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Citizen Engineering: Evolving OSS Practices to Engineering Design and Analysis

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***Abstract*—Open Source Software (OSS) development has much in common with concepts such as crowdsourcing, end-user participation in the design process, citizen science, collective intelligence, human-based computing, and what we call "Citizen Engineering". We report on several pilot projects that apply these shared principles of OSS development to engineering activities beyond those of software engineering. Citizen Engineering (CE) harnesses the human computing power of open communities that commonly consist of a cohort of geographically and/or institutionally scattered citizens - professionals or amateurs - to collaboratively solve real-world problems. From contributors' point of view, the process can be either deliberate or unintended collaborations. In most cases, the problems addressed are challenging to computers, but manageable or trivial for human intelligence. With humans playing major roles in CE projects, whether they are project organizers or problem solvers, the implementation of CE systems is greatly facilitated by the advance of information technology, particularly the Internet, which is a "creative mode of user interactivity, not merely a medium between messages and people." [10] In this paper, we introduce 5 categories that characterize existing crowdsourcing projects first. Then 4 ongoing projects are presented and their impacts discussed, aiming to provide new perspectives and insights for achieving successful CE project designs in future, along with lessons learned and suggestions for future research.**

***Index Terms*—Citizen Engineering, Collective Intelligence, Social Computing, Crowdsourcing, Human Based Computing**

I. Introduction

Open Source Software (OSS) development is often researched for its novel approaches to software engineering. OSS is typically characterized by open processes, distributed and often voluntary participation, and sometimes end user participation in the software engineering processes. Similar open, distributed, possibly voluntary and end user based activities are emerging under various labels such as crowdsourcing, end-user participation in the design process, citizen science, collect intelligence, human-based computing, and what we call Citizen Engineering (CE). Evolving information technologies provide unprecedented opportunities to harness potential contributions average people, i.e., citizens. Two popular examples are Wikipedia and YouTube, where regular citizens can freely contribute and evaluate contents as long as they abide by certain community rules. High speed networks, increasing computational capabilities, and high performance and capacity databases, enable transformative cyber-infrastructures that diminish the barriers among geographically or institutionally dispersed users. People can easily channel their brainpower and cognitive surplus to accomplish meaningful work for a common good, largely in their spare time. Characterizing the existing CE projects, we found there are 5 major categories:

1) ***Crowd Decision***: Exemplified by American Idol, by casting their votes, crowds have the visionary and capacity to percolate up high quality and usually marketable merchandise - due to their already proved popularity.
2) ***Crowd Wisdom***: When a network of participants contribute their time, resources and expertise, if they are well organized, this approach can lead to elaborate artifacts in the end, e.g. Mozilla browser, which could be a satisfactory substitution of proprietary software [7].
3) ***Crowd Byproduct***: Two types of crowd byproducts: *Standalone* and *Piggyback*: in standalone systems, people contribute human processing power as side effects of other activities, but in a dedicated system, such as GWAP [29], whereas piggyback collects information by exploiting "traces" that users leave in that system to solve the target problem [13][23]. For instance, as an approach to search engine optimization, Google records and aggregates users' search history, which can help to prompt keywords prompting and correct spell errors in later use.
4) ***Micro Task***: Certain tasks are suitable for getting divided into pieces, and fulfilled by online workers. These small pieces of work normally require low human intelligence, and the results should be easily aggregated. Online platform Amazon Mechanical Turk and Crowdflower provide relevant services [26].
5) ***Innovation Tournament***: When in-house employees becomes costly or lack of pertinent expertise, outside human resources can pitch in via open challenge or competition. If the ideas/inventions get adopted by the institutions seeking the solution, winners can be rewarded by monetary or non-monetary acknowledgements (i.e., morality-based motivation).

In accordance with the 5 categories explained above, in this paper, we present 4 CE projects that we have been experimenting with, which go under a general umbrella of a

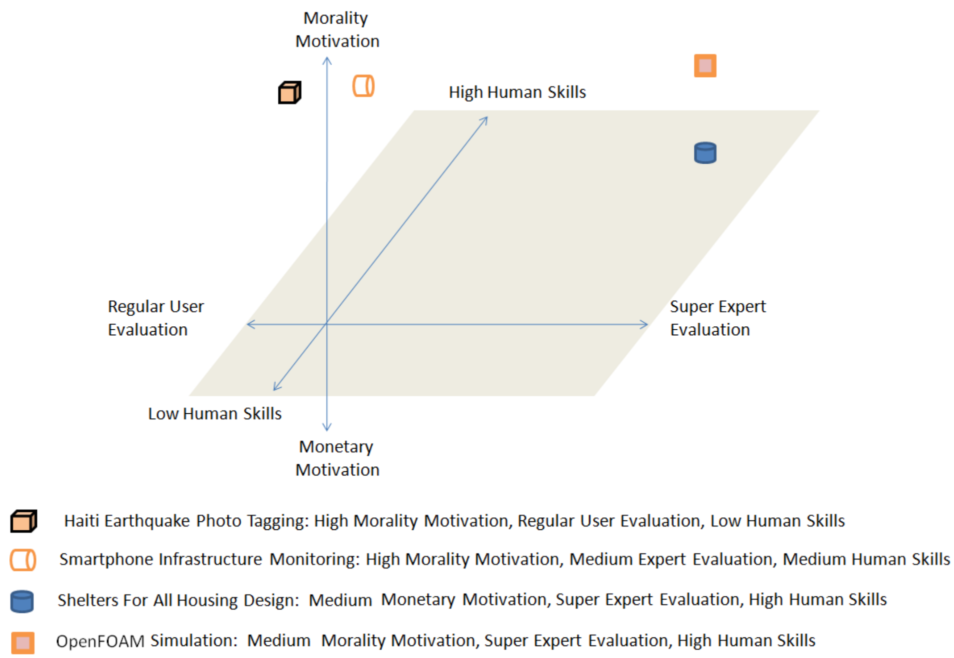

Fig. 1. 3-Dimensional Classification of CE Projects: Contributor Motivation, Skill Level Required and Evaluation

