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Innovation Through Collaboration: Scaling up Solutions for Sustainable Development

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Abstract

The open collaborative philosophy employed in the success of open source software can be applied to hardware design. Specifically, the development of open source appropriate technologies (OSAT) can improve sustainable development efforts worldwide. Yet, widespread OSAT use is far from ubiquitous. Given that lack of communication, access to information and poor collaboration are among the largest barriers to a more effective OSAT dissemination, this paper explores opportunities to overcome such obstacles using four techniques: 1) collaborative on-line platforms, 2) crowd-sourcing, 3) the concept of knowledge commons, and 4) enabled educational institutions through service learning and applied research. The results are analyzed and conclusions are drawn that outline paths to higher multi-user collaboration for OSAT deployment.

Keywords: sustainable development; open source; appropriate technology; knowledge commons, crowd-sourcing

Introduction

Open source appropriate technology (OSAT) is technology that is appropriate for local economic, geographic, political and social conditions, and are easily obtained and utilized by local communities to meet their needs, while being developed in the public domain following the model of open source software (Pearce and Mushtaq, 2009; Buitenhuis, et al., 2010, Pearce, 2012). The open source advantages over the traditional proprietary methods of innovation are in the inclusion of the global collective wisdom to improve and develop life saving technologies, while keeping the design open for others to emulate and build upon. If scaled globally, this approach would harness the power of distributed peer review, design source transparency, as well as the gift culture from the open source movement in the context of sustainable development (Pearce and Mushtaq, 2009). The field of OSAT would assists in solving sustainable development challenges such as food and water security, housing, health, education, access to dignified work, as well as stimulating economic opportunities (Sawnhey et al., 2002; Buitenhuis et al., 2010; Pearce et al., 2012). However, despite this tremendous potential, and the rise of information dissemination instruments such as wikis and mobile phones, there has not yet been a significant uptake of OSAT by the institutions, organizations, researchers and policy makers focused on world development (Pearce et al., 2012).

Lack of OSAT uptake involves social as well as technical barriers that focus on both appropriate technology (AT) as well as the open access (OA) components. The following obstacles have been identified for a higher degree of AT deployment: i) AT seen as inferior or “poor person's” technology, ii) weak technological dissemination weak due to cultural or economic appropriateness, iii) doubts about robustness, iv) transferability and the fit within industrial and policy systems, v) barriers of distance and time in solving rural poverty, vi) problems of stable funding and a better institutional support for AT, vii) social barriers, viii) communication and information specific barriers, ix) barriers to open source technology, x) barriers to technology (AT or in general), and xi) social and technical barriers inter-connected (Carr, 1985; Chambers, 1983; Hazeltine and Bull, 1999; Jequier, 1976; Schumacher, 1973; Smillie, 2000; Buitenhuis et al., 2010;). In addition, the results of a recent study revealed that the most pressing obstacles were social in nature; specifically the need for a much better communication and collaboration between the agencies and communities working in the field of AT to share the knowledge and resources was the most expressed (Zelenika and Pearce, 2011).

This paper explores how fundamental barriers to AT deployment can be overcome with a focus on the increased communication and knowledge augmentation. First the role and the potential of AT in development is reviewed. Then the results of the qualitative study and the interviews of organizations, researchers and academics working in the field of AT is discussed with three interconnected potential solutions to the above mentioned barriers: 1) *further development of the open source and open access paradigms* 2) *crowd-sourcing and online collaboration for development*, and 3) *the role of universities in development of appropriate technologies through service learning*. The importance of the open source design paradigm in the field of AT for sustainable development or the OSAT movement is also critically reviewed. Then the growth of the collaborative online platforms as a key tool for OSAT is examined, including the prospects of crowd-sourcing, knowledge commons as well as the role and the involvement of educational institutions through various forms of service learning and applied research. Finally, obstacles to to this mechanism of development are also discussed, recommendations for future work are outlined and conclusions drawn to find methods to break down barriers to AT deployment with higher multi-user collaboration through the ICTs and OSAT.

Background - The Role of Appropriate Technologies in Development

While the number of organizations working in the field of sustainable development is growing (Black, 2007), the Millennium Development Goals set up for 2015 are still largely out of reach (WHO 2010). Furthermore, pressing issues such as climate destabilization, rising energy prices and the effects of other potential resource scarcities are heightening the urgency of sustainable development in all parts of the world (IPCC, 2007; UN 2010). The urgency is clear: ~50% of the developing world's population - 2.6 billion people - lack even the access to clean water and a hygienic latrine (WHO, 2010), while 4 billion people sustain themselves and their families on less than $2 per day (UN, 2010). Therefore the problem is twofold: on one hand the living conditions of the world's poorest need to be raised to higher levels, while ensuring that global sustainability efforts can match the carrying capacity of the planet.

Development of any form is a complicated process because it functions, effects and is affected by complex social, technical, political and economic web of connections. Even within the technological components of development alone there are often unknown variables whose effects both negative and positive cannot be foreseen or predicted (Smillie, 2000). Even the simplest technologies can enhance living conditions, improve food security, water access, sanitation and also provide education and economic opportunities (Carr, 1985; Schumacher, 1973; Sawhney, 2002, Murphy et al., 2009). For example, introducing affordable and sustainable lighting solutions such as solar powered lanterns instead of traditionally used candles or kerosene lamps can save money, expand lighting effectiveness that increase productivity as well as mitigates negative health and environmental effects (Zelenika and Pearce, 2011). Given the massive need for development worldwide, appropriate technologies can play a significantly role in sustainable development by promoting smart, sustainable, relevant and efficient technologies, especially when solutions are designed with demand-led collaborative engineering. AT was first conceptualized as intermediate technology by E.F. Schumacher in his influential book *Small is*

