INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'09
24 - 27 AUGUST 2009, STANFORD UNIVERSITY, STANFORD, CA, USA

TOWARDS OPEN DESIGN: THE EMERGENT FACE OF ENGINEERING

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ABSTRACT
In today's society, collaboration between individuals and groups thousands of miles away has become increasingly common place. Due primarily to the rapid growth of broadband internet, cheap data storage and fast microchip technology, a new frontier has been opened where engineers and scientists can quickly and efficiently share large amounts of information with colleagues all across the globe. The implications of this technology have been and continue to become increasingly influential on the evolution of not just the sciences, but humanity as a whole. This paper will survey current successes that have been seen in open source software development and the emergent 'open design' realm. From here, parallels are drawn between the two disciplines to illustrate how engineering organizations can benefit from the highly distributed nature that open source software has implemented. In this light, this paper will establish the position that engineering design must make the shift towards a more open and collaborative environment to stay relevant and prosper in the Information Age. Additionally, a basic web framework detailing the technologies needed to see such a shift occur will be outlined. Currently, there is some research being done in this area, but overall the possibilities for growth and innovation are significant.

Keywords: commons based peer production, open source software design, open design, open source hardware, collaborative engineering design, concurrent engineering

1 INTRODUCTION
In today's society, collaboration between individuals and groups thousands of miles away has increasingly become common-place. Due primarily to the rapid growth of broadband internet, cheap data storage and fast microchip technology, a new frontier has been opened where individuals can quickly and efficiently share large amounts of information with others all across the globe. The implications of this technology have been and continue to become increasingly influential on the evolution of how our society produces knowledge and creates innovation [1,2].

Because of these technologies, the upswing in open, collaborative internet projects continues to rise. Two prime examples are Wikipedia, an open encyclopedia, and Linux, an open source operating system. Wikipedia's goal to create a central encyclopedia editable by anyone has found huge success worldwide. Linux, on the other hand, was developed by individuals scattered across primarily Europe and North America and has become the backbone of the internet today. Both projects have been hugely successful, with social contributions that are literally changing society as we know it [3]. While these and similar projects have found success in the software and information worlds, engineering design seems to be one realm that has largely been left in the dust [4]. While it is true that design has benefited greatly from technological advances such as email and desktop design tools, there is still much to be achieved to reach the type of functionality other internet-based environments have to offer [5].

This lack in open innovation may be attributed to the fact that design is generally looked at as a physical good. Software, on the other hand, is a comparatively high-level, abstract product consisting at its core of binary data. In today's age however, design is generally done using programs such as AutoCAD and Solidworks, programs whose output is also ones and zeroes. This is an important realization that should help free engineering design of the archaic constraints of the physical world, and should be quickly progressing towards more advanced methods of sharing and collaboration [3,6].

So why is it that engineering design has not utilized the full potential of the internet? Why are robust collaboration tools openly available to the programmer, but not to the designer? What tools would a designer actually be interested in utilizing? How will issues related to copyright and proprietary data be handled? Do the needs and interests of academia, industry and the engineer converge at any one point?

There are many questions that arise when looking at the issue of collaborative internet-based engineering design. The above questions are just a handful of topics that are being tackled by engineers in academia and industry on a daily basis around the world. These issues will continue to become more complex as the engineering sector becomes more interwoven.

This paper will survey current successes that have been seen in open source software development and the emergent ‘open design’ realm. From here, parallels are drawn between the two disciplines to see how engineering design could benefit from the highly distributed nature that open source software has implemented. In this light, this paper will establish the position that engineering design must shift towards a more open and collaborative environment to stay relevant and prosper in the Information Age. Additionally, a basic web framework detailing the technologies needed to see such a shift occur will be outlined. Currently, there is some research being done in this area, but overall the possibilities for growth and innovation are quite significant.

2 EXPLORING OPEN SYSTEMS

Over the last couple decades, the wide adoption of the internet has allowed for a fundamental transformation in how humans organize that is quickly permeating every aspect of the human social structure [7]. The following sections will survey specifically how economic production has changed and draw important parallels with the open source software movement.