larger-scale study titled *Open Sourcing the Design of Civil Infrastructure* (OSD-CI) [22]. Specifically, these 4 pilot projects are: *Haiti Earthquake Photo Tagging* in Micro Task; *Smart Phone Infrastructure Monitoring* and *OpenFOAM Simulation*, a system focused on citizen engineering requiring a high level of expertise, in Crowd Wisdom; *Shelters For All* in Innovation Tournaments. In Section II-V, we describe them in more detail.

Also, besides the 5 categories, we observe various CE projects greatly vary along 3 dimensions, and by studying them we have gained deeper understanding of CE project implementations: Dimension I: Contributor Motivation, Dimension II: Human Skills Required and Dimension III: Product Evaluation. The projects we present in this paper position themselves in Fig. 1.

II. Project I: Haiti Earthquake Photo Tagging

In 2010, a catastrophic earthquake took place in Haiti. Afterwards, to help local residents rebuild their homeland, civil engineers from University of Notre Dame visited the country, and took several thousands photos of impaired buildings, in the hope that they can recognize common damage patterns, and thus improve redesign and rebuilding efforts [25]. However, soon they realized that the formidable volume of data, mainly photos, overwhelmingly surpassed their capacity to process. Under this circumstances, computer scientists, civil engineers, and sociologists from the same school were motivated to collaboratively build an online platform, where the workforce from crowds could be harnessed to fulfill photo classification tasks.

Rolling out the experiment, students were recruited using announcements on mailing lists and school-wide posters, which resulted in 242 students participating in the experiment as surrogates for citizen engineers. Their online activities were recorded, including photo tagging classifications, the time spent tagging each photo, and login/logout timestamps.[1]

Over 17 days, we received 9318 photo classifications on 400 sample photos. As the photo taggers came from a broad range of backgrounds - some of the participants were civil engineering majors, while others were from finance, history or other humanities - their classifications had volatile qualities. This heterogeneity mimics exactly what is commonly observed in CE projects: highly diverse education levels of users and variable quality of work.

Using the 3-dimension classification scheme: 1) the online crowd input their opinions about the images and collectively produced crowd consensus for organizers to consider, 2) contributors in the system were highly motivated by moral motivations, and 3) high human skills were not prerequisite, since users could use tutorials to acquire all needed knowledge.

A. Workflow Brief Description

Upon agreeing to a consent form, subjects were directed to a sign-up page, and asked to create their login credentials. For details of the procedure, interested readers may refer to [30].

1) ***Registration*** After subjects logged into the website, they saw a consent form with a brief description of the experiment: The task was to classify the type of earthquake damage depicted in 400 photos.

[1]The procedure for photo classification was developed by researchers from the Departments of Sociology, and Civil Engineering and Geological Sciences, University of Notre Dame.

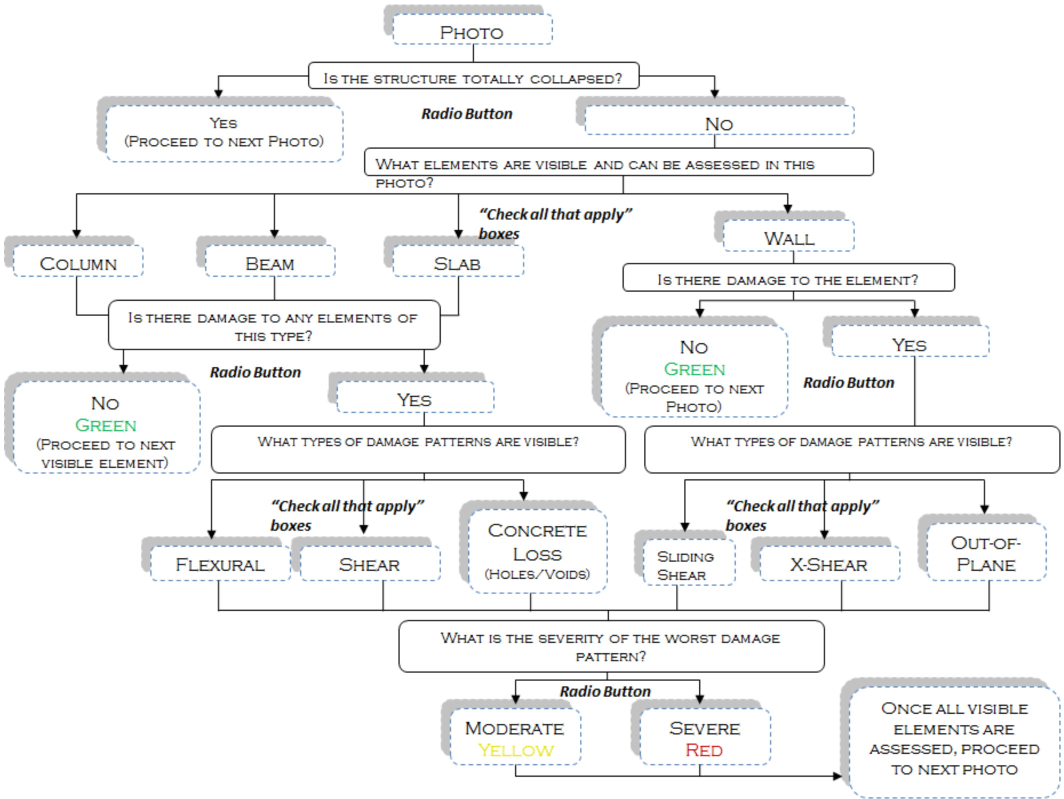

Fig. 2. Classification schema. As online users went deeper along the tree, their answers diversified.

