

Technology-Facilitated Crowdsourcing Systems

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TECHNOLOGY-FACILITATED CROWDSOURCING SYSTEMS

A Dissertation

Submitted to the Graduate School
of the University of Notre Dame
in Partial Fulfillment of the Requirements
for the Degree of

Doctor of Philosophy

by

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Abstract

by

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The latest advances in information and communication technology have made it possible for researchers to design innovative crowdsourcing systems that can harness the human intelligence of online communities. While crowdsourcing system designs have progressed substantially through engineering breakthroughs, some challenges in the crowdsourcing model however remain unanswered, such as (1) System Design: in various crowdsourcing systems, what roles can crowds play and what contributions can they make? (2) Data Analysis: how can the human inputs with varied qualities be properly cleansed, and how can trustworthy results be effectively generated from their myriad inputs? (3) Human Computation Theory: at a higher level, what is the symbiosis between human intelligence and artificial intelligence?

With lessons learned and experiences gained from four projects, this dissertation aims to provide new perspectives and insights into answering these questions. When presenting research observations and results, we discuss a variety of technological and organizational considerations in crowdsourcing system designs.

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CHAPTER 1

INTRODUCTION

1.1 Introduction to Crowdsourcing

The latest breakthroughs in information and communication technologies have accelerated the development of collaborative systems. In the past several decades, *Artificial Intelligence* (AI) has made substantial progress. However, in many areas, machines have not been able to match the complexity, creativity, and flexibility of human intelligence [64]. For instance, we have plenty of computer algorithms at hand to deterministically sort an array of numbers according to their values, but this is rarely the case when the objects to be sorted require perceptual discernments. Can we ask computers to sort a group of animals based on their cuteness, or a list of websites based on their trustworthiness [71]? In situations where perceptual, aesthetic, or comprehensible capabilities are required, human intelligence needs to weigh in and assist artificial intelligence. The focus of this dissertation is the crowdsourcing model, a promising approach to organize human intelligence, usually harnessed from individuals in online settings, to tackle problems that computers cannot successfully resolve alone.

According to Quinn and Bederson [81], crowdsourcing is a sub-area of *Collective Intelligence*, and existing crowdsourcing systems fall into two general types:

- *Intentional Human Computing* (IHC) Systems. In IHC, human intelligence

plays an explicit role in the production process, where participants explicitly make contributions (expertise, fundings, connections, etc.). Their activities are driven by either intrinsic or extrinsic motivations, such as self-satisfaction, personal development (intrinsic), monetary rewards, reputation (extrinsic), etc.

- *Unintentional Human Computing* (UHC) Systems. In UHC, the production processes that generate meaningful results are not the motivating factors for the contributors. Instead, they are the side effects of the main activities. Examples of this type include serious games, search engine keyword suggestion, etc.

Fig. 1.1 illustrates a simple taxonomy of crowdsourcing systems based on these general criteria.

1.2 Intentional Human Computing (IHC) Systems

IHC systems can be divided into three sub-categories as shown in the third column of Fig. 1.1: (1) Systems for social campaigns; (2) Systems for scientific/educational purposes; (3) Systems for commercial/utilitarian purposes. Primarily, social campaign systems and scientific/educational systems are non-commercial.

1.2.1 Systems for social campaigns

In terms of social activism, average citizens can readily form a pervasive network/workforce. For example, *Ushahidi* (Swahili for “testimony” or “witness”) represents a violent activity map as shown in Fig. 1.2. The website was created in the aftermath of Kenya’s disputed 2007 presidential election, and it collected eyewitness reports of violence sent in by email and text-message [9].

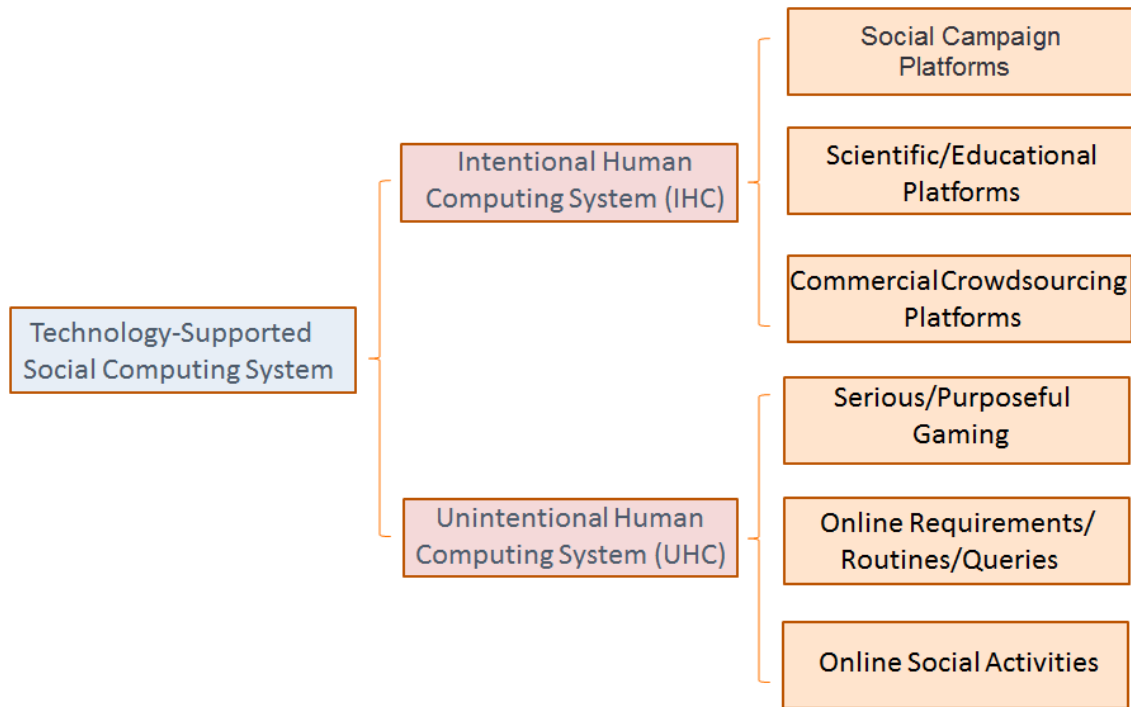


Figure 1.1. Taxonomy of Crowdsourcing Systems. Two major categories: *Intentional Human Computing (IHC)* and *Unintentional Human Computing (UHC)*. Note that in IHC, *Social Campaign Platforms* and *Scientific/Educational Platforms* are primarily non-commercial.

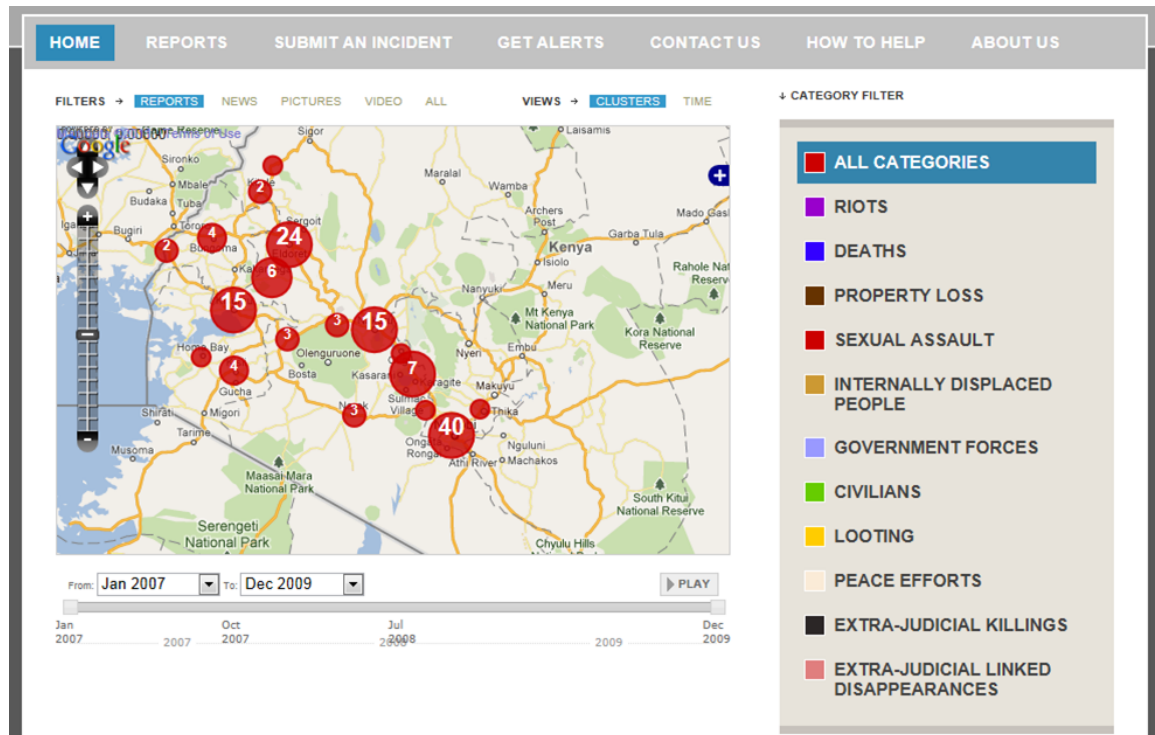


Figure 1.2. Example of General Social Benefit Portal - *Ushahidi*. The interactive map visualizes the locations of violent activities that took place after Kenya's disputed 2007 presidential election.

1.2.2 Systems for scientific/educational purposes

For educational or scientific purposes, many projects share the concept of engaging a large number of participants, organized and mediated by modern cyber-infrastructure. In fact, an increasing number and variety of projects are taking advantage of the opportunities provided by new advances in technology, e.g., Wikipedia [52][46], Stardust@home [96], eBird [85], Linux Kernel [78], Galaxy Zoo [83], and Rosetta@home [55], among others.

1.2.3 Systems for commercial/utilitarian purposes

The crowdsourcing model can also be applied as commercial platforms, which usually take the form of virtual societies. Three typical embodiments are

- *Market Place*, such as Clickworker [15] as shown in Fig. 1.3 and Amazon Mechanical Turk [13].
- *Shared-Interest Community*, such as Threadless [20] as shown in Fig. 1.4 and iStockphoto [19].
- *Crowdsourced Research Center*, such as InnoCentive [18] as shown in Fig. 1.5 and IdeaConnection [17].

1.3 Unintentional Human Computing (UHC) Systems

In this modern age, people enjoy more spare time than ever before. In many creative ways, researchers have developed novel approaches to channeling easily dissipated human brainpower to achieve meaningful goals. Sometimes the humans in the system are not even aware they are doing meaningful work.



Figure 1.3. Market Place – Clickworker.com. *Market Place* is one of the three major forms to organize dispersed online workers to produce meaningful outputs. Clickworker.com is a web-based market place, where clients outsource their tasks to “clickworkers” via an application programming interface (API). Clickworker uses quality control measures to ensure product quality. For instance, when placing an order, clients (buyers) get to choose the guaranteed level of product quality, such as a second clickworker may be hired to double check the work quality of the first clickworker.

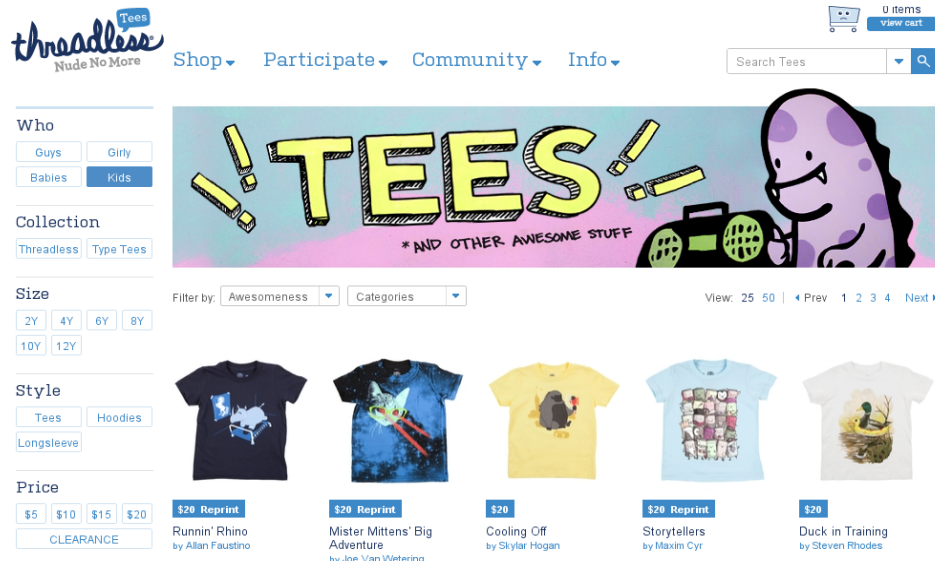


Figure 1.4. Shared-Interest Communities - Threadless.com.

Shared-Interest Community is one of the three major forms to organize dispersed online workers to produce meaningful outputs. T-Shirt designers exchange ideas and designs at Threadless, and the promising designs that collect a large amount of votes will be sent to factories for mass production. In this model, winning designs are more likely to succeed, since the votes they have obtained usually are an indicator of the future market demands.

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Humanitarian Air Drop

Deadline: 05/02/2011 | 318 active solvers


\$20,000 USD



The Economist-InnoCentive Healthcare Information Economy Challenge

Deadline: 03/30/2011 | 645 active solvers


\$10,000 USD



Upload Your Compound Libraries!

Deadline: 01/20/2013 | 92 active solvers

[See details](#)



Remote Human Demographic Characterization

Deadline: 05/02/2011 | 140 active solvers

\$20,000 USD

Figure 1.5. Crowdsourced Research Center - InnoCentive.com.
Crowdsourced Research Center is one of the three major forms to organize dispersed online workers to produce meaningful outputs. InnoCentive is an open innovation and crowdsourcing platform that aims to solve problems by connecting organizations to diverse sources of innovation, such as employees, customers, partners, or other problem-solving marketplaces.

In UHC systems, users do not specifically care about final products that matter to system designers. Instead, meaningful results come out as side effects of the main purpose. For example, von Ahn et al. developed online gaming system named *Gaming With A Purpose*(GWAP) [91], to harness scattered human power. In their GWAP suite, there are games aimed at collecting common-sense knowledge to improve artificial intelligence [93], enhance image search quality [92], and identify objects in images [94]. In those games, people come to play not because they are especially interested in solving a computational problem, but because they seek entertainments [91].

In addition to online games, human brain power spent on routines, requirements or duties can also be channeled and transformed into tangible work. For example, *reCAPTCHA*, derived from Completely Automated Public Turing Test to Tell Computers and Humans Apart (CAPTCHA) [90], utilizes users' brain-power to digitize obscured text material when they perform routines to identify themselves as human beings [95].

A similar system is Animal Species Image Recognition for Restricting Access (ASIRRA) [48] as shown in Fig. 1.6. To authenticate their human identities, users are asked to differentiate photographs of cats and dogs that computers cannot distinguish reliably. Behind this *Human Interaction Proof* (HIP) process [41], a humanitarian purpose takes place: the animals shown in the pictures are from animal shelters, and if users wish, they can conveniently adopt cats and dogs shown in the pictures. In this manner, when showing proof of their human characteristics by specifying animal types, users are unintentionally engaging in an interactive advertisement.

Please select all the cat photos:

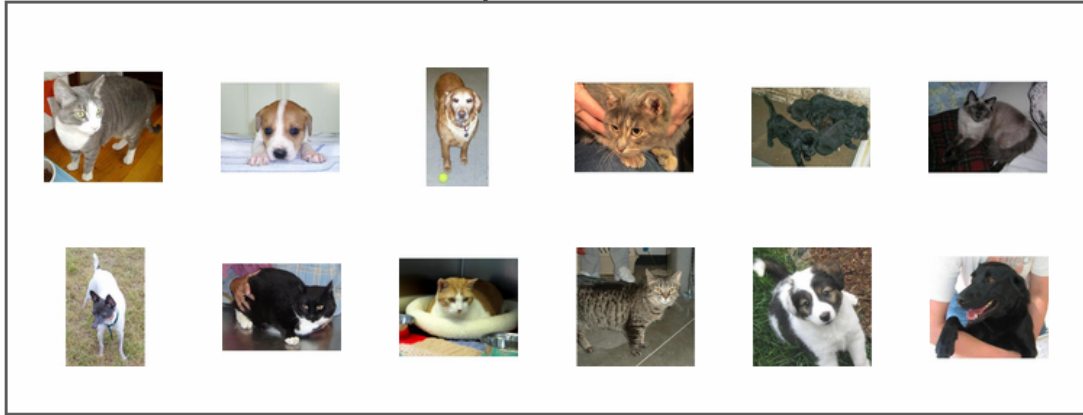


Figure 1.6. Humanitarian *Human Interaction Proof* (HIP) System - ASIRRA. In ASIRRA, when users show proof of their human characteristics by specifying animal types, users are unintentionally engaging in an interactive advertisement.

1.4 Research Questions and Challenges

We have introduced IHC and UHC systems. Generally speaking, in almost every type of crowdsourcing system, designers commonly need to thoughtfully consider trade-offs along three dimensions: *Accuracy*, *Cost* and *Time*, as shown in Fig. 1.7. Specifically, if system designers strive to improve the quality of human submissions, they may have to compensate workers more generously or wait for a longer time. On the other hand, if designers want to shorten the human processing latency, reducing the timespan between task release and completion, they would either have to increase incentives to motivate crowd workers or lower their confidence on the accuracy of the submissions collected.

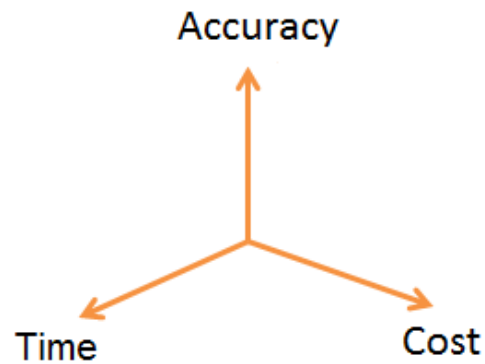


Figure 1.7. Three Dimensions of Trade-off in Crowdsourcing Systems. If system designers strive to improve the quality of human submissions, they may have to compensate workers more generously or wait for a longer time. On the other hand, if designers want to shorten the process latency, reducing the time span between the task release and completion, they would either have to increase incentives to motivate crowd workers or lower their confidence on the accuracy of the submissions they collected.

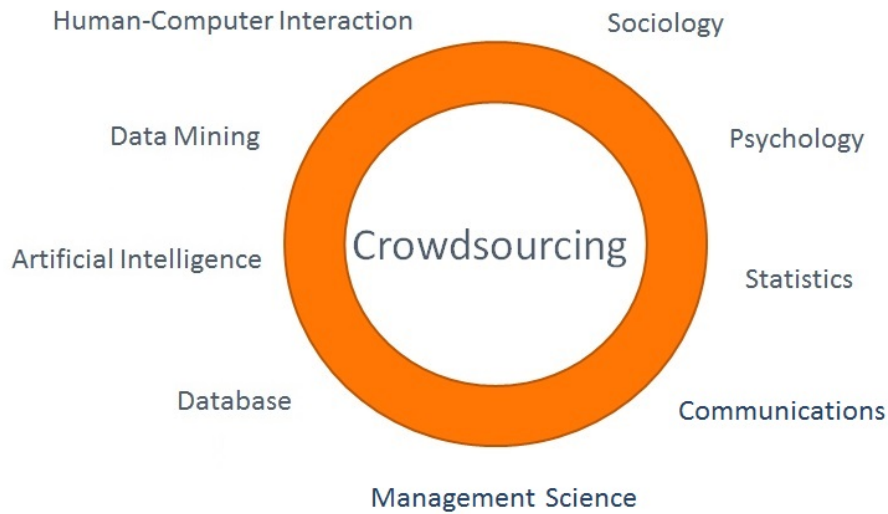


Figure 1.8. Crowdsourcing Systems - Interdisciplinary Research. Research on crowdsourcing models include both technology disciplines, such as computer engineering and communications, and humanity disciplines, such as sociology and psychology.

1.4.1 Questions and Challenges

While the developments of crowdsourcing systems have made progresses at both practical and theoretical levels, due to the interdisciplinary characteristics of the crowdsourcing model (illustrated in Fig. 1.8), a wide range of challenges remain unanswered.

- *System Design.* In various crowdsourcing systems, what roles can crowds play and what contributions can they make?
- *Human Data Analysis.* How can the human inputs with varied qualities be properly cleansed, and how can trustworthy results be effectively generated from their inputs?

- *Human Computation Theory*. At a higher level, what is the symbiosis between human intelligence and artificial intelligence?

The theme of this dissertation is to properly answer these three questions based on the lessons learned and experiences gained in the process of conducting our four projects.

1.4.2 Research Goals and Results

To answer these challenging questions, new theories and mechanisms are required. With experimental results from four projects, this dissertation aims to provide new perspectives and insights into answering these questions.

After a further literature review in Chapter 2, Chapter 3 describes the *Crumbling Infrastructure Photo Submissions* project, in which researchers motivated students to collect information about crumbling infrastructure nationwide. Through this experiment, researchers wanted to explore the concept that crowds can be leveraged as information collectors, and social concerns and monetary prizes can be used as motivations to drive citizens' altruistic behaviors.

Chapter 4 introduces the *Haiti Earthquake Photo Tagging* project, in which hundreds of subjects collectively process earthquake-damage photos taken by civil engineers. Via this experiment, we aimed to answer two questions: (1) With a data set collected from citizen engineers, how can malicious/suspicious inputs be detected and cleansed? (2) How can the inputs from individuals with diversified backgrounds and motivations be appropriately aggregated and organized to generate trustworthy results?

Chapter 5 discusses our study in the domain of *Expert Citizen Engineering*, which aims to answer the questions about the working performance of high-skilled

citizens who usually can do high-intelligent work, meanwhile challenging to recruit and retain.

Chapter 6 is dedicated to the description of the *Shelters For All* competition, an open competition to solicit affordable-housing ideas for developing countries. This competition was open to the global public, and through this competition, we intended to investigate mechanisms and processes for organizing far-reaching and large-scale innovative contests.

Finally, in Chapter 7, we conclude the dissertation and propose some directions for future crowdsourcing research.

CHAPTER 2

LITERATURE REVIEW ON PREVIOUS RESEARCH

Despite advances in artificial intelligence, in many areas, current techniques have not matched human intelligence. Certain real-world problems that challenge computer algorithms are trivial or straightforward to humans. Exemplar applications, where humans usually compete better than computers, include writing reviews of restaurants, movies, or businesses, tagging photos, translating natural languages, evaluating the relevance of search results, etc.

In human computing systems, we can see that modern information technologies, especially the Internet, play a vital role in channeling individual efforts towards a common goal. Often, we see users with diverse expertise recruited by the Internet, their activities coordinated by communication technologies, their inputs aggregated and stored in databases, and the final artifacts/summaries presented online. In this chapter, we first analyze the advances of crowdsourcing systems facilitated by new technologies, then follow with a discussion of crowdsourcing taxonomy from various classification angles.

2.1 Background

2.1.1 Crowdsourcing in History

The practice of engaging citizens to achieve a common goal has a long history. For example, since 1900, the National Audubon Society (NAS) has been conducting bird counts, named Christmas Bird Count (CBC), around the Christmas season at the end of every year [12]. In this century-long research project, the monitoring regions are divided into counting patches. During the Christmas season, hobbyist bird watchers (called birders) count the number of specific types of birds within their own patches and mail records to the NAS data center.

Another form of crowdsourcing that has historic roots is open competitions, where people organize innovation contests aimed to attract the public to submit novel solutions for challenging problems. For instance, at the juncture of 18th and 19th century, the French army solicited solutions for food preservation to support French soldiers on the front. Eventually, in 1810, confectioner Nicolas Appert won the prize by developing food-canning technology.

2.1.2 New Opportunities

While crowdsourcing has a relatively long history, new advances in information technology have provided new opportunities, and a number of factors are now coming together to accelerate its development and evolve it into new directions [82][81][80]. New types of web technology for work decomposition and data synthesis create unprecedented opportunities to dispatch and collect crowd work.

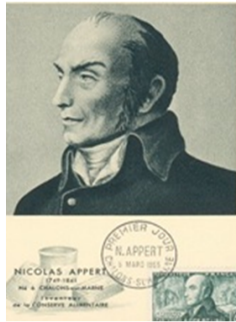
For example, as shown in Fig. 2.1 and Fig. 2.2, by running a competition open to international contestants from 2006 to 2009, the movie renting company Netflix increased the accuracy of their collaborative filtering algorithms by 10.06% [21];



Figure 2.1. New advances in information technologies provide new opportunities to crowdsourcing. Started in 1900, National Audubon Society (NAS) has been conducting Christmas Bird Count (CBC). As a new development, since 2002, the *eBird* web portal launched by the Cornell Lab of Ornithology and National Audubon Society enables the global community of birders to communicate with the server database electronically.

inspired by the Christmas Bird Count, in 2002 the Cornell Lab of Ornithology and National Audubon Society launched the *eBird* project, where its web portal enables international birders to electronically submit their data to the database. Over years, the accumulated data has benefited the global community. As summarized by Sullivan et. al. [85], “An innovative use of the Internet and information technologies better enhances the opportunity for citizens to contribute their observations to science.”

Not limited to the domain of ecology, crowdsourcing projects have engaged science enthusiasts in a wide range of disciplines, such as sensing invasive species



Open Competition for Food Preservation

Competition Started: 1795
Prize Won: 12,000 Franc, 1810
Winner: Nicolas Appert



Netflix Grand Competition For Collaborative Filtering Algorithm

Competition Started: 2006
Prize Won: \$1M, 2009
Winner: BellKor's Pragmatic Chaos team

Figure 2.2. New Opportunities in Open Competition. In the late 18th century, by running an open competition, the French army acquired the technology for food preservation. Two centuries later, via a competition from 2006 to 2009, the movie renting company Netflix globally solicited new algorithms that ended up improving the company's collaborative filtering accuracy by 10.06% [21].

[2][50], urban planning [38], climate change [39], astronomy data [30][83][96], ecosystems analysis [43], civil infrastructure [3][49], and environmental protection [72].