2.1 Commons-Based Peer Production

In the past couple centuries there have been two main modes of economic production occurring in the United States, these being firm production and market-based production. Firm production, as the name implies, is centered around a hierarchical organization, or firm, where the centralized decision-making process is run by supervisors who choose what the subordinates must produce [8]. Examples would include Microsoft producing the Vista operating system or Boeing creating the 787. Market-based production on the other hand works by placing prices on certain jobs, which in turn act as a way to attract individuals to those positions [2]. Paying entry-level engineers high wages to entice students to enter that field of study would be one familiar example. These two models often work hand-in-hand.

With the emergence of nearly ubiquitous internet and affordable computing power, a third mode of economic production has emerged known as “commons-based peer production”. This term, coined by Yochai Benkler, refers to a new paradigm that is distinctly different from the firm or the market. Commons-based peer production, or simply CBPP, is a system that draws from the knowledge and innovation of often geographically dispersed individuals to work on large, complex projects. These projects are generally internet-based, have little hierarchical organization and often no financial compensation [2,9].

The most visible form of CBPP is the open source software movement, or simply open source. Open source has proven to be hugely successful at developing complex and robust software packages through the contributions of volunteers all over the world. Some prominent examples include Apache web server, Linux OS and the Firefox internet browser [3]. The following section will go more in depth into the open source development method and look at why and how it has been successful.

2.2 Open Source Software Development

The open source design methodology has grown from an idea that was somewhat undefined to what many consider a paradigm shift that is threatening the closed systems that have existed for decades. As Eric Raymonds so puts it, “the open source model of operation and decision making allows concurrent input of different agendas, approaches and priorities, and differs from the more closed, centralized models of development [10].” This mode of design is in contrast to the more established institutional methods that were mentioned earlier.

An ‘open source design methodology’ is a relatively unstructured way of developing software packages or products. Simply put, open source software development is a process in which the source code is made available through the Internet and its modification, use and distribution is promoted as essential to the success of the product [11].

Similar to concurrent engineering, the design and implementation is performed in a highly parallel fashion [12] by individuals that may or may not be geographically dispersed. However, there are stark differences to more orthodox methods of economic production. Specifically, those involved are not directly compensated monetarily [13]. Contributors may join and leave whenever they feel like, and have no repercussions for such actions [3]. The source code, or the inner workings of the software, is then distributed openly with the final software product [13], from which others may start separate projects based off the code, also known as ‘forking’. Forking is a somewhat rare occurrence, but has happened several times in more popular programs like Linux and Wiki software [3]. Openness has allowed for a more diverse dialogue to evolve around these projects, and is one of the keys to open source’s success.

Another way to visualize the design process is to use the analogy of the Cathedral and the Bazaar [10]. This model put forth by Eric Raymond has been used extensively to describe how open source design works. The Cathedral represents the firm, a highly organized, closed and hierarchical institution that has the task of producing a product such as software or airplanes. In modern terms, the Cathedral can be likened to corporations such as Microsoft or Boeing. The Bazaar on the other hand represents an organizational structure that is relatively flat and open where contributors have equal say and representation [10]. The visualization of a bazaar as a bustling area where people are presenting their ideas and agendas gives a good idea of how open source works [13]. These descriptions infer a general idea of why each system has had its successes and failures.

Part of the genius of open source is that large, complex projects such as Linux OS or Apache web server can be divided up into smaller tasks that a large group of volunteers can work on. By leveraging this large group, the amount of brainpower that is utilized is literally unmatched in the corporate setting [14]. Of course, there must be a well-defined review process to ensure that quality work is being submitted as well as to avoid the possibility of the code ‘forking’ [15]. Apache’s success in using this method can be seen in the graph below which depicts web server market share from August 1995 to November 2008. Specifically, Microsoft versus Apache clearly shows the ability of the open source development methodology to compete against well established corporations [16].