2) ***Entry Survey*** The purpose of this questionnaire was to collect demographic and attitudinal data from the subjects.
3) ***Tutorials*** The tutorial provides detailed information about how to successfully classify the damage depicted in a photo, and by using hyper-links, subjects could return to this tutorial to deepen their understanding as many times as they wish during the tagging process.
4) ***Damage Classification*** Subjects received a single, randomly chosen photo at a time, until they completed all the 400 photos in the database or the allocated time period expired.
5) ***Exit Survey*** At the end of the seven-day period subjects were asked to complete a brief exit survey. We asked questions like why subjects decided to allocate time to classification work (motivation), the difficulty in classifying photos, the degree to which they found this to be an interesting task, and if they discussed the experiment with others.

B. Tagging Questions

As shown in Fig. 2, to classify a photo, subjects followed a five-step damage assessment process. These steps are:

1) ***Image Content*** Determine if an entire structure or only a part of the structure is visible in the image.
2) ***Element Visibility*** Identify which elements (*beams*, *columns*, *slabs*, *walls*) of the building are visible and can be assessed.
3) ***Damage Existence*** For each of these visible elements, determine if any of those elements are damaged.
4) ***Damage Pattern*** For each of the elements identified as damaged, identify the damage pattern.
5) ***Damage Severity*** For each of the elements identified as damaged, assess the severity of the damage (*Yellow* or *Red*).

Since we asked at most 25 classification questions for each photo, a user can get 25 points maximally from one photo. In particular, for each question, if this user's answer is same as the crowd consensus s/he receives one point. Otherwise, this user does not earn a point on the question. If the crowd consensus is that there is no damage on a certain element of the building, we do not further consider the user's inputs about the damage pattern and severity of that building element. In this regard, the maximal score a user can get from a photo is usually less than 25. Compared to the similar image classification work conducted in [3], this workflow presents a more sophisticated photo tagging schema with great potential to generate new knowledge because of its detail.

Similar to open source software (OSS) development, when the end users are not developers themselves, the factors of human computer interaction (HCI) should be taken into consideration at early stage[18]. Keeping this in mind, we especially emphasized the web interface's friendliness and

TABLE A ★ 2009 *Report Card for America's Infrastructure*

Aviation	D
Bridges	C
Dams	D
Drinking Water	D-
Energy	D+
Hazardous Waste	D
Inland Waterways	D-
Levees	D-
Public Parks and Recreation	C-
Rail	C-
Roads	D-
Schools	D
Solid Waste	C+
Transit	D
Wastewater	D-

AMERICA'S INFRASTRUCTURE G.P.A.	D
ESTIMATED 5 YEAR INVESTMENT NEED	$2.2 TRILLION

NOTES Each category was evaluated on the basis of capacity, condition, funding, future need, operation and maintenance, public safety and resilience

A = Exceptional
B = Good
C = Mediocre
D = Poor
F = Failing

Fig. 3. Grades of American Infrastructure. Sources: American Society of Civil Engineers. (Adapted from [15])

tutorial's clearness when building the system.

III. Project II: Photo Sensing on Deteriorating Infrastructure

Deteriorating infrastructures can lead to tragic disasters. In 2007, the busy I-35W Bridge in Minneapolis, MN, USA, collapsed during evening rush hour, claiming lives of 13 and injuring 145, besides other financial losses. In retrospect, this bridge had evidence of cracking and corrosion before it collapsed. This suggests that similar accidents could be prevented if signs and traces indicating infrastructure dangerous conditions can be timely reported to the authority.

Connecting the dots, researchers are encouraged to design human sensing systems, which engage a large number of volunteers to conduct mobile sensing as a complement of traditional fixed-position machinery sensor network. To this end, we naturally take into consideration the pervasiveness of portable digital devices. Indeed, the 5.3 billion mobile phone subscribers [2] across the globe have made cell phones the most pervasive instrument, which creates the possibility of organizing phone holders as human sensors [20]. This "human sensor network"[17] [12], comprising digital devices and human holders, has demonstrated unique characters compared to traditional fix-positioned sensor network:

- Hand-held digital devices, due to high penetration, can cover a broad spacial-tempo expanse. They could be conveniently carried around by holders, representing a broadly available and affordable technology. The resulting data, which are infrastructure photos in our case, provide significantly better insights when compared to the old fashion systems, which are largely form-based reporting.
- New digital device applications can be periodically created and updated due to human users behind the devices. For example, for smartphones, there are a range of tools/platforms can be leveraged by the developers to write customized apps that can serve specific purposes.
- In a human-based system, each mobile device is associated with a phone holder, whose assistance could be leveraged to achieve complex functionalities. Usually, citizens have intimate knowledge of patterns and anomalies in their communities and neighborhoods, and enabling them to respond is both empowering and valuable to long-term research [11].

The emerging area of people-centric sensing is experiencing growing research effort [1]. For example, in [16], local community members engage in "participatory sensing" and report pollution sources they witnessed around their neighborhood to reduce asthma cases. Following a similar approach, in [5], users spot invasive species by making geo-tagged observations of habitat-destroying invasive plants and animals.