To provide an informative and useful taxonomy, we need to dissect and categorize various existing crowdsourcing models. It is our goal to make the categorization collectively exhaustive and mutually exclusive; however, some instances nonetheless have multiple components, which bear characteristics from different categories. Acknowledging this difficulty, we will give criteria and list typical examples for each category, by which readers can further examine the components and nuances in different crowdsourcing instances.

2.2 Further Discussion - Intentional Human Computing (IHC)

Within the category of IHC, there are three major types: (1) Social Campaign Platforms, (2) Educational/Scientific Platforms, and (3) Commercial Platforms. Both (1) and (2) are primarily non-commercial platforms. We next describe each category.

2.2.1 Social Campaign Platforms (Non-Commercial)

Equipped with modern communication tools, the crowdsourcing model can be leveraged to conduct social and political campaigns. For example, in the domain of citizen journalism, we discussed Ushahidi in Chapter 1, where average citizens can form a pervasive sensor network for social event monitoring. Similar platforms include CNN’s iReport, shown in Fig. 2.3, and NowPublic, shown in Fig. 2.4. On social campaign platforms, regular citizens “playing an active role in the process of collecting, reporting, analyzing, and disseminating news and information.”[35]



Figure 2.3. Citizen Journalism Platform - *CNN's iReport*. iReport is a crowdsourced news website, which exemplifies the model that mainstream media harnesses crowd resources.

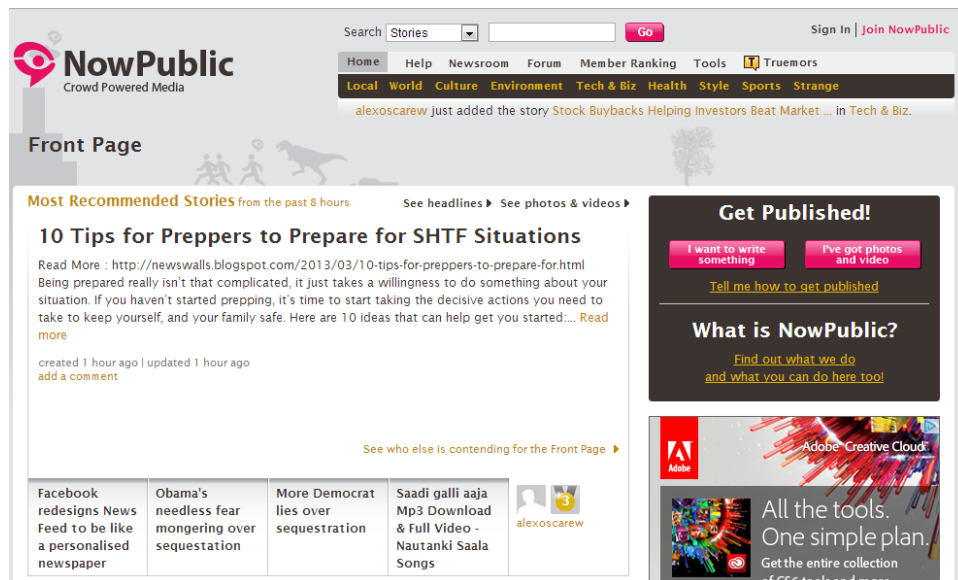


Figure 2.4. Citizen Journalism Platform - *NowPublic*. NowPublic is a multimedia news website that solicits news articles, opinions and videos from the public.

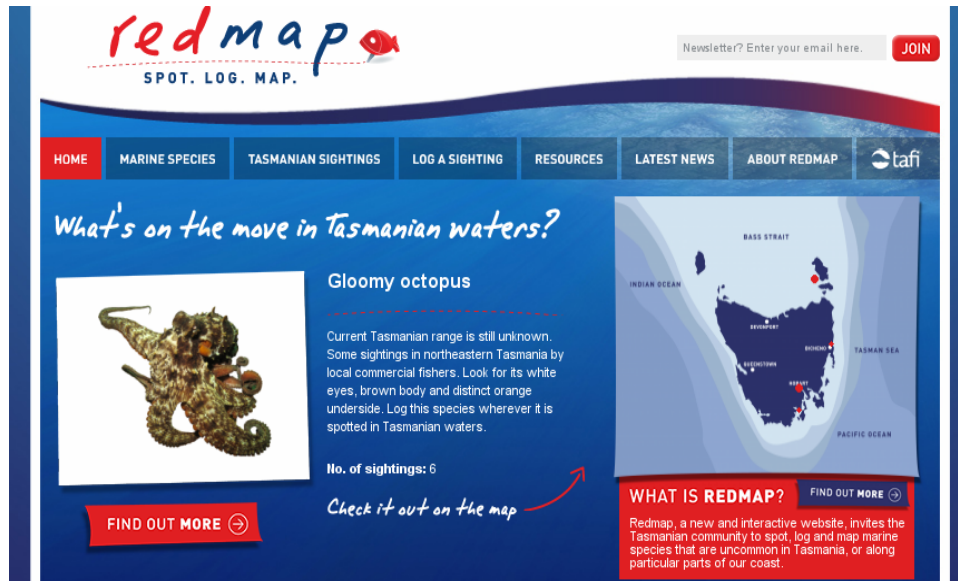


Figure 2.5. Conservation Citizen Science Project - *Redmap*. Conservation projects arouse citizens' awareness for social concerns, such as environmental protection.

2.2.2 Educational/Scientific Platforms (Non-Commercial)

To enhance visibility and increase influence, crowdsourcing systems can also serve as portals for educational or scientific research. Wiggins et. al. [97] classify citizen science projects into five categories: (1) Action, (2) Conservation, (3) Investigation, (4) Virtual, and (5) Education. We simplified the existing citizen science projects into three general categories:

- *Conservation*. Conservation projects arouse citizens' awareness for resource protection conservations, such as environmental protection, where the target of protection can be wild animals, water habitats, rain forest, etc. For instance, *Redmap*, shown in Fig. 2.5, aims to protect coast line around Australia.

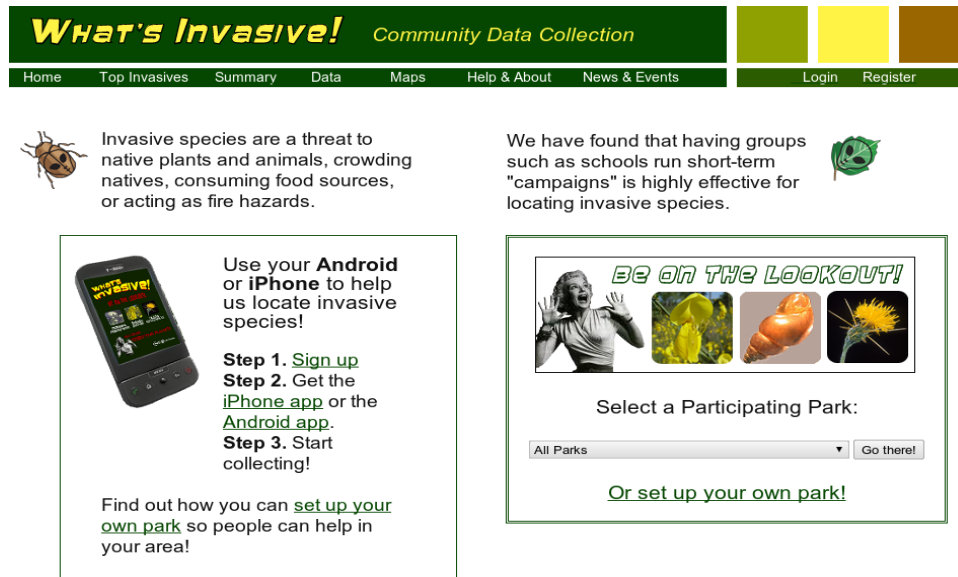


Figure 2.6. Investigation Citizen Science Project - *What's Invasive*. Investigation projects motivate citizens to collect field data in a given area for scientific/educational purposes. In *What's Invasive*, via mobile phone applications, citizens can send the information about invasive species to the central server.

- *Investigation*. Investigation projects motivate citizens to collect field data in a given area for scientific/educational purposes, such as bird population variations or climate change patterns. An example is *What's Invasive*, shown in Fig. 2.6.
- *Virtual Contribution*. In virtual contribution projects, citizens can perform tasks inside the web portal without conducting mandatory ground activities. Examples include *Galaxy Zoo*, *Milky Way* as shown in Fig. 2.7, and *Stardust@home* as shown in Fig. 2.8.



Figure 2.7. Virtual Contribution Project - *Milky Way*. In virtual contribution projects, citizens can perform tasks inside the web portal without conducting mandatory outdoor activities. The Milky Way project is aimed to sort and measure our galaxy. Citizens help astronomers by looking through thousands of images taken by the Spitzer and Herschel telescopes.



Figure 2.8. Virtual Contribution Project - *Stardust@home*. This project engages hobbyists and encourages volunteers to search images for tiny interstellar dust impacts.

2.2.3 Commercial Platforms

Another category is commercial platforms, which may take the form of a microtask system, an out-sourced research center, or a shared-interest online community.

2.2.3.1 Type 1: Online Microtask System

We use Amazon Mechanical Turk (AMT) as an example to illustrate the online microtask system. AMT, as shown in Fig. 2.9, is designed to provide a marketplace for trading human intelligence, where service requesters post tasks and workers vie to provide service for monetary rewards [14]. The tasks on AMT are normally menial and compensated by small payments. In this system, there are three interacting parties:

- *Workers (service providers)*. Workers need to provide services in accordance with the specifications submitted by the service requesters. If the services do not meet the requesters' reasonable expectations, the service will not be accepted.
- *Requesters (service buyers)*. Upon completion of services from workers to requesters' reasonable satisfaction, requesters need to compensate workers for their services. The monetary rewards can vary a great deal depending on the complexity and quality of the work, but, in most cases, rewards are very limited.
- *Platform Managers*. AMT platform plays the role of technical support. The platform facilitates transactions between requesters and providers. However,

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- Pay only when you're satisfied with the results

Fund your account

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Get results

Get Started

Figure 2.9. Online Microtask System - *Amazon Mechanical Turk* (AMT). AMT is designed to provide a marketplace for trading human intelligence, where service requesters post tasks and workers vie to provide service for monetary rewards. The tasks on AMT are normally menial and only compensated by small payments.

in any case, AMT does not directly get involved in the service producing process.

2.2.3.2 Type 2: Shared-Interest Communities

The second type of commercial platforms is online stores based on group interests. Different from traditional online stores, the most valuable part of products are generated by crowds in the community. For example, at iStockPhoto [19] (See Fig. 2.10), photographers, either professionals or amateurs, can exchange their photography experience and upload their work, whether it be photos, illustrations, or videos, to an online repository. Buyers freely browse and select products that suit their needs, and acquire them at a lower price than they would have to pay at traditional markets. The iStockPhoto platform takes commissions from the photos traded.

2.2.3.3 Type 3: Open Innovation Center (OIC)

OIC systems provide a platform on which companies and institutions can open their unsolved problems to online crowds, who may possess the experience or resources to better tackle the challenge.

The increasing availability and capacity of skilled workers are the driving force of open innovation centers. The online crowds are mainly composed of science enthusiasts doing research for fun, professionals seeking a part-time job, or small research companies/labs providing innovative solutions for larger organizations to make revenue.

In InnoCentive, *Seekers* (solution buyers) post questions and solicit ideas, and *solvers* (solution providers) submit their solutions and proposals to compete, in the

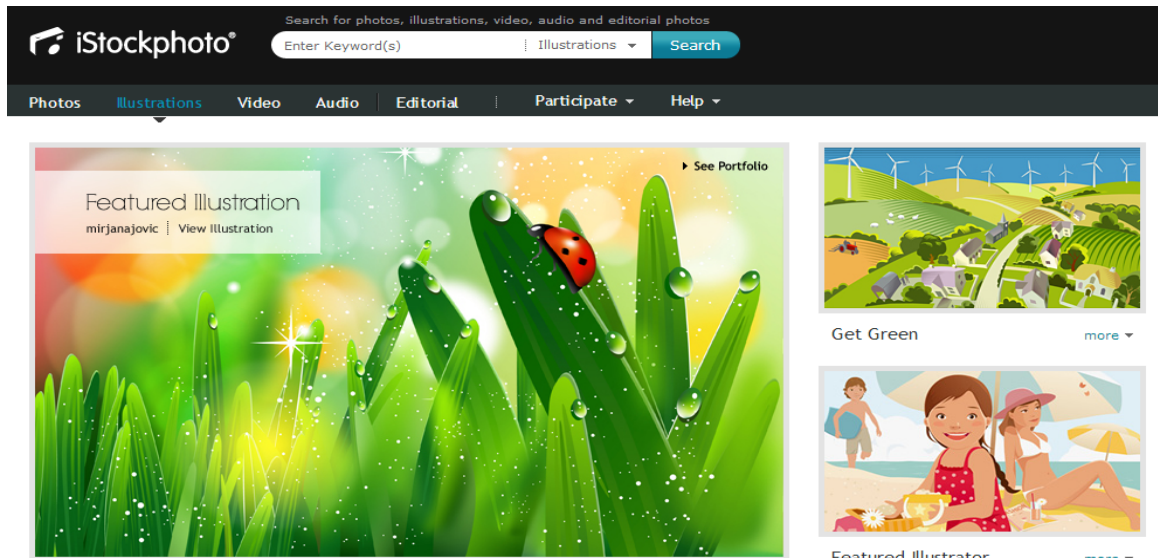


Figure 2.10. Shared-Interest Communities - *iStockPhoto*. At iStockPhoto, where photographers, either professionals or amateurs, can exchange their photography experience and upload their work, whether it be photos, illustrations, or videos, to an online repository. Buyers freely browse and select products that suit their needs, and acquire them at a lower price than they would have to pay at traditional markets.

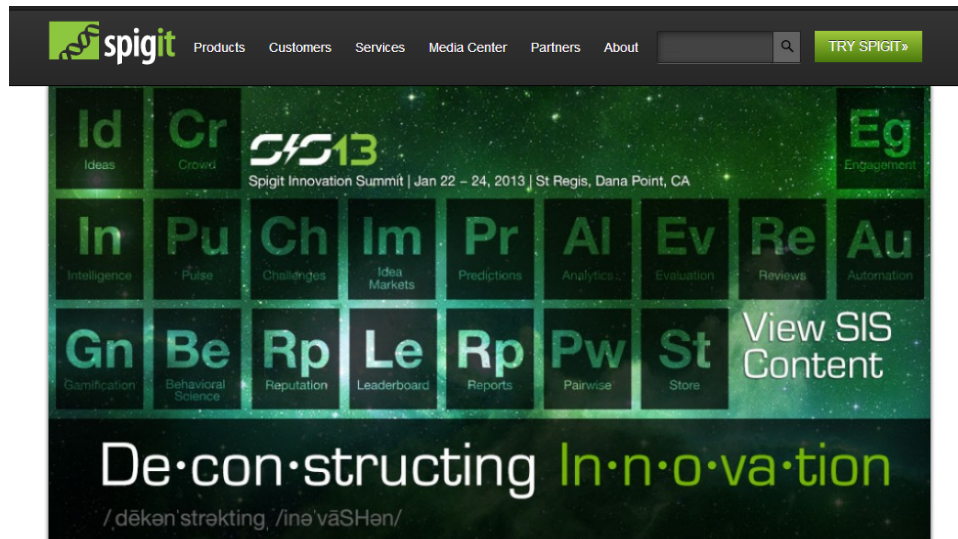


Figure 2.11. Open Innovation Center - *Spigit*. Spigit is a social innovation platform. By running competitions to solicit business ideas, it aims to help clients invent products, generate new revenue streams, build innovation cultures, reduce costs, and improve employee and customer engagements.

hope for winning monetary prizes. Similar to InnoCentive, other examples include Spigit as shown in Fig. 2.11 and Innovation Exchange as shown in Fig. 2.12.

Dramatically different from Yahoo! Answers, which rarely offers financial support to the users that provide answers, these platforms explicitly use monetary rewards as main incentives to attract crowds.

2.3 Further Discussion of Unintentional Human Computing (UHC)

In Chapter 1, when discussing the UHC systems, we explained there are various innovative ways to tap into crowd creativity and sensibility, sometimes even without users' awareness. In our research, however, the four projects we designed and investigated were all in the Intentional Human Computing (IHC) domain,

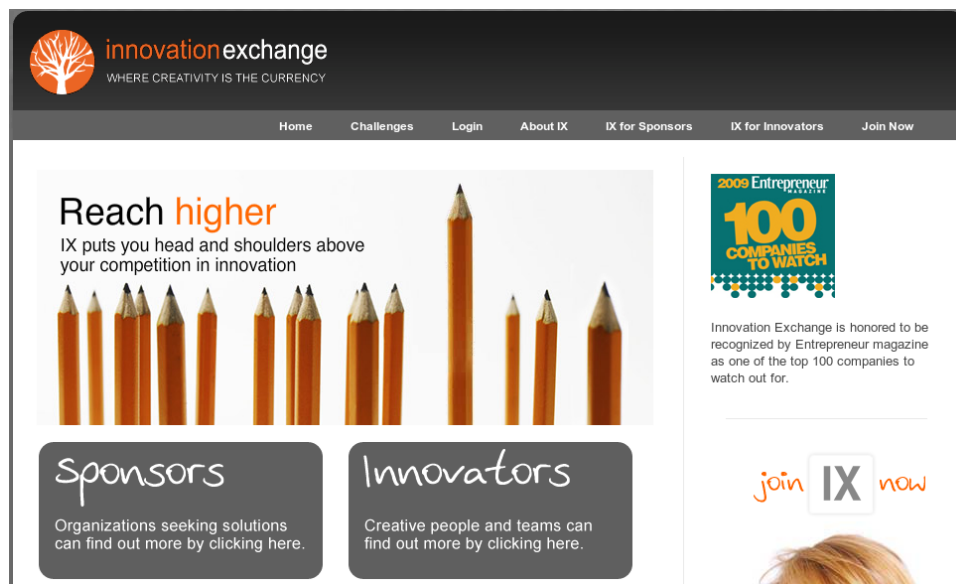


Figure 2.12. Open Innovation Center - *Innovation Exchange* (IX). It is an online open innovation center, where community members from all over the world respond to challenges sponsored by for-profit companies and non-profit organizations.

and thus this dissertation will be focusing on IHC. In the rest of this section, we list three representative cases, without further unfolding the concept. Interested readers may refer to [76][45][70][58] for further information on UHC.

2.3.1 Case 1: Recommender System

In recommender systems, based on customer online activities (viewing, clicking, purchasing), computer algorithms can implicitly collect statistics about behaviors, and then identify patterns and provide recommendations. For example, information about items users have viewed and purchased can be an indicator of group behaviors, where group members share similar likes and dislikes. Fig. 2.13 shows a screen shot of Amazon’s recommender system.

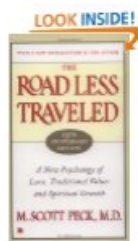
2.3.2 Case 2: Google Search Engine

Another example of UHC system is the Google Search Engine. It manifests how large, loosely organized groups of people can work together in an effective way without knowing that they are doing meaningful work [75].

Google continuously traverses the web in real time with crawlers, which visit web pages, copy the content, and follow links from that page to the pages linked within it, repeating this process over and over until it has crawled billions of pages on the web [6]. Google takes the discernments made by millions of individual website builders [37], and harnesses that collective knowledge of the entire web to produce relevant answers to the questions entered into the Google search bar [75].

Related to Items You've Viewed

You viewed



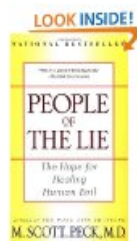
The Road Less Traveled,
25th...

► M. Scott Peck

Paperback

~~\$16.00~~ **\$8.85**

Customers who viewed this also viewed

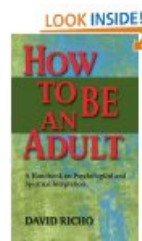


People of the Lie: The
Hope for...

► M. Scott Peck

Paperback

~~\$15.00~~ **\$10.20**

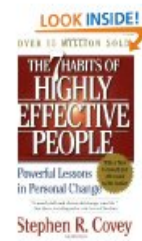


How to Be an Adult: A
Handbook for...

► David Richo

Paperback

~~\$10.95~~ **\$6.55**



The 7 Habits of Highly
Effective People

► Stephen R. Covey

Paperback

~~\$15.95~~ **\$8.69**

► [View or edit your browsing history](#)

Figure 2.13. Unintentional Human Computing (UHC) Example - *Recommender System*. Based on customer online activities (viewing, clicking, purchasing), recommender systems can implicitly collect the statistics about their behaviors and provide recommendations. For example, the information about items users have viewed and purchased can be an indicator of group behaviors, where group members share similar likes and dislikes.

2.3.3 Case 3: Demand Media

Demand Media [5] is a special case, since it combines both strategies of IHC and UHC. It bears UHC characteristics, as it identifies potentially high advertisement value topics by retrieving keywords that users frequently use in their searches. The more users search for a topic, the more attention it gains, and the more potential value it may bring in. Unintentionally, the searching keywords of web users tells Demand Media precisely what they like to see and what they like to read.

On the other hand, Demand Media has an IHC system component. After generating a topic list from a search engine, Demand Media opens up the topics to a pool of freelancers. The freelancers can investigate the topic, write articles, and submit them to editors. Depending on the acceptability of the articles, freelancers can obtain a varied amount of compensation.

2.4 Different Angles to Categorize Crowdsourcing Systems

Above, we provided a taxonomy to categorize existing crowdsourcing systems based on the work structure, within which crowds are coordinated and deployed. Essentially, there are other angles that researchers can take advantage of to classify crowdsourcing systems. These angles include *Crowd Motivations*, *Personal Organizations*, *Decision-Making Process*, etc. We discuss them as follows.

2.4.1 Categorization by Crowd Motivations

According to user motivations, Quinn and Bederson [81] classify existing crowdsourcing systems into five categories:

- *Pay*. Offering financial rewards is an easy way to motivate workers. Examples include *LiveOps* and *ShortTask* (shown in Fig. 2.14).

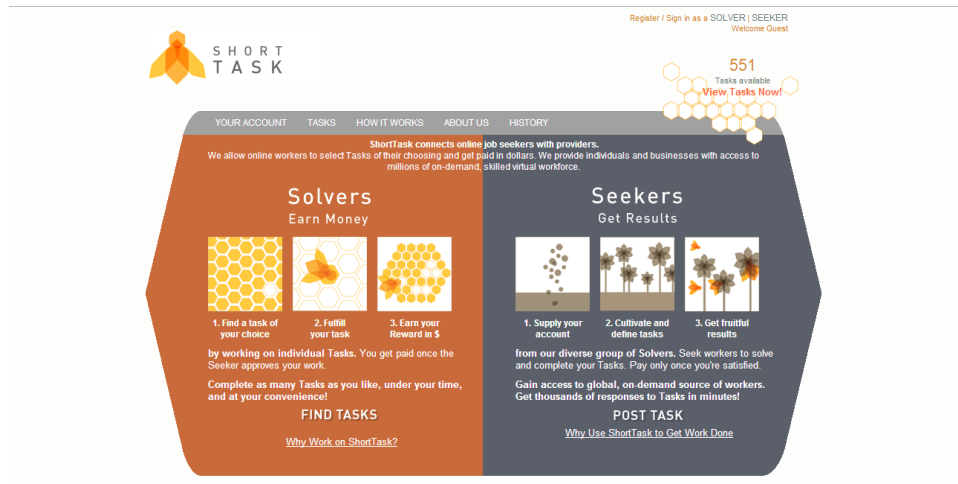


Figure 2.14. Financial Rewards as Motivations - *ShortTask*. ShortTask connects job seekers, who are companies or individuals that need various tasks accomplished without hiring in-house staff, and solvers who are workers that have the human intelligence to complete these jobs.

- *Altruism*. People desire to help when participants think the problem being solved is interesting and important, which was the case in the Jim Gray search in 2007 [54].
- *Enjoyment*. Entertaining activities have the potential to motivate users to solve intriguing or intelligent problems, such as protein folding [44], drug research [16] (shown in Fig. 2.15), and music recognition [70].
- *Reputation*. When problems are associated with prestige or glory, workers can be motivated by the possibility of public recognition and fame. Voluntary work for Red Cross/Crescent fall into this category.
- *Implicit Work*. ReCAPTCHA [95] uses implicit work to piggyback human computation to other online activities.

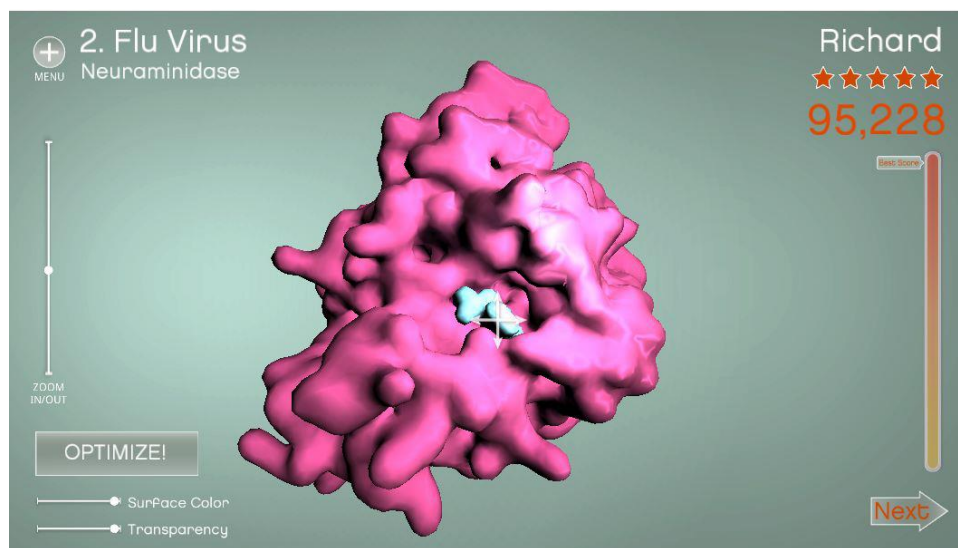


Figure 2.15. Enjoyment as Motivations - *Fit2Cure* [16]. Fit2Cure takes advantage of the human perceptions from online users' gaming activities to identify effective cut-in angles for protein drugs to engage proteins.