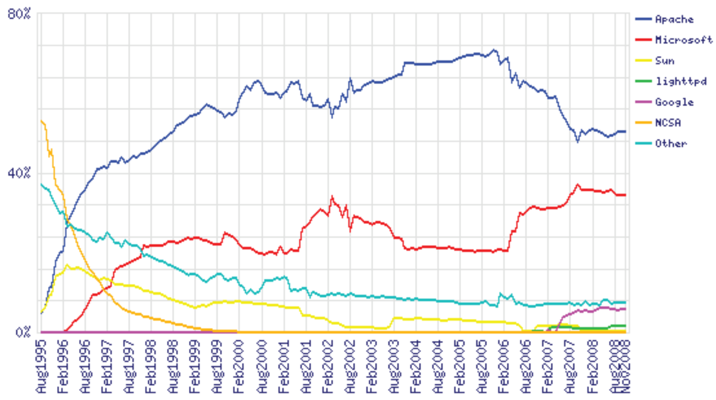

Figure 1. Market Share for Top Servers Across All Domains August 1995 - November 2008 [16]

Similarly, the large group of volunteers allows for the application of Linus's Law, which states: "Given enough eyeballs, all bugs are shallow." [10] What this means is that by leveraging this large network of contributors, any problems in the source code or design can be found and fixed. In the realm of software development, debugging can be a tedious job, especially when dealing with millions of lines of code. By creating an asymmetrical, distributed network, this task is significantly reduced due to the parallel nature of the work [13]. The same idea has been applied by Wikipedia, where information is reviewed and debated by users all over the world, hence creating a robust information database that is unrivaled in recent times.

Similarly, Charles Leadbeater points out that previous organizational models rely heavily on the idea that experts must be assembled in institutions to create products or innovation [17]. Example institutions include Microsoft, Stanford University or the NASA Jet Propulsion Laboratory. The idea of open source flips this idea on its head, and relies not on an institution but rather a community of developers and contributors to create innovation motivated by things such as utility, pride and enjoyment. To many, this may seem perplexing, but makes perfect sense when looking back into history at how people organized around community needs or issues [9]. However, it should be noted that many large corporations, notably IBM and Sun Microsystems, are starting to contribute to the open source movement as a way of tapping into the huge resources the open source method provides [13].

In summary, open source software development is a development framework that is very different from the more established design methods. At its core, open source software development is an egalitarian, internet-based design process that looks to give each individual freedom over what they work on and how they approach design problems. The philosophy behind this process is important to its success and presents a problem to the more established methods that have dominated organizations and institutions for decades. Because of open source's success, the next step seems to point towards broadening the methods used here into other fields, specifically engineering design. Is it possible to accomplish the same complex system design that open source has in the physical realm? The following section will look at the current work being done in what is now being called 'open design' and what sorts of success and failures have been met in its relatively new existence.

3 OPEN, DISTRIBUTED, COLLABORATIVE DESIGN

The concept of open design can trace its roots back to 1998 and Dr. Sepehr Kiani who at the time was finishing his doctorate in mechanical design at MIT [18]. Kiani realized that design could benefit from the ideas currently being pushed by the open source movement. From here, he was able to convince others of the idea, notably Dr. Samir Nayfh and Dr. Ryan Vallance, colleagues studying machine design. But what is the open design method and how does it differ from more traditional methods?

3.1 Closed vs. Open Design

To better understand how open design works, it is best to compare this relatively new approach with more traditional, closed approaches to see how these organizations can utilize it for their benefit. In reality, open design is not as much a methodology, but for established institutions, it becomes an organizational restructuring that creates dialogue with an online community which has become privy to design and product information. The online community gives input in regards to the design, acting as a virtual research and development team [19].

