with these formalities. I just need you to let you know that this interview will be recorded. It's being recorded right now. And the transcript will be send to you for your review and comments prior to the submission of the final version of the thesis. Ahh, so, it's that ok with you?

[P3]: It is OK.

[I]: Perfect, so now let's get started with the actual interview.

So, ahh, first question here is: Can you briefly describe your work? You already mentioned the maker spaces, and you mentioned the windmill and the previous work. But if- if you can start by the maker spaces, can you describe your work there.

[P3]: Well, I'm gonna start with the, with the different organizations that I belong to. And the, the work that I've been doing with them. And, started with I-triple-E, ahhm, myself and, and, and different affinity groups as the "Young Professionals", and also the "Special Interest Group on Humanitarian Technology" "*SIGHT*" members had developed initially to enable young- young people, young students, and young professionals ahhm, to innovate and to create ahh, products and technology ahhm, solutions for- for community challenges.

So maker spaces basically ehh, a project [sic] that we started providing capacity building and training to, students, peers, and mentors on how to use tools, machines, and devices, and they would be able to fabricate and prototype ahh, their own ideas.

Right now, we have a- a space actually located in [Ct1], [C6]. Ehh, it's an open free access space that enables I-triple-E students and non-I-triple-E students to come over and work on Saturdays, Saturday morning sessions ahh, and develop... give continuity [sounds like] follow up to, to the project that have been started and also to initiate new ones.

So this space provides a synergy and- and a mutual collaboration among people from different levels, different skillsets. Ahhm, and innovating, and creating and learning how to do prototyping, and ideally, they can actually ahhm, try to educate [sic] and pass this information to other- to other *people*, and also develop their own start-up or their own innovative ahhm, social enterprise in the future.

[I]: And how long have you been doing this work?

[P3]: This work started in ahh, 2014. Actually it was started ahh, during fundraising ahhm, early 2014. And... by November- December 2014, we ahhm, we launched the- the working sessions. Ahh, that were there days, of ahh, of basically ahh, of work and training and since then, Since February this year 2015 ahh, we've been doing ahh, the Saturday sessions in the new- the new laboratory space.

[I]: And that is ahh, still aah- in [Ct1]?

[P3]: Yes, that is in [Ct1], and it's ahh, it's located in ahh... in a public held [sic], in a *school* and ahh, and actually they are part of our- they are now our partners and that's where- where we have most of our equipment and devices.

[I]: So- so this- so, the maker spaces an [sic] enabling ahh, the people that are coming. You described that part, but can you- in more detail, can you describe your work in this role, for this project. What are you doing specifically for this project?

[P3]: [inaudible] my role in specific is providing leadership and guidance to- to ahh, to the members of, of maker space. Trying to make sure that we follow up [sinc] the process and a plan. Ahh, dividing the activities in different projects. So, we have so far, 4 different make-make "cores". We have focus on medical devices, also focus on- on new alternative energy sources, we have also another component which is... ahh, rapid prototyping with 3-D printers and also coding and electronics.

Ahh, so, I'm making sure of creating the groups and providing leadership. And also to- to raise funding ahh, for new enabling even more workshops and activities; and also trying to engage community members and- and all different interested parts that would be- ahh, willing to belong to the maker space.

[I]: mhh, and what attracted you to this work? Wa- what did you find interesting in- to- for you to invest so much time and effort?

[P3]: That's a very good question. I would say its' - it's ahh, it is basically a concern that I had before, that many of the students and- and very well skilled people that graduate from university, they lack of [sic] opportunities. And they don't have the- the- the capacity or the chances after studying so many years to develop their own ideas. Ahh, also many of these students really put some hard work in doing ahh, the undergrad thesis and then, because of lack of funding and because of lack of electronic devices, they're not able to real- ahh, to complete the project they wanted to implement. So, my role is basically, with these ideas, is to try to connect their skillsets into actions and- and trying to implement these projects. And also, my- my basical [sic] intuition to help the community. To give back to community being a privileged student and a privileged citizen in a- in an underserved country. That's basically the motivation that I had for doing this as a volunteer.

[I]: OK, so I'll ask, I'll ask again the same question but differently- in a different way, if you can name three reasons that attracted you to these projects. So, you named the students and their hard work and not having opportunities. You mentioned also giving back to the community. But if you- if you can summarize the, you know, what attracted you to the work. Can you name three reasons for that?

[P3]: OK, one of them is the... community solutions ahhm, for our country, and the second one would be ahhm, technology, new technologies' implementation. And the third one would be, ahhm, leadership and development of new skills

[I]: So, ahh, ehh, I'll push again on this answer, 'cause it- it- it doesn't align with what you ask- what I asked before. What attracted you, you know, we were talking about ehh, develop-helping students develop their own ideas, and- and the hard work at the undergrad level

interest in that into actual action, and things like that. Which is- there is an educational element that is not part of these top three.

So, if I can ask you again. So you have- you mentioned community solutions for the country, ahh, new technology implementation and leadership development.

So, so, do you wanna rephrase these three elements that attracted you to this work? Or...

[P3]: ... Yes, actually the- the- the third one was leaderships and capacity building. So, into capacity building we can frame ahh, education as well. So it is a space for people to learn new skills or to develop their knowledge and provide a better learning, a better learning environment.

[=> Skipped over question #6. "As you know, I am researching the relevance of open source technology in the context of human development. Based on your experience, would you consider technology to be a significant factor in this context?" <=<]

[I]: OK, Thanks. So if we get back to the project, and not so much the ahh, what attracted you... In a range from 1 to 10, 1 being the lowest and 10 being the highest. How successful do you consider ahh, the maker spaces?

[P3]: [pause – 3 seconds] The maker space in particular or the maker spaces in general?

[I]: Maker spaces- your project in [C6]. The work you've been doing...

[P3]: ...OK...

[I]: ... how successful do you think it has been in the past- it has been about a year.

[P3]: Yes. Ahhm... I would say it's been- it's been 8 out of 10. It's been... successful so far. 'cause one of the ahh, one of the- the- the hard things to- do is to start and it's to get attention, and it's to get funding, and it's to get ahh, people involved and we have achieved that. Ahh, so, we have to make sure that we ahh, implement the projects right now. Which is actually what it's- what it's been- what is coming so far. And afterwards the cycle is going to be completed and- and created and scaled basically.

[I]: Mhh, OK. So, ahh, if it's 8 out of 1-. Can you name three factors to which you attribute that value?

[P3]: Yes. I mentioned, ahh, one of the factors is... ahh, having- having people's interest. So, that's one of the first ones. Ahh, the second one is ahh... trying to find all the resources that- that are needed to ahh, to develop this initially [computer typing noise]. And the third one, is because we have ahh, lots of potential. We have recorded [sic] ahh, different kinds of- of partners and also ehh, different kind of mentors and people who is [sic] interested to work with us. That- that it's been basically ahh, a- a very good environment. We have found *resources, people*, we have fund basically that- that perseverance that we were looking for to create this project.

[I]: OK, Thanks. That's- that's incr- that's a good answer. Thanks.

Ahh, we're almost half-done already in the questionnaire. So, we're doing great. So...

[P3]: ... Thank you...

[I]: So ahh, so you mentioned this project it's bee- has been implemented ehh, in [C6], **mainly in [Ct1]**. So, hav- have you deployed or done something similar outside of- of that environment. Have you been ahh, bringing the way you're doing your project to other places?

[P3]: Yes, we've been developing ahh, outreach in the communities. Ahh, and since 2013, we have been working in partnership with ahh, Innovative Engineers; that is a group from the university of Minnesota, it's a group of student. And, creating ahh, technol- technology transfer and impacting ahh, high school students and local technicians to learn better skills in the country side, it's been actually one of the- ahh, one of the things we've been doing.