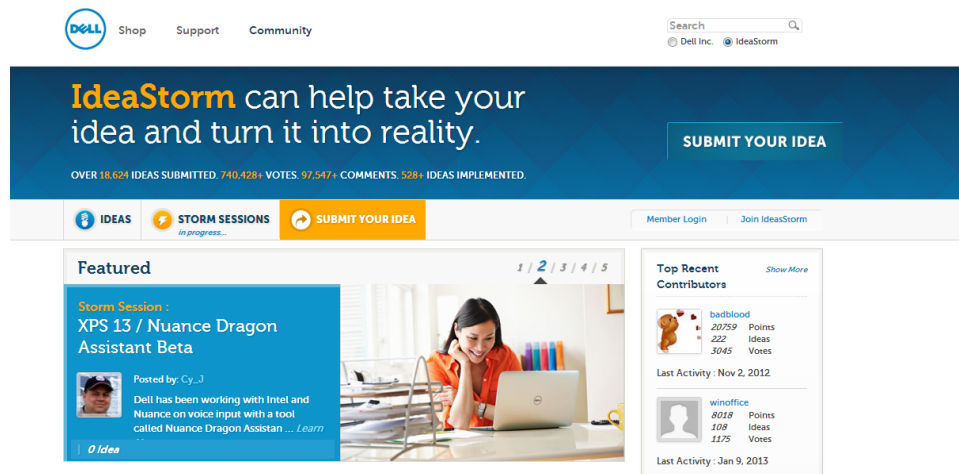


Figure 2.16. Contest - *Dell Social Innovation Challenge* (DSIC). The DSIC identifies and supports social innovators in solving the pressing problems with their transformative ideas. DSIC provides university students with teaching and training, start-up capital, and access to a network of mentors and advisors.

2.4.2 Categorization by Workforce Organization

Research [75] suggests that three typical approaches can be leveraged in a crowdsourcing project.

- *Collection.* If workers in the crowd generate content independently, project organizers can collect worker submissions, such as YouTube and Flickr.
- *Contest.* If only a very limited number of items (it is possible that there is only one item accepted, such as the one from the competition winner) in the crowd submissions are to be accepted, then project organizers can use the Contest model. Competition platforms, such as InnoCentive and Dell Social Innovation Challenge (shown in Fig. 2.16), use this approach.
- *Collaboration.* If workers in the crowd work together to create artifacts

and inevitable dependences occur among their pieces of work, then project organizers should consider using collaboration. Wikipedia is a typical online collaboration system.

2.4.3 Categorization by Decision-Making Process

After content has been created by crowds, a new challenge involves evaluating the quality of results to decide if they are acceptable. Two mechanisms are widely used: *Crowd Decisions* and *Hierarchy Decisions* [75].

- *Crowd Decisions.* The use of crowd votes to evaluate the quality of a new content is called crowd decisions. In this scheme, crowds play the role of both the content creators and arbitrators. For example, after a new post is created, crowds will collectively cast their votes (voting up/voting down) to rate its quality. Based on the crowd consensus, posts will either go up or drop down.
- *Hierarchy Decisions.* Associating hierarchical privileges to crowds to control product quality is called hierarchy decisions. An example is Wikipedia, where a hierarchy is deployed to maintain article quality: *Administrators*, *Bureaucrats*, *Stewards* and *Director*. At a lower level, administrators decide the acceptability of new content and mediate possible edit fightings, and at a higher level, bureaucrats monitor and supervise administrators to fulfill their responsibility. In some special situations, stewards can fill the vacancy of both administrators and bureaucrats. Percolating up along the hierarchy, if there are unsettled disputes, they may eventually reach the director. As of February, 2013, the English Wikipedia has 1,453 administrators, 36 bureaucrats, 39 stewards, and 1 director globally [11].

2.5 Our View - Categorization by Worker Roles

Based on previous research in literature and our own study, we present a new dimension for categorization of crowdsourcing systems, which concerns the different *Roles* that citizen workers play in the production process.

2.5.1 Roles

- *Collector*. Citizen workers can be leveraged as information collectors. For example, in the eBird project, birders count the number of birds in their own patches. Together, birders form a human sensing network composed of information collectors.
- *Processor*. Citizen workers also can be leveraged as data processors. For example, in Peekaboom [94], humans help computers retrieve information embedded in the images.
- *Contributor*. When acting as contributors, members can submit a video clip, a piece of a journal article, or a small amount of funding. Having aggregated pieces of contributions together, the product becomes significant and valuable. For example, the citizen journalism works this way.
- *Creator*. In open competition, citizens contribute novel ideas, designs or travel plans, and, in doing so, they become creators of intelligent content.

It is pivotal to discern different roles that crowds play in various crowdsourcing systems, because roles that crowds play may determine how they are to be recruited. For example, to use humans as creators, it is important to recruit a diverse crowd where individuals can make independent decisions and become potent

generators of new ideas. On the other hand, if crowds use information processors, diversity is not required and may even become a disadvantage.

2.5.2 Summary

Previously, we have discussed categorization of crowdsourcing platforms from different angles. Next, in Chapter 3, we describe our first experiment, which leverages crowds as information collectors to investigate nationwide crumbling infrastructures. In Chapter 4, we tap into crowds as processors to classify thousands of post-earthquake images. In Chapter 5 and Chapter 6, two projects are designed to utilize the “wisdom of crowds” at a higher level, using crowds with expertise as creators of new ideas. Finally, in the Chapter 7, we summarize this dissertation and propose several directions for the future research.

CHAPTER 3

CASE STUDY I: PHOTO SENSING OF CRUMBLING INFRASTRUCTURE¹

In Chapter 2, we stated that crowds can be harnessed as information collectors. This chapter presents a prototype, where a cohort of distributed citizen engineers collaboratively gathered data on crumbling infrastructures nationwide.

3.1 Background

3.1.1 Urgency of National Infrastructure Sensing

According to *American Society of Civil Engineers* (ASCE), the general condition of civil infrastructure in the US is in a worrisome situation. When evaluating the overall condition in 2009, the ASCE issued an alarming score of D for America’s infrastructure [8] (See Fig. 3.1). Four years later, when ASCE evaluated the overall infrastructure condition again, there were no signs that the condition had significantly improved (See Fig. 3.2).

As a painful lesson, in 2007, the busy I-35W Bridge in Minneapolis, Minnesota, collapsed during evening rush hours, claiming 13 lives and injured 145. Unfortunately, this bridge had exhibited evidence of cracking and significant corrosion before it collapsed [26]. In hindsight, corresponding authorities need to put a greater emphasis on infrastructure assessment and disaster prevention.

¹Results presented in this chapter have been previously reported in a conference paper [100].

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-
<div> <div>AMERICA'S INFRASTRUCTURE G.P.A.</div> <div>D</div> </div> <div> <div>ESTIMATED 5 YEAR INVESTMENT NEED</div> <div>\$2.2 TRILLION</div> </div>	
<p>NOTES Each category was evaluated on the basis of capacity, condition, funding, future need, operation and maintenance, public safety and resilience</p> <p> A = Exceptional B = Good C = Mediocre D = Poor F = Failing </p>	

Figure 3.1. 2009 Report Card for America's Infrastructure (Source: American Society of Civil Engineers (ASCE)). Note that the overall America's Infrastructure GPA is D, which indicates the possibilities of future infrastructure failures in the US.

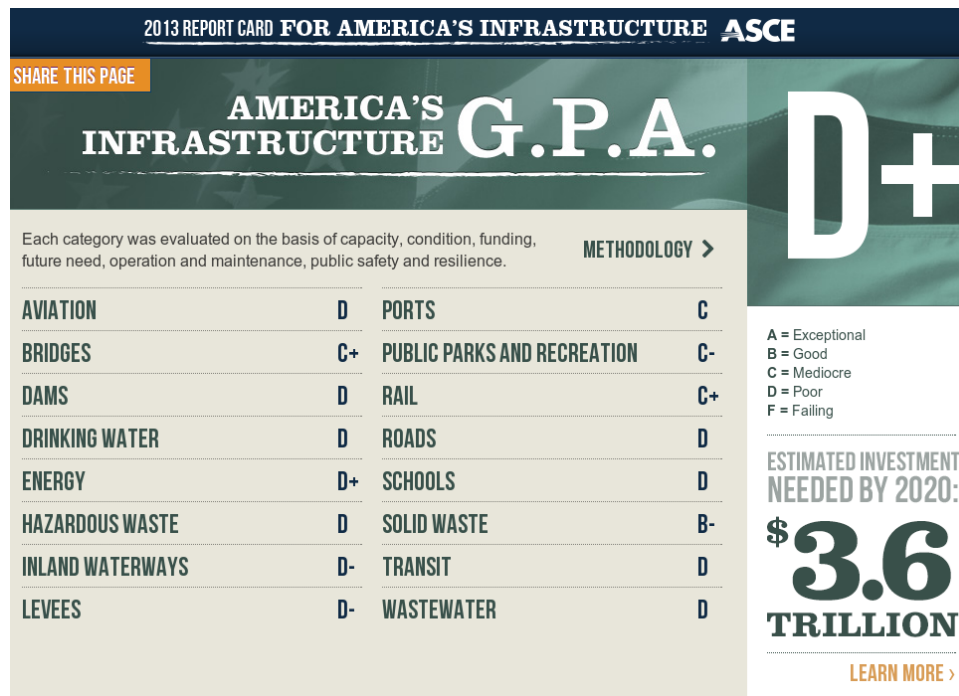


Figure 3.2. 2013 Report Card for America's Infrastructure (Source: American Society of Civil Engineers (ASCE)). Note that the overall America's Infrastructure GPA is D^+ . Compared to that in 2009, it can be observed that there is no significant improvement on the overall condition of America's infrastructure (D in 2009 vs. D^+ in 2013), and the amount of investment becomes more demanding.

However, an inevitable challenge is that infrastructure usually spans over a broad area, and it usually overwhelms the capability of government inspectors. Under these circumstances, we need to develop a practical, affordable, and effective sensing system, and citizen engineering can provide a promising solution to answer this call.

3.1.2 Mobile Sensing Network

With the advance of digital technology, recent research has shown a future for *Participatory Sensing* with digital devices [38]. The latest information technologies have equipped mobile devices with a wide range of functionalities (video/audio recording, accelerometers, GPS location, etc.). Together, mobile devices and their human users form a new type of network. This new type of network usually has a broader spatial coverage, less power supply concerns, and more powerful sensing functionality, thanks to the human intelligence behind the mobile devices.

Compared with the traditional network where sensors are largely fixed at certain positions, there are at least three advantages to a mobile sensing network:

- *Low Investment.* Hand-held digital devices, exemplified by cell phones, represent a high proliferation and pervasiveness. According to Mobile Marketing Association (MMA), currently 5.3 billion mobile devices are in use globally [27]. This fact indicates the feasibility of establishing a human-empowered sensor network with a broad spatial coverage and a low initial investment.
- *Human care.* Each mobile device is associated with a human user, whose human intelligence could be leveraged to conduct sophisticated activities. For instance, a human user may help to photograph flawed concrete from

an up-close angle. Also, mobile phone sensors have a more reliable power supply, because users have to take care of battery charging for their basic communication usage.

- *Educational Purposes.* When helping collect data about their environment, such as noise level or invading species, very often users have raised their awareness and social concerns about the issue as well.

3.1.3 Previous Work

Previously, researchers have conducted a series of experiments. In those practices, citizen sensing applications range from wild animal protection, to real-time environmental monitoring. Here are some studies in literature:

- *What's Noisy* A project that records and shares geo-tagged audio clips describing what sounds annoying [10].
- *What's Invasive!* An effort to document invasive plants in national parks [2].
- *BudBurst Mobile* A national campaign to observe plants' responses to climate and record environmental conditions [4].

Inspired by these previous studies, in the summer of 2010, we launched the citizen sensing project, which was intended to collect data about crumbling infrastructure nationwide. The crowd in this project was composed of juniors and sophomores from two engineering departments at a midwest university. Since their hometowns are dispersed across the country, when spending their summer break at home, they had diverse exposure to the civil infrastructures at their location.

That was a major consideration when we sent off our invitation letters, two weeks before the fall semester officially started.

3.2 Database Structure ^{2 3}

The database structure in this project was intentionally designed to accommodate the data from citizen inspectors.

The user table has an ID as a primary key, which is simply an auto-incremented integer. The name field is a unique *username* which is chosen at registration. The *password* encryption algorithm is an alternation between MD5 and SHA512 one thousand times with two salt variables mixed in. The key field is a value that is generated in a similar way and used to identify the user through cookies. The referred field is a foreign key indicating which user ID referred them to the table. The date joined and last visit are stored as Unix timestamps.

Each photo also has an ID primary key as well as a foreign key indicating the author of the given photo. Besides the *author information*, the *date* it was uploaded, *mime-type*, and *IP address* are also recorded. We store the original filename so that the user can easily see which photos they have already uploaded and avoid duplicates. On the server side, the files are renamed according to the date and user ID, to avoid conflicts with other users. Finally, we have a Boolean variable flagging whether or not the location was detected (approved), and the decimal values for the latitude and longitude.

²The cyber-infrastructure established for this project was the collaborative work of the author of this dissertation and Andrew Weber, then an undergraduate student from the Department of Computer Science and Engineering.

³The file system in this project is presented in Appendix A.

3.3 Workflow

The development of a citizen sensing system needs to address both technological challenges and human issues. The synergy between the crowd and the system is a vital part to project success and should be taken into consideration carefully.

Research [53] lists eight components to be considered when establishing a *Participatory Sensing* project, which are *Coordination*, *Capture*, *Transfer*, *Storage*, *Access*, *Analysis*, *Feedback* and *Visualization*. Based on this model and the experiences we gained from our practice, we propose a 10-component framework to guide for future citizen sensing project design. In this framework, as shown in Fig. 3.3, we particularly emphasize the interactions between organizers and crowds. In the following sections, we use our project as an example to illustrate the concept, but rules and principles can be generalized to other citizen sensing projects.

1. *Task Definition*

Before starting to motivate crowds, project organizers need to ponder the objectives of the project, and further decide its scope and scale, including the demographics of the crowd, and the goals and time frame of the project.

2. *User Recruitment*

User motivations are essential to user recruitment. There are extrinsic motivations, such as financial rewards and reputation enhancement, and intrinsic motivations, such as social concerns and self-fulfillments. In our practice, solicitation emails were distributed to engineering undergraduates, in which we promised prizes for participants with high quality submissions. We also circulated an open letter to arouse students' social concerns about the crum-

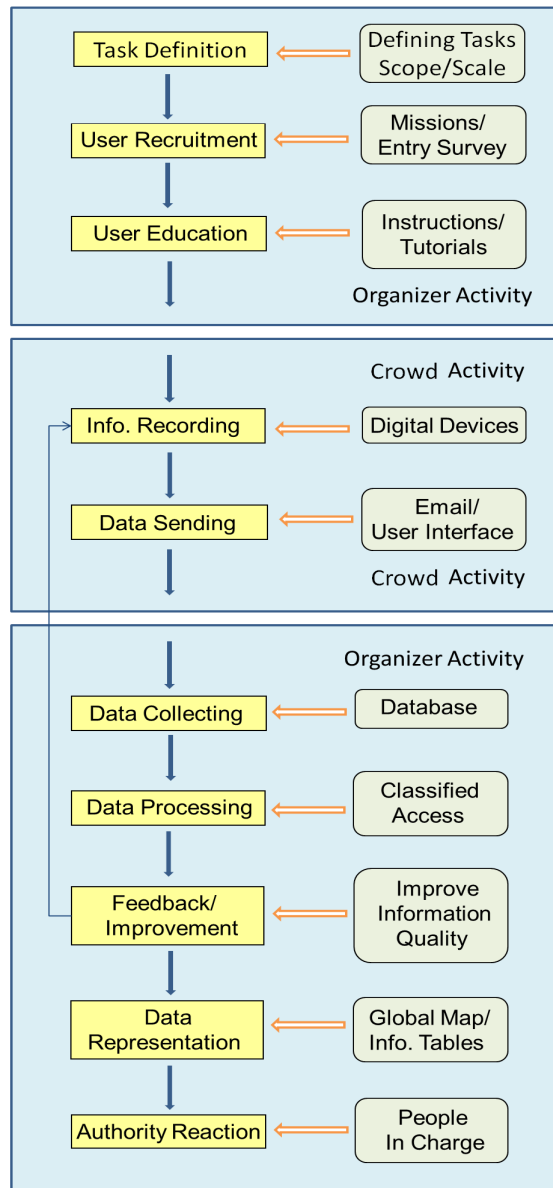


Figure 3.3. Framework of Citizen Sensing Projects. In this framework, 10 modules are presented, divided into Crowd Side and Organizer Side.

bling infrastructure in the country. A snippet of the open letter is shown as follows, and the content of the whole letter can be found in Appendix A.

*“... Sadly this infrastructure is in dire need of repair and the current visual inspection process only evaluates critical infrastructure elements like bridges once every two years. As a result, this research program seeks to involve citizens in the assessment process by asking them to take photos of damaged infrastructure in their communities and upload these images to our database so they can be evaluated and the relevant authorities can be notified in the event of significant damage that occurs between inspection cycles. This individual is participating in the program as a registered user...”*⁴

3. *User Education*

Research in psychology shows that individuals motivated by goals that are clear-defined and challenging tend to exert higher levels of efforts than goals that are too easy or vague [74]. As such, well-organized and easy-to-follow tutorials are likely to improve data quality greatly.

4. *Information Recording*

Citizen inspectors were encouraged to go outdoors and snap photos of problematic infrastructure, such as cracked structures, crumbling concrete, broken piers, and leaking tunnels. As the photo-taking functionality is inherently built into most digital devices, such as smart phones, there was no need to develop new photo capture applications in this study.

⁴This open letter was drafted by Prof. Tracy Kijewski-Correa from the Department of Civil & Environmental Engineering & Earth Sciences.

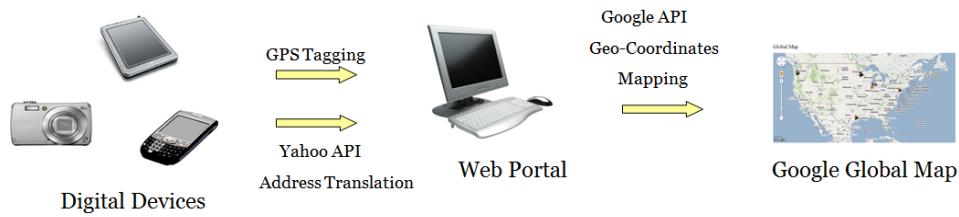


Figure 3.4. Two Options for Photo Submissions. With smart phones equipped with the geo-tagging function, users can email us photos with geo-coordinates directly or upload photos via web interface. Otherwise, they can either input a street address or use a movable marker to pinpoint the location on a Google Map embedded in the uploading page.

5. *Data Sending*

Two options were provided for photo submissions, as shown in Fig. 3.4:

- If users have any type of smart phones equipped with the geo-tagging function, they can email us photos directly or upload photos via a web interface. Our software can automatically retrieve geo-coordinates from the submissions.
- If their digital devices cannot geo-tag the photo automatically, users can either input street address or use a movable marker to pinpoint the location on a Google Map embedded in the uploading page (See Fig. 3.5).

6. *Data Collecting*

A data repository hosts the web service, receiving data from the digital devices through different approaches. A MySQL database saves the metadata of each photo into database tables.

Upload Photos

You may upload as many images at a time as you'd like, with an 8 MB total limit. Images must be in JPG format.

Please upload images with different addresses separately.

Photos

- Select User -

Browse...

Upload

Enter an address or click on the map to place a marker. Please zoom in as much as possible.

Street City State [Locate on Map](#)

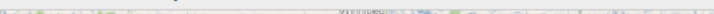


Figure 3.5. Two Uploading Options for Digital Devices without Geo-Tagging Functionality: *Street Fields* Vs. *Map Markers*. Users can use either street addresses or map markers to indicate the locations of where the photos were taken.

7. *Data Processing*

As mentioned previously, the users should trust the data management procedures. More specifically, the data managers should ensure data security and user privacy. On the other hand, the portal and database should be protected against malicious entities/items that may compromise system functions.

8. *Feedback and Improvement*

If data was found missing, citizen inspectors could be notified and then may revisit the venue and retrieve supplementary data, possibly from varying angles and distances, thanks to the human intelligence associated with the digital device.

9. *Data Presentation*

In our project, aggregated data was visualized with color balloons on a global map, with each color balloon representing one damaged infrastructure photo, as shown in Fig. 3.6.

- Note that the intricacy and importance of data security and user privacy should always be emphasized [38]. Data access was managed according to terms and conditions agreed to by participants. This is a two-fold issue: (1) Privacy concerns: over time, timestamps on photo submissions, combined with geo-space information, provide traceable data about citizen inspectors' life patterns; (2) Homeland security: the weak points of the national infrastructure may become targets of potential terrorist attacks. In this regard, the protection policy on our experimental portal was that all photos coming from an individual were

Global Map

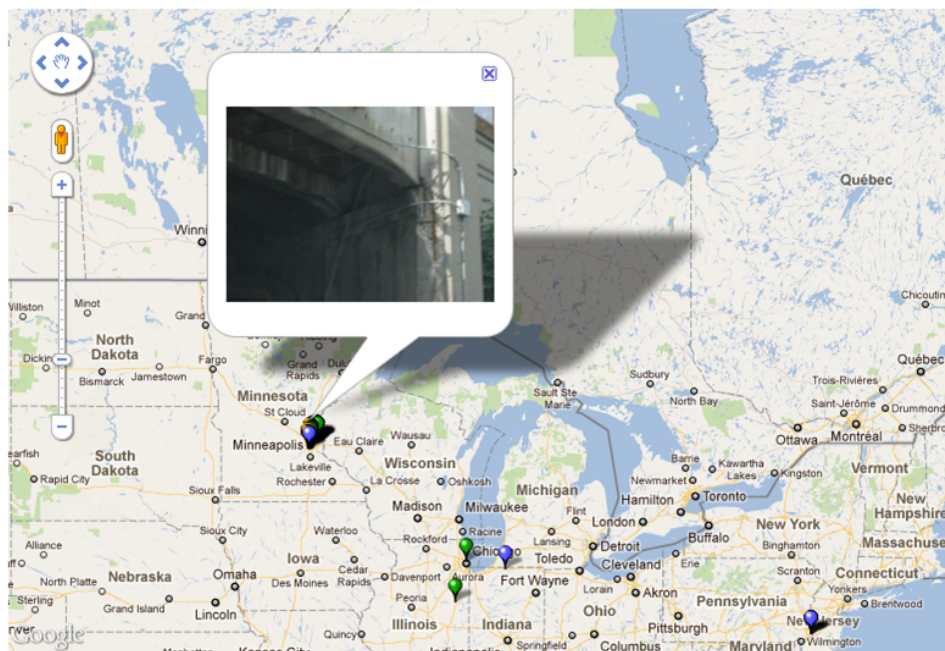


Figure 3.6. Global Map: Data Representation and Visualization. As a small scale experiment, our human subjects took over 200 photos of crumbling buildings from 6 states.

only visible to that individual. The global map, where overall infrastructure photos were aggregated and presented, was only visible to project organizers, masked from the public.

10. *Policy Influence*

Relevant authorities can be reached and informed, and, if necessary, the location and severity of infrastructure conditions can be further investigated to have a finer resolution.

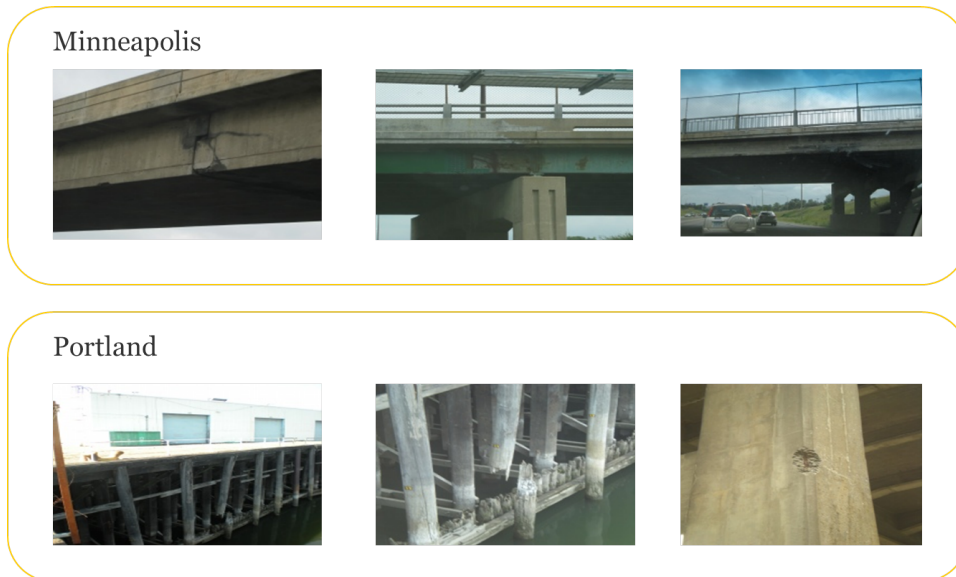


Figure 3.7. Sample Submissions from Citizen Inspectors. The three samples from the top row were from Minnesota, from which we can observe that some bridges/overpasses have started to crumble. The three samples from the bottom row were from Oregon, which have demonstrated the early signs of collapsing.

3.4 Results

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 deteriorating infrastructure, with a large portion of submissions of fairly high quality (6 sample photos are shown in Fig. 3.7). This study provides a new approach, where the citizen engineering can be leveraged to enhance the human ability in detecting infrastructure flaws, reducing financial resources, and, more importantly, saving lives.

3.5 Discussion

3.5.1 Main Contribution

In this chapter, we demonstrated the concept that dispersed citizens can be motivated and coordinated to form a human-empowered sensing network. Also, we present a 10-module framework that researchers and practitioners may find helpful to organize similar citizen sensing projects. Note that not all of the modules are required to occur in a project, and organizers should tailor the workflow to suit their unique situations.