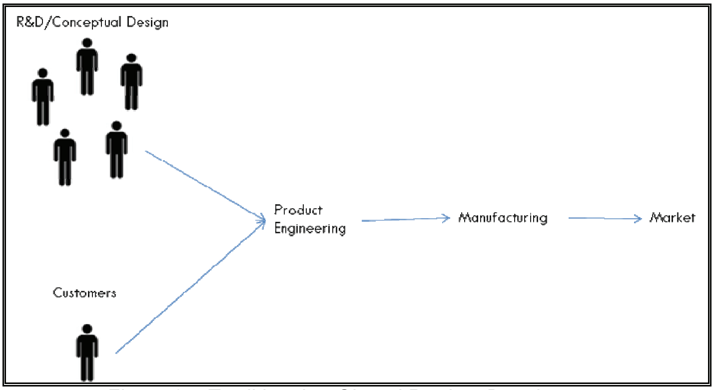

Figure 2 – Traditional or Closed Product Development

Figure 2 shows the basic flow of product development in traditional or closed engineering organizations [20]. Designs are created in-house, and any related information is generally kept proprietary due to fears of competition and intellectual property issues. However, this model is quickly becoming outdated in an economy where the cost to duplicate such information has become negligible and the importance of collaboration is key to the success of any firm [21]. Additionally, the ability of engineers to quickly reverse engineer a product to gain a competitive edge has become common practice [22]. What this paradigm shift in information production allows for is the creation of an altered product development flow chart that is depicted below in Figure 3.

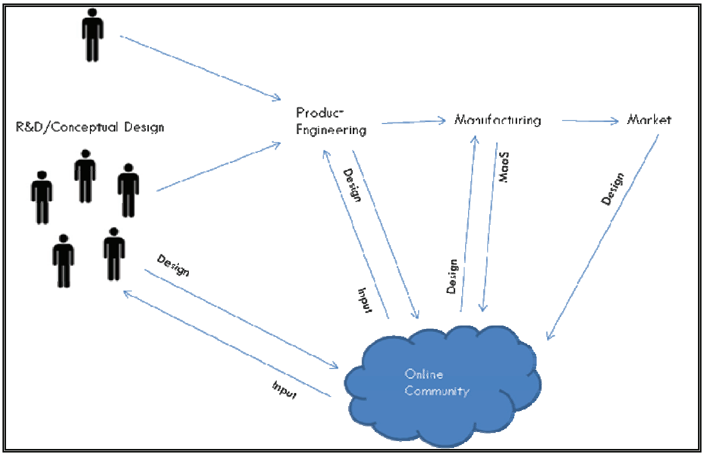

Figure 3 – Open Design Product Development

Essentially what occurs in this new approach is that the internet blurs the line between consumer and developer by allowing consumers to be involved in the development process by making suggestions or leaving feedback on an ‘open’ project, creating a virtual research and development team that costs little and is theoretically infinite [19]. By implementing such strategies, organizations can drastically reduce costs and increase innovation. Such open development is currently being performed by industry giants like IBM, and has been a staple of the open source software community for the last couple of decades [21]. Products such as Linux, Apache and Firefox are prime examples of this method at work. Of course, each organization will have to decide for themselves if an ‘open’ approach is right for their business model.

It should be noted that the research and development process can start within the online community also, and often does. The above illustration is meant more to display how established organizations can utilize the new methods for their own advantage. The importance of designs coming from the online community will continue to rise, similar to how open source software has created products that often outperform their proprietary counterparts [16].

For contributing and giving input on the design, the online community in return gets access to the design information. With this information, the community is free to do what they please with it, including fabricating it themselves. This is the point that many would worry that there is no room to turn a profit for the manufacturer, but this is untrue. The common person is not going to have the equipment to manufacture such a machine, and will have to turn to either the organization that originated the design or an outside entity for help in this realm [19].

Many groups have already started working to fill this void, performing what is termed 'Manufacturing as a Service', or MaaS [23,24]. These are community based manufacturing shops that allow members to utilize highly specialized equipment to develop or build their projects [25]. What this allows is for the common person to bypass the large corporations or manufacturing facilities to create what they need. Of course, not everything can be created in such small facilities and the real threat to established manufacturing is minimal at this time. However, it is a shift that industry should take note of as it is quickly growing in popularity.

3.2 Current State of Open Design

In the open source community, SourceForge.net, freshmeat.net and GitHub.com have become renowned as project and design repositories where collaborators can upload and share code they are developing, as well as recruit collaborators to work on their respective projects. Because of this, the open source movement has been extremely successful in terms of collaboration. However, in open design, there are few websites that are working towards emulating SourceForge [26], and none that have the robust features that SourceForge demonstrates [27].