Beautiful: Economics as if People Mattered (1973). Schumacher called for development within the limits of planet's carrying capacity with a focus on non-violent and small-scale technical solutions promoting human self-reliance, dignity and creativity with an emphasis on rural development (1973). AT is a concept based on sustainable and smart engineering, working within local contexts and environments, and designing with end-users in mind (Buitenhuis et al., 2010). The AT criteria can incorporate technical innovations such as water purifiers, biodigesters, food grinders and food processors, solar cookers, and toilets; but can also include the theoretical 'know-how' or the software components of technological design and function by incorporating local and traditional knowledge. Furthermore, while AT has traditionally been associated with low-cost and low-tech solutions given its application in rural and impoverished areas, AT also can include 'high-tech' and complex technologies such as solar photovoltaic powered lanterns, wind powered generators, cell-phones and computers. As Ian Smillie points out: 'The issue for developing countries is not a trade-off between high and low technologies: it is a trade-off between appropriate and inappropriate technologies' (Smillie, 2000, p. 256). In the same regard, AT is not only intended for developing areas but can and should be applied world-wide in industrialized regions as well. Most importantly, what is appropriate for a given community under given circumstances may not be for others even if they share some similar characteristics. Given the ever-changing nature of economic, social and technical components that shape society, AT is also in constant flux and thus evolves to match changing needs.

Despite the global growth in aid funding as well as the number of agencies working in the field of sustainable development (Black, 2007; UN, 2010), the AT movement and the benefits it holds have not yet scaled to reach critical mass. According to critics and proponents, there are several main reasons: i) there is the inconclusive meaning of the term 'appropriate', which causes disambiguation, and ii) the stereotype of AT as inferior and ‘poor people's’ technology, which significantly downplays the significance and importance (Pursell, 1993). In addition there are also issues associated with the technological design, implementation and dissemination of AT, as well as constraints of permanence, robustness and transferability of AT to technical and economic spheres (Carr, 1985; Smith, 2009). Lack of institutional support, access to stable funding and policy groundwork are also crucial components needed to elevate the movement's influence (Chambers, 1983; Carr, 1985). Despite these roadblocks, there are still numerous organizations and researchers working with AT for development. Unfortunately their effectiveness is limited given that majority of AT research and knowledge is not often published or shared with the communities or organizations who need the information (Pearce et al., 2012). AT research is often completed in isolation and via trial and error, which significantly dampens the effectiveness and the rate of technological dissemination and development (Buitenhuis et al., 2010; Pearce, 2007). To bridge these knowledge gaps and take advantage of new ways to disseminate information via information and communication technologies (ICTs) via collaborative open design, it has been proposed that the same open access philosophy employed in the success of open source software can be applied to engage open source appropriate technology to improve development efforts worldwide (Sawnhey et al. 2002, Buitenhuis et al., 2010; Pearce and Mushtaq, 2009; Pearce et al., 2012). The open source software licenses are designed under a premise that grants anyone a right to access, view, copy and improve upon the 'code' or the design for the benefit of everyone who uses the software. The licenses can vary, but in most cases allow accessibility, use, modification and re-sale under the stipulation that any derived work is also published under the same license allowing for continuous improvements, accessibility and affordability (Deek and McHugh, 2008). Open-source software is booming and currently accounts for over 60% of all Internet software used; beating out the proprietary alternative while demonstrating reliability and functionality (Deek and McHugh, 2008, p. 54; Netcraft 2011). While the interest in all forms of ICTs for sustainable development is growing, the opportunities to tap into the potential of collaborative open source innovation and online efficiency have not yet been scaled.

Methodology

Seventeen interviews were conducted with twenty one participants, which followed the semi-structured 20-30 minute interview method developed by Mikkelsen (1995), supplemented by informal conversational interview techniques (Babbie and Rubin, 2007). All interviewees were asked the same questions pertaining to key barriers as well as solutions to higher engagement of OSAT in development. The interviews provided a wide scope to examine the research question and offer qualitative data on overcoming the most pressing obstacles to OSAT, while also allowing the interviewees to elaborate on development topic or details they deemed necessary furthering the scope of the research.

Attempts were made to include a diverse group of participants to balance the type of respondents, but time and availability restrictions limited the ability to obtain equal representation of respondents from all sectors involved in AT development. As such, the final interview respondent breakdown included five academics working in the field of development, eight non-governmental organizations, one governmental, as well as feedback from two entrepreneurial organizations and two independent voices of which one is an open data activist. The academic field researchers included professors from Arizona University, Cooper Union, Hope College, St. Thomas and Western Washington University. Non-Governmental and Not for Profit Organizations participating in the interviews included: American Society of Mechanical Engineers (ASME), the Appropedia Foundation, Appropriate Technology Collaborative (ATC), Appropriate Infrastructure Development Group (AIDG), Compatible Technology International (CTI), Digital Green and Practical Action. Governmental agency input was provided by the Canadian Crown Corporation - International Development Research Center (IDRC). The research also included feedback from the entrepreneurial sector - AYZH and Kopernik, as well as open data movement activist David Eaves and development activist Vinay Gupta.

The majority of the interviewees were chosen by the 'reputation method' style as devised by Laumann and Knocke (1987), which implies that respondents are selected based on their merit and reputation in the field. Although the field of AT is still growing, there are half a dozen organizations considered at the forefront of the development, which were thus chosen as the base for the interviews. A number of academic interviewees came out of the process of peer recommendation from discussions at the 2010 NCIIA Conference in San Francisco. Once the University ethics board clearance was granted, prospective interviewees were contacted with an invitation to the research outlining the background of the study as well as the interview consent forms. Of those that agreed to the interview all but one granted the permission to record, and all but one interviewee gave permission to use their name in publications. Most interviews were 30 minutes in duration, while some exceeded that length. As per the ethics guidelines, the interview data, including audio files, transcriptions and consent forms are stored in a locked location on an encrypted disc using the open source software TrueCrypt.