3.5.2 Data Usage

In this project, the quality and quantity of the data collected matched design goals. As for the data potential usage in similar citizen sensing projects, this is a multi-fold issue, and future project designers should consider following aspects:

- *Data management.* The data management should be systematic and reliable, so that data security and user privacy are consolidated.
- *System Protection.* The portal and database should be protected against suspicious entities/items that may come from low-skilled or sometimes malicious users.
- *Citizen Inspectors' Benefits.* The citizen inspectors from the crowd that participate in a given citizen sensing project should receive benefits from data collected by the crowd. For example, some early warnings about potential dangers in their living areas could provide timely feedback to the citizen inspectors and their local authorities.

3.5.3 Untapped Opportunities

In this project, we utilized the photo-taking and geo-tagging functionalities of mobile devices. However, as the new technologies and new widgets emerge, such as accelerometers and temperature sensors, we can expect mobile devices will become more powerful with more options on data granularity and information types.

As a result, the sensor network of mobile devices will provide unprecedented opportunities for innovative applications on citizen sensing.

CHAPTER 4

METHODS FOR OBTAINING HIGHLY TRUSTWORTHY RESULTS THROUGH CROWDSOURCING¹

The main principle of citizen engineering is to leverage a large number of publicly accessible citizens to collaboratively solve real-world problems. In the previous chapter, we described a photo submission project that utilizes crowds as information collectors. In this chapter, by introducing an image classifying platform, we demonstrate that crowds can also be leveraged as data processors.

Although crowdsourcing is a promising approach to tackle problems that are challenging to computer algorithms, it inevitably has issues that need to be further addressed. One challenge is to retrieve quality results from various inputs of multiple participants. In this chapter, we present an online platform that organized citizen engineers to perform a complex image labeling task – classifying damage photos after an earthquake. This study aims to provide a new perspective to crowdsourcing project designs – especially when it comes to extracting results from a cohort of small size submissions collected from a large number of subjects.

¹This chapter was previous published as a conference paper [99], and an ongoing research aims to replicate the tagging procedures on Amazon Mechanical Turk (AMT). The comparisons between the two platforms – the on-campus platform and AMT – will be presented in future publications.

4.1 Introduction

Evolving information technologies provide unprecedented opportunities to build new web applications, and people are increasingly being woven into online communities, where they collect information, share knowledge and keep in touch with online friends. Observing that some of these human brain cycles could be leveraged to generate meaningful product, researchers come up with various web applications to channel scattered human computing power towards achieving common goals. In this chapter, we apply citizen engineering models to tackle problems in the domain of civil engineering.

In the civil engineering community, information and expertise on large-scale designs are usually trapped inside proprietary systems, and, due to intellectual property concerns, projects rarely benefit from the full knowledge available within the civil engineering community. This undesirable situation motivates us to design innovative systems via the crowdsourcing model to meet these challenges.

To investigate the effectiveness of the crowdsourcing model in resolving real-world problems, we designed a photo classification task. This task is to classify damage patterns in photos collected from the aftermath of the 2010 Haiti Earthquake. According to UN reports, physical damage due to large-scale natural disasters is frequently experienced in many populous areas worldwide [88]. In the regions devastated by disasters, a clear assessment of the loss is vital for local communities to conduct better damage analysis, infrastructure inspection, remediation and reinforcements [89].

4.2 Photo Tagging Platform

On January 12th, 2010, a massive 7.0 magnitude earthquake struck Haiti. After the earthquake, civil engineers flocked to the country and took thousands of photos on-site. Quickly, engineers found that the volume of photos exceeded their capacity to process them. As such, online human computation emerged as a feasible solution. Over one semester, an interdisciplinary team composed of civil engineers, sociologists, and computer engineers, established an online platform² (See Fig. 4.1) targeted at the challenge. College students were recruited through campus-wide posters and emails, and they performed tasks as surrogates for citizen engineers.

They signed up and followed procedures to perform photo classification tasks, and their online activities were recorded in detail. Over 17 days, the crowd submitted 9,318 photo classifications on 400 sample photos. As commonly seen in crowdsourcing projects, citizen workers, who were recruited online via an “open call” [56], submitted their answers with varying qualities. This fact challenged data analysis later on.

The following sections describe major steps in the experiment workflow.

4.2.1 Experiment Workflow

1. ***Entry Survey.*** The purpose of this questionnaire was to collect demographic and attitudinal data from the subjects.
2. ***Introduction Page.*** The introduction page describes task background and

²The procedures in this experiment were designed by David Hachen, a professor from the Department of Sociology, Zack Kertcher, then a post doctoral researcher from the Department of Sociology, and Tracy Kijewski-Correa, a professor from the Department of Civil & Environmental Engineering & Earth Sciences. The author of this dissertation implemented the cyber-infrastructure.

OSD-CI EXPERIMENT

[Help](#)[Introduction](#)[Tutorial](#)[Photos](#)[Logout](#)

IMPORTANT INFORMATION ABOUT THE EXPERIMENT

To give you a sense of the earthquake damage in Haiti, we ask that you watch the following video. Please click on the link below.

Port-au-Prince Before and After

Port-au-Prince Haiti

BEFORE

PARLIAMENT



GOOGLE EARTH

0:00 / 1:17

☐ I have watched this video.

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info@crowdstudy.org

Figure 4.1. A video of earthquake damage in Haiti, 2010. For the individuals in the *Moral Group*, before getting into real work, *citizen engineers* watched this video to obtain background information. (Note: The *Moral Group* and *Utilitarian Group* are the two motivation groups named by the two sociologists on this project. For detailed motivation studies in this project, readers may refer to [59].)

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Photo Classifying Tutorial

Jump To
Step 2: Primary Elements

Step 2: Identify which primary elements of the building are visible and can be assessed

Question: What primary elements are visible and can be assessed in this photo? (Select all that apply)

Note: Not all elements will be visible in every photo, but photos can have multiple elements. Please identify all visible elements in the photo including both damaged and undamaged elements if they are visible.

Response Options (select all that apply)	Definition of Elements	Example
COLUMN	Vertical element where the height (H) is considerably larger than the depth (D) and width (W).	
BEAM	Horizontal element where the width (W) is considerably larger than the depth (D) and height (H).	
SLAB	Horizontal element used as a roof or floor where the width (W) and depth (D) are considerably larger than the height (H).	
WALL	Vertical element used for partitioning where the height (H) and width (W) are considerably larger than the depth (D).	
Cannot determine	Photo does not appear to have any of the above elements.	

Figure 4.2. A sample page of the tutorial. Users are required to go through this tutorial before classifying photos, and they can revisit it anytime during the tagging process.

explains the experimental conditions, which was intended to arouse moral sentiments to help local residents in Haiti.

3. **Tutorials.** Tutorials, as shown in Fig. 4.2, provide detailed information on how to precisely classify the damage depicted in a photo, and by using hyperlinks, subjects can return to tutorials to reaffirm their understandings about the task.
4. **Damage Classification.** Subjects received one random photo at a time (a sample photo is seen in Fig. 4.3), until they completed all of the 400 photos



Figure 4.3. Web interface of a sample photo, in which a frame of questions is on the right. Subjects received one random photo at a time, until they completed all of the 400 photos in the database or the allocated 7-day tagging session expired.

in the database or the allocated 7-day tagging session expired.

4.2.2 Tagging Questions

As shown in Fig. 4.4, to classify a photo, subjects followed a 5-step damage assessment process. These 5 steps are:

1. ***Structure Recognizability.*** Determine if the whole or only a part of the structure is damaged in the image. A third option is the building thoroughly unrecognizable due to the damage, which leads to the answer “Cannot Determine.”

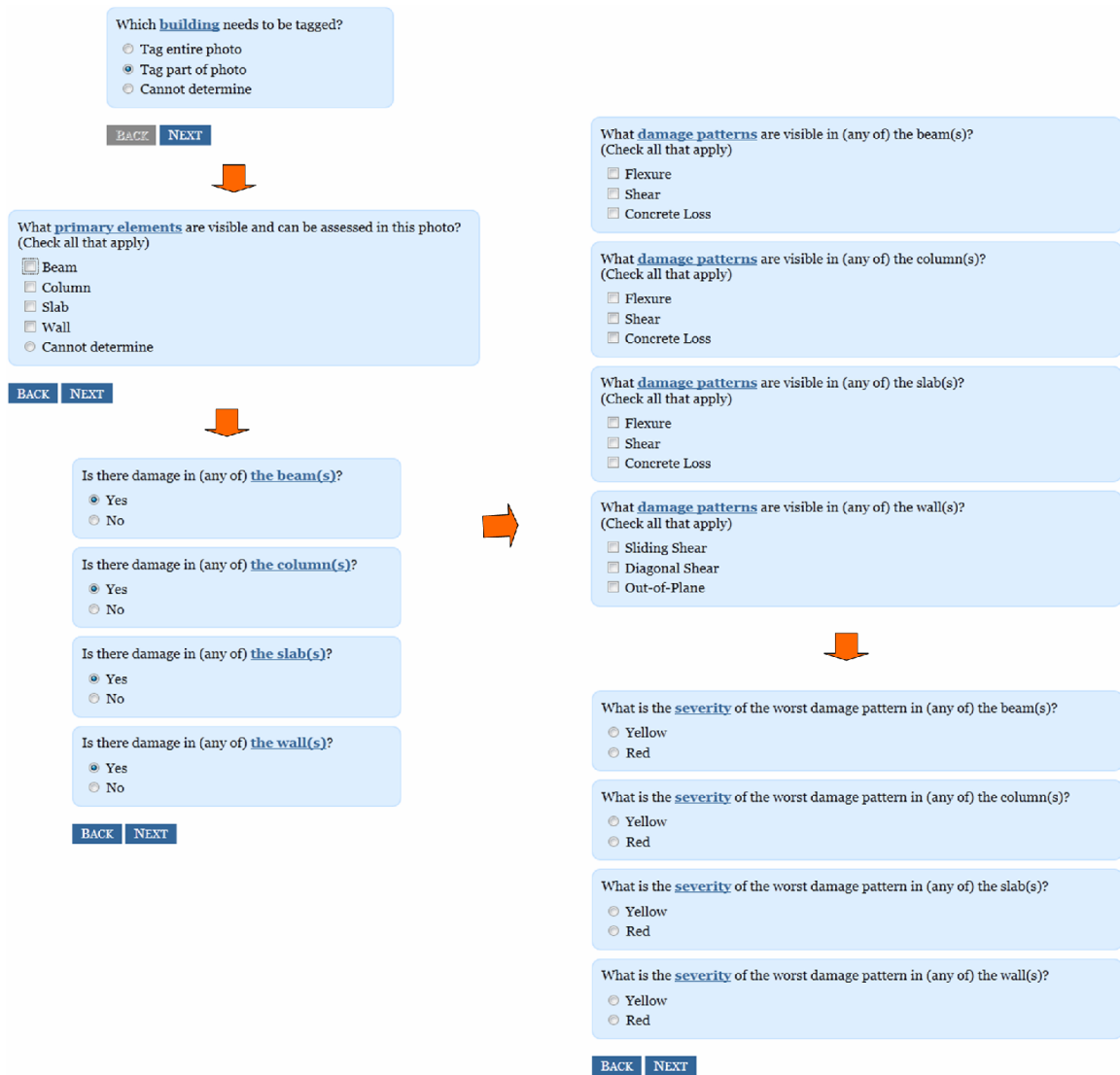


Figure 4.4. Question Flow. To classify a photo, subjects needed to follow a 5-step damage assessment process. When analyzing the submissions, we found that as the workflow went deeper, citizen workers' answers became increasingly diversified.

2. ***Element Visibility.*** Identify which elements (*beams, columns, slabs, walls*) of the building are visible and thus can be assessed.
3. ***Damage Existence.*** For each of the assessable elements, determine if any of those elements are damaged.
4. ***Damage Pattern.*** For each of the elements identified as damaged, discern its damage pattern.
5. ***Damage Severity.*** For each of the elements identified as damaged, appraise the severity of the damage (*Yellow* or *Red*).

The civil engineers on the study designed these classification questions. This workflow is more comprehensive and detailed than other photo classification research using crowdsourcing [42][79]. Also, workflow steps have uni-directional dependency, which means, in the same photo, the appearance of the next question is dictated by the answer of the previous question. Depending on the damage displayed and subjects' perceptions of the photo, the classification process may terminate at an intermediate step if the subject believed that certain building elements have no appearance or are not damaged.

4.2.3 Defining Ground Truth

To support the evaluation of our methods in this research, the ground truth for the 400 sample photos used in the experiment was obtained from experienced professionals - three senior PhD graduate students specialized in structure engineering (mentioned as *Professionals* hereafter) reviewed the 400 photos³. Their answers, used to infer the ground truth, fall into three categories:

³For detailed professional evaluations on these 400 photos, see Appendix B.

1. ***Unanimous Consensus*** All three Professionals converged to the same answer. Among all questions, the unanimous consensus accounted for approximately 29.6% of answers.
2. ***Majority Consensus*** Two out of three Professionals agreed with each other, and the third person disagreed with the other two. The majority consensus accounted for 53.2%.
3. ***Total Divergence*** Three Professionals entirely diverged. 17.2% of the answers showed total divergence. In the question flow, most questions only have two options, which indicates three Professionals unlikely give three different options. However, total divergence can happen when one Professional terminated processing a given building element early, when she believed this element was not assessable or no damage existed on it.

One of our observations was that similar to crowd consensus, the three Professionals also gradually diverged from each other along the question flow, as shown in Fig. 4.5.

When designing algorithms to process crowd inputs, we kept two criteria in mind:

1. ***Absolute Accuracy*** after applying the algorithm on the dataset collected from the crowd, we would like to see crowd data achieve 100% accuracy, or as high as possible.
2. ***Relative Accuracy*** even the crowd dataset cannot achieve extremely high accuracy after applying our algorithms, if the crowd accuracy is comparable to the Professionals' average accuracy, the crowdsourcing model is still a promising approach to process image data. The reason is that the

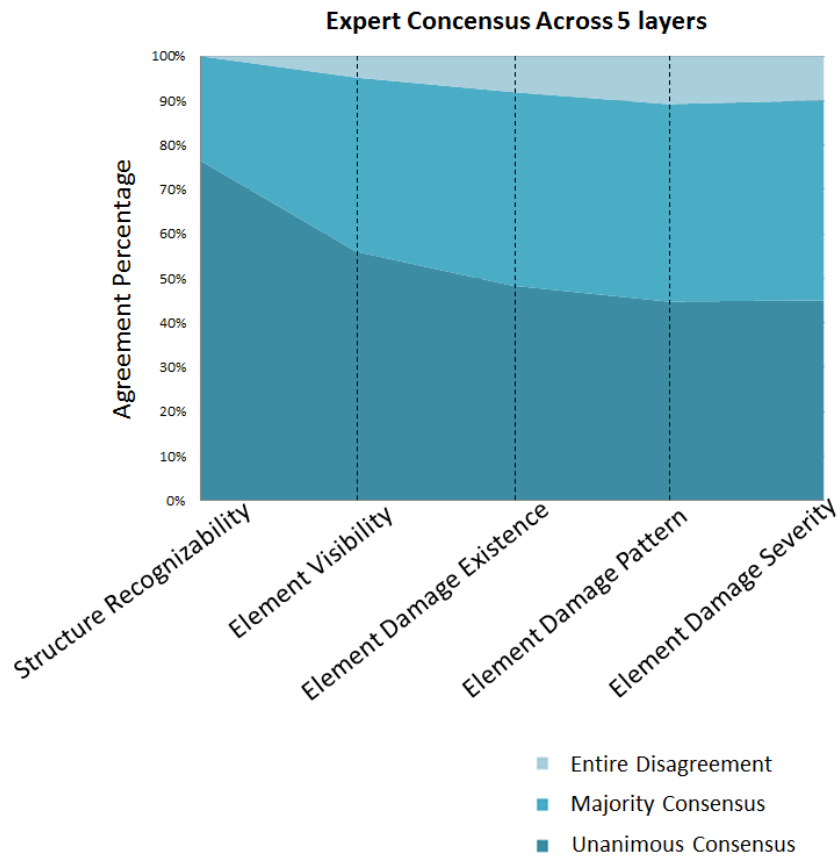


Figure 4.5. Professionals' Agreement. Three Professionals had a decreasing consensus along the question flow shown in Fig. 4.4. The area in the lightest color indicates the questions that Professionals had an entire disagreement upon.

crowdsourcing model almost always has two advantages in comparison to the traditional in-house solution model: (1) with acceptable quality, crowd work usually has a much shorter latency, and (2) from the financial perspective, citizen workers usually have lower unit cost, compared to in-house employees.

In our study, we consider the *Majority* and *Unanimous Consensus* as the ground truth, and disregard those 17.2% questions, where *Total Divergence* appears. This way, we can have a more reliable ground truth to evaluate the quality of collective work from citizens. Specifically, after normalization, 3 Professionals have a combined 78.6% ($(29.6\% + 53.2\% * 2/3)/(1-17.2\%) = 78.6\%$) accuracy, which indicates the frequency of one given Professional's answer being in the majority of the three Professionals. Also, note that the ground truth defined in this section is not part of the algorithms we discuss in the next section. Rather, the ground truth only helps in evaluation of the four algorithms introduced in the section *Algorithm Design*.

4.3 Data Cleansing

In our study, we observed that some participants had a rapid decrease in their average classification time. This sharp decrease of question-answering time may be an indicator of low quality responses. We plot the average classification time across all subjects in Fig. 4.6, where the subjects in the left-most bins spent much less time than average subjects did.

To identify unreliable subjects and deal with their noisy data, we investigated three different data-cleaning approaches:

Approach 1 - Averaging tagging time. Delete subjects whose average

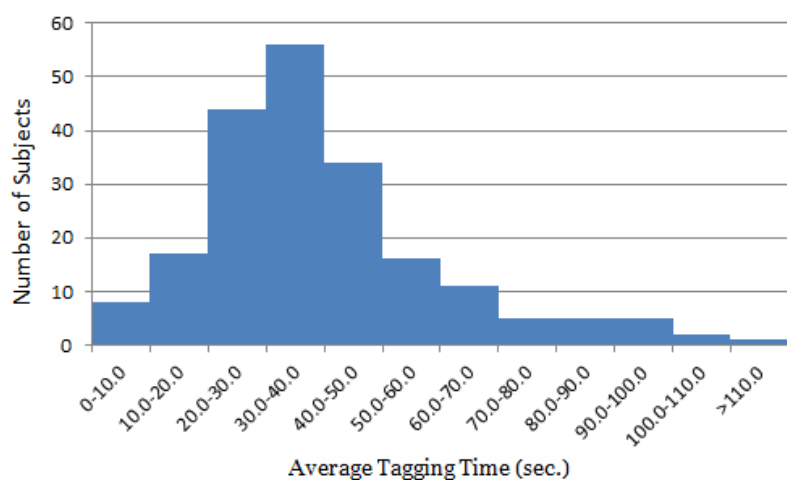


Figure 4.6. Subject distribution on average tagging time, shown with equal-width discretization. The first bin represents users that spent lowest average tagging time.

photo classification times are far below the average time across all subjects. In our case, it is estimated to take 30-60 seconds to classify one photo. If a subject's average classification time is lower than a threshold (e.g., 10 seconds), this subject is suspected to be a free loader who entered low quality data.

Upon further review of the data set, a significant cause of the low classification time is some dubious long “Cannot Determine” sequences. As described in the section *Damage Classification Workflow*, Step 1 includes a high level question, asking subjects whether the whole building structure damaged by the earthquake is still recognizable. If a subject assessed that the structure had entirely collapsed, a shortcut, “Cannot Determine,” can be the answer to the photo. In other words, if “Cannot Determine” was chosen, the classification process on this photo has completed after the very first step, and the whole photo may take less than one second for a subject to process. Examining the data, we found a portion of subjects

“gamed” the system by repeatedly using “Cannot Determine” as a shortcut to skip additional classification steps.

Approach 2 - Shortcut proportion. Subjects are identified as free loaders if the percentage of their shortcut answers is higher than a threshold. In our case, the shortcut is the “Cannot Determine” answer.

Approach 3 - Shortcut sequence. If the length of consecutive shortcut answers exceeds a threshold, then this sequence becomes suspicious. In our case, according to the Professionals, there is only a small portion of photos (less than 10% ⁴) among the 400 photos where building structures cannot be assessed due to severe damage, where “Cannot Determine” is a legitimate answer.

As shown in Table. 4.1, before going for the shortcut, suspected free loaders spent a regular amount of time classification photos just as normal subjects did (See Fig. 4.7). Likely, this portion of photo classifications is still useful. Another observation is that even serious subjects may suffer low accuracy periods after long classification sessions. Under these considerations, the third data cleansing approach is most plausible. In our case, instead of throwing away all classifications from suspicious subjects, we cleanse only the low-quality data, which is, namely, the dubious “Cannot Determine” sequences. The rationale of using Approach 3 for data cleansing is also supported by following two statistical analyses.

4.3.1 Intraclass Correlation Coefficient (ICC)

Intraclass correlation coefficient (ICC) is a descriptive statistic that measures the resemblance of data entries within groups. The closer the data points resemble one another within the groups, the higher the intraclass correlation coefficient

⁴Interested readers may refer to Appendix B.

TABLE 4.1:
FIVE USERS WITH LOWEST TAGGING TIME

User Index	Number of Classified Photos	Average Tagging Time	“Cannot Determine” Sequence Appearance in Classified Photos	Number of Photos in Sequences	Average Tagging Time on Sequences (sec.)	Average Tagging Time on the Rest of Photos (sec.)
1	400	2.235	54 th -400 th	347	<1	11.22
2	400	2.715	76 th -400 th	325	<1	10.74
3	400	7.573	114 th -400 th	287	<1	24.59
4	400	8.678	172 th -382 th	209	<1	17.32
5	400	9.238	138 th -400 th	263	<1	25.51
...

Note: It is commonly seen there are long, suspicious “Cannot Determine” sequences in free loaders’ submissions, which bring down the average tagging time. Note that workers used more time in the beginning.

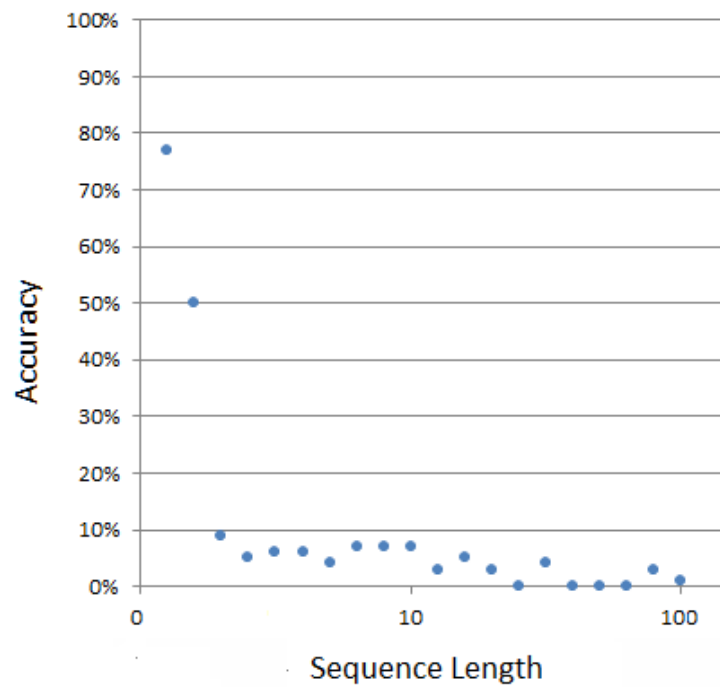


Figure 4.7. Accuracy vs. “Cannot Determine” Sequence Length. There a rapid decrease in accuracy as sequences grow longer, and sequences longer than 3 have very low accuracy (below 10%). The third approach, instead of removing entire tagging sets from suspicious users, allows us to keep the regular portion of data in the users’ tagging process, even these users might become careless later on.

is. Among the three approaches, crowd data showed the highest ICC after being pruned by Approach 3, which means the crowd has the highest degree of consensus.

ICC is a good indicator of crowd congruity. Also, we want to measure the crowd consensus' accuracy, which is achieved by the following metric – crowd consensus accuracy.

4.3.2 Crowd Consensus Accuracy

For each question, there are multiple inputs from multiple subjects, we calculate the crowd consensus for that question by identifying the answer that has the most subjects agreeing on. To compute the crowd accuracy, we compare the answers from the crowd consensus with the answers from the Professionals' ground truth: for each question, if the answer of the crowd consensus and the answer of Professionals are identical, the crowd receives one point. Otherwise, they receive zero points on this question. If there is a tie, the crowd receives a fraction of the point. The crowd consensus score is the total number of points that the crowd received, and accuracy is the total points that the crowd received divided by maximal number of points the crowd can possibly receive. Note that different photos have variable maximal points, depending on the damage existence and visibility in those photos.

For the data set in the experiment, we find that the crowd consensus achieves highest accuracy with data cleansing Approach 3. The following discussion is based on the experimental data after applying Approach 3 on the dataset.

4.4 Algorithm Design

4.4.1 Algorithm Principles

The ultimate goal of the following four algorithms is to retrieve highly trustworthy results from subjects' collective inputs. Algorithm 1 is named "Simple Voting," where individuals in the crowd have an equal voice in the final answer. In other words, individuals in the crowd are considered to have the same level of expertise. Algorithm 2 is called "Branch Composite", where each element of the damaged building, represented by a question branch in the workflow, randomly selects one individual and uses her answers as the final answers to all questions related to this building element. Algorithms 1 and 2 do not explicitly consider the variability in the quality of individuals' answers. Undoubtedly, there are always skilled individuals and error-prone individuals in the crowd, and they submitted their answers with different qualities. We can improve the answer quality by emphasizing the assessments from skilled individuals and minimizing the negative impact of the error-prone individuals. In this way, the final answer will be more reliable, as we differentiate individual credibilities in the crowd. This consideration is the rationale behind Algorithms 3 and 4.

4.4.2 Algorithm 1: Simple Voting

For each question, we can calculate the crowd consensus in a straightforward way, where we do not differentiate accurate individuals from error-prone individuals. All individuals are considered to have the same level of credibility, and the answer that the most individuals agree upon is the final answer. This calculation is rather crude; nonetheless, this is a simple algorithm that can serve as a starting point for more complex Algorithms 3 and 4.