Examples of current sites utilizing the open design framework include OpenFarmTech.org, a research group that is developing sustainable agricultural technology in northwestern Missouri. Appropedia.org is also developing sustainable technologies, specifically in the appropriate technology realm [4]. Both of these sites are using the wiki format to mediate collaboration between interested parties [28]. While both groups have been successful, there is still much to be desired in terms of using a wiki-style site to collaborate on design projects. The limitations of learning a new markup language, as well as the inability to efficiently and seamlessly upload CAD, FEA and related documents presents a technological barrier that may push many traditional engineers away from collaborating which such groups.

Other project sites that look to have great promise, but still fall short of creating an open design web portal are Akvo.org, a site dealing with water sanitation [29] and Open Innovation Projects, a site that houses general information on open design projects [30].

Similarly, VOICED, or Virtual Organization for Innovation in Conceptual Engineering Design, is a multi-university project that is working specifically on capturing design knowledge in an online repository and allowing those in academia and industry to utilize this information for conceptual design. The project could have significant influence on the ability of local as well as geographically dispersed engineers to create innovative and complex designs not previously thought possible [31]. Currently, there is still much work to be done, but in terms of robustness, VOICED looks to be leading other design sites. Key features unmatched in previously mentioned sites include having a standard lexicon [32,33] that ensures that future engineers will be able to utilize past design information as well as the ability to model the design functionally and analyze where future problems may occur [34].

3.3 Open Design Web Portal

The key to a successful open design framework is having a robust web portal where engineers can 'meet' to collaborate on projects. Ryan Vallance presented a simple model for how designers could collaborate on projects based on a Client/Server model seen in Figure 2 [35]. Each designer would have access to the Internet Server from which they could 'fetch' and 'submit' CAD, FEA, scripts, documentation and other necessary data to work on the design project. The system would also contain versioning software so past work is archived for future reference [35]. The basic idea is similar to what has been done with SourceForge, but currently there is no reliable implementation of this model in the open design realm. Research and development has commenced for such a site, but work is still in the early development phase.

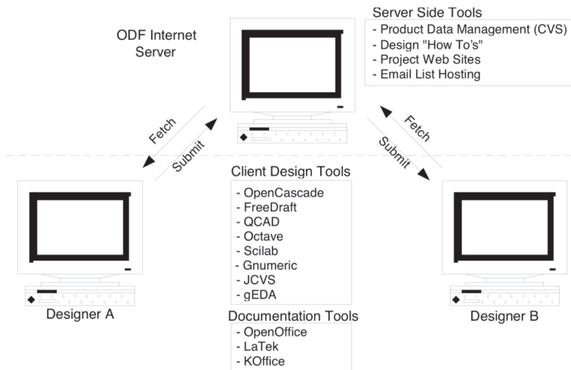

Figure 2. Client/Server side open design collaboration schematic [35]

The basic model presented above is a good start to what must be done in order to create an online open design community, but at this time is somewhat outdated. The key to the success of such a community is that the web portal or central access point must be robust in that all needs of the engineer/designer are taken into consideration. Similarly, the site must be intuitive in that the community is allowed to thrive on its own accord without the interference of the webmaster or site owners [36]. This line of thought is hugely important to the success of web applications in the emergent 'web 2.0' landscape [14,37,38].

In order to accomplish the goal of creating a robust open design web portal, there are six main areas that must be integrated into the web framework. These are:

- Project Overview – main page detailing basic overview of design project
- Documentation & Design Repository – store detailed project information
- Communication – infrastructure for individual and team communication
- User Identification Standard – utilize secure & standard log-in for members
- Funding – link projects to appropriate funding streams
- Licensing – protect the intellectual property of designers

The following sections give a brief explanation of the above features that an 'open design' website must have to allow for unobstructed design collaboration. As part of this research, these features are currently being integrated into a website with the idea being to understand how on open design community can improve the overall design process.

3.3.1 Project Overview

In normal, everyday human interaction, the first impression is the one of the most important determining factors in deciding how one feels about another individual. Web sites are no different in that the first impression is key in whether the user decides to continue using that specific tool [36]. For this reason, the main project page, or project overview page, must be designed so that a user can gather and input the maximum amount of information in a simple and unobtrusive manner.