Using local resources, like material, and components, and doing that technology transfer... with support of international students from Minnesota and also local students from [Ct1]. So we have been developing these kind of outreaches. And at least two- two or three outreaches per year, and we are proving this knowledge. In the future, in 2016, hopefully we will be ahh, carrying more workshops to the community with ahh, with prototyping equipment and devices.

[I]: OK, but ahh, I just wanna to make sure that I have things right. You mentioned that this outreach that you have been doing since 2013 with the University of Minnesota; but earlier you mentioned that the maker spaces is something that you have been doing since 2014. So, the- the dates do not align, so I just wanted to make sure that I understood correctly. Soo, ahh, specifically for the maker spaces and the work you've been doing since 2014: has that model and that type of activity, have you taken that outside your current settings in [Ct1].

[P3]: Not yet, not yet. Maker space in particular has been just done in [Ct1] and in [Ct2]. So those are the two cities that are not country side. Ahh, however I explained that we've been- we've been doing different kinds of *workshops*. Which is basically the idea of- of the maker space. So officially, we are just doing [sic] maker space since 2014 trying to get resources and people involved. And in 2015 it has been fully operational. But ahh, but right now we haven't- we haven't done any kind of projects or activities like the work- like the maker space in other places.

[I]: OK, so, so I'll- so that's a clearer answer now. Considering just the maker spaces. So, let's- let's ask- this is a hypothetical question. So, if ahh, you know, if ahh, a remote community or ahh, a community outside of [Ct2] and [Ct1] contacts you and says: "oh, we've heard great things about your project and we wanna do something the- eh, you know, a similar thing in our community." Ahh, and then they work on that and- and ahh, start working on, you know, just copying what you have done now and they- they went along and just start using that model that you have used. Ahh, wha- how do you think they will do over a period of a year? Do you think that, you know, what you have to transmit? The knowledge of that you can share with them, ahh, and what you have developed so far. How successful do you think they will be one year from now, if they started exactly from where you are right now in [Ct2] and [Ct1]? Do you think in a year from now, they will be, you know, a 1? an 8? a 10? How would you rate their chances of succeeding over a year if they took whatever you have right now?

[P3]: It will be very successful, I am sure. The experiences that we have had should reinforce them; and- and actually our- our partner organizations, they will provide even more help for scaling this project. So I think, ahh, that will be very successful. And- and I am sure that they will not just consider the projects that we are doing right now, but also the ahh, their own ideas and- their own intuition.

[I]: OK, wow! That soun- sounds very confident. [Chuckling]...

[P3]: ...Yes...

[I]: So ahh, the next question now. Ahh, on a scale from 1 to 10, can you tell me on your opinion, how familiar you are with open source technologies?

[P3]: In a scale from 1 to 10, I am familiar with- with open source technology ahh, in the scale of 7. Let's say.

[I]: Oh, that's pretty good, that's very high. So, I have here a- a definition of open source, that I- I just- just to make sure we understand open source technology in a similar way for the- for this interview. So, do you agree with this definition: "Open Source technology is a

technology that has been developed collaboratively in a way that promotes free redistribution and access to the design, implementation details and documentation available at no cost?”

[P3]: [pause – 3 seconds] Yes, I would agree with that.

[I]: OK...

[P3]: It's been- it's been basically a communi- technology creat- developed and created by the community, the community members [pause -2 seconds]

[I]: OK. Ahh, and ahh, thanks and. So, now that we agree on terminology and at least on what we mean by open source technology. On a scale from 1 to 10: what are- do- your extent of your *use* of open source. How much have you used open source technology, yourself?

[P3]: Myself, in a scale from 1 to 10: 7 again, I've been using ahh, *more* than- than licensed technology.

[I]: Have you used it in you projects? Like the maker spaces?

[P3]: Yes, I have.

[I]: OK, in what way. How have you used it?

[P3]: We have been using ahh, microcontrollers to ahh, enable weather stations. Ahh, and so- and gather data and- and process it and analyse it. So microprocessors are one of them...

[I]: which ones?

[P3]: We've been using Raspberry Pi and Arduino. Ahh, Arduino Leonardo, and Arduino Uno, Arduino Mega. Ahh, we've been also using their- their software platform and their documentation, as well as ahh, we have been doing and- and using the ahh, the mi- the open Microsoft [sic] basically tha- that requires no license. We've been using Linux. Ahh, we have also been using micro-take which is a- a technology that will be deployed soon, by the end of the year, to create an internet access point. Ahh, as well as [clearing throat], as other technologies that have been created by- by- by the community members in rapid prototyping, like- like 3-D printers as well. Ahh, so it's- it's a- there are a few- a few devices and- and elements that are right now in the market available ahh, to work with, and they are- they're very accessible in terms of affordable.

[I]: Wow. That's ahh, that's a lot more than I have used. Open source technologies. That's very impressive Mario...

[P3]: ...Thank you...

[I]: So, so now given your experience with open source technologies. Different types, and different hardware and software implementations. Ahhm, would you recommend the use of open source technologies for human development *needs*? And- and by that I mean, human development needs are: health needs or, of course there is the educational part that you mentioned, but there are other things like egene- energy access and things like that. Do you think open source technologies are suitable for human development?

[P3]: Indeed, yes. I believe, these are ahh, ahh, open source technologies are very important and play a significant role in the development of new solutions.

Ahh, basically because it's- it's more affordable and it's very low cost ahh, for- for people who want to implement these technologies to work with. And also it- it's, the open source devices, they don't have any sort of regulation or they're [sic] not been banned or they're [sic] not controlled in their use by any kind of a government or any king of- of hierarchy that you need to ask for permission.

So they're very, very accessible in... it also provides access to create devices in- in a- in a- uhhm, in health technologies that you mentioned, before in- in power and energy systems, in computer- in computer science and communication systems and some many different field actually. So, I guess besides the importance that it's very affordable and low cost, it is also- it

provides actually a quite good ahh, mix of intero- interoperability. So you can- you can even work cross sectional with other kinds of technologies, sometimes they are compatible. They could even synchronize, so, and that makes it even more interesting for the end-user.

[I]: Mhh, That- that sound interesting. Ahh, ahm, I heard you mention in your answer about the- ahh, not having regulations or government control over the use of the open source technologies. And you also mentioned that it makes it more accessible. Ahh, living in a developed country- here in Canada, you know, that would- having the regulations and government control it's seen as a *good* thing, because, you know, it prevents misuse or mishaps. But you mentioned this as being something positive in your context, can you just develop on that?

[P3]: [pause – 3 seconds] The- the problems of regulation are very different in- in- in different countries. So, it varies on the way that- that- that the government interest or the multiple stakeholder's interest is. But I would say ahm, it is- it is good for the freedom of access to technology to have no regulations and to have ahh, a- a- an open use, and a freely [sic] use in terms of, ahh, in terms of the technology banning ahh, in our particular case what I would mention is that... our governments in developing countries, like in **[C6]**, they would like to have control of everything.

They avoid competition they avoid basically ahh, commercialization, they avoid any kind of ahm, ahh, imports that- that- that provides even- even educational access. So all of those kind of different things actually are- are being considered form- from different perspectives. Soo, the countries- the countries' interests' change sometimes, and actually, I am- I am devoted in my particular case to have no control under the ahh, under the use of this.

And also because there is no incentive besides of the fact. So, we haven't seen any kind of interest to promote this kind of open source technology in our communities. So, and that's actually, you know, it's a limitation, basically.

So, I would say in our perspective it- it's the use that we don't have any control about this, and no regulations.

[I]: Mhh, Wow. Thanks, thanks for that. That clarifies a lot about ahh, your point of view. Thank you very much for that.