Once completed the interviews were transcribed and coded for key barrier categories that were counted to assess their frequency while extrapolating themes, patterns and top barriers. To analyze the data two techniques were employed: logical and pattern coding. First, the interview responses were analyzed using logical analysis procedures, based on Patton (1990), which explored emergent themes and barriers throughout the interviews and their frequency. Next, the pattern coding was employed to group summaries of data into smaller number of overarching or linked themes (Miles and Huberman, 1984).

Results

The Case for OSAT

The results of the interviews with AT researchers and practitioners showed that the primary obstacles to the deployment of OSAT are dominated collaboration, communication, and dissemination as seen in Figure 1. Respondents repeatedly focused on the need for much better communication and collaboration between the agencies and communities working in the field of AT to share the knowledge and resources and work in partnership.

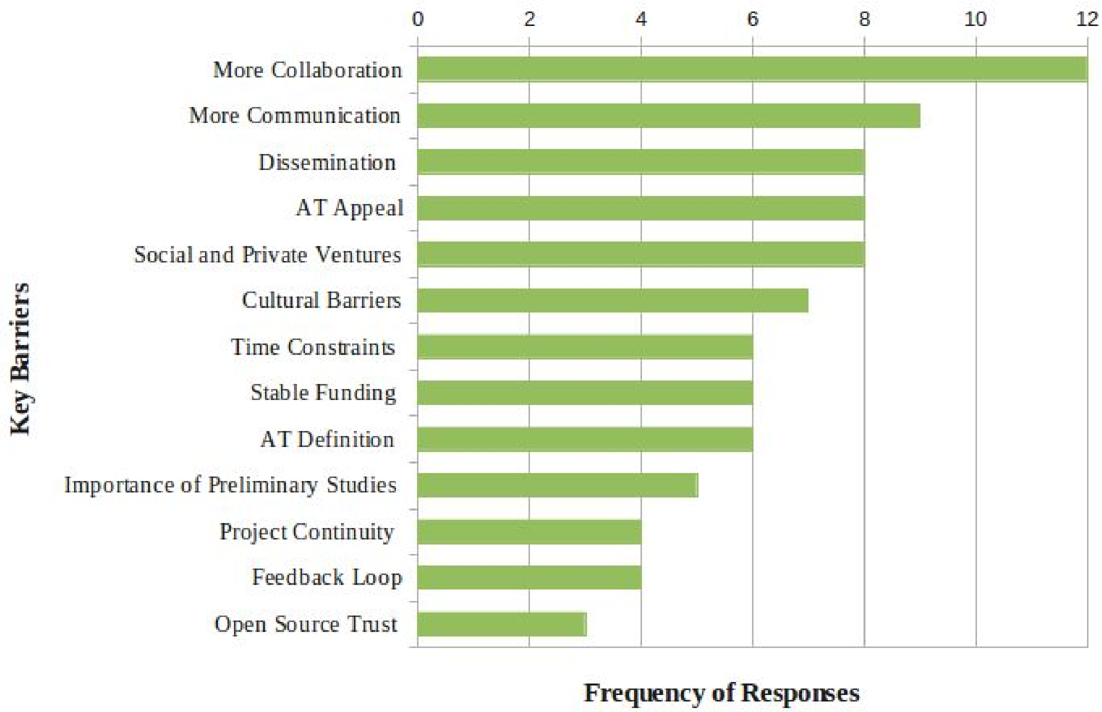

Fig. 1. The frequency of response of key barriers to OSAT deployment.

There is a strong case to be made for a larger inclusion of ICTs for more effective development process. Overall, respondents were very supportive of an online database or a repository for knowledge with features to enable collaboration and exchange of data. Researchers spoke of the need to share details and design specs of successful projects, but they also commented on the importance of sharing problems and limitations encountered in the field as well, because that knowledge can be equally valuable. For others, better linkages with agencies in the field, knowing who has what technologies, skills and tools to offer, as well as having the ways to showcase one's technology were among key positives of such an online repository. Dr. David Grimshaw of Practical Action, who has also worked with Science for Humanity and the U.K. Department for International Development (DFID), agrees that “In the future ideas will be developed very differently: much in the style of crowd-sourcing as a way to pool resources, technologies and ideas together.” [i] Vinay Gupta of the Hexayurt Project went a step further: using the example of William Kamkwamba (2009), a fourteen year old boy from Malawi who used spare scrap parts and designed a windmill electricity system for his family home based on a photo he saw at a library, Gupta professed:“Ten years from now there will be 2 billion people with a broadband Internet access but no toilet! Those people will go online, find solutions and self-educate using [the] Internet.” [ii]