The project page must contain basic information into the project or product, such as concise project descriptions, tags (searchable keywords or identifiers), institutional information, licenses and other pertinent background knowledge. Also, project news or updates are necessary to allow for quick dissemination of the latest advances on the project. Again creating a lasting impression is integral to whether users continue using a site, and must be kept in mind so as to ensure widespread use of this open design platform [36].

3.3.2 Documentation & Design Repository

Important to any design project, be it software or engineering, is the often overlooked and tedious task of documentation and knowledge transfer. With the introduction of wiki collaboration, this job has become much easier. Wikis are essentially dynamic web pages that allow groups to collaborate on and easily change the page's content. Because of this, documentation collaboration of any type has become nearly effortless, allowing for what used to be a tedious process of emailing text files back and forth to transform into a relatively fluid procedure [39]. For this reason, the open design site will heavily utilize wikis to allow project collaborators to document the ongoing design of their specific project allowing for easy knowledge transfer to future collaborators and end-users.

Similarly, the VOICED design repository will be integrated into the site to allow for a more advanced method of capturing and analyzing the design knowledge of the online projects. By utilizing a functional basis for standardization of the functional modeling information [32], VOICED allows for the creation of a large database of design knowledge. This functional model can then be mapped to heuristic failure data to identify failure possibilities [40,41]. Integrating VOICED into the open design portal is an obvious choice as it will organically grow as more designers join the community and contribute their own designs, products and ideas.

Additionally, there must be the ability to upload traditional engineering files such as CAD or spreadsheets, as desktop programs will still be extremely important even as engineering design moves towards a networked landscape. To handle these files two systems must be utilized to ensure their integrity. The first is a 'Check In/Check Out' system that ensures others working on the project do not upload copies of the same file to avoid the possibility of erasing the others data. By locking the file, or 'checking it out', this can be avoided [42]. Secondly, a version control system (VCS) must be implemented to keep track of the various iterations that a particular file has gone through. This ensures access to past file versions in case problems occur downstream [43,44]. Both systems exist in the open source community in stable forms and are easily implementable.

3.3.3 Communication

In order for any project to be successful, no matter the discipline, communication must occur between all parties. This is especially true when dealing with geographically distributed engineers that may not have the opportunity to meet face-to-face [45]. Because of this, there must be three main forms of communication: group, one-on-one and real time. Group discussion consists of a forum or bulletin board system that allows project members to start topics that can spur discussion around ideas relevant to the project, the goal being to allow the public to add their ideas and possibly solutions to what the team might be struggling with. On the other hand, one-on-one discussion acts identical to email in that it will be private and allow for members to discuss topics not suited for the public. Finally, real time communication using programs such as Skype [46] are important when holding meetings where several members must be present to discuss a certain topic. All these systems have mature iterations available in the open source format and can easily be integrated.

3.3.4 User Identification Standard

As more and more people utilize the internet as a daily work tool, the problem of standardizing login procedures becomes a real issue that web sites must consider. To remedy this problem, an open and distributed user identity standard known as OpenID will be implemented. This standard allows for users to easily move from web site to web site without having to create new usernames and passwords, a process that becomes tedious very quickly [47]. In addition, OpenID has widespread use by internet giants such as Google and Yahoo, as well as many other sites [48]. By implementing this standard user identification, the familiarity that users will experience will increase tremendously, and, as mentioned earlier, allow for increased adoption of the open design web portal.

3.3.5 Funding

As is generally the case when undertaking any sort of major project, funding is an issue. Open design is no different and suffers from this problem on two fronts. The first is on the back-end or server side where the projects would be hosted. Due to the typically large size of engineering files, this will be a major hurdle to cross when creating a robust design repository that is on par with sites operating in the open source realm. This can be remedied by requiring that 'closed' projects pay for the use of the website based on the size of the project and similar criteria.

On the second front, funding will be needed to advance many of the open design ideas from purely conceptual ideas to actual physical products. In reality, this seems like it would be fairly easy, especially if the design has commercial value. In this event, investors and corporations would be able to save tremendous amounts of money by investing in and helping bring to market these open designs as they would be able to avoid the upstream investment in the research [49].