And ahh, while we are don't to the last question any... any final thought about using open source technologies for ahh, human development like we mentioned? Even for emergency response? Do you see areas that you would like to mention, or something else that, you know, maybe came to mind at the end of the- of the interview and that you would like to share.

[P3]: And what would be the *question*... again?

[I]: Any final thoughts about eh, the use of open source technologies in tha- in the areas like- human develop- like hum- human development or emergency response, or disaster response or some type of help for people in need.

[P3]: OK. Ahh, so final thoughts on this is that it could be.. it could be increased, the use of open sour technologies.

By 2020, the internet of things so- is planning- which is a project- is planning to ahh, to connect more than ahh, more than 50 million of devices to communicate with each other. In- in- in this regard, you have ahm, different kind of portable devices such as: smart telephones, tablets, you have machine-to-machine. Any kind of devices that can enable transportation, energy, communication ahh, and so on.

So, I would reflect from that, and- and we need to provide better condition in our- in our countries, in our sectors, that promotes this kind of technology, that promotes this kind of

access. That basically ahh, trying to push more into the digital world, which is actually coming very rapidly right now. And, and in this regards we can- we can provide more solutions to our challenges, and to our problems.

So, the ehh, the starting point is ahh. We need to work more on- on education. We need to create more skillsets in people. We need to make awareness in different universities, and in different educational centers. So when the opportunities come, and- and when we need to work with them we're very prepared to do it.

[I]: Mhh... Oh, thank you. Thanks- than you very much [P3]. Thanks excellent. That finishes the questions that I had on- for the interview.

So, I appreciate your time. And this is the end of the interview. So, do you have any- any questions, or comments with regards to the- the interview?

[P3]: Oh, Ahh, no. I don't have any other comments. And I appreciate your- your interest in making this interview for myself.

[I]: OK, Wow. Thank you very much.

[P3]: Thank you, Alfredo.

[End of recording – 31:43]

Appendix 5: Open Source and Product Lifecycle Management

Managing the Lifecycle of IEEE's Humanitarian Technology with Peer-Review

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Abstract—The objective of this paper is to describe a Product Lifecycle Management process for IEEE's Humanitarian Technology (HT) "Solutions" that leverages IEEE's peer-review. In 2011, the Humanitarian Initiatives Committee (HIC) of IEEE Region 7 organized a student design competition [1] with the specific objective of understanding the design process of HT "Solutions" to be made available as open source. The 2011 competition was an initial effort to understand open source licensing, open source hardware and the open source development model. Adoption of the open source development model was a stated objective of IEEE's Humanitarian technology Challenge (HTC) [2]. The HIC held a student paper competition in 2013. The goal of the 2013 competition was to nurture the growing interest in Humanitarian Technology in Region 7; to address HIC's concerns from the 2011 competition, more effort was focused in the paper review process for the 2013 competition and standard IEEE peer-review tools and processes were used. This document presents in Section III the lessons learned during these two competitions, and proposes in section IV a Product Lifecycle Management framework for the Intellectual Property Rights (IPR) of OSI development that leverages IEEE's peer-review process.

Keywords— *Free and Open Source, Open Source, Innovation, Intellectual Property Rights, IPR, Product Lifecycle Management, PLM, Humanitarian Technology, Peer-Review.*

I. INTRODUCTION

Technology has been used to improve the living conditions of impoverished populations; for example, through the work done during IEEE's Humanitarian Technology Challenge (HTC) which had two goals: (1) the creation of artefacts for specific humanitarian technological needs, and (2) development of a repeatable methodology for collaboration on technology-based humanitarian projects [2]. One of the HTC objectives was that the results of volunteer work would be broadly available to anyone for their use in providing humanitarian products or services, a characteristic of free and open source technology. The HTC project used online collaboration to assist the solution development process and to ultimately provide a repository for to archival and sharing, a characteristic of the open source development model.

The success of free and open source software typifies the ability of collaborative development to create marketable goods. The high quality of free and open source software is often attributed to its particular peer-review process [13]. In this paper we will use Balka's (2009) general definition of Open

Source Innovation (OSI) which extends the open source development concept beyond software [4]: OSI is characterized by a non-contractual sharing of information between actors, under rules defined by a license. Actors share information with the clear intention of contributing to a joint development, which is part of a larger collaborative design task. Market exploitation of the OSI includes private and commercial contexts in a way that promotes the freedom to redistribute and to access the design and implementation details at no cost. There is a growing community extending the free and open-source model to technologies beyond software: hardware, publications, etc. [3], [4], [8], [10], [14].

With the completion of the HTC, many offshoot activities have emerged [5]; with the Special Interest Group on Humanitarian technology (SIGHT) recently emerging as a rallying global initiative [6]. These initiatives share to different degrees HTC's free and open source ideal; but they also inherit HTC's lack of a clear governance structure and a development process that are rooted in sound Product Lifecycle Management (PLM) principles. It is important to note the need for these elements because IEEE does not have the mandate nor the capability to manufacture products or to provide broad-scale humanitarian services - third parties must be responsible for manufacture, install and operate IEEE solutions, so that they are effectively implemented. Total cost is known to be a critical element of the economic viability of Humanitarian Technology solutions and it may create a barrier to their adoption. For this reason, the IEEE favors partnerships for solution deployment. The IEEE wants to encourage many third parties, without unduly favoring or disfavoring any, in order to use marketplace competition to minimize total cost, and in order to keep Humanitarian Technology solution costs as low as possible.

II. CONCEPTUAL FRAMEWORK

The HTC framework shown in Figure 1 was intended to enable the generation of ideas. Within this framework, presented by Rich Baseil at the HTC conference in June 2009, a Humanitarian Technology (HT) "Solution": is (a) a hardware/software product or process; that (b) meets agreed-upon standards; that (c) includes a corresponding Operations, Administration and Maintenance plan; and (d) is driven by an Economic Implementation plan.

The HTC framework focused on the development and production phases of PLM, at the detriment of the distribution,

use, maintenance and disposal phases [15]. Within these limits, a measure of success was the development and deployment of prototypes for field trials [2]. In a similar way, SIGHT's framework defines three project phases with education aligning with HTC's OA&M plan.

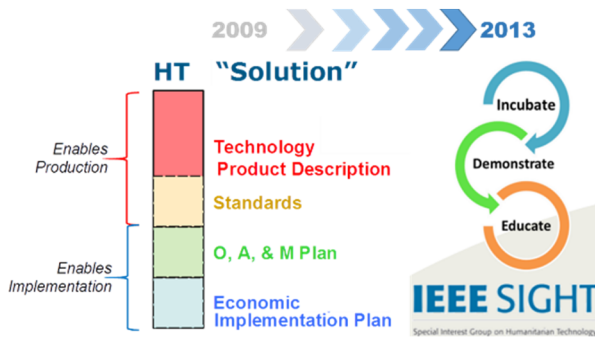


Figure 1: HTC framework (left); SIGHT framework (right).

In comparison Balka (2009) denotes the following factors as indicators of the level of success of OSI: (a) the size of the community; (b) the participation of commercial contributors; (c) activity; (d) addressing an advanced audience; (e) development tool/environment. Conversely, highly restrictive licenses have a negatively impact on project advancement [4]: the reason licensing is so prominent in our analysis.

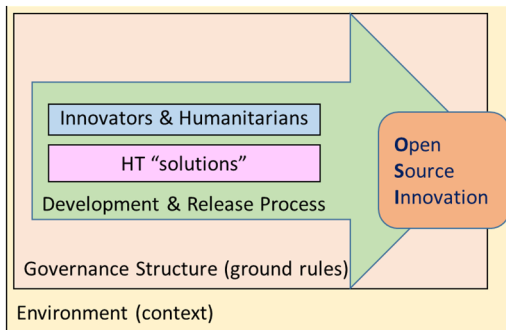


Figure 2: OSI conceptual model for IEEE Humanitarian Technology, adapted from Balka, Raasch and Herstatt (2009) [4].