A. Components and Considerations

Inspired by previous research [1][27][16], we established a infrastructure monitoring system. The workflow is shown in Fig. 4. The following components were our major considerations:

1) ***User Recruitment***
Users participating in the project were college juniors and sophomores. Since their hometowns are well across the country, collectively they had good coverage of the nationwide civil infrastructures. This was a major consideration when we sent off our solicitation letter in the summer, two weeks before the fall semester officially started.
2) ***User Education*** Research in psychology shows that individuals motivated by goals that are both well-specified and challenging tend to have higher levels of effort and task performance than goals that are too easy or vague[24]. Thus, in design, we strove to provide a well-structured and easy-to-follow tutorial, which gives users guidance on making meaningful contributions.
3) ***Information Recording*** Users were encouraged to go outdoors and snap photos of questionable infrastructure, which includes cracked structures, crumbling concrete, broken piers, or leaking tunnels. In this study, off-the-shelf digital devices with their built-in functions are

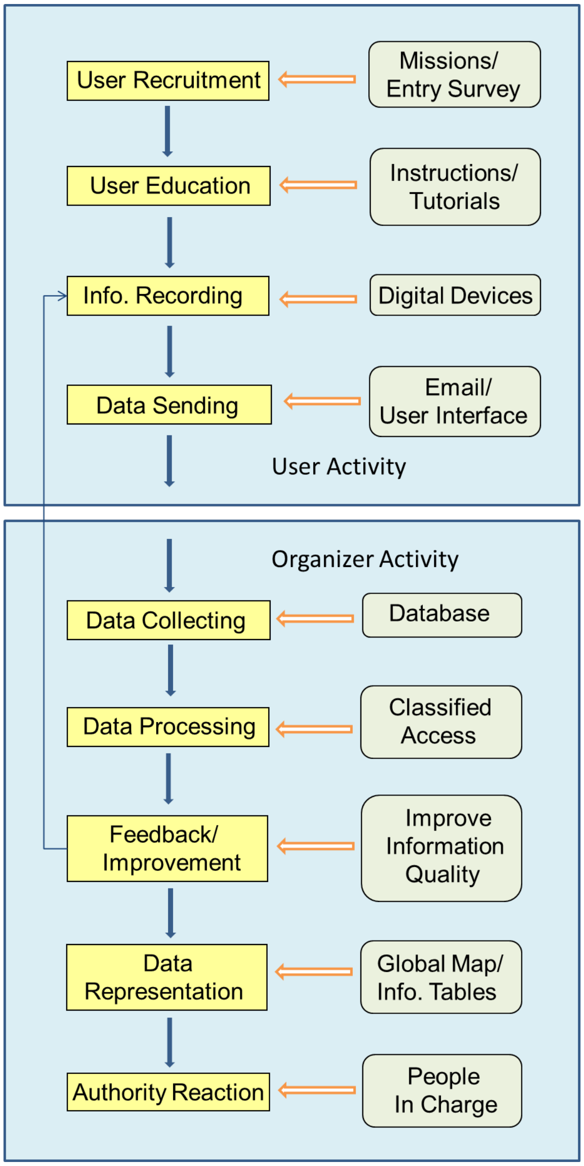

Fig. 4. Framework of Participatory Sensing

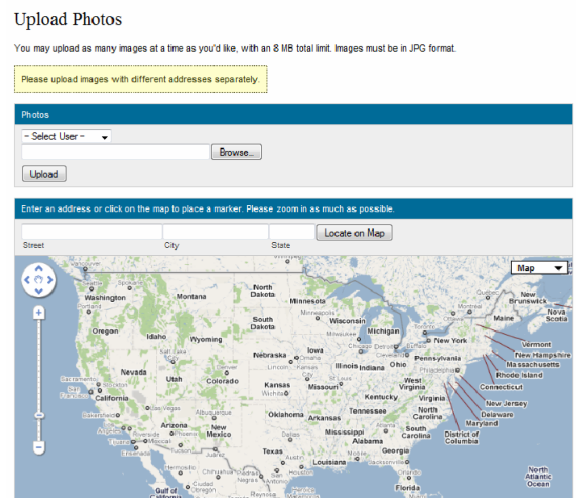

Fig. 6. Two Uploading Options: Street Fields Vs. Map Markers

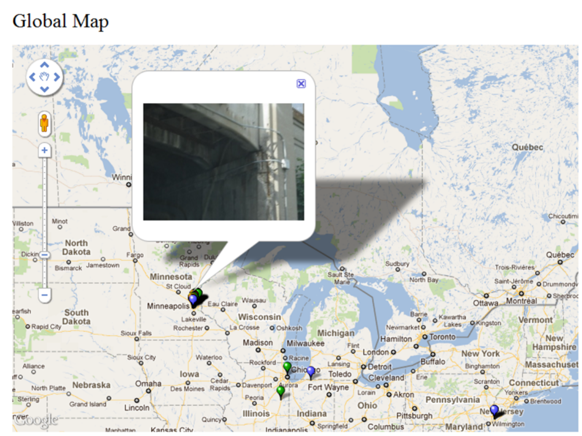

Fig. 7. Global Map: Data Representation and Visualization

sufficient to take photos, so there is no need to install any applications.

4) ***Data Sending*** Two options were provided for photo submission, as shown in Fig. 5:
   - If the user has any type of smart phones, equipped with geo-tagging functionalities, s/he can email us photos directly or upload photos personally, without providing other GPS information.
   - If the digital device does not have the geo-tagging function, users can either input street address or use a movable marker to pinpoint the location on a Google Map, which is translated into latitude and longitude coordinates. As shown in Fig. 6, we provide street input fields as well as a map holding the marker.