Eleven interviewees voiced support for open source and open access principles citing low costs and compatibility as key strengths. For the Appropedia Foundation, Appropriate Technology Collaborative (ATC), Ayzh and Digital Green, employing open access innovations and anti-proprietary solutions was a deliberate choice. As Zubaida Bai of Ayzh points out, "If the goal is high quality low cost solutions, then IP would impede on that vision. The main thing is that technology reaches the intended people and if that happens with copying we as a business are ready for it."[iii] Bai also explains that given the research and development expert components associated with innovations, it is simply not practical just to copy, and customers continue to order directly from them. While on the ground-level open source is picking up momentum, it was noted that there is still a lot of convincing higher up to be done to showcase the reliability and security of open source solutions such as software when compared with the traditional proprietary types. David Eaves, an Open Data Movement activist and Fellow at the Centre for the Study of Democracy at Queen's University explained that a big deterrent of open source and open access is the counter-intuitiveness when it comes to free items: "Free is simply not seen as trustworthy in terms of quality given that people and governments are used to paying large amounts of money for products and services".[iv] Eaves added that higher engagement of open access and open data in Government and other sectors can lead to many surprising efficiencies between departments given that governments are the biggest users of data. For example, he cites a case where open data helped his friend expose fraudulent charities and saved Government of Canada $3.2 billion (Eaves, 2010). However had the Government made that free information accessible online, this money would have been saved earlier, instead of going the traditional 'call in, reference check and paper mail route'. To Eaves this one example of efficiencies brought on by citizen engagement and data availability is just the tip of the iceberg of opportunities. The same principle can be as effective in the development sector where so many organizations are working for a common goal and access to data can save time and resources.

Discussion and interview responses on open source and open access to knowledge were insightful, and demonstrated general receptiveness to the core principles of knowledge commons, open source and innovation through collaboration. However, not all interviewees are taking part or has experience in it. The reasons for lack of engagement included lack of time, not knowing where to look for information, too many websites with information, a lack of assurance that they have valuable knowledge to contribute and lack of trust and background knowledge on open source licenses and principles to protect innovations. The interest and awareness of the benefits brought on by better collaborative methods exists, and perhaps what is missing are the right tools and easier interfaces to allow for that collaboration to blossom and reach its full capacity. Therefore, it is clear even with the leaders in the AT field, efforts need to be made to demonstrate potential of open collaborative innovation and most of all make it easier for researchers and organizations to share, build knowledge and interact with each other.

The Role of Open Source Philosophy in OSAT

In order to fully capitalize on the opportunities of the digital age, it is imperative the services be accessible, available and as free as possible to everyone to maximize the network effect and knowledge exchange. This philosophy is supported by Hess and Ostrom (2007) that state, "the more quality information there is the greater the public good". Similarly, it can be argued that the speed by which the Internet and its online platforms have evolved is directly linked to the amount of free and open source software applications and programs it runs on, as well as the fact that the Internet's inventors resisted privatization and enclosure of the Internet in its early stages (Berners-Lee, 1996). Berners-Lee is still a vocal proponent of a free and accessible Internet for all, especially for the 80% of the world's population who still do not have access to it, of which many are poor and living in rural underdeveloped areas (Fildes, 2010). He suggests that access to the Web is as crucial as providing water and health care because it can allow people to "Create their own communities and share their own information about health, agriculture and business" (Fildes, 2010). The Internet is an example of what happens when channels of communication are left open for participation and growth and the open source software work has demonstrated not only how well the Internet can be used for collaborative developments, but also the efficiency, profitability and opportunities of the open source paradigm over its proprietary counterparts (Raymond, 1999). Among the most influential open source projects is the Linux kernel operating systems. Although starting with no budget, the Linux project had one advantage not even the wealthiest software corporations could afford: a large number of dedicated beta testers and co-developers working together online to build and continuously improve the software code making it more robust and innovative (Soderberg, 2008; Raymond, 1999). In addition, this open collaborative model that programmer and open source advocate Eric Raymond refers to as the "bazaar" style of innovation (Raymond, 1999) makes the software more relevant and reliable to the users (Kogut and Metiu, 2001) because the creators of the software are also the users and co-developers. Today, Top Supercomputers reports tat Linux is the operating system of choice for 82.8% of the top 500 supercomputers in the world (2010). The success of open source software provided an alternative to expensive and proprietary systems, reduced research and development costs (Lakhani and von Hippel, 2003), and also showcased alternatives to the linear hierarchical structure used to design products (Mockus et al., 2002). Furthermore, it demonstrated the efficiency of collaboration, demand-driven innovation and the power of the Internet for a global collective good. The success was a social triumph as much as it was technological, but the fact that it was both left long-lasting impression on the possibilities for a similar integration, organization and innovation of science and technology (Zelenika and Pearce, 2011).

Raymond explains that a key premise behind open source success has always been to "help one's neighbor" and provide an alternative to proprietary software and copyright laws that infringe on users natural right to copy in order to innovate (DiBona et al., 1999, p. 54). Copyright and patent law intends to reward and protect the inventor against unlawful exploitation, thereby spurring further innovation due to reward system of intellectual property (IP). However, given the exclusive monopoly of IP licenses, the owner of the patent or copyrighted property has the monopoly right to withhold the access and use of the intellectual creation from anyone else but the owner, thereby limiting knowledge sharing and the innovation process (Merges and Nelson, 1990; Hemphill, 2005). With IP, the profit motive is a strong incentive to disseminate the "asset" by collecting royalty fees or monetary compensation from the licensee (Hemphill, 2005), all the while maintaining the monopoly. Current IP law therefore enables opportunistic monopolies and forces the "re-invention of the wheel" in both software and hardware contexts instead of enabling innovators to build on the existing technology improving designs to maximizing efficiency as well as innovation capacity.