When applying this algorithm on our data set, according to the Professionals' ground truth, this simple voting model generates 74.0% accuracy (Table. 4.4 has a detailed comparison between the 4 algorithms we discussed in this section.) We calculated the accuracy as follows:

1. After determining the crowd consensus, we can calculate the number of points the crowd obtained from each photo.
2. For each photo question, if the crowd answer agrees with the Professionals' ground truth, we give one point to the crowd. Otherwise, the crowd does not receive any points for question.
3. The crowd accuracy is the ratio of the points that the crowd collected across all photos divided by the maximal points that the crowd could possibly get over the 400 photos.
4. Besides crowd accuracy, we also can calculate each individual's accuracy across all photos that this individual has classified. The way we accomplish this is that we can easily compare the answer from the individual and the answer from the crowd consensus on all questions this individual has answered.

4.4.3 Algorithm 2: Branch Composite

Another naive approach is to randomly pick one individual's answer as the final answer for the entire photo. This approach can quickly generate results, yet, due to its randomness, the quality of photo classifications is not consistent, and is entirely dependent on the credibility of the individual. To mitigate the risk of

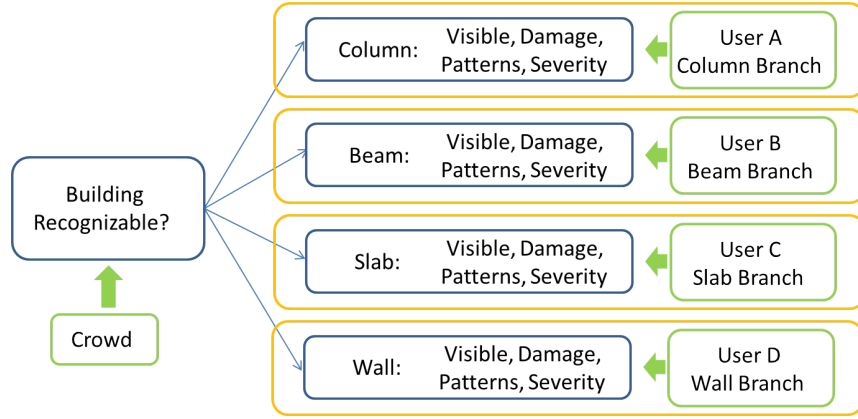


Figure 4.8. Branch Composite. The 25 questions associated with one photo fan out into 4 branches. One user answers one branch.

using a single individual's answer, a little better approach is to let one individual classify one branch, as shown in Fig. 4.8.

Since there are always multiple individuals working on the same photo, the inconsistency issue of the output in the single individual model is reasonably alleviated. After repeatedly running the same Branch Composite algorithm 10 times on the data set, with identical experimental settings, the 10 crowd accuracy rates in these 10 runs fall into a range, 55%-72%. The calculation of accuracy that Algorithm 2 generated is the same as that in Algorithm 1 - the points that the crowd actually collected divided by the points that the crowd could maximally acquire for the 400 photos, in accordance with the ground truth. The Algorithm 2 has 63.5% accuracy (See Fig. 4.4), after taking an average of 10 runs.

4.4.4 Algorithm 3: Leader Verdict

The third algorithm is derived from the collaborative robot control model presented by Bigham et. al. [69]. Bigham et. al. investigated mediating strategies

to enable crowds to collaboratively direct a mobile robot to reach its destination. The process aggregates multiple controlling inputs to reach a common goal. Similarly, in our study, we also want to generate reliable answers from multiple inputs of the crowd.

This model of collective work is to allow multiple classifications from multiple individuals to answer the same question. Based on Algorithm 1, Simple Voting, we developed Algorithm 3, where instead of using a simple majority, we want to use the answer from accurate individuals, and minimize the noise from error-prone individuals.

Firstly, we need to calculate the individual score and individual accuracy. The individual score on each photo is the total points this individual received from classifying this photo. If an individual’s answer agrees with the crowd consensus, this individual receives one point. Otherwise, this individual does not receive any points on this question. The photo score for an individual is calculated by Eq. (1), where S_p is the score of photo p , s_{pk} is points the individual obtained from a single question k in photo p .

$$S_p = \sum s_{pk} \quad (4.1)$$

Note that the maximum points that an individual can receive from a single photo is a variable, which is decided by the crowd consensus. The majority of individuals in the crowd may agree that some building elements, e.g. columns, are not visible, not damaged, or even that the entire photo is not recognizable. In those cases, the maximum points an individual can receive from a single photo is

less than the number of designed questions in the workflow. Also, note that there may be multiple appearances of the same building element within a single photo. To address this issue, in the tutorial, we made it clear that citizen engineers in the crowd are expected to report all visible building elements and their damage patterns.

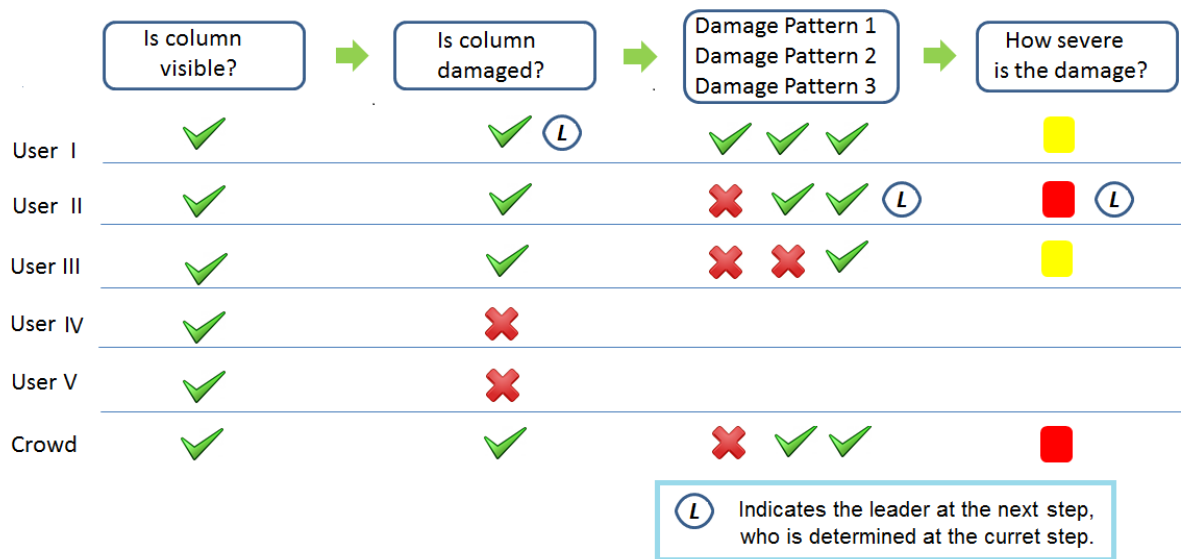
Having calculated the individual score on each photo, we generate Table. 4.2, which, photo by photo, shows points that individuals have collected and the maximum points an individual can possibly collect. For each photo, the individual with the highest score is the initial leader to start with in Leader Verdict algorithm).

From Table. 4.2, Algorithm 3 picks the individual who has the highest score for a given photo, and this individual is the initial leader at Question 1 of this photo. At any step, the leader’s answer is the final answer at the current step, whether it agrees with the consensus or not. Meanwhile, the leader is also “checked and balanced” to ensure that she does not stray afar from the crowd consensus. At the current step, if the leader’s answer agrees with the crowd consensus, at the next step, the algorithm will use the same leader. Otherwise, the leader will be dethroned, and a new individual, who has the second highest score and whose answer is identical to the crowd consensus at the current step, will be the new leader for the next step. The process is illustrated in Fig. 4.9.

By using leader judgments, which are supposed to comprise the most plausible answer at each step, we minimize the impact of error-prone individuals.

4.4.5 Algorithm 4: Iterative Processing with Dynamic Weight Assignment

Similar to that used in Galaxy Zoo [73], the fourth algorithm emphasizes the inputs from individuals whose answers are consistently close to the crowd consen-



The current leader is User I. For each photo, the individual who gets the highest score across the entire photo is the leader to start with.

The choice of the current step is "Yes" from User I.

User I agrees with the crowd. So, the leader at the next step is still User I.

The current leader is User I.

The choice of the current step is "Yes" from User I.

User I agrees with the crowd. So, the leader at the next step is still User I.

The current leader is User I.

The choice of the current step is "yes", "yes", "yes" from User I.

User I disagrees with the crowd. So, the leader at the next step will be User II, who agrees with the crowd.

The current leader is User II.

The choice of the current step is "Red" from User II.

This is the last step. No need to decide the leader for the next step.

Figure 4.9. The majority votes decide the leader of this step, and the leader gets to decide the answer at the next step. If a leader agrees with the crowd, she keeps leading, and otherwise will be dethroned. The user denoted by "L" marker is the leader at the step.

TABLE 4.2:
INDIVIDUAL SCORE (TOTAL POINTS) ON EACH PHOTO

	Photo 1	Photo 2	Photo 3	...	Photo 400	Individual Total Points	Individual Total Maximally Possible Points	Individual Overall Accuracy (Total Points/ Max. Possible Points)
Maximum Possible Points \rightarrow	20	25	21	...	19			
Individual 1	19	10	N/A	...	10	1301	3202	40.63%
Individual 2	19	N/A	20	...	N/A	222	1209	18.36%
Individual 3	10	N/A	N/A	...	15	125	278	44.96%
...

Note: From the photos the individuals classified, represented by columns, they received some points.
N/A means this individual did not classify this photo.

TABLE 4.3
GROUP ASSIGNMENT

Group Index	Number of Users	Weight
1	40	5
2	40	4
3	40	3
4	40	2
5	42	1

sus. In this algorithm, individuals in the crowd are divided into different groups according to their classification accuracy, and by assigning weights to different groups, this algorithm lets individuals from groups associated with higher classification accuracy have a bigger voice in the final answer.

Specifically, the algorithm progressively increases the weight of the groups composed of accurate individuals who have a higher classification accuracy, and decreases the weight of the groups composed of error-prone individuals with lower classification accuracy. Within the same group, all individuals have equal weight. When calculating the crowd consensus, the algorithm not only takes into consideration the answers of the individuals, but also the credibility of individuals embodied by the group weight. This algorithm makes the crowd consensus tilt towards the answers of the more reliable individuals.

4.4.5.1 Crowd Consensus Calculation

Firstly, we assign an equal weight to all groups. Since all individuals have the same weight, the value of the weight does not have an effect on the crowd consensus calculation. Having calculated Table. 4.2, we have the statistics of individuals' overall accuracies, and now we can assign them into different groups according to their accuracies. Group weights are tied with the individual accuracies. A higher accuracy means more credibility and a heavier weight.

The effect of weight assignments is that the higher the weight of an individual, the larger proportion this individual's answer will take into the final answer. Note that individuals from heavyweights have more votes tied to their answers. For instance, a skilled individual selects answer A , and an error-prone individual selects answer B for the same question. It is possible that answer A may get 5 times as many votes as answer B does, simply because of the high weight associated with the skilled individual's answer.

When calculation the consensus, consider the following example: for instance, 4 individuals classified photo k , where individual A has weight 2, individual B has 4, individual C has 6, and individual D has 8. When answering question i , individuals A and B selected answer x as their answers, and individuals C and D selected answer y . In this manner, answer x will get $(1*2+1*4) = 6$ votes, and answer y gets $(1*6+1*8) = 14$ votes. Therefore, the crowd consensus on question i of photo k is answer y , since answer y obtained more votes than answer x .

4.4.5.2 Group Assignment

As shown in Fig. 4.10, based on the individual accuracy, the valid individuals can be divided into groups (one sample assignment is shown in Table. 4.3). The

high-skilled individuals are assigned into a group with high weights. The error-prone individuals are assigned into a group with low weights, which represent the low credibility.

4.4.5.3 Next Iteration

After reassigning weights, the loop goes to the next iteration. Based on the new weight assignment, a new crowd consensus can be calculated, as well as updated individual scores and accuracies. Consequently, new group assignments are calculated. This loop continues until the stop criterion is met.

4.4.5.4 Stop Criterion

Between two consecutive iterations, if there are few changes on individual weights, this means that crowd consensus and individual scores have converged and become stable. In practice, we set the stop criterion with a *1% individual Rule*, which means if there are less than 1% of individuals who have to change their weight assignments between two consecutive iterations, then the loop terminates, and the algorithm outputs the current crowd consensus as the final result.

4.4.5.5 Crowd Performance

Applying algorithm 4, Dynamic Weight, to the data set, it is observed the crowd accuracy has improved from 74.0% to 79.2%, as shown in Table 4.4.

4.4.6 Pseudocode

To better illustrate Algorithm 4, we present its pseudocode in Code 1.

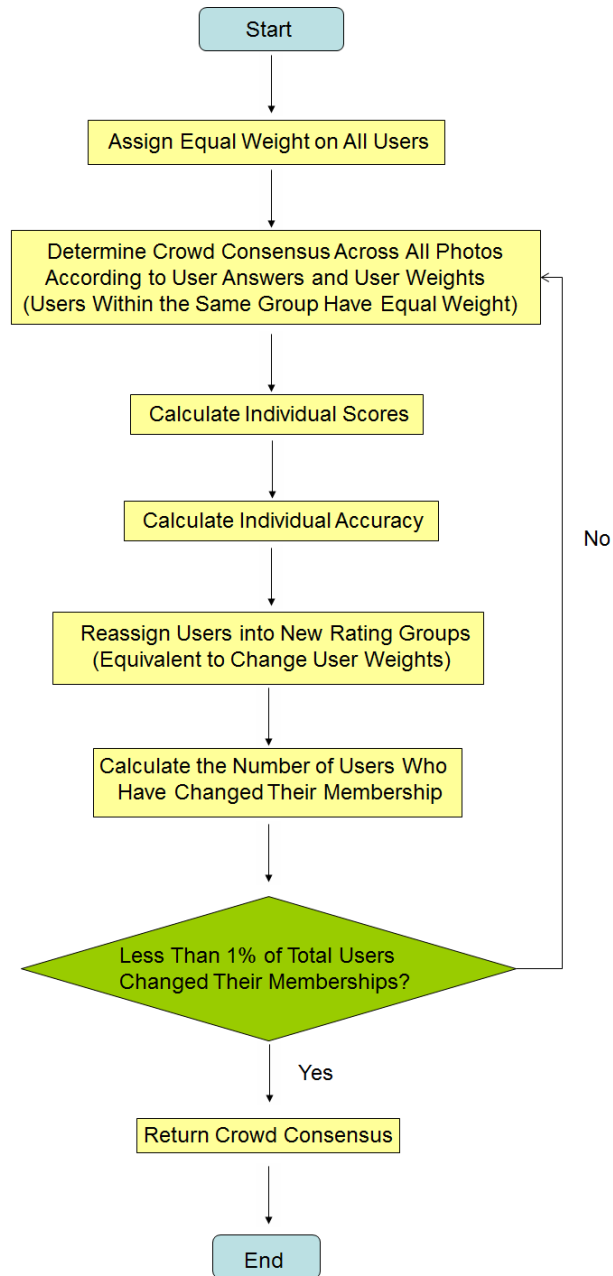


Figure 4.10. Algorithm 4: Iterative Processing with Dynamic Weight Assignment (The figure is adapted from Zhai et. al. [99]).

Algorithm Code 1: Iterative Processing in Algorithm 4.

Let all users have the same initial weight 1

Let weightChange = inf.

while *weightChange* \geq 0.01 **do**

for *Each photo* **do**

for *Each question in this photo* **do**

Calculate the crowd consensus on this question in this photo

(The option that gathered the most votes is the crowd consensus)

end for

end for

for *Each user* **do**

for *Each photo this user has classified* **do**

Calculate the points this user obtained from this photo

end for

Calculate the overall score of this user across all photos

Calculate the overall accuracy of this user across all photos

end for

Rank all users based on their accuracy

for *Each user* **do**

Assign this user into a group based on the ranking

end for

$\text{weightChange} = U_c / U_{\text{total}}$

U_c is the number of users that change their group memberships

U_{total} is the number of users in total

end while

Return crowd consensus

4.5 Discussion

4.5.1 Sample Size and Confidence Level

In this experiment, 242 subjects registered, out of whom 204 subjects had classified at least one photo (38 users did not have any inputs on any photos). Based on their submissions, we used statistical methods to infer plausible answers to each photo.

One issue to discuss is “can we achieve more accurate results by increasing the number of subjects in the crowd.” For example, if we double the number of subjects, could we end up getting more trustworthy results that are closer to the ground truth?

The conclusion we reached is that increasing the number of human subjects in the experiment does not necessarily enhance its accuracy, relative to ground truth. Increasing the number of subjects, i.e., enlarging the sample size, can better predict population statistics. The population statistic in our case is the citizen workers’ common sense answer to the question, reflecting how a sensible citizen worker would answer the question after reading the tutorial.

However, more reliably reflecting this “common sense” answer of general citizen workers may or may not lead to a more accurate answer, which is evaluated in our study by the ground truth estimated by 3 structural engineering experts.

Here is an intuitive example that shows people’s common understanding or common sense beliefs, may not necessarily align with the “truth”. Based on an ancient belief that diseases were caused by imbalance of blood and other body fluids, in many western cultures, bloodletting was a popular practice to cure diseases and maintain health. In bloodletting, patients voluntarily withdrew often small quantities of blood. As a common medical treatment, bloodletting was trusted

and practiced in Europe for almost 2,000 years. It was not until the late 19th century that it was gradually discredited and more scientifically defensible medical means were promoted.

From this example, we can see an “old common sense truth” can later be proved wrong. Also, it needs to be empathized that citizen workers, about whom we try to make inferences based on the 242 human subjects we have, should have similar demographics and training level to the 242 experiment subjects.

Another important facet about the sample size is that the effect of increasing the number of subjects has less impact on clear-shot photos than it does on controversial photos. For example, if photo was shot up-close from a proper angle, the damaged building elements in the photo become conspicuous. In this case, citizen workers tend to reach strong consensus quickly and unequivocally. Putting in more workers unlikely bring in any significant change on the crowd consensus.

Examining the 400 photos in the experiment, we found there were 4 types of photos that subjects had strong consensus on:

4.5.1.1 Category I: Strong Consensus

Type 1. Building has no significant damage This is an extreme case. When building has no significant damage (e.g. Fig. 4.11), subjects converged quickly.

Type 2. Building entirely collapsed (Cannot not determine) This is another extreme case. When a building has entirely damaged, e.g., suffering pancake damage (e.g. Fig. 4.12), subjects also quickly reached the consensus.

Type 3. Up-close Shot Photos When the building damage was limited to a small area and well presented, answers become obvious (e.g. shown in Fig. 4.13).

Type 4. Prominent damaged element in clear contrast with other elements

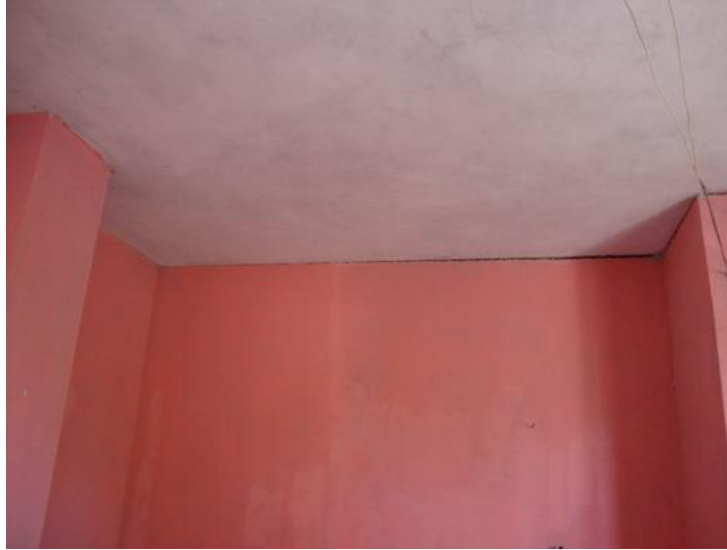


Figure 4.11. Strong Consensus Type 1:
Building has no significant damage



Figure 4.12. Strong Consensus Type 2:
Building entirely collapsed.



Figure 4.13. Strong Consensus Type 3:
Local damages that were well presented.

Damages with a large scale usually cause disagreement, but if the damage was clearly recorded, human subjects tends to reach a strong consensus (e.g. Fig. 4.14).

4.5.1.2 Category II: Weak Consensus

On the other hand, some photos may not have a clear answer, subjects tend to fall into different camps with conflicting opinions, and the standard deviation of this sample group could be large (in other words, the crowd only has a weak consensus). In this case, a bigger sample size can lead to a more reliable estimate on how citizen workers at large would classify this photo using their common sense. Here are some examples of weak-consensus photos:

Type 1: Multiple elements with multi-level damages (e.g. Fig. 4.15).

Type 2: Multiple elements viewed from a long distance.



Figure 4.14. Strong Consensus Type 4:
Damaged element was prominent and well recorded.



Figure 4.15. Weak Consensus Type 1:
Major damage at column and minor damage on wall.



Figure 4.16. Weak Consensus Type 2:
Multiple building elements with a long-distance view.

All 4 elements can be found, but due to the long distance, their damages are vague and the crowd barely reaches consensus (e.g. Fig. 4.16).

4.5.1.3 Challenging Cases: Contra-Intuitive Damages

The most challenging situation happens when the common sense of the crowd leads to wrong conclusions. In other words, if the “true” answer for the ground truth (as determined by the Professionals in our study) is different from the citizen worker’s common sense, more subjects in the crowd may occasionally move the crowd consensus away from the ground truth in those cases when initially several citizens randomly do in fact agree with the Professionals. An example photo falling into this category is shown in Fig. 4.17.

In this photo, 3 Professionals drew the conclusion that the build was entirely



Figure 4.17. Contra-Intuitive Case:
crowd and experts diverged significantly

collapsed and damage cannot be reliably determined. However, a weak majority of crowd believed that they can classify beam and column damage in the photo. In fact, some subjects in the crowd did agree with the Professionals on this photo, but because they were in minority, their more “accurate” opinion did not become the crowd consensus.

4.5.2 Experimental Significance

We discussed four algorithms in Section 4.4. Law et al. compared the human computation algorithms with the traditional computer algorithms [71], and cited that *Input*, *Output*, *Finiteness*, *Effectiveness*, and *Definiteness* are the major properties of machine computer algorithms [67]. Law et al. further contended that the two main criteria to evaluate human computer algorithms are *Correctness* and

Efficiency.

Our goal of running these algorithms is to achieve highly trustworthy results from a large number of submissions, and the metrics we use to evaluate these algorithms are the ground truth from the Professionals. It would be ideal if we could achieve 100% accuracy; however, in contrast to previous photo classification practices based on the crowdsourcing model, such as ImageCat [7], the question tree we designed and utilized in our photo classification workflow is lengthy and complex. As shown in Fig. 4.4, our question tree has 4 layers with 25 questions. Due to the depth of this question set, even three Professionals have disagreement over a substantial proportion of photos, and accuracies of individual Professionals vary in a range, 65% - 85%, according to the ground truth built upon the collective work of the three Professionals. We believe, when applying proper data analysis algorithms, if the crowd work is equivalent to and comparable to the average accuracy of the three individual Professionals, which is 78.6%, in our study, then we have confidence that crowd work has demonstrated its strength, since, generally speaking, crowd work can be completed in a cheaper and faster manner.

In the Table. 4.4, there are more detailed comparisons of four algorithms and the average Professional performance.

4.6 Post-Task Interview

In the post-task interview with Professionals, they indicated that, when reviewing the photos, oftentimes they tended to exert their expertise to evaluate the damage patterns behind the scenes.

For example, when classifying a given photo (e.g. the photo shown in Fig. 4.18), Professionals may have different emphases: either being comprehensive or conser-

TABLE 4.4:
COMPARISONS BETWEEN THE FOUR ALGORITHMS

	Algorithm 1 Simple Voting	Algorithm 2 Branch Composite	Algorithm 3 Leader Verdict	Algorithm 4 Dynamic Weight	Professionals' Average
Accuracy	74.0%	63.5%	79.0%	79.2%	78.6%
Effectiveness	$O(nm)$	$O(n)$	$O(n * m \log m)$	$O(gen * (nm + m \log m))$	
Note		Accuracy is averaged over 10 runs	Accuracy is averaged over 10 runs	gen denotes the generation, which depends on the stopping criteria.	3 Professionals
The number of photos is denoted as n , and the number of classifications that each photo received is denoted as m .					



Figure 4.18. While 3 Professionals achieved agreements on the *Column* damage in Area 1 and *Wall* damage in Area 2, they took different positions on whether there was a *Beam* damage in Area 3. (Professionals were not required to draw frames while tagging photos.)

vative. Traditional photo classification projects, goals are usually to judge the existence of certain targets and human biases can be effectively rectified by providing detailed tutorials and instructions. In contrast, in post-earthquake photos, misjudgments can go opposite directions, as damage demonstrated itself in volatile situations. As a result, various types of flaws/damage are unlikely to be fully addressed in tutorials, and thus relevant biases usually cannot get satisfactorily neutralized.

This concern is evidenced by the following statements from the Professionals:

Comprehensive:

- *Could not fully see what happened to the walls, but I know the damage exists.*

- *Difficult to decide on the damage pattern: shear vs. flexure, so I chose both of them, 2 damage types out of three.*

Conservative:

- *Pretty much everything is damaged, but hard to tell what is what though. So, I selected Beam, Slab, and Wall that can be clearly seen.*
- *Again, all are damaged, but it's hard to differentiate building parts from the photo. I decided to leave Column out.*

4.6.1 Suggestions for Future Work

In future designs, there are three techniques we suggest to take so as to improve classification quality, which we next describe.

4.6.1.1 Blending objective questions.

As suggested in work [47], by blending objective questions into the questionnaire, such as “what is the magnitude and epicenter of the earthquake” or “where is the most populous area in the country,” we are likely to trace if users have acquired basic knowledge about the task. Also, these objective questions with clear answers send signals to users that their answers can and will be assessed in the data analysis phase. This technique may help to prevent gaming behaviors, potentially increasing effort [63], and helping the project organizer preclude inferior inputs.

4.6.1.2 Measuring confidence level.

In our experiment, we observed that users showed signs of over-classification, where users subjectively guessed the potential damage of building components in

the obscure parts of the photo. In future design of social-benefit projects, e.g. risk reduction, environment surveillance, etc., confidence levels of the users about their opinions should be taken into account. Users are expected to submit their answers as well as how sure they are about their answers. This way, designers can make pruning-retaining decisions in accordance to hierarchical confidence levels.