In OSI terms, as seen in figure 2, an IEEE Humanitarian Technology conceptual framework can be described as the collaboration between innovators and humanitarians (actors) for the development of a HT "Solution" (object) of varying complexity (innovative outcome) in a humanitarian context (environment). Collaboration takes the form of non-contractual sharing of information under rules defined by a license (governance structure), in a process that relies on third party manufacturers, integrators and channel partners (development process). This paper addresses the need for a development process and governance structure suitable to manage the IPR of solutions created by volunteers in the different IEEE humanitarian activities. There are three needs identified by the IEEE leadership during HTC-related activities. Only the third need is in scope of this paper, and described in Section III as it became understood during the HIC's competitions:

- Actors contributing to solution development and their affiliated institutions need to understand and to agree that

their contributions will be documented and shared following an open source model.

- Development and governance structure are needed to facilitate the integration of Intellectual Property that external actors have separately and independently generated and wish to donate.
- Development and governance structure are needed for HTC-like activities to manage their quality (peer-review), to manage its evolution and publication (release), and to safeguard IEEE's IPR (licensing).

The legacy of HTC-like activities is the production of knowledge; this paper presents a licensing model to protect the value of the knowledge created in such endeavours and to enable its use in a manner that takes advantage of the benefits OSI provides [3], [4]. Openness must be balanced with Intellectual Property Rights (IPR), a balance that is well understood by the Free and Open Source Software community but that is only beginning to be understood for hardware [14]. Licensing strategies presented in this paper pertain to safeguarding the value of the IPR created by IEEE volunteers; while PLM aspects presented are associated with their peer-review and release. Both of these activities relate to managing the quality of the IPR created by IEEE volunteers. Of the two, peer-review may be interpreted differently depending if it is knowledge sharing: (a) using the OSI conceptual model [13], or (b) through an IEEE publication [11], [12]. Peer-review is a widely used practice for successful open-source software projects [9]: "The core idea is simply to get an expert to examine your work to find problems you can't see." In the OSI context, a successful peer-review depends less on the process than on the expertise of the people involved; and as seen in Figure 3, it is a collaborative activity of a community of users and developers that release an open source design for the community to debug, examine, fix/modify, etc.

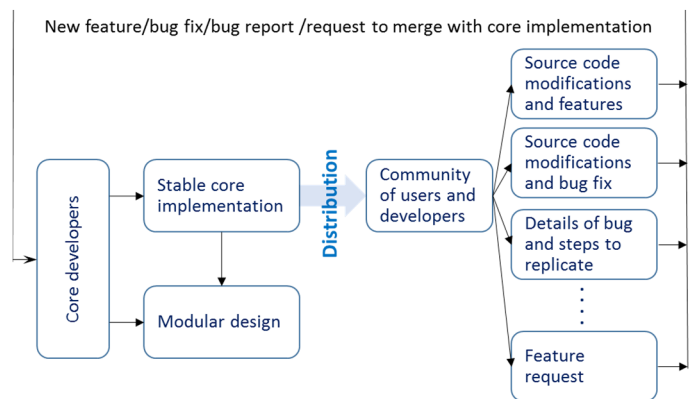


Figure 2: Open Source development model, modified with permission from Senyard and Michlmayr (2004) [13].

In an IEEE context, peer-review is the examination by a group of experts of the work of their peers to seek: plagiarism, self-plagiarism, or copyright infringement [12]. Within this context, peer-review often uses criteria like [11]: (a) relevance to the publication topic, (b) technical merit, (c) trustworthiness, (d) originality, (e) significance.

In Section III, we present lessons learned during the two competitions organized by the HIC in 2011 and 2013; and in section IV, we propose a PLM model suitable for HTC-like OSI leveraging IEEE's peer-review process with the needs of the OSI and the IEEE contexts in mind.

III. LESSONS LEARNED

A. Lessons from HIC's 2011 student design competition

Since its inception, the HIC embraced HTC's vision of creating open source designs. In 2011, it organized a student design competition [1] with the specific objective of learning how to apply the open source methodology to the context of Humanitarian Technology design. Adoption of an "open source" model was a stated objective of IEEE's humanitarian activities [2], but details of what IEEE meant were still unclear two years into the HTC program. Open source was first defined for software, and many efforts have taken place to apply this definition beyond software [3], [4], [8], [10], [14]; open source software has five principles [7] that apply to a licensor, a licensee and open source software. Licensees are: (1) free to use open source software for any purpose whatsoever; (2) free to make copies of the open source software and to distribute them without payment of royalties to a licensor; (3) free to create derivative works of open source software and to distribute them without payment to royalties to a licensor; (4) free to access and use the source code of open source software; (5) free to combine open source and other software. While the concepts and constructs around open-source are well understood in the software community, these notions are not yet fully embraced or grasped by the hardware community. The Open Source Hardware Association (OSHW) has created a definition of open-source hardware [8] that stipulates that open-source hardware is:

"hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design. The hardware's source, the design from which it is made, is available in the preferred format for making modifications to it. Ideally, open source hardware uses readily-available components and materials, standard processes, open infrastructure, unrestricted content, and open-source design tools to maximize the ability of individuals to make and use hardware."

The open source hardware and open source software definitions share many similarities. But it is important to note that the creation of open source hardware can potentially give rise to a number of additional and often complex issues such as design and product liability or patent infringement. We learned was the need to understand the critical differences between open source software and hardware in an HTC-like context. This is one of the reasons why the HIC continues its work on this for the benefit of the larger IEEE community.

During HIC's 2011 competition [1], students were asked to work on solutions for the WECARE Solar Suitcase™. The designs could be improvements for the system, or accessories to complement it. Participants were required to follow an open source approach. Three finalist teams were selected, and their work was licensed to the IEEE and to WE CARE Solar. The standard Creative Commons license was initially used to share

requirements between the competition organizers and participants; and the intention was to use it to license the finalist designs to IEEE and WE CARE Solar. We learned that the Creative Commons license was not suitable to cover the concerns of WE CARE Solar's legal counsel: multiple iterations, over two months, were needed until a license agreement was drafted that was usable for the purposes of the competition. The final version was significantly different from the Creative Commons model initially selected.

The participants' designs of the 2011 competition were reviewed by a panel of judges using on-line communications. We learned that a standard IEEE peer-review process could not be followed due to difficulties in handling design files and also due to the need for design review iterations not usually encountered for conference papers.

B. Lessons from HIC's 2013 student paper competition

The HIC held a student paper competition in 2013 with the goal to continue nurturing the growing interest in Humanitarian Technology by Region 7 volunteers. The HIC was determined to attain a level of quality from submitted papers that enabled publish them in an IEEE publication. To this effect significant effort was put for the paper review process and a standard IEEE peer-review tool was introduced. The top three teams were invited to the Canadian Conference on Electrical and Computer Engineering (CCECE) to present their papers; all submissions were made through CCECE's online paper submission system (EasyChair). The HIC student competition chair was in close coordination with the CCECE 2013 technical committee, and was added to CCECE 2013 EasyChair to facilitate access and assessment of the student papers. Each paper was reviewed by two HIC members anonymously (papers identified by numbers, names removed). Every HIC reviewer was given login access to EasyChair, and they all completed the evaluation form. The HIC student competition chair collected all paper review evaluations and submitted the peer-review evaluation reports to the CCECE2013 Technical Committee which in turn contacted the top three student authors to announce acceptance of their papers and to invite them to CCECE 2013. By the time of the conference, the HIC student competition chair had formed a panel of three judges to listen and interact with the students during their oral presentations. Every student was given 20 min to present their work, giving to the HIC panel of judges the opportunity to select a winner. The winner was sponsored to attend the 2013 Global Humanitarian Technology Conference (GHTC). One lesson learned was about the process to recruit and build a database of qualified reviewers. During the 2013 competition, HIC members had the breadth and depth of knowledge necessary to review the submitted student papers; but that may not be the case in future events. The review process shall include a step to maintain a roster of suitable reviewers.