The open source and free software movements recognized the danger IP law posed to development and accessibility of software and web applications and set out to establish an alternative licensing system to promotes innovation and development while granting the creator authorship rights. Currently there are a number of Copy Left, GNU General Public Licenses and Creative Commons Licenses with a multitude of licensing options that protect the creator's innovation while allowing for others to access, copy, modify and improve designs as long as they license it under the same degree of openness. This open and collaborative principle of licensing are easily transferred to hardware designs to propagate appropriate technological innovation for sustainable development. Some successful open source hardware examples include the Arduino[v] electronic prototyping platform, DIY book scanners[vi], as well as the RepRap[vii] – the self replicating 3D printer (Pearce et al., 2010). The open collaborative approach can have profound changes for development of life-saving technologies and hardware world-wide, especially for the 4 billion people living in dire poverty. The premise behind OSAT design is to tap into the global collective potential and design in the same open source method as OS software to speed up development process, exchange of information and help scale innovation (Pearce and Mushtaq 2009). The philosophical principles behind open source software are very similar to Schumacher's principles of designing affordable and flexible technologies for development, working in synergy and partnerships, supporting sustainability, celebrating human creativity, facilitating innovation and independence (Schumacher, 1973,

p. 40 - 65).

Crowd-sourcing and Online Collaboration for OSAT

Apart from open source software success, the most illustrative examples of the collaborative innovation potential via the Internet and public engagement are projects employing distributed computing to utilize the collective power of millions of eyes, hands and brains – also known as 'crowd-sourcing'. As people come online to learn, share, socialize and change the world, they are also gradually recognizing and taking up the ability to add content rather than be passive receivers of information. Some of the best examples of online crowd-sourcing are UC Berkley's Open Infrastructure for Network Computing (BOINC), NASA's Galaxy Zoo and Mars mapping projects, as well as the Open Street Map.

BOINC is a non-commercial middleware system for volunteer and grid computing. Individuals throughout the world have the opportunity to donate their unused computer's power (or idle time) to BOINC and as such help create the Earth’s most powerful supercomputer with a capacity for 5.428 PetaFlops [viii](BOINC Stats, 2010). BOINC's supercomputing projects include a wide range of themes such as Astronomy, Biology, Physics, Computing, Software testing, Climate as well as Humanitarian research on disease, natural disasters and hunger (BOINC Projects, 2011).

In a similar way NASA Clickworkers project showcased the benefits of crowd-sourcing and the increased efficiency through collaborative engagement in task solving. The Mars mapping project consisted of identifying and classifying the age of Mars craters, however when the project experienced shortage of funding, the project was was re-designed into modular tasks and opened to the public for participation. More than 85,000 users visited the site in the first six months making contributing to more than 1.9 million entries. Quality analysis tests showed that volunteer click-workers did as good of a job with equal accuracy as highly trained geologist on full-time salaries (Benkler, 2006. p. 69). Given the success of the Mars mapping, the Galaxy Zoo project was launched in 2007, which also relies on volunteer power of click-workers to classify over sixty million galaxies (Galaxy Zoo, 2011).

Another collaborative online networking example showcasing social humanitarian impact is the Open Street Map project during the Haiti earthquake. Prior to the earthquake of 2010, the mapping of Port au Prince was very poor – it consisted of only several crudely defined streets and no landmarks or buildings (Berners-Lee, 2010). When the earthquake hit, a commercial satellite company called GeoEye gathered 3,000 square kilometers of high resolution digital satellite imagery of Port au Prince and released it to the Open Street Map to be used for map building. Within days, over 2000 users started piecing the images and adding layers of content to the map, including roads, landmarks, and most importantly refuge relief spots and hospitals as seen in Figure 2. In a matter of days the OpenStreetMap of Port au Prince became the go-to map for relief workers and agencies as its accuracy and comprehensive detail was unprecedented (Berners-Lee, 2010). What makes the project all the more noteworthy is the speed by which volunteers completed the map - typically it would have taken months for that much data to be assembled under normal circumstances, not days.

Just as UC Berkeley’s distributed computing projects tapped into the unused processing power of millions of individual computers, distributed labor networks are using the Internet to exploit the spare processing power of millions of human brains (Howe, 2006). The same crowd-sourcing and open collaborative approach can be applied to developing sustainable and affordable technologies for development. Given the opportunities for poverty reducing strategies, communications, education and a diffusion of life-changing technologies, many organizations and researchers are already incorporating Internet platforms and collaborative approaches to their development processes. Open educational tools like the Wikipedia, Project Gutenberg, Open Journal Systems (OJS), the Human Genome Project, Open Energy Information and Scientific Commons are examples of collaborative knowledge sharing taking place online.

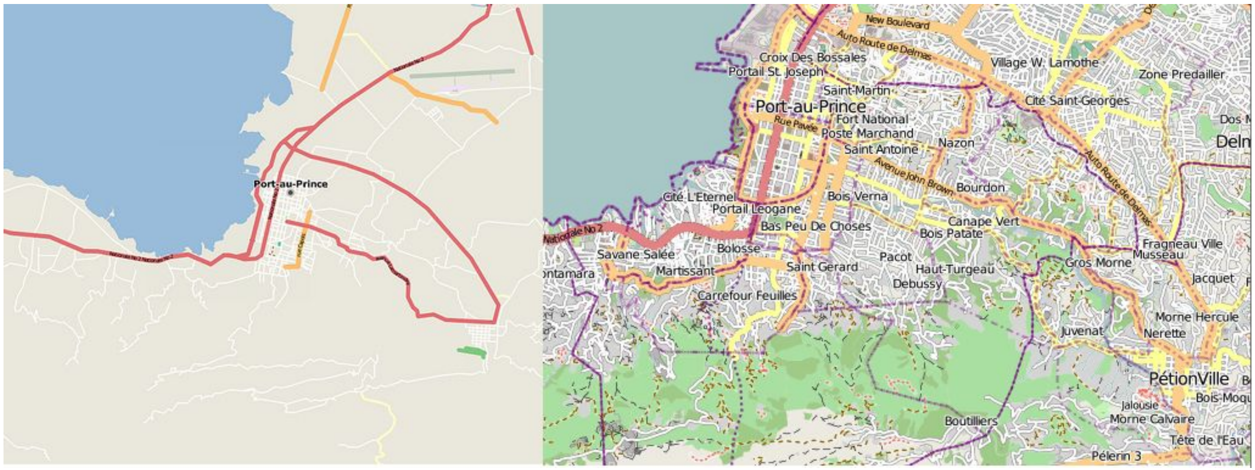

Fig. 2. Map of Port-au-Prince, Haiti before the earthquake and after. In a period of days over 2000 users helped build the most complete Port au Prince map that became the go-to map for relief workers and aid agencies.[ix]