4.6.1.3 Providing Morale.

There are several approaches that can be used to motivate users with stronger encouragement.

- Send them thank-you notes on behalf of the local residents suffering from natural disasters.
- Acknowledge taggers' efforts, and feature their contributions in social media, such as the school newspaper or websites.
- Recognize users with token/kudos recognitions, such as stars and medals.

4.7 Conclusions and Future Work

In this chapter, we introduced a pilot project - Haiti Earthquake Photo classification - where online volunteers collectively performed basic human computations [61]. For projects that strive to tap into unidentified online crowds, quality control is necessary to achieve trustworthy results. In this project, we used crowd consensus self-check and statistical pruning to achieve high trustworthiness. Certainly, there are other strategies worth further investigations, such as *Ground Truth Seeding* [81], *Multilevel Review* [32] and *Defensive Task Design* [40]. Due to the limited time frame, we did not investigate these techniques in our study.

Effectively recruiting and motivating crowds is another related research topic. In this study, during the recruiting phase, we did not encounter any particular recruiting difficulty when enlisting college students to participate. In future research, however, to scale up this crowdsourcing system beyond the college campus, we may need to investigate different motivating mechanisms such as: *entertainment*, *camaraderie encouragement* [63], *social recognition*, *intrinsic satisfaction*, and possibly a combination of the above.

Regarding the user base, an issue that may rise is the representativeness of experiment subjects. College students are generally believed to be individuals with a high education level and strong moral motivations, which may not be representative of the online workforce. To address this concern, we would like to extend our research to commodity crowdsourcing platforms such as Amazon Mechanical Turk (AMT), and we believe a comprehensive comparison between experimental data collected from these two platforms – AMT and our on-campus platform – would bring more insight and perspectives to citizen engineering research community.

CHAPTER 5

CASE STUDY III: EXPERT CITIZEN ENGINEERING^{1 2}

In previous chapters we have discussed various implementations of the crowdsourcing model. This chapter introduces Citizen Engineering (CE), which is the idea of engaging a cohort of physically dispersed citizens, connected by the Internet, to collaboratively solve real-world problems. Citizen engineers in the CE systems usually come from different backgrounds, from amateurs, lacking practical experience, to professionals/licensed engineers with years of systematic training. As such, there is a wide spectrum of human resources that CE system designers can harness. The goal of this chapter is to investigate proper approaches to effectively engaging and supporting expert citizens, who usually have unique strengths/demands. The discussion in this chapter is based upon a web platform developed for *Complex Fluid Dynamic* (CFD) simulation.

5.1 Introduction

To design a successful citizen engineering system, researchers must overcome the challenge that contributors, i.e. citizen engineers (professionals, researchers,

¹In particular, the author would like to thank Peter Sempolinski for his work on the establishment of the simulation infrastructure.

²The work discussed in this chapter was previously published as a conference paper [101], and a following-up study is ongoing among collaborators on this project. A journal paper based on the expansive study is planned to publish on the ACM Transaction on Intelligent Systems and Technology.

students, and even the public at large), usually have a broad range of expertise and talents, as individuals are at various stages in their careers. Among citizen engineers, there is a certain portion of seasoned high-skilled users, 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 [1], and as such there are pragmatic incentives for licensed engineers to engage in citizen engineering activities.

To leverage the expertise that skilled citizens may offer, who usually have unique goals and expectations that are different from average citizens, we need to develop new principles and guidelines to achieve successful designs.

5.2 Related Work

One of the most prominent examples of online collaboration is the HubZero platform [77] and its primary deployment NanoHub [66]. In contrast to the previous work, which collaborated primarily with results, HubZero focuses on collaboration in the software tool-chain. This framework gives developers an opportunity to create tools for other users in scientific applications.

Our goal in this project is to engage experts to produce useful results for expert engineering tasks. When building such open simulation platforms, designers must consider the vastly diversified backgrounds of users and the possibility of malicious users. This uncertainty raises challenges in result aggregation and product quality. If we want to engage a large number of expert citizen engineers to fulfill high-end tasks, it is essential to develop a practicable workflow to secure the product quality.

Based on previous work [28][51] and our own practice, we identify the following

three challenges as unique to expert citizen engineering.

- *Task Complexity.* In expert citizen projects, tasks usually demand a high expertise and skill level. For example, expert citizens can be asked to operate complex high-performance computing platforms.
- *Recruitment Difficulty.* Due to the complexity inherent in these tasks, available human resources are limited and membership is rather selective, in contrast to traditional crowdsourcing tasks.
- *Resource Requirement.* High-end tasks may require sophisticated analysis tools and computational resources [60]. For example, nonlinear finite element analyses can quickly stress in-house computational capabilities of many laboratories.

These challenges drive us to investigate more effective engineering designs that can leverage expertise and experience afforded by expert citizen engineers. In the following sections, we introduce the methodology deployed and lessons learned in our study. The engineering problem to be solved was fluid dynamic simulations, designed by civil engineering professors. This is a small-scale test based upon a controlled user base, where advanced graduate students participated as expert citizen surrogates. Our goal is to investigate some basic characteristics of the CE system, learn what pieces are still missing, and provide more guidance for future expert citizen project designs. Fig. 5.1 shows the homepage of the portal.

OSD-CI Expert Citizen Engineer Experiment

[Home](#)[Login](#)

Welcome to the OSD-CI Expert Experiment

You are invited to participate in an online experiment run by the OSD-CI. If you decide to participate, we will ask you to login to a secure website, answer a few questions and take a brief tutorial.

- **Prior to the tutorial, you will also receive information about additional benefits you may derive from participating in this experiment.**
- **If you choose to participate this experiment, it is important that you do not discuss the details of the study with others.**

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. BY CLICKING THE "I WOULD LIKE TO PARTICIPATE" OPTION YOU INDICATE THAT YOU ARE A NOTRE DAME STUDENT AND HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

➤ [I would like to participate.](#)

✖ [I would not like to participate.](#)

Figure 5.1. Homepage of the simulation portal. In this project, our goal is to investigate basic characteristics of the CE systems, studying what pieces are still missing, and provide more guidance for future expert citizen project designs.

5.3 Procedures

5.3.1 Overview

Expert engineers used in this study were from a graduate level course – Wind Engineering, offered by a civil engineering department at a midwest university. This advanced graduate-level course covered primary architectural designs under various wind types. Topics included 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, eight graduate subjects were enrolled in the course, with several visiting scholars auditing. All were extensively trained in civil engineering, and knowledgeable in this professional area.

5.3.2 Web Platform

As shown in Fig. 5.2, the website includes the front-end web interface and the back-end simulation platform, and the workflow designed for subjects to perform their tasks is illustrated in Fig. 5.3.

Front-end User interface:

- *Entry Survey.* Investigates subjects' background information, such as their GPA, gender, year, etc., as shown in Fig. 5.4.
- *Lecture Quiz.* Tests users' understanding of course materials, as shown in Fig. 5.5.
- *Tutorials.* Explained how to use the computation platform to run simulations, as shown in Fig. 5.6.
- *Submission Interface.* The web page where subjects submit their parameters.

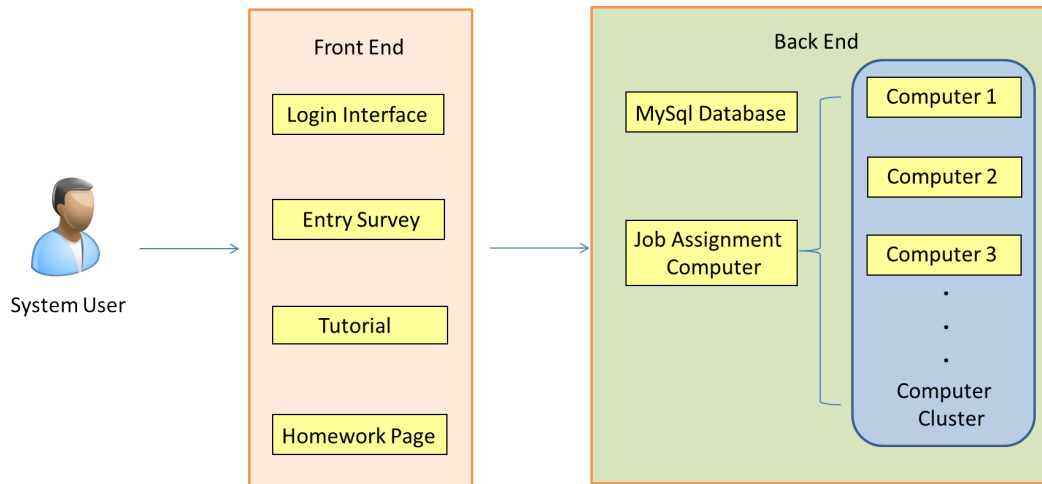


Figure 5.2. Website Architecture. The web portal included a front-end web interface and a back-end simulation platform.

Back-End Simulation Platform:

- *Database.* Keeps subjects' profile information, such as their academic backgrounds and lecture answers, etc.
- *Computer Cluster.* Takes parameters submitted by users, generates data sets, runs simulations, and visualize simulation results.

The first task we released on the platform was to simulate a turbulent flow in a zero-pressure gradient plane channel (for technical details, readers may refer to the article [62]). In this project, subjects are encouraged to try multiple simulation configurations and visualize their results.

5.3.3 Result Evaluation

A typical challenge associated with high-end citizen engineering projects is that tasks are sophisticated and results are difficult to assess. For a CFD simulation,

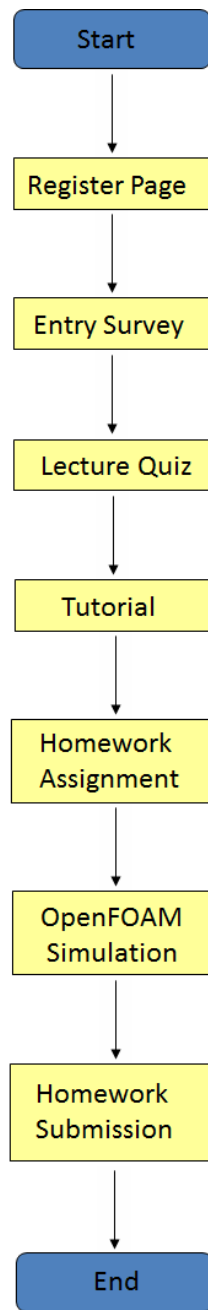


Figure 5.3. Workflow of the simulation platform. There was a front-end and a back-end. Surveys, Introductions, and Tutorials were at the front-end; the computation facilities (the computer cluster) and the database ran at the back-end.

Entry Survey

You are:

- ☐ Male
- ☐ Female

What year are you currently in graduate school?

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6

On average, how many hours per week do you spend on school work?

You have a good understanding of C++.

- ☐ Strongly agree
- ☐ Agree
- ☐ Neither Agree Nor Disagree
- ☐ Disagree
- ☐ Strongly Disagree

Figure 5.4. Sample Questions from Entry Survey. Entry Survey was to investigate subjects' background information such as their GPA, gender, year, etc. Based on the demographic information of subjects, system designers may be able to identify a subset of the users that would be more likely to succeed.

Preliminary Questions

Q1. Reynolds Number is the ratio of?

 and

Q2. List a few of Turbulence modeling methods.

Q3. List a few of Discretization Approaches.

Figure 5.5. Sample Questions from Lecture Quiz. The lecture quiz was to test users' understanding of course materials.



Figure 5.6. User interface with a brief movie introduction. The introduction video brief explained how to utilize the computation platform to conduct simulations and what the final results would look like.

there are several aspects to evaluate the simulation quality.

- Simulation Set Up.
- Aerodynamic Data Generation.
- Output Representation.
- Results Interpretation and Discussion.

The criteria listed above are rather subjective and qualitative, mostly depending on the personal judgments of the reviewers. To evaluate the quality of complex job submissions, we utilized the expertise of professors in the department³. In future research, one of the feasible solutions that can automatically assess simulation quality is the deviation of the curve from an ideal curve. If there is an unacceptable difference between the two curves, we consequently lower our confidence about the simulation quality of this particular citizen engineer.

5.4 Simulation Toolkit

One of the challenges in facilitating user participations is that software tools need to be sufficiently capable of allowing contributors to perform the necessary analysis. In our case, since the task in question involved fluid dynamics, we provided *Computational Fluid Dynamics* (CFD) software as a computation support.

To satisfy the needs, we built a simulation system with three major parts:

- *CFD package*. An underlying software support.
- *Web-based front-end*. A gateway to OpenFOAM software.

³The submissions were evaluated by Danial Wei, a post doctoral researcher from the Department of Department of Civil & Environmental Engineering & Earth Sciences at the University of Notre Dame.

- *Distribution System.* A dispatch controller to send simulation jobs to hardware resources.

5.4.1 OpenFOAM Package

In this study, subjects 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., 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 turbulence, and its openness for customizing and extending its existing functionality were among the major reasons why it became the simulation tool on our platform.

Also, OpenFOAM is one of the most popular CFD simulation tools, widely deployed by practitioners across the world, and has been validated and verified from various perspectives [98]. As such, 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.

5.4.2 Web-based Front-end

As CFD package is highly complex, rather than requiring users to download the software package, install, and use it on their own computers, we installed it on the server system and designed a user-friendly web interface to facilitate users accessing specific software features.

The web front-end restricted the users to producing and simulating channel-

flow cases. Meanwhile, the system gave the users the flexibility to specify the mesh parameters and simulation time steps, and users also had the ability to browse case files and download results.

For a collective system to work, especially when it comes to an expert-citizen system, we identified three major challenges:

- User-experience had to be carefully considered. If the system was too complex, users could get frustrated and confused. If the system was so restrictive that it turned users away, then there was little point to a study of collective work systems.
- Since these simulations could run a long time, we had to design our interface to account for the fact that computations did not happen instantly when a user clicked. In multiple cases, impatient users initiated several replicate simulations when they were not sure what was happening.
- Many of the parameters of the CFD jobs had a tremendous effect on the duration of these jobs. In particular, contributors had to learn, often by trial-and-error, how mesh generations in a simulation setting affected job durations.

In CFD, “meshing” is used to define a finite number of elements to represent the geometric structure, in which the denser meshes made more accurate data generations, but also cost more computational resources.

5.4.3 Distribution System & Hardware Back-End⁴

For this project, we needed to provide computation facilities to allow CFD jobs to run. Our computing back-end was several virtual machines running on an on-campus private cloud computing environment. The task manager was designed to take queued tasks from the front-end and dispatch them to the back-end. High-performance computation is not the focus of this dissertation. Readers interested in high-performance computing infrastructure established for this study may refer to [84] for further information.

5.5 Results and Discussion

When reviewing reports submitted by human subjects, we have seen some high quality simulations. For example, Fig. 5.7 shows a participant's mesh generation, and Fig. 5.8 shows a sample velocity curve.

5.5.1 Simulation Quality vs. Lecture Quiz

The simulation reports were graded in accordance with several pre-designed evaluation criteria, such as the reasonableness of the simulation setups, the closeness of generated data points to the theoretical data set (deviation between generated and ideal curves), and the thoroughness of result analysis and discussion, etc.

⁴The establishment of the computation facilities in this study was done by Peter Sempolinski, a graduate student from the Department of Computer Science and Engineering.

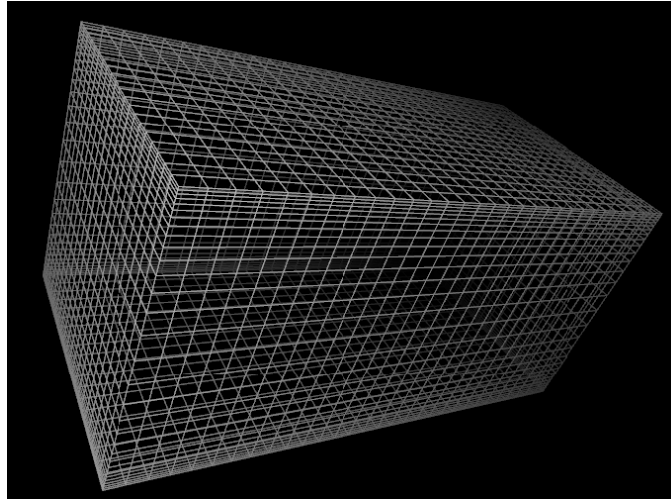


Figure 5.7. Mesh visualization of the channel flow. This 3-D screenshot was excerpted from one subject's report. The student had the choice to specify the granularity of the mesh grid.

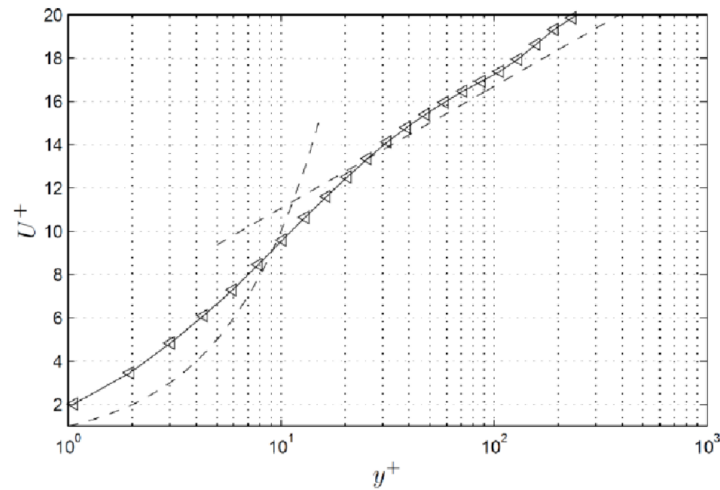


Figure 5.8. Velocity profile from one subject's report. The solid line marked by triangles represents the simulation curves generated by the subject, and the dashed line is the ideal curve.

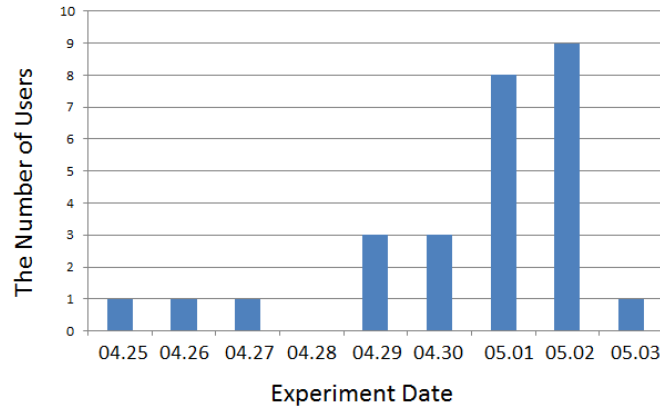


Figure 5.9. Variations of the number of users working simultaneously on the simulation platform. It shows a burst of job submissions (9 users) at the night before the deadline (05/03/2011)

5.5.2 Uneven Workload

As illustrated in Fig. 5.9, it was observed that the workload exerted on the platform was not evenly distributed during the one-week working period – there was an obvious task burst when it was close to the deadline. As such, in practice, project organizers need to prepare a system sufficient to cope with burst workloads or keep some leeway for deadlines.

5.5.3 Simulation Time

Another category of information is subjects' simulation time. System data shows that time durations subjects spent on the simulation platform varied widely. Examining the log data further, we also found there was no statistically significant correlation between the time that a given subject spent on simulation tasks and that subject's simulation quality.

One of the reasons that possibly accounts for this phenomenon is that some

users may not have submitted their simulation tasks to the platform until it was very close to the deadline. A large number of users running their tasks simultaneously significantly slowed down the system. When this happened, some impatient users repeatedly submitted their jobs, which worsened the situation, and artificially prolonged the simulation time. We have observed from the system log files that one user continually pushed the same job to the system more than ten times in a very short period of time.

In a real development of an expert-citizen system, where we commonly see dependencies of user contributions, deadlines are inevitable. Even if deadlines are not imposed by some authority, users conducting collaborative work often expect results from peer users at given times. Therefore, the computation facilities may experience burst workloads. In this regard, a recommendation for future designers is that designers should anticipate this situation, supporting users with enough computation capacity, meanwhile equipping protection mechanisms that can throttle overdue submissions, preventing them from overloading the system.

5.5.4 User Experience

After the simulation tasks were complete, we interviewed subjects who both experienced the platform and submitted their simulation reports. Most concerns were centered around the robustness of the simulation platform. Users' concerns showed that expert citizens specifically emphasized the reliability and stability of the system that can help them perform complicated tasks.

5.5.5 Limitations

We acknowledge that there are three limitations on this expert-citizen study that need to be further addressed, which are discussed in the below.

- *Lecture Quiz Design.* The lecture quiz was intended to measure citizen engineers' expertise level, and test the correlation between subjects' understanding of course material and accuracy of their simulation results. When analyzing user submissions, we did not observe statistically significant correlation between the quiz score and the lab report score, as illustrated in Fig. 5.10. We believe the reason that may account for this observation is that most questions in the lecture quiz were designed for investigating participants' understanding of theoretical concepts rather than their practical simulation skills. As such, human subjects' lecture quiz scores did not accurately indicate their CFD simulation quality.
- *User Population.* Because of the highly selective user base, this prototype system only engaged nine users in total, including both advanced graduate subjects and visiting scholars. To generate reliable inferences from this study, we need to enlarge the user base and enrich the data collection to reach convincing conclusions.
- *Result Evaluation.* In this study, the researcher who gave the lecture and graded the reports weighed in as a "super expert." However, if we want to scale up the system to serve more users, the "super expert" will consequently become a scarce resource, so we need to develop new approaches to effectively automate at least part of the evaluation process. As discussed previously, the curve deviation could serve as a plausible candidate.

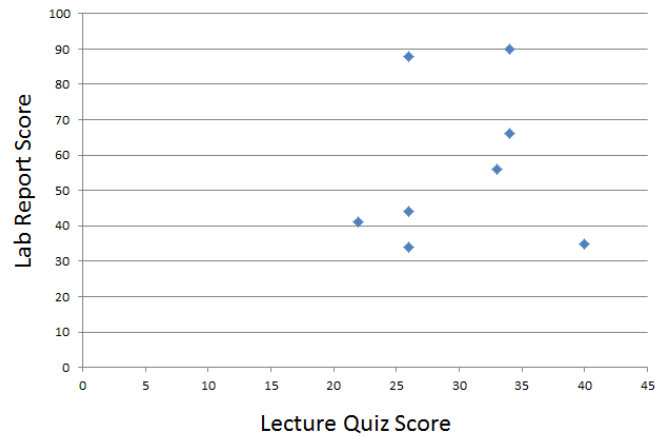


Figure 5.10. Scattered Plot of Lecture Quiz Score vs. Lab Report Score.
No statistically significant correlation between the two scores has been observed from this plot.

5.6 Conclusion

To leverage the expertise from skilled citizens, we need to develop new principles and theories that can guide system designs to satisfy the unique needs of these high-skilled users. In this pilot project, through an expert-citizen system prototype, we illustrated social and technical considerations and proposed solutions.

Undoubtedly, there are unanswered questions remaining. For example, how should we properly team up individual contributors, and make them collaborate effectively? These questions motivate us to investigate more effective system designs in future, in order to further our understanding of the principles of expert citizen crowdsourcing system.

CHAPTER 6

CASE STUDY IV: SHELTERS FOR ALL COMPETITION^{1 2}

When organizations encounter limited human resources to solve challenging problems, they can pursue ideas outside of the organization via open competitions, namely innovation tournaments. For example, Netflix Prize [31] runs competitions to solicit movie recommendations algorithms, and IBM uses Innovation Jam [33] to collect ideas for sales improvement.

Inspired by previous experiments [68] [29] and other commercial competition platforms, such as Fig. 6.1, we initiated a new challenge for soliciting innovative housing ideas, titled “Shelters For All Competition.” By conducting this open competition, we aimed to achieve two goals (1) acquire feasible designs for affordable housing in underdeveloped regions throughout the world; (2) assess the pros and cons of the innovation tournament model in organizing crowdsourcing work.

¹The mission and focus of this competition was defined by Tracy Kijewski-Correa, a professor from the Department of Civil & Environmental Engineering & Earth Sciences. The procedures in this competitions were designed by David Hachen, a professor from the Department of Sociology, Zack Kertcher, then a post doctoral researcher from the Department of Sociology, and also Tracy Kijewski-Correa. The author of this dissertation implemented the cyber-infrastructure.

²Results presented in this chapter have been previously reported in a conference paper [100]. Also, a journal paper based on this study is planned to publish on the IEEE Transaction on Systems, Man and Cybernetics, Part A: Systems and Humans.

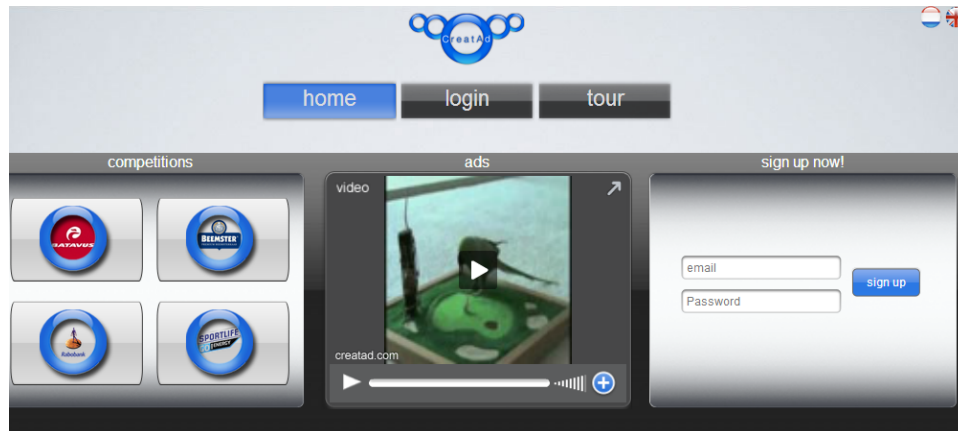


Figure 6.1. Competition Platform - CreatAd. CreatAd is an online platform for consumers to interact with brands via competitions. Competitions invite customers to create advertisements for brands and customers can win prizes with their ads.

6.1 Competition 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. This unfortunate reality results in densely populated, unstructured settlements or slums, with a lack of safe drinking water, proper sanitation, and other basic necessities. Recognizing the need for housing innovations, this competition was designed to tap the creativity of the public as both individuals and teams to design low-cost, safe housing for the world's urban poor.