IV. PEER-REVIEW BASED PLM

A. Proposed (OSI) governance structure

While the HIC 2011 competition has provided certain IPR and licensing learnings, a significant number of issues still need to be addressed. These include: (a) the IPR ownership structure for IEEE's Humanitarian Technology open innovation projects including determining the entity that owns the IPR; (b)

managing project contributions; (c) the identity of who carries responsibility and liability for IEEE’s Humanitarian Technology IP; and (d) deciding on the licensing model for the project results. In particular, the selection of the licensing model is a central element to any proposed framework for IEEE’s OSI because: (1) selecting a restrictive licensing model will be detrimental [4]; and (2) it is important for the IEEE not to select a licensing model that may lead it to become, or be perceived as, a competitor to partners actively designing an HT “Solution” of their own. Partners are key to the success of the HTC-like initiatives that could otherwise become a stale collection of documents in a server instead of being deployed to people who would benefit from them. Portfolios of IEEE HT “Solutions” could potentially be developed and licensed using a suitable open source license, for example: Creative Commons for documentation [13], GPL for software [7] and OHL for hardware [14]. We propose the following three licensing model options:

- 1) **CO-DEVELOPMENT MODEL:** a third party partner owns a platform and evolves it from idea to fully functional product. IEEE plays role of key contributor. IEEE grants rights to the platform owner, but the platform owner owns and manages the platform.
- 2) **PARTNERSHIP MODEL:** IEEE and third party partners co-own the platform. IEEE focuses on its core activities (design services, peer-review, publication, etc) while the third-party partners focus on their core activities (requirements definition, field trials, deploy through its network, etc).
- 3) **HUB-AND-SPOKE MODEL:** IEEE owns the platform and is primarily responsible for evolving it. Peer-reviewed versions of the platform are released under a licensing model selected by IEEE. Third party partners, who will use the platform primarily as distributors, are potential contributors back to the IEEE managed platform.

B. Proposed (PLM) development process

We hereby define a development process meant for managing IEEE’s Humanitarian Technology Intellectual Property Rights (HT IPR). This process is based on the assumption that general support from the relevant IEEE Societies can be obtained to oversee design review of HT “Solutions”. These reviews shall be conducted under the peer-review rules and processes normally used by IEEE entities [11], [12]; for example: by (1) using an online paper review environment (EDAS, EasyChair, etc.); and (2) by publishing the reviewed designs in one of their publications (proceedings, standard, journals, etc.). The proposed development process allows for the management of IEEE’s Humanitarian Technology IPR using IEEE’s peer-review and publication mechanisms; by combining describing our development process (peer-review and publication) in terms presented in Section II, we bring the benefits of OSI and the open source development model to the HTC/SIGHT framework; and by using our proposed governance structure (licensing) we provide a means to safeguard IEEE’s HT IPR.

In OSI terms, an IEEE Humanitarian Technology conceptual framework can be described as the collaboration between innovators and humanitarians (actors) for the development of a HT “Solution” (object) of varying complexity (innovative outcome) in a humanitarian context (environment). Collaboration takes the form of non-contractual sharing of information under rules defined by a license (governance structure), in a process that relies on third party manufacturers, integrators and channel partners (development process).

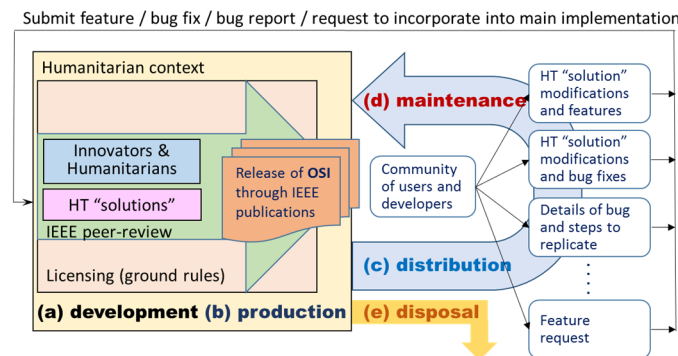


Figure 4: Proposed PLM conceptual model for IEEE’s HT IPR.

Finally, we proposed a conceptual model, seen in Figure 4, where we identify the following PLM phases [15]: (a) development, (b) production, (c) distribution, (d) maintenance, and (e) disposal. Based on it, and using OSI terms, IEEE’s HT IPR PLM process is defined as: the collaboration between innovators and humanitarians for the development of a Humanitarian Technology “Solution” of varying complexity in a humanitarian context. Collaboration takes the form of non-contractual sharing of information under rules defined by a suitable license, using IEEE’s peer-review and publication mechanisms to manage the transfer of OSI thus created to third party manufacturers, integrators, channel partners, and the open source community at large.

V. CONCLUSIONS AND FUTURE WORK

Further discussion and analysis is required to frame remaining concerns to develop of a framework that maximizes volunteer involvement in-line with IEEE’s goal of advancing technological innovation and excellence for the benefit of humanity. In the meantime, the HIC plans to further its work in this area, notably by holding a second student design competition based on the framework presented in this paper.

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Appendix 6: Open source licensing of commercial product

Sustainable Solar Headlamp: *An Open Source Consumer Medical Device*

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Abstract—This paper describes the adoption of an open source hardware release process for a wearable headlamp as a way to improve prototyping and promote regionally-appropriate technology. The headlamp has been developed to satisfy a communicated need for hands-free, directional lighting that can be charged with renewable energy technology in remote areas that lack reliable electricity. The design of the headlamp emphasizes the importance of built-in resilience as way to achieve durability. Utilizing a highly-adaptable mechanical design accompanied with guiding design principles enables the headlamp to be implemented in an unlimited number of locations; during manufacture, the product will be embedded with locally-appropriate features that complement the materials and skills available in the region. Releasing the product with an open source hardware license fosters product adaptation for the design, manufacture, and use of the headlamp in various locations. Working prototypes have been developed, and kits are available under the IEEE open-source hardware license.

I. INTRODUCTION

During a visit to Villanova University in 2010, Dr. Laura Stachel communicated the need for low-cost, low-power devices to aid in maternal healthcare. Dr. Stachel co-founded the WE CARE Solar organization that developed the Solar Suitcase™ system, which provides low-power, solar-charged devices for application in rural healthcare clinics. Dr. Stachel proposed that students develop devices that could be used in conjunction with the solar suitcase. For example, a low-power suction device was developed and implemented in Nicaragua for use with the Solar Suitcase™. [1] Another need communicated by Dr. Stachel was the lack of reliable electricity and the importance of light during maternal medical emergencies. “Night-time deliveries were taking place in near-darkness. The results were often tragic.” [2] As communicated by Stachel, there was and need for reliable, off-grid lighting. The Solar Suitcase™ was originally designed for emergency obstetric care, but it has since been used in a range of medical and humanitarian settings. [3] Given the relatively high cost of the Solar Suitcase as compared with the available capital in rural developing communities, there is an opportunity to develop a more affordable solution. Interviews with local medical attendees revealed that a common practice was to buy large hand-held flashlights for \$2 USD. During emergency maternity care, health practitioners cradle the light between the shoulder and the head in order to use their hands while also directing light at the subject. It was reported that the flashlights broke frequently, and needed alkaline batteries to work, which are not rechargeable. [4] A lighting device worn on the head allows a health practitioner to perform procedures without needing to hold or reposition a lighting fixture, which can impede continuity and focus. In a study to observe luminary

actions during surgical procedures, a surgeon was observed to execute a luminary action (e.g., repositioning of a pendant light) approximately every 7.5 minutes, which interrupted the surgeon. [5] Rural health practitioners often work alone, which is another reason to develop a hands-free device.