In the field of AT for development there are also online wikis, forums and websites operating on the knowledge commons approach to solving the world's development problems and many are building searchable databases, interactive portals and linking technology seekers with providers and donors. Organizations such as Appropedia, Catalytic Communities, Engineering for Change, Full Belly Project, Global Giving, Kiva, Kopernik, Open Sustainability Network, Practical Action, Science for Humanity and Village Earth are among the most active examples. In the same manner, individuals, communities, and organizations are making strides in developing open source and creative commons AT such as water purification systems (Hashmi and Pearce, 2011), charcoal manufacturing (MIT D-Lab, 2011), solar refrigeration, treadle pumps (Appropriate Technology Collaborative, 2011) and shelter (Hexayurt, 2012). Appropedia.org, the largest online AT wiki, focuses on sustainable development and poverty reduction using a collaborative approach. In a typical wiki manner, Appropedia is an open platform for stakeholders to come together to create, find and improve scalable and adaptable solutions to AT via designs, schematics, how-to and illustration about sustainable development . The data is published under the Creative Commons Attribution-Share Alike license (CC-BY-SA)[x], which allows anyone to use the content and copy designs as long as they share derived innovations in the same way and acknowledge the author of the original work.

However, like the AT movement itself, the OSAT online collaboration is presently lacking critical mass and a higher level of engagement on all levels is necessary. For example on April 13th, 2012, Appropedia only had 9,152 registered users and 34,754 pages (Appropedia Stats, 2012), compared with Wikipedia which had 16,612,410 registered users and 26,900,032 wiki pages (Wikipedia Stats, 2012). Furthermore, in 2000 graduate students at MIT recognized the benefits of ongoing peer-review community-based design leading to a more rapid and innovative design iteration and created an open source web based collaborative site called ThinkCycle (Sawnhey et al., 2002) that is now unavailable due to lack of critical mass. A decade after ThinkCycle was first proposed, the Internet is much more widespread. With millions of people online, connected at any point in time, and with better tools, applications and databases to build, share and exchange knowledge, the potential is clearly much better for an OSAT revolution. In addition, today's web users are not only more tech savvy, but as Watson explains, newer generations have never known life without the Internet, and they are developing affinity to the world wide web of connections, and finding a multitude of applications that are changing the world (Watson, 2009). Watson also notes that "This new technology and the human urge to communicate is creating the basis for the golden age of activism and involvement, increasing the reach of philanthropy and improving the openness of our major social institutions" (Watson, 2009). Yochai Benkler agrees and adds that the intrinsic human desire for acquiring and sharing knowledge with the Internet as a platform, is a key driver in making it easier and faster for people to participate in the online peer-to-peer (P2P) social exchange (2006). Because information, knowledge and culture are central to human freedom and development, the change brought on by the networked information environment hold a lot of promise "first as a dimension of individual freedom, as a platform for better democratic participation, and in an increasingly information dependent global economy, as a mechanism to achieve improvements in human development everywhere" (Benkler, 2006).

The Role of Universities in OSAT

Global databases and websites contain only a fraction of the available content on AT. Furthermore, as pointed out by many of the respondents the information is scattered, and at times hard to search, categorize and build upon. The groundwork laid out by Appropedia, Practical Action, CatCom, Appropriate Technology Collaborative, and others is being supplemented by new organizations and applications such as Engineering For Change and Kopernik to facilitate collective collaboration. The contribution of Colleges, Universities, academic researchers and students, which has historically been at the forefront of OSAT development, can still help expedite development and growth of the OSAT systems. World development problems and AT designs contain both social and technical elements and can with careful pedagogical design be fit within class curriculum, providing students with the valuable hands-on experience while helping solve global challenges.

University projects can be highly engaging and motivational for students when development and applied components are integrated within the curriculum. Most of all, such a 'community service learning' approach represents a vast, and still largely untapped, resource for accelerating sustainable development, while enhancing course-based learning (Bringle and Hatcher, 1996; Panini and Lasky, 2002; Pearce, 2007a; Pearce, 2009). As Bridges and Wilhelm suggest: "Through education, we can inform our students about the global predicament and help them gain knowledge and skills they need to act as sustainability advocates within organizations at which they will one day be employed." (Bridges and Wilhelm, 2008, p.33). Benefits and characteristics of service-learning programs involve students developing academic skills, sense of civic responsibility and commitment to community while working on challenges that addresses local needs" (Campus Compact, 2000 p. 17). Hands-on service learning courses also help build knowledge systems on crucial components of development, sustainability and innovation while doing research with real world implications and enhancing the curriculum. For example service learning within engineering has a long history of enhancing traditional curriculum while teaching sustainable design principles (Logan, 1980; Vader, et al., 1999; Vaz, 2005; Bryden, et al., 2002; Green, et al., 2004), and has also led to development of such instrumental organizations as Engineers Without Borders U.S.A., Canada and Australia. This approach can not only enhance and contribute to global development, but also help resolve some of the obstacles in AT development, including design, testing, dissemination as well as the online collaboration. Applying principles of service learning to sustainable development offers an enormous opportunity for both science and engineering programs at educational institutions (Logan, 1980; Pearce, 2007a), as well as for problem solving whenever help is needed, such as in developing communities (Pearce et al., 2012). This allows those with problems to take advantage of free services brought on by the university research and development, while harnessing the advantages brought on by service learning enhancing student learning, retention, motivation as well as hands-on practical experience (Cohen and Kinsey, 1994; Giles and Eyler, 1994; Pearce, 2001; Pearce, 2007a; 2007b).