5) ***Data Collecting*** A data repository hosts the web service, which accepts data form the digital devices and the MySQL database saves the metadata of each photo into a table.

6) ***Data Processing*** Data access was managed according to terms and conditions agreed by project organizers and participants. It is difficult to overstate the importance and intricacy of data security and privacy [11]. As we dig further into sensing, privacy concerns and homeland security must be addressed. This is a two-fold issue: first of all, over time, these personal behavior devices, combined with geo-spatial tracking systems, provide a fair amount of tractable data about an individual's life pattern. Secondly, the weak points of the national infrastructure may become the targets of future terrorist attacks. Regarding these two issues, the protection policy on our experimental portal was that any photos coming from an individual were only visible to this specific user, as well as system administrators. The global map, where overall data sets were represented, was not open to the public.

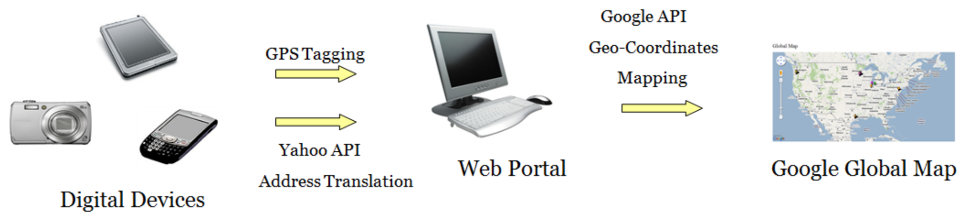

Fig. 5. Two Options for Photo Submission

7) ***Feedback and Improvement***
   If data was found missing, the user could revisit the venue and gathering more comprehensive data. Users can photograph the problematic part from variable angles and different distances, thanks to the human intelligence associated with the digital device.
8) ***Data Representation***
   Aggregated data was visualized with color balloons on a global map, where each color balloon represents one damaged infrastructure photo, as shown in Fig. 7.
9) ***Authority Interaction***
   Relevant authorities can be reached in the event of significant damage that occurs between inspection cycles. The location and severity of deterioration can be reported in detail if necessary.

B. Result and Discussion

In a period of 12 days, we received 170 photos from 25 users, covering 30 cities/townships across 6 states in US. Most photos identified crumbling infrastructure as expected, and a large portion of submissions were in fairly high quality (6 sample photos shown in Fig. 8). This study demonstrates the CE approach that we can leverage to enhance our ability to detect potential infrastructure failures, save financial resources, and even more importantly save lives.

IV. Project III: Shelters For All Competition - Safe and Affordable Housing for the Developing World

As explained in Section I, when organizations encounter limited human resources to solve the problem or seek better solutions, they can pursue ideas outside the organization via open calls, namely innovation tournaments. Practices belonging into this category include NetFlix Prize [8] for recommendation system and IBM Innovation Jam [9] for sale improvement. Another successful example is the Goldcorp Challenge offered by a Canada-based gold mining company named Goldcorp. The company released its confidential geological data and offered the public cash prizes for ideas on how to mine its gold deposits. The results of the newly identified gold reserves exceeded six billion dollars [28].

Based on these examples, we initiated a new innovation contest, titled ”Shelters For All Competition”. The major benefit of the study is the novel solutions/designs that may help developing countries to improve local residents' living conditions. Specifically, by conducting this open competition, we hoped to achieve two goals (1) facilitate the actual design of housing in underdeveloped, poor regions of the world and (2) assess the pros and cons of different ways of organizing crowdsourcing work.

A. Background

Fifteen of the twenty most populated cities in the world are currently located in developing countries, reflective of a wider trend that the majority of the world's population are increasingly hosted in urban zones. However, cities oftentimes cannot support the hiking number of new immigrants, who are seeking greater educational and economic opportunities. This results in densely populated, unstructured settlements or slums, and the lack of adequate shelter, safe drinking water, proper sanitation and other basic necessities dominates this landscape.

Recognizing the need for housing innovations, this competition is designed to tap the creativity of the open public and teams to deliver low-cost and safe housing to the world's urban poor. This is a challenging problem solicits, from the global community, creative solutions that tackle this problem in new and innovative ways. While adoption and sustainability by a target country or region is important, it is hoped that innovative solutions can be used in other places. To effectively meet our goals of improving living conditions of developing countries, we hoped novel designs can have following properties:

1) ***Resiliency*** can insure life-safety and protection against natural disasters and other environmental factors.
2) ***Feasibility*** can be practically implemented using locally available technologies, capabilities and materials.
3) ***Sustainability*** can be supported indefinitely using local resources (economic and natural), technologies and skill sets of the community and can adapt with their evolving need.
4) ***Viability*** can earn the support of most local stakeholders as culturally appropriate, so that ideas are not just accepted, but embraced and promoted.
5) ***Scalability*** can be applied in other communities beyond the particular country or region used for solution development.

The welcome page of the competition platform is shown in Fig. 9, and competition prizes and awards include:

1) ***The grand prize*** $10,000 (USD), granted to the best design among all submissions.