The co-creation of a headlamp prototype in Nicaragua reinforced the need for a flexible design that could be adapted to the region. For example, even in small towns in Nicaragua, it was not possible to find a small, replacement switch for the headlamp, which is a component with a higher likelihood of mechanical failure given the frequency of use over the lifetime of the light. Therefore, a switch made of commonly-available components might be a superior alternative than a common modern switch manufactured using precision machinery. [6]

This paper discusses a method for more rapidly developing working prototypes of a hands-free, directional lighting device that is appropriate for the local infrastructure for technology through the IEEE open source hardware license [7].

II. OVERVIEW OF CIRCUIT AND DEVICE

The headlamp prototype features a voltage-boost circuit so that a rechargeable AA battery can power a 1-watt LED. A typical off the shelf headlamp will use two or three AA or AAA batteries, which can make the headlamp cost-prohibitive for people in developing countries. The circuit allows for a slowly decaying lumen output for seven hours. The initial brightness will be 70 lumens and decay to 30 lumens over the seven hour period. The 1-watt LED is powered from one AA battery. The simple voltage-boost circuit is currently constructed with thru-hole components to facilitate in-country manufacture and repair. The circuit features a toroid made of a ferrite bead wound with laminate wire; one, 1kohm, ¼ watt resistor, and a NPN transistor. The circuit schematic is illustrated in Figure 1.

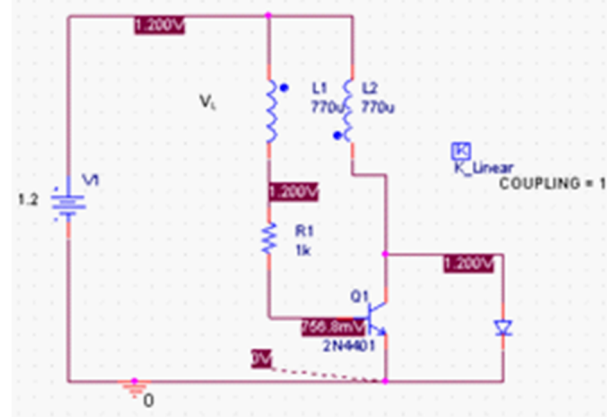


Fig. 1. Electrical schematic diagram of headlamp circuit.

The voltage produced at the LED is just above the turn on voltage of 2.8V as seen in Figure 2. The battery can be charged with a 2.0-2.5V, 600mA solar panel in 1 to 2 hours of full sunlight. [8] However, the method of charging the battery is not limited to solar charging; any available charging method is acceptable.



Fig 2 Sustainable Solar Headlamp kit, version 1.0.

There should be a robust enclosure for the electrical components that is also designed for hand-free use. The design of this aspect is kept intentionally generic to encourage location- and user-specific design. [8]

III. BUILDING RESILIENCE THROUGH APPROPRIATE DESIGN

Ensuring that a device will sustain routine use in a setting that lacks infrastructure for advanced technology can be challenging. In such areas, the lack of a qualified technician or a reliable system of goods transfer results in a decreased rate of sustained device operation.

“One way to attain resilience is to ensure that the device can be maintained and repaired locally. In order to facilitate this maintenance, the complexity of the technology is reduced to a lowest common level of skill and capacity for any region of the world. As the technology is introduced to a region, the skill and capacity of the region is increased to support the advanced technology.” [8] Furthermore, there is an educational and entrepreneurial opportunity for the local community in which the device is repaired or maintained.

The Sustainable Solar Headlamp has evolved in both its mechanical and electrical design. [4], [6], [8] Currently, the focus for developing the headlamp further is through a kit that is available for purchase on-line. There are examples of patented designs for head harnesses and eyeglasses to support the attachment of a light for medical application. However, the materials specified in the patent are not materials that could be commonly found in developing countries. For example, one device describes the use of “synthetic light-weight plastic

material” for the annular headband. [9] As described in a paper by MIT Media Lab, High-Low Tech Group, small but significant niches of people are sharing advice on how to build real world products through web-enabled communities and a growing ability to manufacture at a personal scale. [10] The Solar Headlamp aims to use the innovative techniques of “crowd-sourced” development facilitated by open-source hardware licensing, and adapt it for development of appropriate technology in developing countries. The headlamp is well suited to be adopted by communities that lack access to reliable electricity; for example, rural volunteer healthcare personnel who travel by foot to see their patients would benefit from reliable, hands-free, directional light. Communities in rural Central America and parts of Africa (The Gambia, Ghana, etc.) could be early adopters of the technology.

IV. APPLYING THE OPEN-SOURCE LICENSE AND DISTRIBUTING THE DESIGN

A. Open-Source license

The license chosen to release the design of the headlamp is the IEEE open source license. Through this license, the Licensor can release the design through various media (e.g., schematic diagrams, charts, mechanical drawings) to licensees who wish to develop a successive version of the design. The license protects existing copyright and trademark notices while allowing the open-source design to be copied and communicated to the public as the Licensee wishes. It indicates that the Licensee may modify the documentation that serves as the design instructions, but that this person needs to make the modified documentation available such that it can be easily located by the original Licensor, and that it should be accomplished through a preferred format. The Licensee is then free to manufacture and distribute products provided the recipients of the product are also provided easy means of accessing the product documentation. [7] “With the open-source license, it is possible for a distribution of modular tasks to take place with anyone able to contribute to any module, while the threshold for participation is as low as possible. And [...] sharing the created goods does not diminish the value of the good, but actually enhances it.” [11]

B. Distributing the product via kits

The headlamp will be physically distributed to various participants both in North America and overseas in areas such as Nicaragua, The Gambia, and Ghana via visiting groups of people with pre-established community relationships. The kit will be delivered in formats that vary the completeness of the product to test the success of implementation. For example, some kits will consist of only the minimum electronic parts necessary for contraction and a user-friendly PCB while others would receive a pre-built electronic component. The kit will also be made available for purchase on-line for anyone interested that also has full access to advanced manufacturing. Assembly documentation on will feature image-centric instructions, and will be available both on-line and in paper format for distribution with the kit. As seen in the *The Case of the Helix T Wind Turbine*, giving the idea for a product to a community of enthusiasts can help developers become

informed of issues about which they are previously lacking knowledge, which results in a greater overall performance. [10] In a similar way, the Solar Headlamp design reinforces that the involvement of the in-country maker is important to the sustained functionality of the device, because he or she will imbue locally-relevant information in the design of the device.

V. CONCLUSION

The next development phase of the Solar Headlamp device will be accomplished through both physical dissemination in developing countries and virtual dissemination using web-enabled techniques. Adopting the IEEE open source hardware license [8] for the Sustainable Solar Headlamp can significantly aid in more rapidly developing headlamp prototypes in various regions across the world to achieve wide availability. This approach improves co-development and opportunity for entrepreneurship, and promotes regionally-appropriate technology.

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Appendix 7: IEEE's Humanitarian Open Source

IEEE's Humanitarian Open Source

A path to Open Standards and Interoperability

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Abstract— IEEE has been developing organizational capability to create open source innovations for humanitarian needs since the 2004 Tsunami. In 2009, IEEE held the Humanitarian Technology Challenge (HTC); where one of the stated objectives was that the results would be broadly available to anyone for their use in providing humanitarian products or services. Since then, various Humanitarian Open Source activities have been sponsored by the IEEE, notably under the Special Interest Group on Humanitarian Technology (SIGHT) program. This paper presents some of these activities, and their accomplishments, commenting its link to the global open source movement. It presents IEEE's open source licenses meant to protect IPR developed by IEEE volunteers under the humanitarian activities it sponsors. Finally, Open Standards and interoperability are briefly discussed in relation to IEEE's stated humanitarian goals.