In history, a number of open competitions at an international level have achieved significant successes. For example, Goldcorp Challenge [57] was organized 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 mining

its gold deposits. In the end, solutions generated from the competitions led to extraordinary success. The contestants identified 110 targets on the Red Lake property, 50 percent of which had not been previously identified by the company. [87].

6.2 Competition Goals

In our competition, it was required that proposals have the following properties to effectively meet the goals of improving living conditions of developing countries:

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

6.3 Prize Assignments

The home page (www.sheltersforall.org) of the competition platform is shown in Fig. 6.2, and main account page is shown in Fig. 6.3. Competition prizes and awards were designed as:

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

6.4 Cyber-Infrastructure – Front-End

6.4.1 User Interface

Basically, there were three types of users that regularly accessed our website:

- *Competition Participants.* To help participants better understand the mission and goals of this competition, we provided a detailed information source (Fig. 6.4) and FAQ page (Fig. 6.5).
- *Administrators.* To provide a console of organized statistics about the competition, there was an aggregated administration page, where administrators had a quick review of all submissions and their meta data (Fig.6.6).
- *Visitors.* After we closed the competition, to showcase high quality designs, we established a virtual gallery, where interested visitors can find the authors' information and review the merits of their design. As such, visitors



Figure 6.2. Home Page of Shelters For All Competition Website. Participants needed to agree on the competition terms before they can access the competition materials.

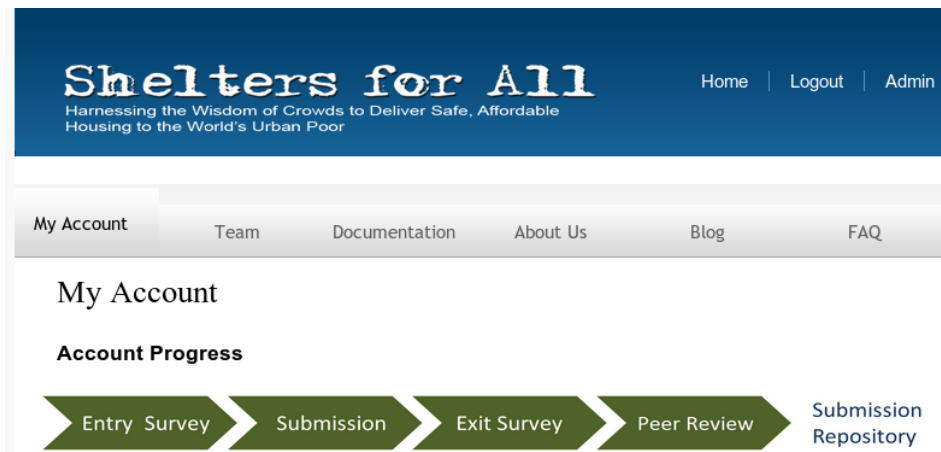


Figure 6.3. Main User Account Interface. After users signed up and logged in, they started with their own account pages.

can conveniently evaluate various candidate proposals for their unique situations (Fig.6.7).

6.4.2 Entry Survey

The demographics of participants are vital information that need to be collected for future data analyses, in order to improve competition efficiency. As such, as part of the procedure, the competition required all participants to fill out a survey before they started, as shown in Fig. 6.8. Information retrieved from this survey can help us obtain valuable information to better understand participants in these types of challenges, and also the factors that contribute to the winning solutions.



[Competition Brief](#)



[Competition Rules, Terms and Conditions](#)



Screen Shots of Submission Form Questions

[Additional Resources](#)



UN-HABITAT The Challenge of Slums



UN-HABITAT World Cities



Munich Re Mega Cities Mega Risks

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info@sheltersforall.org

Figure 6.4. Documentation Page. This page is a detailed resources for the participants to gain information about the competition process. One of the documents, *Competition Introduction*, can be found in Appendix C.



Figure 6.5. FAQ Page. This page is a quick resource for the participants to obtain competition information.




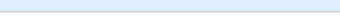
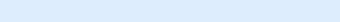

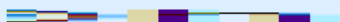

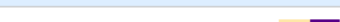
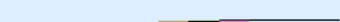
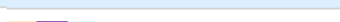


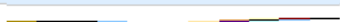
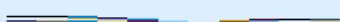

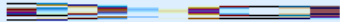
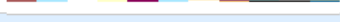




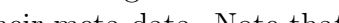

No.	User Email	Submission Merged
1		Merged
2		Merged
3		Merged
4		Merged
5		Merged
6		Merged
7		Merged
8		Merged
9		Merged
10		Merged
11		Merged
12		Merged
13		Merged
14		Merged
15		Merged
16		Merged
17		Merged
18		Merged
19		Merged
20		Merged
21		Merged
22		Merged
23		Merged
24		Merged

Figure 6.6. Administration Page. Administrators have a quick review of all submissions and their meta data. Note that, for privacy concerns, the email addresses of participants were intentionally blurred by the author when writing this dissertation.



Figure 6.7. Shelters For All Gallery. Interested visitors can find the authors' information and review the merits of their design. As such, visitors can conveniently evaluate various candidate proposals suitable for their unique situations.

Thank you for taking this survey.

Normally competitions like this one do not require participants to provide much information about themselves. Because this competition is part of a larger National Science Foundation study, we need to obtain more information from you about such things as your educational background, job history, work habits, and social ties. This survey should take 15-20 minutes to complete. If you need to, you can stop at any point during the survey and close the survey window. Then when you visit the My Account page at SheltersForAll.org and click on the Entry Survey link you will go back to where you left off.

Any information that is obtained from you through this survey and that can be identified with you remain confidential. Your name or any information that can be used to identify you will *never* be released. Any reporting of results or sharing of data will only be done in an aggregated form so that individual answers to questions can not be identified. We are collecting information from you *only* for research purposes.

If you have any questions please email us at info@sheltersforall.org.

Thank you -- The Shelter For All Competition Team

>>

[]

Figure 6.8. Entry Survey. Information retrieved from this entry survey helped us obtain valuable information that we can use to better understand participants in these types of challenges and understand the factors that contribute to winning submissions.

6.5 Cyber-Infrastructure – Back-End Database

In this competition, to help participants formalize their ideas, we designed closed- and open-ended questions. Examples of closed-end questions are

- *What is the target location of your proposal?*
- *What construction materials are you propose to use?*

Examples of closed-end questions are

- *What is the biggest issue preventing access to adequate urban housing in this region?*
- *What single aspect of your housing model best addresses this issue?*

The answers to these question were stored in a relational database (RDB).

Fig. 6.9 shows a snippet of the database.

The screenshot shows the Starfield Technologies, Inc. database interface. On the left is a sidebar with a tree view of database tables. The main area on the right displays a grid of data for four tables: IssueUrban, IssueModel, Innovation, and Weakness. Each row in the grid contains the table name, its data type (all are 'text'), a dropdown menu, a checkbox, and a text area containing a sample answer.

Table Name	Data Type	Dropdown	Checkbox	Text Area
IssueUrban	text	[Dropdown]	<input type="checkbox"/>	The most important question is the inpayment of the poor people_nation heating expense.
IssueModel	text	[Dropdown]	<input type="checkbox"/>	The heating expense of the buildings covered with the land low
Innovation	text	[Dropdown]	<input type="checkbox"/>	On the one hand the alternative energy, on the other hand the unobstructed, third the minimisation.
Weakness	text	[Dropdown]	<input type="checkbox"/>	The necessity of the crane.

Figure 6.9. A Snippet of the relational database used in this project. Database stored participants' answers to the competition questions. These questions included both closed- and open-ended questions.

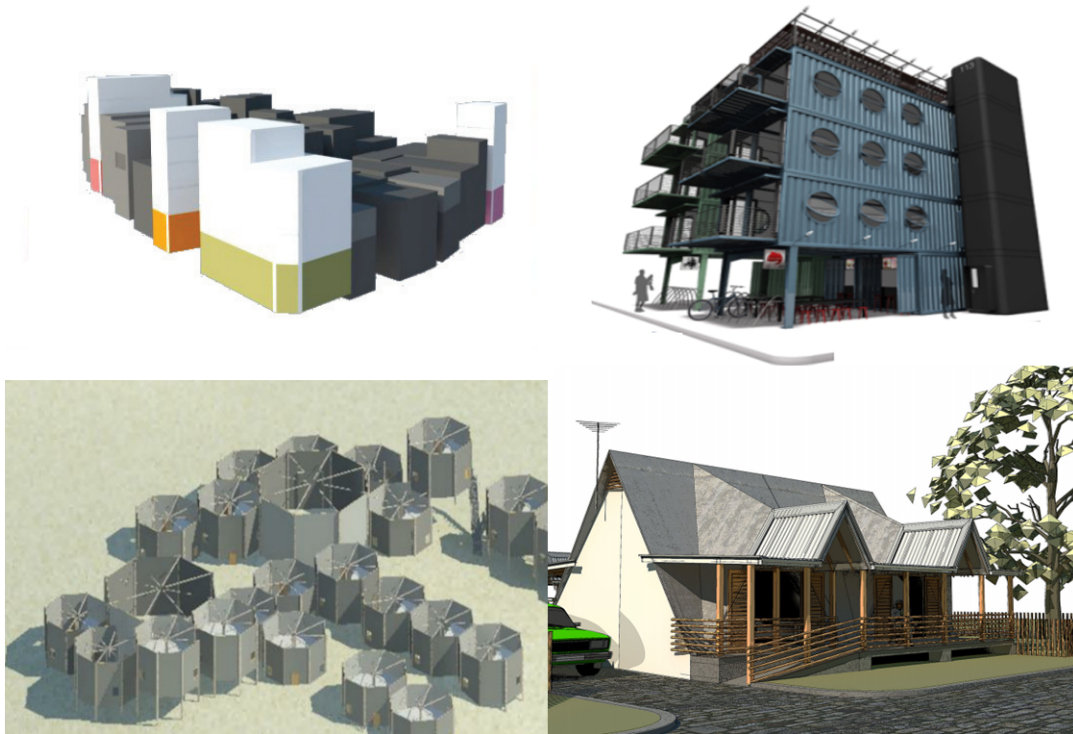


Figure 6.10. Sample Housing Designs from Participants' Submissions. Designs were targeted at different areas, suitable for different conditions.

6.6 Discussion

6.6.1 Results and Impact

By the time we closed the submissions site on Jan. 22, 2012, we collected 99 valid solutions from 26 teams and 73 individuals. Most designs reflected participants' unique perspectives and considerations on tackling the affordable housing challenge. We present some sample submissions in Fig. 6.10.

6.6.2 Lessons Learned

Participants in this open competition are global competitors with dramatically different working habits. One lesson we learned from organizing this competition is that even a very short period of blackout on the server side would frustrate a certain number of participants. As such, throughout the competition, we made particular emphasis on the system stability and scalability.

6.6.3 Subject Personality and Submission

In the entry survey, there were a group of 12 questions that asked about participants' self-perceived innovation level. It is possible that we use the answers from participants to predict their likelihood of submitting solutions in the end. Some initial analyses based on this consideration are shown in Appendix D.

6.6.4 Experiment Conditions

From the computer science point of view, before we launched the competition, we hoped we could answer three questions by the time we closed the competition. These three questions squarely challenge open competition organizers:

- In the traditional R&D solution model, the procedure usually is that domain experts, employed or contracted, acquire relevant knowledge, do the field study, and propose feasible solutions. Compared to this traditional solution model, how much improvement has the open competition model achieved in terms of solution quality and cost-efficiency?
- What is the most suitable organizational structure of open competitions and under what conditions? Specifically, should competition organizers increase

the competition level by introducing more competitors, or should organizers decrease the competition level by rewarding more participating teams?

- To enhance solution quality, should competition organizers promote collaborations between participating teams or intentionally isolate them from each other? Also, should the organizers provide career networking opportunities to the participants?

In the later phase the competition, when analyzing the submissions, we strove to answer these three questions, but found out that we were unable to satisfactorily answer any of the above three questions.

Firstly, we do not have historic data targeted at the same challenging issue but generated from the traditional R&D solution model. Therefore, it is almost impossible to compare the efficiency between the traditional model and the open competition model. Also, the most reliable assessment about solutions' validity comes from the real practice and usage. With the reality that it would take months or even years for a long-term solution to take effect, we cannot reach any convincing conclusions until we have collected first-hand information and feedback from the actual users.

Secondly, regarding the optimal competition level, because this competition was the first one of its kind that we designed to help residents in developing countries, and there are no similar competitions recorded in recent literature, again, we did not have historic data to compare with. Therefore, we were not sure if the competition conditions that we set up, such as information release channel, reward assignments, and question designs, had been the most suitable ones. In future trials, we can and will vary experiment conditions, e.g. increasing or decreasing the competition level, to investigate what competition conditions critically decide

competition outcomes. Currently, based on the reviews and comments of civil engineering professionals, we can qualitatively say that a large proportion of the proposals do bear high quality and are feasible to implement in their targeted areas.

Lastly, one of future directions in open competitions is that competition organizers promote different teams to collaborate with each other to enhance their overall competitiveness. We cannot answer this open question based on the current data set we currently have. In our study, when the competition was still open, we purposely kept teams separated from each other, where team members' information was carefully protected and curated. To do comparative studies, in future, we certainly can design new competitions, where cooperation and collaborations are encouraged and promoted between competition participants.

In the literature, regarding the question of collaborations between competitors, a plausible answer is given by Lakhani et. al., whose research [68][34] concludes that for challenging and high expertise-demanding tasks, organizers should promote collaborations between competitors to gain high quality solutions, but for less intelligence-challenging tasks, more collaborations will not necessarily have positive impacts on solution quality.

CHAPTER 7

SUMMARY AND VISION FOR THE FUTURE

7.1 Research Summary

In this dissertation, a background of technology-supported social computing systems has been introduced and the related literature has been examined. With experimental results, this dissertation aims to provide new perspectives and insight to a range of challenging issues centered around the crowdsourcing model. Specifically, the dissertation is aimed to answer the following three questions.

7.1.1 System Design

Question: In various crowdsourcing systems, what roles can crowds play and what contributions can they make?

In Chapter II, based on previous research in literature and our own study, we presented four categories that citizen workers can collectively make contributions:

- *Collector.* Citizen workers can be leveraged as information collectors, such as in the crumbling infrastructure sensing project.
- *Processor.* Citizen workers also can be leveraged as data processors, e.g. photo tagging and audio transcribing.

- *Contributor.* When acting as contributors, members can submit a video clip, a piece of a journal article, or a small amount of funding. Having aggregated pieces of contributions together, the product becomes significant and valuable.
- *Creator.* In open competition, citizens contribute novel ideas, designs or travel plans, and, in doing so, they become creators of intelligent content.

7.1.2 Human Data Analysis

Question: How can the human inputs with varied qualities be properly cleansed, and how can trustworthy results be effectively generated from their inputs?

In Chapter III, when conducting the photo classification project, we investigated three data cleansing strategies, which are *Average Tagging Time*, *Shortcut Proportion*, and *Shortcut Sequence*. For the second question, “how can trustworthy results be effectively generated from their inputs?”, we developed four data mining algorithms, which are *Simple Vote*, *Branch Composite*, *Leader Verdict*, and *Dynamic Weight*, aimed to retrieve high-quality results from a large number of inputs, which were submitted by individuals with diversified backgrounds and motivations.

7.1.3 Human Computation Theory

Question: At a higher level, what is the symbiosis between human intelligence and artificial intelligence?

There has been an intriguing synergy between AI and human intelligence [64], where human intelligence can guide artificial intelligence in some areas, while artificial intelligence can complement human intelligence in others. For exam-

ple, artificial intelligence can help to coordinate human subjects' activities in the crowdsourcing workflow. On the other hand, human intelligence can help to generate training sets to improve the accuracy and efficiency of computer algorithms. In our study, we summarized that when tasks require three categories of skills, which are *Perceptual Skills*, *Cognitive Skills* and *Language Skills*, human intelligence performs better than artificial intelligence.

7.2 Four Case Studies

We summarized that in the crowdsourcing model, there are primarily two general categories: Intentional Human Computing (IHC) Systems and Unintentional Human Computing (UHC) Systems. Having introduced the background and previous research in literature, we investigated the technological and sociological considerations in the crowdsourcing model through four case studies.

- Case Study I in Chapter 3 described the *Crumbling Infrastructure Photo Submissions* project, in which researchers motivated students to collect information about crumbling infrastructure nationwide. In this research, we proved the concept that crowds can be leveraged as information collectors, and social concerns and monetary prizes can be used as motivations to drive citizens' behaviors, be it altruistic or utilitarian. Also, we proposed a 10-module frame work that is aimed to help practitioners organize successful citizen sensing projects in future.
- Case Study II in Chapter 4 introduced the *Haiti Earthquake Photo Tagging* project, where hundreds of subjects collectively processed earthquake-damage photos. At the data processing stage of this experiment, we investi-

gated three different data cleansing strategies, and developed four computer algorithms to extract trustworthy results.

- Case Study III in Chapter 5 discussed our research in *Expert Citizen Engineering*. This case study aimed to answer the question about system designs and optimizations for improving work performance of high-skilled citizens, who usually can perform high-intelligent tasks, but meanwhile have high demands on underlying computation facilities. Our prototype proved the concept of expert citizen engineering. Specifically, in our practice, based on a relatively small user base, we have observed high quality simulations.
- Case Study IV in Chapter 6 discussed our experience gained and findings discovered in the process of running the *Shelters For All* open competition. This competition was open to the global public, by which we intended to investigate effective mechanisms and processes that can enable far-reaching and large-scale innovative contests. Because this competition was the very first open competition we initiated and operated, to reach more convincing conclusions, more trials in future are expected to be conducted and first-hand information and feedback from real users are avidly anticipated.

7.3 Discussion

7.3.1 Crowdsourcing and OSS

Open Source Software (OSS) development has much in common with concepts such as crowdsourcing, citizen science, collective intelligence, and human-based computation. The four case studies we discussed in the Chapters 3-6 apply shared principles of OSS development to engineering activities that reach beyond software

engineering.

On one hand, crowdsourcing models harness human computing power from open communities, which commonly consist of a cohort of geographically and/or institutionally scattered citizens. On the other, OSS is typically characterized by its openness, its distributed and often voluntary participation, and its end-user participation in the software engineering processes.

7.3.2 Six Categories

In this last chapter, we want to examine various crowdsourcing practices one more time, and categorize them from a vantage point as a summary. Observing the existing crowdsourcing projects, they may well fall into six categories:

1. *Crowd Decisions.* Exemplified by the Reddit and Digg reader voting systems, crowds have the capacity to collectively identify high quality products through voting.
2. *Crowd Submission/Funding/Journalism.* Individuals in the crowd can make directed contributions, which could take the form of submitting of a piece of content, chipping in a small amount of money, or reporting on what one has heard, witnessed, or interpreted. Together, pieces of contributions are channeled and possibly merged, and the results are either fed back to serve community interests or to stir up broader social attentions.
3. *Crowd Wisdom.* Networks of organized participants contribute their knowledge in specific areas, oftentimes leading to elaborate artifacts, considered as suitable alternatives for proprietary counterparts, e.g., the Mozilla web browser.

4. *Crowd Byproduct.* *Standalone* and *Piggyback* are the two major types[47] in this category. In standalone systems, users contribute human-based computation as a byproduct of major activities, e.g. Biogames [76]. Piggyback systems collect “user traces” generated out of other purposes to solve target problems [65]. For instance, in search engine optimization, Google record the query history for users and uses those records to prompt search keywords and suggest spell corrections.
5. *Micro Task.* Certain tasks can be divided into small units and assigned to online workers. Such small units of work usually require lower human skills, and their results are easy to merge. The online platforms, such as Amazon Mechanical Turk and Crowdfunder, provide such services.
6. *Innovation Tournament.* Outside human resources can be harnessed via open challenges or competitions. If the ideas/inventions get adopted by the institutions seeking solutions, winners can be recognized with monetary rewards, non-monetary acclaims, or both, e.g., the DARPA red-balloon competition [86].

7.3.3 Three Dimensions

In addition to the six categories, we see crowdsourcing projects along three dimensions for a deeper understanding: 1) Contributor Motivation – what motivates citizens to do their work, 2) Human Skills Required – how tasks get performed, and 3) Quality Evaluation – how results get evaluated. Fig. 7.1 shows how the four projects are positioned in this 3-dimensional feature space.

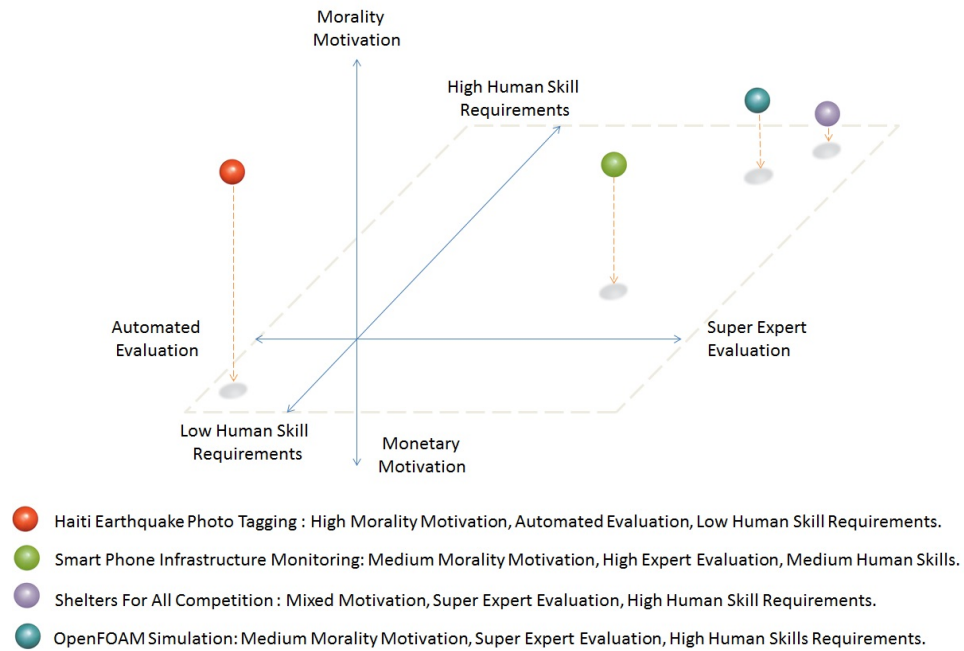


Figure 7.1. 3-Dimensional Classification of Crowdsourcing Projects: *Motivation, Skill Level, and Evaluation*. Note that the *Morality Motivation* and *Monetary Motivation* are not mutually exclusive. Instead, this figure shows, along the motivation continuum, which factor is the dominating one among multiple motivation factors.

7.4 Vision

In our four studies, citizens were leveraged as infrastructure inspectors, image processors, idea contributors, and job submitters. However, all of these activities are coordinated and/or facilitated by cyber-infrastructure and computer algorithms. Computers are indispensable to crowdsourcing systems. While humans play fundamental roles, whether they are project architects or problem solvers, the implementation of the crowdsourcing model is greatly facilitated by the advance of information technology, particularly the Internet, considered as “creative mode of user interactivity, not merely a medium between messages and people” [36].

In this dissertation, we presented four pilot crowdsourcing projects, which come from a larger NSF funded study – *Open Sourcing the Design of Civil Infrastructure* [61].

As always, more research problems emerged than were answered. Nonetheless, we hope this dissertation could help the future research and development of crowdsourcing systems, more effectively leveraging the “wisdom of the crowd”.

APPENDIX A

OPEN LETTER AND FILE SYSTEM IN CASE STUDY I

A.1 Open Letter

In the Citizne Sensing Crumbling Infrastructure project, we used an open letter to arouse students' social concerns about the crumbling infrastructure in the country. This open letter was drafted by Prof. Tracy Kijewski-Correa from the Department of Civil & Environmental Engineering & Earth Sciences, and the content of whole letter is shown in Fig.A.1.

A.2 File System

When designing the system we took into consideration the possibility that code may be reused in future and thus it should be well structured and well annotated.

- *connect.php* Pages that display content first requires the *connect.php* file to connect to the database, declare some global variables, strip all data of malicious values, and detect whether the user is logged in or not. If guests try to access restricted pages, they are redirected to the login screen.
- *function.php* The *functions.php* script is called by *connect.php* to define common functions, e.g. encryption and cookie setting.



Civil Engineering and Geological Sciences

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To Whom It May Concern:

The Department of Civil Engineering and Geological Sciences and Department of Computer Science and Engineering at the University of Notre Dame is currently conducting a research project sponsored by the US National Science Foundation to study how everyday citizens can become more involved in assessing, managing and even designing the basic infrastructure upon which our country relies.

Sadly this infrastructure is in dire need of repair and the current visual inspection process only evaluates critical infrastructure elements like bridges once every two years. As a result, this research program seeks to involve citizens in the assessment process by asking them to take photos of damaged infrastructure in their communities and upload these images to our database so they can be evaluated and the relevant authorities can be notified in the event of significant damage that occurs between inspection cycles. This individual is participating in the program as a registered user.

This program will provide an unprecedented opportunity to enhance our ability to catch damage in infrastructure and repair it quickly to minimize service disruptions, save money and even more importantly save lives.

More information on this project can be obtained at www.nd.edu/~crowds. Please feel free to contact me by phone or email if you should require further clarification of these activities, this individual's role, and how this information is being used.

Sincerely,

Tracy Kijewski-Correa
Associate Professor and Associate Department Chair
Project Lead Investigator
tkijewsk@nd.edu | Office: 574-631-2980 | Cell: 574-220-3679

Figure A.1. The open letter we used to arouse students' social concerns about the crumbling infrastructure in the country.

- *header.php* The *header.php* file is called by almost every page. It displays the banner and tabs, and links to the JavaScript and CSS files.
- *header.php* Common JavaScript functions used across most pages are defined in *global.js*, while specialized uploading functions are stored in *multifile.js* to save bandwidth.
- *geo_lookup.php* When retrieving GPS coordinates associated with an street address, *geo_lookup.php* is called through Ajax and utilizes the Yahoo! Maps API to return the longitude and latitude.
- *coords.php* Displaying the maps with pins for each photo is handled through *coords.php*, which combines JavaScript and PHP to display the information using the Google Maps API.