Fig. 8. Sample Photos from User Submissions

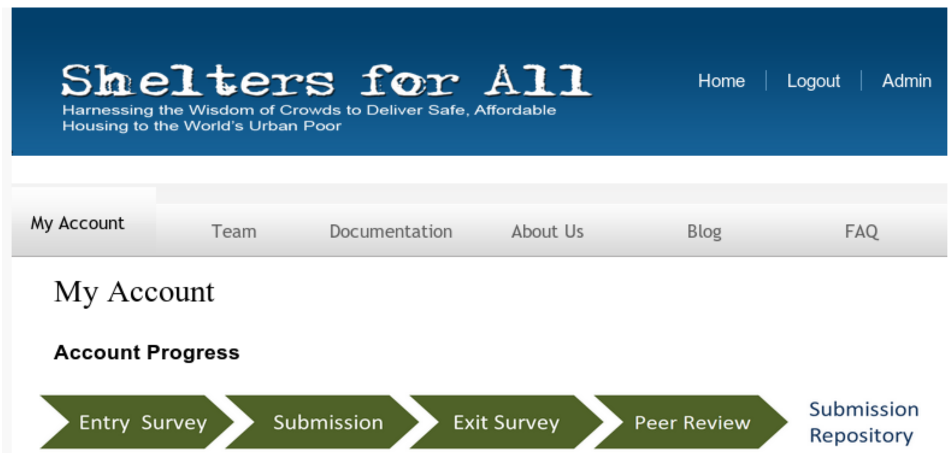

Fig. 9. User Interface of Shelters For All Competition Website

2) ***Popular vote award*** $1,000, awarded to the submission that obtains the highest score in peer reviews.
3) ***Referral award*** $600, distributed to the 3 individuals whose referrals result in the most submissions.

B. Results

By the time we closed the submissions site on Jan. 22, 2012, there were 99 valid solutions from 26 teams and 73 individuals. Most designs reflected participants' unique perspectives and considerations behind the innovative designs.

To our knowledge, creating new paradigms for low-income urban housing in developing countries is a multi-stage process requiring research into zoning regulations, financing systems, and community dynamics, as well as detailed engineering analyses and calculations. However, the objective of this competition is not to execute such a comprehensive process.

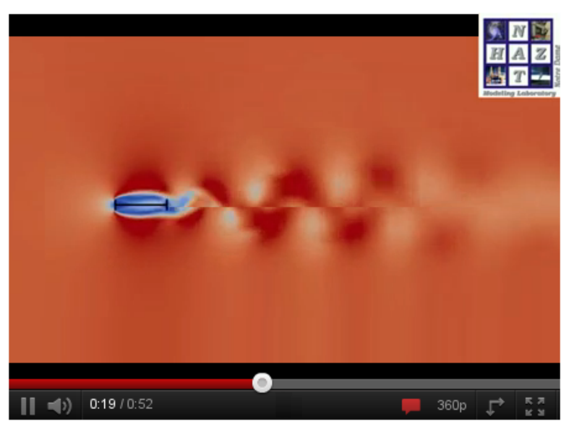

Fig. 10. Main Interface with a Brief Movie Tutorial

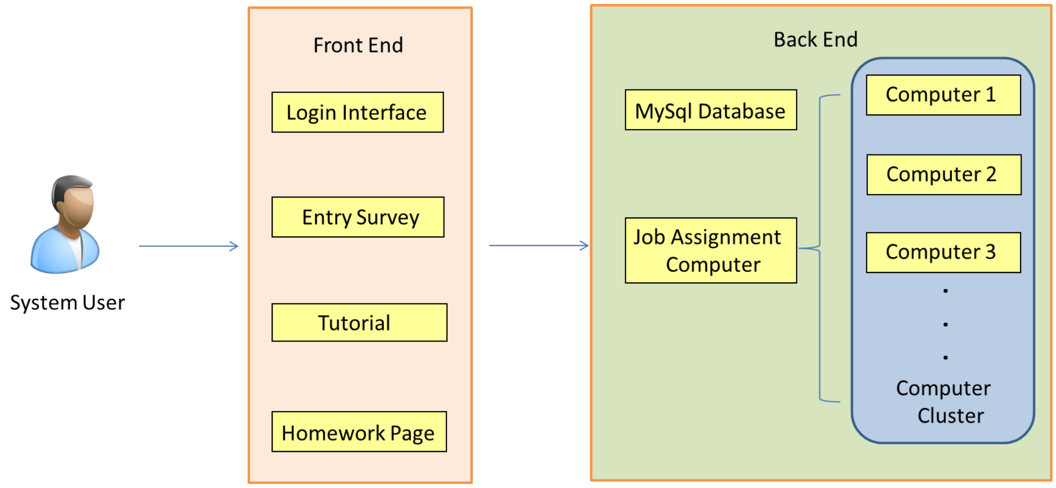

Fig. 11. Website Architecture

Rather the objective is to "jump-start this process with new ideas for housing in the developing world, supported by preliminary analyses that reflect the submitter's considerations of the many nontechnical factors that dictate whether designs will ultimately be successful.

V. Project IV: Expert-Citizen Experiment - OpenFOAM Simulation

To design a successful Citizen Engineering (CE) system, an inevitable challenge is that the contributors, i.e. *Citizen Engineers* - professionals, researchers, students, and even the public at large - usually have a broad range of expertise and talents, since individuals are at various stages in their careers. Among them, there is a certain portion of well-trained professionals, who have received formal training and/or have years of practical experience. While engineers are extrinsically motivated to provide voluntary service to society, for licensed engineers, Professional Development Hours (PDHs) are necessary to maintain licensure, and as such there are pragmatic incentives for licensed engineers to engage in citizen engineering activities.

To leverage the expertise skilled citizens may offer, who usually have unique goals and expectations that are different from average citizens, consisting of mostly hobbyists in traditional citizen science projects, we need to develop new principles and guidelines to achieve successful designs. Predictably, these new guidelines may be significantly different from the strategies for fulfilling tasks that require less experience.

Inspired by previous research on leveraging "citizen expert groups" to achieve common social scientific goals [14][6], in the engineering domain, we identify the following 3 challenges that are unique to expert citizen engineering projects.