Keywords—humanitarian technology; licensing; open source; standards; interoperability

I. IEEE'S ENTRY INTO HUMANITARIANISM

The IEEE is dedicated to advancing technological innovation and excellence for the benefit of humanity. Its Constitution [1] defines the purposes of the organization as for "the advancement of the theory and practice of Electrical, Electronics, Communications and Computer engineering, as well as computer science, the allied branches of engineering and the related arts and sciences." IEEE's desire to enter the Relief and Development sector seems like a natural evolution of its vision to "be universally recognized for the contributions of technology and of technical professionals in improving global conditions" [2], but it may as well be perceived as a stretch of that vision outside IEEE's core areas of activities. Historically, IEEE has measured its impact on the human condition by its technical contributions through publications, standards and enablement of member's achievements. But regardless of the point of view taken, it is obvious that the emergence of Humanitarianism at the IEEE can be confirmed from the extent of the HTC and SIGHT initiatives.

In 2008 the IEEE launched a three year effort funded by the IEEE Foundation, the Vodafone Foundation, and the UN Foundation: the Humanitarian Technology Challenge (HTC). It was a very unique up-front, formalized collaboration between technologists (led by IEEE) and humanitarians (led by UN Foundation) to identify three challenges and drive solutions that were implementable and sustainable in the field, tailored to local socioeconomic conditions. The HTC had two goals [3]: (1) the creation of artefacts for specific humanitarian

technological needs, and (2) development of a repeatable methodology for collaboration on technology-based humanitarian projects. The IEEE showed its commitment to establishing itself as a contributor of solutions to humanitarian problems. In 2011, the Board of Directors approved the consolidation of the stronger elements of the HTC initiative into the SIGHT program. SIGHT's mandate is to manage the creation of IEEE Humanitarian affinity groups, reporting to the Humanitarian Ad-Hoc Committee (HAC) under the New Initiatives Committee. This unusual organizational structure testifies to the desire of investing time and effort in finding the most effective means to operationalize the IEEE Humanitarian program; IEEE's board of directors has agreed to make this Ad-Hoc committee permanent, starting in 2016.

II. RECENT IEEE HUMANITARIAN WORK

A. Differences between HTC and SIGHT

There are notable differences between HTC and SIGHT, as shown in Figure 1, below.



Figure 1: differences between HTC and SIGHT [4]

The HTC, which took place between 2008 and 2011, was a focused collaboration with NGOs, and all IEEE Organizational Units, and it was a great learning experience for the various levels of IEEE (staff, TAB, MGA, sections, members). The HTC framework was meant to enable the implementation of ideas and their hand-off to partners for deployment and maintenance. Within the HTC framework, a Humanitarian Technology (HT) "solution" was defined as: a hardware/software product or process: that (a) meets agreed-upon standards; that (b) includes a corresponding Operations, Administration and Maintenance plan; and that (c) is driven by an Economic Implementation plan [4]. In a similar way, SIGHT's framework is meant to drive member participation; it has focused on creating opportunities for members to devote time and talents to humanitarian work by inviting them to create groups associated with an IEEE Organizational Unit (i.e.,

Section, Student Chapter or Society) and to work on activities that: inspire, enable or connect members. These types of activities shall lead to a Humanitarian technology project.

The legacy of HTC and SIGHT activities is the production and sharing of knowledge [5]: this is generally accepted as a way to increase the value of ideas and information; since their value will increase to the degree they can be shared with and used by others [6]. The more knowledge created by IEEE Humanitarian activities is diffused and adopted, the greater its value. But HTC and SIGHT have used different strategies: HTC's knowledge sharing strategy was to use on-line collaboration (crowd-sourcing), coupled with workshops. Results of HTC's volunteer work were always meant to be broadly available to anyone, a characteristic of free and open source technology. The knowledge created and shared by SIGHT, up to now, has been mostly administrative: indicating how to get started, defining what activities are in scope, identifying what are the sources of funding, etc. Since its original mandate (2012-2014), SIGHT has focused on building organizational capacity, mostly by equipping new SIGHT "chapters". No activity has yet been taken by SIGHT to continue the work started by the HTC. This means that the interoperability work planned for the later stages of the HTC never started; and any IEEE volunteer(s) developing humanitarian technology IPR must face that task alone.

SIGHT's mandate was indirectly reaffirmed in November 2014 by the Board of Directors, with a renewed vision starting in January 2016 when the HAC becomes permanent: "*IEEE will possess a large network of volunteers around the world carrying out and/or supporting impactful humanitarian activities on the local level*".

SIGHT's focus continues to be on activities that shall lead to a project, which is unique to this programme among all other IEEE activities. SIGHT sponsored projects shall support sustainable humanitarian technologies with measureable impact in alleviating poverty or lack of access to: energy, health care, sanitation, communication and similar technologies for vulnerable and underprivileged communities.

Let's remind readers that IEEE does not have the mandate or capability to manufacture products or to provide broad-scale humanitarian services directly. To be successful, IEEE must continue to improve how it coordinates access to its volunteers for Relief and Development work. It must also identify knowledge gaps. IEEE's global strategy must seek to incubate self-sustained enterprises where free and open technology is a key enabler, and knowledge re-use and adaptation are part of the process because it is through such an ecosystem that it can best leverage the knowledge networks it already has in publications, standards and education. Open Standards in health like the OpenMRS [7], for medical records, and the OpenECG [8], for electrocardiogram, are good examples.

B. Accomplishment of IEEE humanitarianism

The HTC was IEEE's first deliberate humanitarian project, but not the first attempt: the emergency response of the Kerala section to the 2004 Tsunami was the first significant undertaking [9] in relief work. The Tsunami devastated the whole of the Indian Ocean region, from South East Asia to

South Asia to Africa; killing over 100,000 people. IEEE volunteers stepped in for rescue/relief work after the first two days, providing help in communications, logistics, planning and co-ordination. The response of the Kerala section to the 2004 Tsunami helped sensitize the IEEE leadership on the need to use and develop technology for humanitarian work, and it was influential in bringing the Humanitarian Technology Challenge to life. The Kerala section has since continued to contribute a constant flow of humanitarian activities, with the particularity of being a grass roots initiative and not the result of an IEEE program. Their contributions include: Free and Open Source software stack and computing for the visually impaired, off-grid power supply, community mapping for Disaster Risk Reduction. In addition, during the HTC the IEEE:

- worked with 15 NGOs and Foundations in four focus groups to research needs;
- selected 3 from 37 identified humanitarian needs, that had technology solutions: (a) Patient ID, (b) Data Connectivity, and (c) Reliable Electricity;
- had 22 Societies (out of 49 technical societies and councils) joined its Society Partnership Group;
- had representation from all 10 Regions;
- had 35 external strategic partners for field tests;
- had over 1000 volunteers involved;
- used \$3M+ budget over four years, including funding from: IEEE's New Initiatives Committee, the UN Foundation, the IEEE Foundation, the Nuclear and Plasma Sciences Society (NPSS), and the Power and Energy Society (PES).

The HTC was one of many demonstrations of technology-based human development, similar to: the UN Millennium Villages project [10]; FrontienSMS and Ushahidy [11]. All of which successfully leveraged free and open source software/hardware for Humanitarian work; thus establishing this type of technology as a viable alternative.