Students can work on, research and solve real-world problems while fulfilling curriculum requirements.

There are many successful programs offering projects for communities overseas: MIT, Caltech, Brown, Colorado University and the Michigan Tech all feature courses dedicated toward developing sustainable AT within a context of engineering or science curricula (Pearce, 2009, Zelenika and Pearce, 2011). Many of the previously-mentioned examples of AT solutions have been designed in whole or in part through service learning and student engagement. While the field of service learning is growing, it is still not a standard practice (Bielefeldt, et al., 2005; Sandekian, et al., 2005), and there is a significant opportunity to leverage service learning at educational institutions to meet their curriculum needs while educating future generations about sustainability (Pearce et al., 2012). Similarly, open source collaborative learning can produce many benefits by sharing design knowledge and allowing an open evolution of ideas based on public peer-review and contributions from diverse participants (Sawnhey et al. 2002; Pearce et al., 2012). The Appropedia Foundation recognizes and encourages student and classroom engagement hosting a portal dedicated to service learning[xi], and is thus acting as a platform for a virtual version of service learning in engineering for development as well as in language education for translating the pages (Pearce, 2009; ter Horst and Pearce, 2010). Appropedia features includes a list of past and current AT projects and classes as well as a blog and tools for teachers and students. Applied collaborative service learning for sustainable development can enable students to take part in solving real-world challenges, learn the necessary social and technical skills of demand-led innovation, and most importantly see themselves as participants and become life-long contributors to OSAT. As their work can contribute to solving real-world challenges, it can also entrench the "can do" attitude of active participation that is often the main ingredient for action and change in the future (Pearce, 2009; Branker et al., 2010; Corbett et al., 2010; Zelenika and Pearce, 2011). Furthermore, online collaboration via various web channels can teach skills such as coding in the wiki markup language and editing. Appropedia hopes to expand this service leaning aspect by involving new schools and partners, as well as incorporating funding.

As Raymond once wrote "Given enough eyeballs all (computer) bugs are shallow" (1999), meaning, the more eyes collaborating the larger the potential for identifying and solving problems. Collective power of many hands, eyes and brains working together throughout the world wide web can develop and provide solutions against extreme poverty, provide food and water security and speed up innovation on a scale never seen before. Various individuals and organizations in the field of AT are moving to tap into this potential, but as true critical mass and the concomitant rewards are yet to be reaped, a higher engagement of various contributors is needed. Significant contribution to solving global sustainability and development challenges can be achieved with a much greater involvement of post-secondary institutions providing an infinite amount of the classroom laboratory research. Given the urgency of global development challenges and the minimal requirements for much of the AT research and development, the potential of service learning in all departments is substantial. Furthermore, with the help of ICTs and open collaborative networking opportunities, there is an even larger capacity to cut research costs, improve designs, instill social responsibility and most importantly build knowledge for all.

Discussion

Barriers to AT include social and technical components to technological design and dissemination, as well as better collaboration and exchange of information. Open source collaborative innovation via Internet platforms can be of significant help, but this approach is not without obstacles as well. Given the novelty of open source and open access licenses (OS/OA), there is a trust barrier associated with the adaptation and propagation of OS/OA, as was documented in the interviews with AT researchers. This obstacle can be overcome with a successful tutorial and a quick demonstration of licensing alternatives and examples in use. This social barrier is connected with a mind-shift to explore different licensing options and make the switch toward the one that promotes equality and collaboration. Future work is needed to examine best practices to engage collaborative participation, spur development of websites, tools and platforms to organize content, maintain productivity, and make sure the technologies involve and reaches those for whom the innovation is intended.

While there may not be a single ready-made recipe for making a successful wiki or a collaborative website, there are guidelines, functions and criteria to enable the collaborative online design and ensure growth and prosperity of the project. Raymond cites three crucial ingredients for a successful open source collaborative project: a) clear idea or a defined as set of goals; b) management coordination, and c) a tool as good as Internet (1999). As discussed in the AT barriers section, the definition, scope and implications of the AT do present a significant barrier because of the ambiguity of what is considered 'appropriate'. In addition while there are many organizations working in the field of sustainable development and AT, goals and the approach to development can vary and be a dividing factor. On the other hand, global calamities such as climate change and resource scarcity can be a rallying cause for a more unified consensus and a clear set of goals to be achieved, such as the Millennium Development Goals.

Although a tool as versatile as the Internet is available, however merely supplying ICT is not a solution (Ashraf, et al., 2007). Arunachalam points out that the majority of ICT projects flooding the developing world are doing so in an irresponsible manner and for the primary benefit of hardware and software companies (2002). He, like many others calls for a more "people-centered" approach so the technology contributes toward a participative developmental methodology (Arunachalam, 2002). In addition, one has to be aware of the limitations with Internet access and availability in all areas of the world, especially for those for whom the development is intended (Buitenhuis et al., 2010). Language can also be a significant barrier especially given many languages and dialects throughout the world, and even more so rural areas of Africa, South America and Asia (ter Horst and Pearce, 2010). This barrier can be solved through multilingual databases enabled by applications such as universal translators, or ensuring that content is presented with a diverse array of multi-media such as drawings, diagrams or videos that do not require too many words.