- *Task Complexity* In expert citizen projects, tasks usually demand high human intelligence and skill level. For example, citizen experts can be asked to conduct a whole range of experiments to provide objective, insightful and trustworthy consultancy.
- *Recruitment Difficulty* Due to the complexity inherent in tasks, available human resources are limited and membership eligibility is rather selective, compared to traditional crowdsourcing tasks.
- *Resource Requirement* Complicated tasks may require sophisticated analysis tools and substantial computational resources [21]. For example, current analysis and design methods, such as nonlinear finite element analyses of complex structures, can overstress in-house computational capabilities of many firms and laboratories and far exceed the resources of most citizen engineers.

These challenges drove us to investigate more effective engineering designs that can leverage expertise and experience afforded by high-end citizen engineers. For detailed discussion, readers can refer to [31].

A. OpenFOAM Package

In this experiment, students were expected to take advantage of the CFD platform to conduct flow analysis for a channel flow situation. The basic simulation tool was the OpenFOAM (Open Field Operation and Manipulation) CFD Toolbox developed by OpenCFD Ltd [4], which is a free, open source software package, licensed under the GNU General Public License (GPL).

As open source software, the OpenFOAM package's ability to simulate complex fluid flows of turbulence, and its openness to allow users to customize and extend its existing functionality were the main reasons that we used it as a major simulation tool on our platform. Also, OpenFOAM is one of most popular CFD simulation tools, widely deployed by practitioners around the globe, and has been validated and verified intensively [4]. In this regard, our design goal of providing users a functional and robust simulation platform can be satisfactorily met. Lastly, OpenFOAM has an embedded meshing utility, which helps users better visualize their results.

B. Experiment Procedures

Expert engineers used in this experiment were from a graduate level course - CE 80200 Wind Engineering, offered by the Department of Civil Engineering and Geological Sciences at Notre Dame. This senior graduate-level course covers primary design considerations under a variety of wind types. Topics include the analysis of structural response due to wind loading, modeling of wind-induced forces, and principles of design to resist damage due to high wind loads. In total, 8 graduate students were formally registered, with several visiting scholars auditing the course. All of them received formal training in civil engineering, knowledgeable in their professional area.

C. Workflow

First, users were presented with a question set - a lecture quiz, in which questions were designed based on the class lectures, and intended to test users' understanding of the class material. After the lecture quiz, users were taken to the main interface, Fig. 10, where they could receive the work assignment, review the previous documents, logon to the simulation platform and submit their results.

D. Post-experiment Interview

After the experiment was complete, we interviewed subjects who experienced the platform and submitted their simulation reports. Most concerns were centered around the robustness of the simulation platform. When users were asked this question, "Please describe the difficulties you had using the simulation platform?", here are some representative responses:

- *"The performance, error handling and reliability of the computing services could be improved."*
- *"Sometimes, I cannot proceed with my simulation because of the high traffic on the platform."*

Users' concerns show that when our web site has provided basic functionalities, expert citizens especially emphasize the reliability and stability of the system that can help them to fulfill complicated tasks. In this sense, the retention of expert citizens, when competitive sources available, to a large degree depends on the satisfaction of their high expectations on user experience. "Being usable and being likable are two different goals" [32]. Easiness and smoothness may play a more primary role for professional users than it does for average users.

VI. Discussions and Future Work

In this paper, we introduced 5 common categories of CE practices: Crowd Decision, Crowd Wisdom, Crowd Byproduct, Micro Task, and Innovation Tournament. In a sense, open source software is a form of Crowd Wisdom, where loosely connected online software engineers make large or small amounts of contributions over time, and the quality of the collective artifacts gradually get improved. We can apply the same approaches/principles proved successful in open source software development to other engineering domains. We are convinced that a network of engineers are capable of creating not only software but also labels, graphics, videos, news articles, innovations, etc, and the 4 ongoing applications presented in previous sections are meant to provide new angles and insights for citizen engineering.

When developing new open systems, we recommend designers pay close attention to some common characteristics of the crowd workforce [19]: (1) crowd possesses high expertise and malicious users, (2) while a large portion of crowd artifacts are cheesy and noisy, the crowd has the intelligence to sift through and percolate up superior products in the end.

As always, there are more research questions emerged than solved. For example, in Micro Task, what is the optimal number of users to work on the same piece of work to secure a quality result? How should we rate and group online users based on their performance? In Crowd Wisdom, how can we efficiently aggregate and evaluate crowds' work, when it becomes complicated and non-obvious? Can we always find "super experts"? If not, how can we automate the testing and evaluation process? In innovative tournament, how can a competition be more appealing to those users with strong expertise? Higher monetary prize or wider social recognition? Answers to these questions will help the future research and development of CE systems to succeed, and more effectively leverage the "wisdom of the crowd".

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References

[1] CENS. http://research.cens.ucla.edu/, Retrieved Aug. 2011.

[2] Global mobile cellular subscriptions. http://www.itu.int/ITU-D/ict/statistics/, Retrieved Aug. 2011.

[3] ImageCat. http://www.imagecatinc.com/, Retrieved Aug. 2011.

[4] OpenFOAM. http://www.openfoam.com/features/index.php, Retrieved Jul. 2011.

[5] What's invasive. http://sm.whatsinvasive.com/, Retrieved Aug. 2011.

[6] M. Ahlheim, B. Ekasingh, O. Frör, J. Kitchaincharoen, A. Neef, C. Sangkapitux, and N. Sinphurmsukskul. Using citizen expert groups in environmental valuation - Lessons from a CVM study in Northern Thailand. Technical Report 283/2007, Department of Economics, University of Hohenheim, Germany, 2007.