3.3.6 Licensing

Licensing is an area of open design that is in need of more research and development. Currently there exists the Open Design License created by the Open Design Foundation [50]. However, there has been little development of this realm in recent years, and Dr. Kiani, one of the original authors, has expressed a need for more development [27]. The reasoning behind the importance of developing licensing schemes once again draws off the open source movement as well as other creative endeavors such as film and music, in that it allows the intellectual property to be used only for what the author sees fit.

Lawrence Lessig, developer of Creative Commons and leading intellectual on topics related to law and the digital realm, has written extensively on why more open licenses are needed to promote innovation. The most important reason is that by placing a copyright on something, one has essentially placed a stranglehold on others using that knowledge for good use. From a profit standpoint, this can be extremely useful, but from an innovative standpoint it causes problems that often are only solved through expensive lawsuits and litigation [51,49].

By creating a web portal with the aforementioned attributes, a vibrant internet-based design community will thrive. This is based on the premise that by creating an internet community the 'problem' or project is taken to the contributor. This is in stark contrast to creating an institution and bringing the contributor to the problem, which entails many issues such as management problems, instilling structure (economic, legal, physical) and the exclusion of many intelligent individuals [14]. For these reasons, the necessity of building cooperation into the open design web site is key to its success.

4 FUTURE RESEARCH

There are several areas that will need to be looked into to move the ideas of open design forward. The most important of these is to create a robust web portal (detailed above) that can act as a centralized collaboration point for all projects being pursued in a collaborative and distributed fashion. VOICED currently holds the most promise in this realm as it is the only engineering site that currently contains a robust and sophisticated design repository capable of truly giving future engineers access to past design information.

To accomplish this goal, a team of designers and web developers must be assembled to create such a web portal. Currently, a large part of the team is already assembled as part of the VOICED project, and will be responsible for adding the above features to the current VOICED site. Research will need to be commenced on the viability of integrating these technologies into one site, so as to avoid conflicts between competing database structures. Similarly, the site must be designed for growth, an issue that is hugely important when analyzing how other 'open' sites have grown in popularity in relatively short spans of time [52]. Currently, work has commenced on such a site, but is still in early development.

Additionally, the usability of the web portal must be analyzed to ensure that the site architecture is the optimal configuration for the users. In order to evaluate the usefulness, several entities from industry, academia as well as non-traditional engineers and students have been tapped to participate in a focus group. The goal of this experiment will be to seek feedback on the usability of the portal, as well as isolate bugs and other issues that might hinder the user's ability to efficiently collaborate and work with others on pre-defined projects. This experiment will be extremely important in gaining valuable insight into how actual users will be utilizing the resources of the open design portal.

Finally, once the web portal is constructed and stable, its ability to increase productivity and efficiency, enhance communication and spark creativity will be explored to understand the effects the said portal will have on the future of engineering design. While these qualities may be hard to measure, understanding how they have been affected will shed light on where engineering design is headed and what sorts of changes will become standard protocol in the engineering community. This insight will not only look at how industry benefits from the use of more collaborative technologies, but also how the next generation of engineers will become familiar with these changes while they are still learning the basics of engineering design. To evaluate these shifts, undergraduate students at several universities will be introduced to the web portal through their design courses, similar to how the VOICED design repository has been utilized in classrooms. Feedback will be collected on the user experience, usefulness, and other related issues to gain a better understanding of the influence the web portal has had on the overall design experience.

5 CONCLUSIONS

Overall, there are many indicators that point to commons-based peer production being an important paradigm shift in how engineers and designers collaborate on projects. From increasing innovation to rapid development to lowering economic capital needs, the philosophy and process of open design proves to be a concept that will continue to grow [14]. Especially with the successes of open source, it seems inherently obvious the advantages that a more open and collaborative paradigm shift would present in engineering design. While this may seem obvious to academia and its culture of sharing, industry will most likely have reservations [1]. However, if the benefits can be shown and proven, moving all institutions towards a more open organizational structure will have huge benefits for not only industry, but academia and humanity as a whole.

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