ICTs are merely tools, and social components such as the user-driven content, participation and the functionality are the defining foci for the success of the collaborative structure. The nature of many of the AT barriers indicated that too much emphasis is placed on technology and not on the "software" or the know-how and social elements of which technology is part. Social barriers to OSAT have been identified as the most predominant, because culture, beliefs and approaches to development vary widely throughout the world. This is why community driven participation and demand-led innovation must be the underlying component of OSAT development to ensure that as many stakeholders as possible are involved in the dialogue process and have the access as well as the ability to be active participants. The success of any project or enterprise depends on deep engagement of the participants (Watson, 2009), of which the sense of ownership is a crucial component.

Project continuity can also be an obstacle, especially when OSAT development is accomplished in a classroom setting where changes in tenure, curriculum and student involvement can be significant. This was one of the key barriers for the eventual disintegration of ThinkCycle. However, there are risks of continuity outside of an educational setting as well. For example, even in the case of Wikipedia - the best and biggest example of a collaborative wiki, statistics trends indicate a gradual decline in new and active editors (Wikimedia Editor Trends, 2011). Given that Wikipedia's content is growing more complete each day, the workload has decreased tremendously and therefore there may simply be no need for as many editors as in the early stages. However, the culture that has developed in the Wikipedia community is now much less open to encouraging new contributors and threatens the projects continued success.

Fortunately, the content, mirrored on many sites throughout the Internet, remains available for others to access and build on, leaving room for future generations of Wiki editors to do their part. The same wiki or database approach can work for OSAT development, because while there may be changes in the role or involvement of particular organizations or researchers, the work is not lost as it has been historically.

An OSAT database or an online platform should be designed to allow for fragmented collaboration that matches an array of participant skills, expertise and time commitments. Furthermore, the structure cannot be too rigid and in the best case scenario should be based on an open principle where the collaborators are given the power to expand features and add applications as needed. This is the principle recently adapted at Engineering for Change[xii] established by the American Society of Mechanical Engineers. The design of the databases and the approach needs to be dynamic, multidimensional and open to allow for a wide and diverse group of contributors as well as benefactors. Another area of future work is improvements in the syncing of information from various databases and websites already in existence. As information on AT continues to grow, whether there becomes a single repository for the content or not, there will be an issue of confederating data or linking websites to yield more efficient searches, thus making it easier to acquire and share knowledge and designs.

Individual Action

The discussion covered the systems level changes necessary to overcome barriers to more widespread OSAT adoption, but for those interested in participating on individual level, less substantial and less broad efforts are still needed. Individuals can begin to develop OSAT in their specific areas of interest or specialty. The contribution will be dependent on the individuals level of specialization. For highly specialized individuals, like scientists who often develop their own scientific hardware, they can contribute these plans the public domain using free and open-source methodologies to provide low-cost, customizable scientific tools for research and education (Pearce, 2012b; Gildea & Milburn, 2013; Zhang, et al., 2013; Pearce, 2014). For example, Zhang, et al., present an open-source optics library that enables schools to use low-cost RepRap 3-D printers to print $15,000 worth of physics labs for $500, thus improving access to education (2013). Scientists can be incentivised to take this extra step of sharing their designs, because the open source community will provide feedback and potential improvements to the design for free. Those individuals that consider themselves 'makers' can assist by experimenting on technologies specifically meant to assist development such as low-cost farming tools being developed by Open Source Ecology. Individuals with more money than time can directly support OSAT non-profit groups or help finance OSAT projects directly on crowd funding sites like Kickstarter and Indiegogo. Individuals that use an OSAT for themselves in their hobbies can also make concrete contributions. For example, gardeners that use such OSAT as drip irrigation for their gardens can add reviews, helpful hints, or design improvements to centralized sites like Appropedia, Catalytic Communities, Engineering for Change, Full Belly Project, Global Giving, Kiva, Kopernik, Open Sustainability Network, Practical Action, Science for Humanity and Village Earth. Even individuals with no technical expertise or experience can help by improving wikis like Appropedia by copy editing, adding hyperlinks, importing out of print information, helping document the good work of others or translating popular articles into other languages. Again, each small contribution has an additive effect as the global OSAT community incrementally improves to provide rich sustainable lives for everyone.

Conclusions

Given the urgency and magnitude of development challenges amidst resource and climate difficulties, new partnerships and alternatives within the field of sustainable development are needed. A number of barriers to appropriate technology diffusion can be solved by a greater inclusion of open source collaborative innovation via Internet platforms. With a better collection, transmission and exchange of life-saving data, and with a greater emphasis on collaborative crowd-sourcing and networking, organizations working in the field of AT development can increase their efficiency and effectiveness for global collective good. Service learning projects in higher education, as well as greater crowd-sourcing can help eradicate some of the problems of content building and engagement via the world wide web. Collective power of many hands, eyes and brains working together throughout the world wide web has a tremendous potential to develop and provide technologies and systems to eradicate extreme poverty, provide food and water security, and speed up innovation of and dissemination of open source appropriate technologies.

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[v] Arduino http://www.arduino.cc/
[vi] DIY Book Scanners http://www.diybookscanner.org/
[vii] RepRap http://reprap.org/
[viii] A flop is the floating point operation speed of a processor. A typical computer runs at about 7 GigaFlops. One PetaFlop is 10^{15} Flops.
[ix] Left: Kelso's Corner, (2010). http://kelsocartography.com/blog/?tag=port-au-prince; and Right: OpenStreetMap.org, (Accessed August 10th, 2011)
[x] http://creativecommons.org/licenses/by-sa/3.0/
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