[7] J. P. Allen. Three strategies for open source deployment: Substitution, innovation, and knowledge reuse. In *Proceedings of Open Source Software: New Horizons - 6th International IFIP WG 2.13 Conference on Open Source Systems*, volume 319, pages 308–313, Notre Dame, IN, USA, 2010. Springer.

[8] J. Bennett, S. Lanning, and N. Netflix. The netflix prize. In *In KDD Cup and Workshop in conjunction with KDD*, 2007.

[9] O. M. Bjelland and R. Chapman Wood. An inside view of ibm's innovation jam. *MIT Sloan Management Review*, 50(1):32–40, 2008.

[10] D. C. Brabham. Crowdsourcing as a model for problem solving: An introduction and cases. *Convergence: The International Journal of Research into New Media Technologies*, 14(1):75–90, 2008.

[11] J. Burke, D. Estrin, M.Hansen, A. Praker, N. Ramanathan, S. Reddy, and M. Srivastava. Participatory sensing. In *ACM Sensys World Sensor Web Workshop*, Boulder, CO, USA, Oct. 2006.

[12] A. T. Campbell, S. B. Eisenman, N. D. Lane, E. Miluzzo, R. A. Peterson, H. Lu, X. Zheng, M. Musolesi, K. Fodor, and G.-S. Ahn. The rise of people-centric sensing. *IEEE Internet Computing*, 12:12–21, 2008.

[13] A. Doan, R. Ramakrishnan, and A. Y. Halevy. Crowdsourcing systems on the world-wide web. *Communications of ACM*, 54(4), Apr. 2011.

[14] F. Fischer. Citizen participation and the democratization of policy expertise: From theoretical inquiry to practical cases. *Policy Sciences*, 26:165–187, 1993.

[15] . R. C. for America's Infrastructure Advisory Council of ASCE. *2009 Report Card for America's Infrastructure*. American Society of Civil Engineers, 2009.

[16] J. Goldman, K. Shilton, J. Burke, D. Estrin, M. Hansen, N. Ramanathan, S. Reddy, V. Samanta, M. Srivastava, and R. West. Participatory Sensing: A citizen-powered approach to illuminating the patterns that shape our world. *Foresight & Governance Project, White Paper*, 2009.

[17] M. Goodchild. Citizens as sensors: the world of volunteered geography. *GeoJournal*, 69(4):211–221, Aug. 2007.

[18] H. Hedberg and N. Iivari. Integrating HCI specialists into open source software development projects. In *Proceedings of Open Source Ecosystems: Diverse Communities Interacting, 5th IFIP WG 2.13 International Conference on Open Source Systems*, volume 299, pages 251–263, Skövde, Sweden, 2009. Springer.

[19] J. Howe. 5 rules of the new labor pool. *Wired*, 14(6), June 2006.

[20] A. Kansal, M. Goraczko, and F. Zhao. Building a sensor network of mobile phones. In *Proceedings of the 6th international conference on Information processing in sensor networks*, IPSN '07, pages 547–548, Cambridge, Massachusetts, USA, 2007. ACM.

[21] T. Kijewski-Correa et al. http://www.ne.edu/~opence/, Retrieved Jul. 2011.

[22] T. Kijewski-Correa et al. Open sourcing the design of civil infrastructure (OSD-CI): A paradigm shift. In *Proceedings of Structures Congress*, Las Vegas, NV, USA, Apr. 2011.

[23] A. Kittur, H. Chi, and B. Suh. Crowdsourcing user studies with mechanical turk. In *Proceedings of CHI 2008, ACM Pres*, pages 453–456, 2008.

[24] E. A. Locke and G. P. Latham. *A theory of goal setting and task performance*, volume 16. Prentice-Hall, 1990.

[25] D. Mix, T. Kijewski-Correa, and A. A. Taflanidis. Assessment of residential housing in leogane, haiti after the january 2010 earthquake and identification of needs for rebuilding. *Earthquake Spectra*, Oct. 2011.

[26] M. Negri, L. Bentivogli, Y. Mehdad, D. Giampiccolo, and A. Marchetti. Divide and Conquer: Crowdsourcing the Creation of Cross-Lingual Textual Entailment Corpora. 2011.

[27] S. Reddy, M. Mun, D. E. J. Burke, M. Hansen, and M. Srivastava. Using mobile phones to determine transportation modes. *ACM Transactions on Sensor Networks*, 6(2), February 2010.

[28] D. Tapscott and A. D. Williams. Innovation in the age of mass collaboration. In *Special Report*. Bloomberg Businessweek, Feb. 2009.

[29] L. von Ahn and L. Dabbish. Designing games with a purpose. *Communications of The ACM*, 51, Aug. 2008.

[30] Z. Zhai, D. Hachen, T. Kijewski-Correa, F. Shen, and G. Madey. Citizen engineering: Methods for "crowd sourcing" highly trustworthy results. In *Proceedings of the Forty-fifth Hawaii International Conference on System Science (HICSS-45)*, Maui, HI, USA, Jan. 4-7 2012.

[31] Z. Zhai, P. Sempolinski, D. Thain, G. R. Madey, D. Wei, and A. Kareem. Expert-citizen engineering: "crowdsourcing" skilled citizens. In *DASC*, pages 879–886. IEEE, 2011.

[32] P. Zhang and G. M. von Dran. Satisfiers and dissatisfiers: A two-factor model for website design and evaluation. *Journal of the American Society for Information Science*, 51(14):1253–1268, 2000.