III. IEEE HUMANITARIAN OPEN SOURCE

A. Why Open Source for IEEE Humanitarian

Active IEEE members are very generous of their time, contributing many hours as constituents of a committee, elected officers of a section, delegates to conferences, participants in standards activities, etc. To its credit, IEEE understands how to leverage individual volunteer's commitment and experience to generate an impressive amount of knowledge. The IEEE is a major publisher: having more than 3.5 million documents in its online Digital Library; publishing annually 170 transactions, journals and magazines; and overseeing 1,300 standards and projects under development. It sponsors over 1,300 conferences in 92 countries, attracting over 419,000 participants. For its humanitarian activities, IEEE volunteers not only contribute in the "traditional way", but also with systems and component design. As stated earlier, one of IEEE's earliest goals (during the HTC) was to make such designs available to all as open source; and this paper presents the selected hardware and software licenses for such contributions. Licenses are a required element of open source development, defining the terms to share and use trademarks, patents and copyrights. A license

often includes elements other than copyright, such as patents, trademarks, implied warranty, and liability [12].

B. IEEE open source licenses

Katz offers a good review of open source licenses, issues and compromises [13]. IEEE decided to adopt from existing licenses for its humanitarian technology IPR. After a careful review of alternative licenses in connection with the objectives of its humanitarian activities, the IEEE selected the CERN Open Hardware License version 1.2 (“OHL”) [14] for open hardware and the Apache license version 2.0 [15] for open source software for use in connection with its humanitarian projects. The benefits of an Apache license are well explained in [13]; but because no existing apache version of a hardware license exists at this time, the CERN license was chosen, notably because of the boundary problem described by [13].

CERN developed the OHL as a solid legal framework for open hardware after it determined that the existing software or documentation licenses were not sufficient. The OHL governs the use, copying, modification and distribution of hardware design documentation as well as the manufacturing and distribution of products based on the design. The OHL sets out a number of legal protections for both users (such as an explicit patent grant from contributors) and contributors (such as the disclaimer of warranties and limitation of liability). In additions, the OHL, by requiring new developments to be published under the same terms, ensures that improvements made by the open hardware community to the covered design will be accessible to everyone.

The Apache open source software license is a well-recognized and widely used OSI approved license. The Apache license permits users to freely download and use the covered software, in whole or in part, for any purposes including the use such software in packages or distributions created by users. Users are required to include a copy of the Apache license, as well as clear attribution notices and notice of any modifications, in any redistribution that includes covered software. Like the OHL, the Apache license sets out a number of legal protections for both contributors (such as the disclaimer of warranties and limitation of liability) and users (such as an explicit copyright and patent grant from contributors). While the Apache license does not require the user to provide the source for any modifications, contributions back to the community are encouraged.

The IEEE believes that the open source objectives of its humanitarian activities will be best supported through its combined use of the Apache version 2.0 and OHL version 1.2 licenses as the foundation for its Humanitarian engineering Licensed Protocol (“HeLP”). As noted above, the solid legal frameworks of the selected licenses provide clarity with respect to the licensing of intellectual property rights in the projects for both contributors and users. Equally importantly, both of the licenses contain disclaimers of warranties and limitations of liability that help to protect contributors from liability that could arise from the use of the hardware designs or software.

C. IEEE humanitarian open innovation

Searching in IEEE Xplore for humanitarian open source design reveals multiple papers on the topic. Most of these are a result of the Global Humanitarian Technology Conference (GHTC) which has been held in Region 6 annually since 2011. Open Source has been discussed presented and showcased at this conference, but none of it has been licensed back to IEEE so that volunteers and collaborators may examine these designs, adapt them, or share them with others. Examples include: a free and open source software [16]; a standards-based open source application for Health Data [17]; a tele-health application [18]; an open source communication tower [19]; and an open source programmable logic controller [20]. Share design files in proceedings and journals is uncommon, even when publishing about open source designs. The medical head lamp design presented at the 2015 International Conference on Consumer Electronics [21] is simple design will purposely share design files to be a reference of IEEE volunteer-developed humanitarian open source designs.

D. Interoperability and Open Standards

The first definition of open standards compatible with open source is attributed to the World Wide Web Consortium (W3C) in 2002 by [12]. In their study of the interplay between standards and IPR [22], the European Union found out that out the several hundred thousand standards they analyzed, only a fraction (736) distinct standards include any of the more than 62,000 disclosed “essential IPRs”. Their study confirms that understanding IPR issues benefits their use and distribution in standards. One risk of ignoring IPR in standards is posed by what Retzig et al. in [22] call “sharks” or “trolls”, where patent holders wait for a standard to be widely adopted before asserting their patent rights, and this circumventing Fair, Reasonable, And Non-Discriminatory (FRAND) terms in the standard. This risk is one that IEEE wanted to address by having a licensing mechanism for its humanitarian technology IPR: to sort out patent claims.

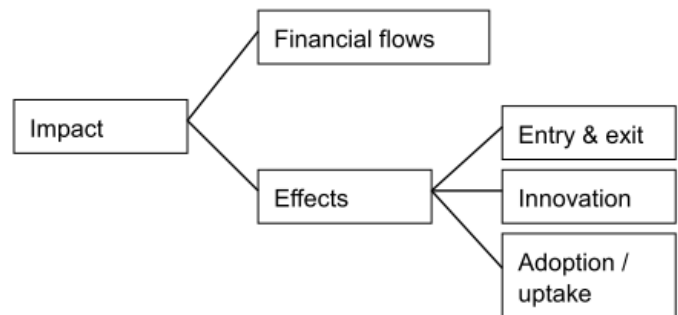


Figure 2: impact of patents in standards, from [22].

The adoption of a licensing strategy for volunteer-developed hardware and software potentially opens new areas for IEEE. It is true that IEEE does not have first-mover advantage; but if it can use its strong brand to leverage its knowledge diffusion and standardization capabilities, IEEE will establish itself quickly as an invaluable contributor of open source. For example, by making sure that its humanitarian open source contributions, under the licenses presented in this paper, are compliant with relevant standards, as exemplified by *The Open Group* [23] and *OpenStandards.net* [24].

IV. CONCLUSION AND FUTURE WORK

This paper is the third and last in a series of articles meant to define IEEE's model for developing, releasing and sharing open source hardware and software designs. A first paper was presented at ITMC 2014 [4] to summarize early work on the subject and describe a suitable Product Lifecycle Management (PLM). A second paper was presented at ICCE 2015 [21] with a simple open source design to illustrate how the peer-review process could be leveraged. As described in [4], the combinations of open source's peer-review and IEEE's peer-review provide a good way to assess the quality of a particular contribution to an IEEE library of designs for humanitarian work. This paper has presented the selected licenses to protect such work by IEEE volunteers to frame the development terms but also its sharing with partners for its deployment and maintenance. To use these licenses, the designers must adopt the IEEE license and include it in with its design source files. Once ownership has been determined, these licenses protect IEEE against any individual or organization who may stake improper and unwarranted claims against: (a) any volunteer participant's individual idea, and (b) the project's collective Intellectual property (IP), claiming it as exclusively their own. By also adopting a PLM process [4] that leverages IEEE's peer-review, they also give third party partners and NGOs who build and use IEEE's solutions some reasonable assurance that they won't be later victimized by other parties claiming IP ownership rights. Finally, once a protocol has been established for the licenses use, it shall give participants' employers and educational institutions a mechanism to delimit their own IP from the volunteer's work done in the context of humanitarian work; this shall prevent these organizations from asserting and enforcing IP rights or non-disclosure clauses on participants' contributions.

In closing, we are grateful for the opportunity and hope to actively continue the work of promoting IEEE's new open source licensing, the integration and aggregation of open source humanitarian technology and the standards and regulatory approval of such systems and components. To support this work, an official IEEE GitHub repository shall be setup shortly and initial work shall be hosted at the University of Ottawa.

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