A.3 Global Variables

To build a web portal that is both robust and maintainable, global variables must be defined.

- *\$_DOMAIN* and *\$_EMAIL*

If the hosted domain or the primary contact email address changes, simply modifying these values will make the change across the entire website.

- *\$_USER* (*id, name, admin, email, loggedin, gps, approved, ip, ref*)

This associative array stores data about the user. This array is populated in *connect.php* with default Guest values and then through the database values if the user is logged in. This makes it easy to access common user

fields without redundant MySQL queries. The GPS value is stored so that the user can be directed to the appropriate tutorial (with or without GPS).

- *\$_PAGE* (*id*, *title*, *public*, *restricted*, *js*)

Every PHP page which displays content defines the `$_PAGE` array. *ID* is used to identify which tab to highlight, *title* is displayed in the window, and *public* indicates whether this page should be visible to guests or not. If guests try to access unauthorized pages, they are redirected to the login screen. In addition, some pages are restricted to the administrator only. If the file needs an extra JavaScript file, this can be specified by the *js* key.

APPENDIX B

PROFESSIONAL EVALUATIONS ON EARTHQUAKE PHOTOS

In Chapter IV, we mentioned that three professionals gave their professional evaluations on the 400 Haiti earthquake photos. Based on the opinions from the three professionals, we assessed individuals' accuracy and the four algorithms' performance. In the appendix, we attached the professionals' data.

In Supplement Data Set I, the four colors in the attachment correspond to the 4 building elements, and each building element have 400 entries, which take 8 pages to account for in the attachment. Also, when calculating the agreement among the three professionals, we use five numbers (0, 1, 2, 3, 4) to represent the five different types of agreements among the 3 individuals. For Professional A, B, and C, those numbers represent,

- 0, $A \neq B \neq C$.
- 1, $A = B \neq C$.
- 2, $A = C \neq B$.
- 3, $A \neq B = C$.
- 4, $A = B = C$.

APPENDIX C

PROPOSAL GUIDELINES FOR SHELTERS FOR ALL COMPETITION

This competition is searching for urban housing designs that meet the needs of the developing world in a feasible, sustainable, and viable way. Supplement Data Set II provides an outline of the basic requirements of a submission to this competition.

In this competition, specifically, the mission and focus was defined by Tracy Kijewski-Correa, a professor from the Department of Civil & Environmental Engineering & Earth Sciences. The procedures in this competitions were designed by David Hachen, a professor from the Department of Sociology, Zack Kertcher, then a post doctoral researcher from the Department of Sociology, and also Tracy Kijewski-Correa. Finally, the author of this dissertation implemented the cyber-infrastructure.

APPENDIX D

INITIAL RESULTS OF DATA ANALYSIS (SHELTERS FOR ALL PROJECT)

D.1 Questions

In the entry survey, there were a group of 12 questions that asked about participants' self-perceived innovation level. It is possible that we use the answers from participants to predict their likelihood of submitting solutions in the end.

The 12 questions about self-perceived innovation level in the entry survey.

1. I avoid cutting corners.
2. When I am working in a team, I try not to oppose team members.
3. I am thorough when solving problems.
4. I adapt myself to the system.
5. I address small details needed to perform the task.
6. I am good at tasks that require dealing with a lot of details.
7. I like to do things in an original way.
8. I prefer tasks that enable me to think creatively.
9. I act only if given permission.
10. I have a lot of creative ideas.
11. I am innovative.
12. I perform tasks precisely over a long time.

D.2 Results

The figures (Fig. D.1–Fig. D.12) were generated using a statistical tool named STATA.

Based on the statistics we collected, we concluded that, for 0, 1 and -1 row percentages, all of the 12 variables tend to fall into a 10% range, 70%-80%.

Code in Fig. D.1–Fig. D.12 :

D.2.1 Independent variables

1. **1** = Strong Agree, Agree, Somewhat Agree
2. **-1** = Strong Disagree, Disagree, Somewhat Disagree
3. **0** = Neither Agree Nor Disagree

D.2.2 Dependent variables

1. **No *subm*** = no submission
2. ***Individ*** = submitted individually
3. ***Team su*** = submitted as a team

Key
<i>frequency</i>
<i>row percentage</i>
<i>column percentage</i>

en_creat_i nn_1	submitstatus			Total
	0-No subm	1-Individ	2-Team su	
-1	48	9	8	65
	73.85	13.85	12.31	100.00
	13.11	12.50	14.55	13.18
0	43	5	13	61
	70.49	8.20	21.31	100.00
	11.75	6.94	23.64	12.37
1	135	30	21	186
	72.58	16.13	11.29	100.00
	36.89	41.67	38.18	37.73
.	140	28	13	181
	77.35	15.47	7.18	100.00
	38.25	38.89	23.64	36.71
Total	366	72	55	493
	74.24	14.60	11.16	100.00
	100.00	100.00	100.00	100.00

Figure D.1. Question 1: "I avoid cutting corners."

Key
frequency
row percentage
column percentage

en_creat_i nn_2	submitstatus			Total
	0-No subm	1-Individ	2-Team su	
-1	70	13	14	97
	72.16	13.40	14.43	100.00
	19.13	18.06	25.45	19.68
0	48	5	9	62
	77.42	8.06	14.52	100.00
	13.11	6.94	16.36	12.58
1	110	26	19	155
	70.97	16.77	12.26	100.00
	30.05	36.11	34.55	31.44
.	138	28	13	179
	77.09	15.64	7.26	100.00
	37.70	38.89	23.64	36.31
Total	366	72	55	493
	74.24	14.60	11.16	100.00
	100.00	100.00	100.00	100.00

Figure D.2. Question 2: “When I am working in a team, I try not to oppose team members.”

Key
frequency
row percentage
column percentage

en_creat_i nn_3	submitstatus			Total
	0-No subm	1-Individ	2-Team su	
-1	13	1	3	17
	76.47	5.88	17.65	100.00
	3.55	1.39	5.45	3.45
0	10	1	0	11
	90.91	9.09	0.00	100.00
	2.73	1.39	0.00	2.23
1	206	42	39	287
	71.78	14.63	13.59	100.00
	56.28	58.33	70.91	58.22
.	137	28	13	178
	76.97	15.73	7.30	100.00
	37.43	38.89	23.64	36.11
Total	366	72	55	493
	74.24	14.60	11.16	100.00
	100.00	100.00	100.00	100.00

Figure D.3. Question 3: "I am thorough when solving problems."

Key
frequency
row percentage
column percentage

en_creat_i nn_4	submitstatus			Total
	0-No subm	1-Individ	2-Team su	
-1	31	4	7	42
	73.81	9.52	16.67	100.00
	8.47	5.56	12.73	8.52
0	22	6	2	30
	73.33	20.00	6.67	100.00
	6.01	8.33	3.64	6.09
1	176	34	33	243
	72.43	13.99	13.58	100.00
	48.09	47.22	60.00	49.29
.	137	28	13	178
	76.97	15.73	7.30	100.00
	37.43	38.89	23.64	36.11
Total	366	72	55	493
	74.24	14.60	11.16	100.00
	100.00	100.00	100.00	100.00

Figure D.4. Question 4: “ I adapt myself to the system.”

Key
<i>frequency</i>
<i>row percentage</i>
<i>column percentage</i>

en_creat_i nn_5	submitstatus			Total
	0-No subm	1-Individ	2-Team su	
-1	10	2	5	17
	58.82	11.76	29.41	100.00
	2.73	2.78	9.09	3.45
0	19	2	3	24
	79.17	8.33	12.50	100.00
	5.19	2.78	5.45	4.87
1	200	40	34	274
	72.99	14.60	12.41	100.00
	54.64	55.56	61.82	55.58
.	137	28	13	178
	76.97	15.73	7.30	100.00
	37.43	38.89	23.64	36.11
Total	366	72	55	493
	74.24	14.60	11.16	100.00
	100.00	100.00	100.00	100.00

Figure D.5. Question 5: “I address small details needed to perform the task.”

Key
<i>frequency</i>
<i>row percentage</i>
<i>column percentage</i>

en_creat_i nn_6	submitstatus			Total
	0-No subm	1-Individ	2-Team su	
-1	15	2	2	19
	78.95	10.53	10.53	100.00
	4.10	2.78	3.64	3.85
0	13	3	5	21
	61.90	14.29	23.81	100.00
	3.55	4.17	9.09	4.26
1	201	39	35	275
	73.09	14.18	12.73	100.00
	54.92	54.17	63.64	55.78
.	137	28	13	178
	76.97	15.73	7.30	100.00
	37.43	38.89	23.64	36.11
Total	366	72	55	493
	74.24	14.60	11.16	100.00
	100.00	100.00	100.00	100.00

Figure D.6. Question 6: “I am good at tasks that require dealing with a lot of details.”

Key
<i>frequency</i>
<i>row percentage</i>
<i>column percentage</i>

en_creat_i nn_7	submitstatus			Total
	0-No subm	1-Individ	2-Team su	
-1	12	2	1	15
	80.00	13.33	6.67	100.00
	3.28	2.78	1.82	3.04
0	17	3	2	22
	77.27	13.64	9.09	100.00
	4.64	4.17	3.64	4.46
1	200	39	39	278
	71.94	14.03	14.03	100.00
	54.64	54.17	70.91	56.39
.	137	28	13	178
	76.97	15.73	7.30	100.00
	37.43	38.89	23.64	36.11
Total	366	72	55	493
	74.24	14.60	11.16	100.00
	100.00	100.00	100.00	100.00

Figure D.7. Question 7: “I like to do things in an original way.”

Key
<i>frequency</i>
<i>row percentage</i>
<i>column percentage</i>

en_creat_i nn_8	submitstatus			Total
	0-No subm	1-Individ	2-Team su	
-1	10	1	2	13
	76.92	7.69	15.38	100.00
	2.73	1.39	3.64	2.64
0	6	0	0	6
	100.00	0.00	0.00	100.00
	1.64	0.00	0.00	1.22
1	213	43	40	296
	71.96	14.53	13.51	100.00
	58.20	59.72	72.73	60.04
.	137	28	13	178
	76.97	15.73	7.30	100.00
	37.43	38.89	23.64	36.11
Total	366	72	55	493
	74.24	14.60	11.16	100.00
	100.00	100.00	100.00	100.00

Figure D.8. Question 8: “I prefer tasks that enable me to think creatively.”

Key
frequency
row percentage
column percentage

en_creat_i nn_9	submitstatus			Total
	0-No subm	1-Individ	2-Team su	
-1	114	20	25	159
	71.70	12.58	15.72	100.00
	31.15	27.78	45.45	32.25
0	36	9	6	51
	70.59	17.65	11.76	100.00
	9.84	12.50	10.91	10.34
1	79	15	11	105
	75.24	14.29	10.48	100.00
	21.58	20.83	20.00	21.30
.	137	28	13	178
	76.97	15.73	7.30	100.00
	37.43	38.89	23.64	36.11
Total	366	72	55	493
	74.24	14.60	11.16	100.00
	100.00	100.00	100.00	100.00

Figure D.9. Question 9: "I act only if given permission."

Key
frequency
row percentage
column percentage

en_creat_i nn_10	submitstatus			Total
	0-No subm	1-Individ	2-Team su	
-1	6	1	1	8
	75.00	12.50	12.50	100.00
	1.64	1.39	1.82	1.62
0	11	0	2	13
	84.62	0.00	15.38	100.00
	3.01	0.00	3.64	2.64
1	211	43	39	293
	72.01	14.68	13.31	100.00
	57.65	59.72	70.91	59.43
.	138	28	13	179
	77.09	15.64	7.26	100.00
	37.70	38.89	23.64	36.31
Total	366	72	55	493
	74.24	14.60	11.16	100.00
	100.00	100.00	100.00	100.00

Figure D.10. Question 10: “I have a lot of creative ideas.”

Key
frequency
row percentage
column percentage

en_creat_i nn_11	submitstatus			Total
	0-No subm	1-Individ	2-Team su	
-1	4	1	2	7
	57.14	14.29	28.57	100.00
	1.09	1.39	3.64	1.42
0	11	4	3	18
	61.11	22.22	16.67	100.00
	3.01	5.56	5.45	3.65
1	213	39	37	289
	73.70	13.49	12.80	100.00
	58.20	54.17	67.27	58.62
.	138	28	13	179
	77.09	15.64	7.26	100.00
	37.70	38.89	23.64	36.31
Total	366	72	55	493
	74.24	14.60	11.16	100.00
	100.00	100.00	100.00	100.00

Figure D.11. Question 11: "I am innovative."

Key
frequency
row percentage
column percentage

en_creat_i nn_12	submitstatus			Total
	0-No subm	1-Individ	2-Team su	
-1	22	2	6	30
	73.33	6.67	20.00	100.00
	6.01	2.78	10.91	6.09
0	38	8	5	51
	74.51	15.69	9.80	100.00
	10.38	11.11	9.09	10.34
1	167	34	30	231
	72.29	14.72	12.99	100.00
	45.63	47.22	54.55	46.86
.	139	28	14	181
	76.80	15.47	7.73	100.00
	37.98	38.89	25.45	36.71
Total	366	72	55	493
	74.24	14.60	11.16	100.00
	100.00	100.00	100.00	100.00

Figure D.12. Question 12: “I perform tasks precisely over a long time.”

APPENDIX E

ENGINEERING VIRTUAL ORGANIZATION - EVO

E.1 Background

A VO is created by a group of individuals and/or institutions, whose personnel and resources may be dispersed globally, yet who function as a coherent unit through cyber-infrastructure (CI) [25]. EVOs remotely engage geographically dispersed researchers. This approach has the potential to revolutionize the conduct of science and engineering research, education, and innovation.

In the following sections, we introduce the establishment of an EVO experiment named VORTEX-Winds, which we built for organizing professionals in the area wind engineering around the globe.

E.2 Virtual Organization

As shown in Fig. E.1, we built VORTEX-Winds based on *Drupal*, a web-based content management system, in which multi-media contents can be aggregated, retrieved, and presented to users in response to the requests received from web-browsers. Supported by *Drupal*, we can readily build new features, aimed at offering a shared access to geographically dispersed resources with respect to the modeling of wind effects on structures. Next, we will systematically introduce the main features of this EVO.

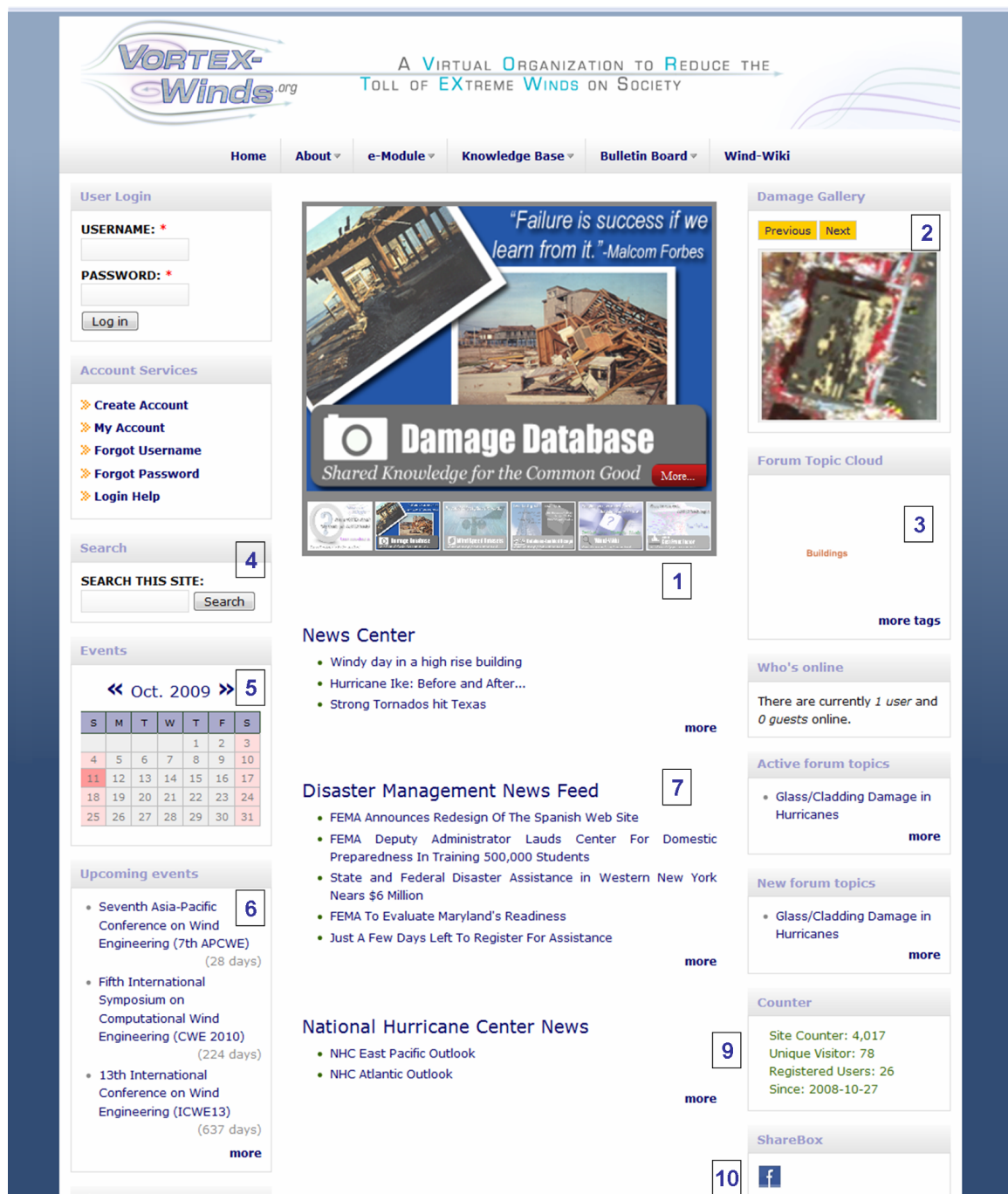


Figure E.1. Homepage of Vortex-Winds. The numbers in the rectangular boxes match the subsection titles in this section, indicating the 10 features. For example, 1 is the Dynamic Display Block feature in subsection A.3.1.



Figure E.2. Dynamic Display Block. At each frame, the carousel advertises a page, as well as a teaser of further content on that page. A link which would take the user to the advertised page is also present.-

E.2.1 Dynamic Display Block

On the front page, the *Dynamic Display Block*, shown in Fig. E.2, aims to showcase featured contents in- a prominent place. Besides a picture, at each frame, the block also displays a tease that briefly explains the target page. On the top of the tease, there is a link that would take the users to the page. We hope that this feature provides users with an intuitive and convenient entrance to the website.

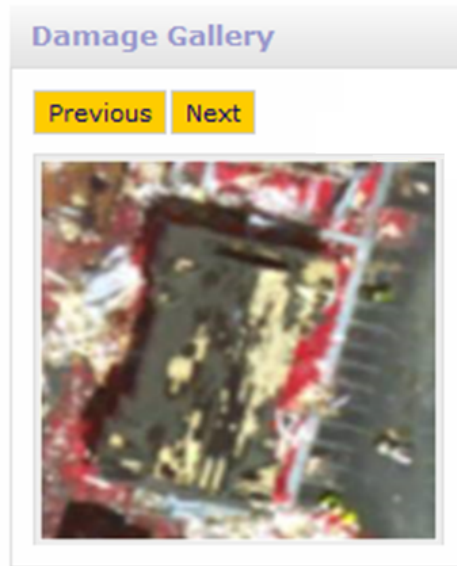


Figure E.3. Damage Gallery. It allows users to view images uploaded by fellow VORTEX-Winds members. The images are sorted by location, event classification and damage attributes.

E.2.2 Damage Gallery

Damage database is a digital repository of documented wind damage to structures. The *Damage Gallery*, powered by Google Earth, allows users to view images uploaded by fellow VORTEX-Winds members. The images are sorted by location, event classification and damage attributes. This feature enables users to have a quickly updated view on what is happening around the globe.

E.2.3 Topic Cloud

We implemented the *Topic Cloud* feature to display forum topic categories, as shown in Fig. E.4. By using Flash's 3D rotation function, the topic cloud feature provides a vivid view to users, which demonstrates the topic trends currently

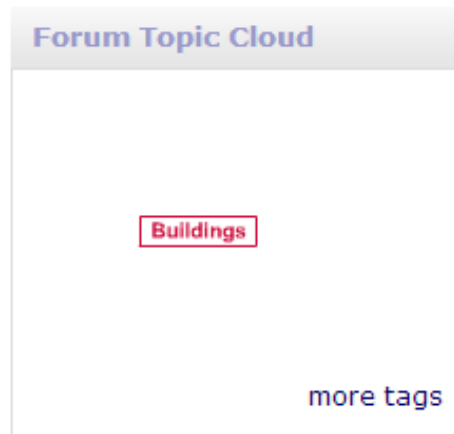


Figure E.4. Topic Cloud. In the topic cloud, the size of the topic name indicates the frequency of the forum category being used.

happening on the forum. In the topic cloud, the size of the topic name indicates the frequency of the forum category being used.

E.2.4 Search Box

As the VORTEX-Winds web portal incorporates more content, it takes more time for visitors to locate specific information they need. As such, the portal provides a *Search Box* (see Fig. E.5) on the front page, which is intended to help users locate the content they need faster.

E.2.5 Calendar Block/Event Manager

As shown in Fig. E.6, together, *Calendar Block* and *Event Manager* provide an aggregated listing of upcoming events. Users may choose any one of the following options:

1. Participate in a conference.

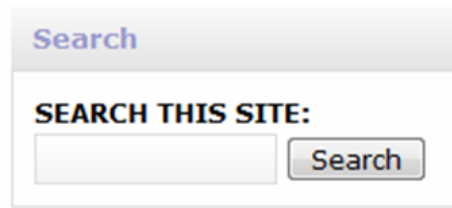


Figure E.5. Search Box. The search box on the front page is intended to help users locate the content they need faster.

2. Participate in a colloquium.
3. Participate in a workshop.

E.2.6 RSS News Feed

RSS (Really Simple Syndication) is an XML-based format for sharing and distributing web content. Using an *RSS New Feed*, users can view data feeds from various news sources. On VORTEX-Winds, via RSS, we made a link directly to the Federal Emergency Management Agency (FEMA) website as shown in Fig. E.7, which facilitates users to receive the latest news, disaster declaration notices, and real-time information.

E.2.7 Live User Map

Live User Map displays the locations of users that are currently visiting the portal. Their geographic information is retrieved by parsing their IP addresses.

Events						
« Oct. 2009 »						
S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

Event Calender

Upcoming events	
<ul style="list-style-type: none"> Seventh Asia-Pacific Conference on Wind Engineering (7th APCWE) 	(28 days)
<ul style="list-style-type: none"> Fifth International Symposium on Computational Wind Engineering (CWE 2010) 	(224 days)
<ul style="list-style-type: none"> 13th International Conference on Wind Engineering (ICWE13) 	(637 days)
more	

Event Listing

Figure E.6. Calendar Block and Event Manager. They provide an aggregated listing of upcoming events.

Disaster Management News Feed

- FEMA Announces Redesign Of The Spanish Web Site
- FEMA Deputy Administrator Lauds Center For Domestic Preparedness In Training 500,000 Students
- State and Federal Disaster Assistance in Western New York Nears \$6 Million
- FEMA To Evaluate Maryland's Readiness
- Just A Few Days Left To Register For Assistance

[more](#)

Figure E.7. RSS New Feeds. By using RSS linked to the Federal Emergency Management Agency (FEMA) users can receive the latest news, disaster declaration notices, and real-time information

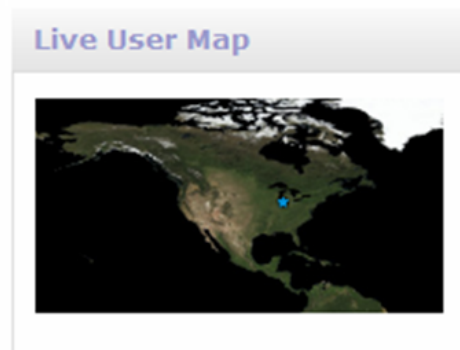


Figure E.8. Live User Map. It displays the locations of users that are currently visiting the portal. Their geographic information is retrieved by parsing their IP addresses.



Figure E.9. Visitor Counter. It records demographic statistics of the users, such as the number of visitors, the duration they are preset, the number of unique visitors, the number of count registered and unregistered users, the client IPs, the pages they visited, etc.

E.2.8 Visitor Counter

Visitor Counter records demographic statistics of the users, such as the number of visitors, how long they stay at the website, the number of unique visitors, the number of count registered and unregistered User, the client IPs, the pages they accessed, etc.

E.2.9 Share Box

By the *Share Box* widget, we offer users links to several social media websites, where they can share the news/topics with their friends or people with similar interests.

APPENDIX F

WIND ENGINEERING – DAMPING DATABASE

The latest advances in information technology have facilitated the development of innovative cyber-infrastructures. Characterized by broadband networks, high-performance computation units, and super-large storage capacities, new developments have brought fundamental transformations to our daily lives. In this section, we show a damping database implementation as shown in Fig. F.1. This database aggregates the data of high-rise buildings in Japan.

The damping database is meant to be open to wind engineers of varying nationalities, who may have different educational backgrounds and working habits. As such, when building the database, we tried to make the help information comprehensive and easy to access. Using JavaScript, we used pop-up windows to show the help information, which are shown in the following figures.

- *Shape*. Information about the *cross-section shape*. For example, is the building a circular building or a triangular building?
- *Purpose*. Information about the building's *purpose*. For example, is the building a school building or a hotel building?
- *Excitation*. Information about the *test excitation*. For example, does the building have free vibration or forced vibration?

- *Estimation.* Information about the *damping estimation method*. For example, was the damping estimated by the logarithmic damping factor method or the random decremental technique?
- *Structure.* Information about the *structural type*. For example, does the building have a steel framed structure or reinforced concrete structure?

Damping Database

Country	Japan ▼		
X-Section: B-D Value	B (Short dimension): from: 0.0 ▼ m to: No Limit ▼ m D (Short dimension): from: 0.0 ▼ m to: No Limit ▼ m		
X-Section: Shape Type	<div style="display: flex; flex-wrap: wrap; padding: 5px;"> <div style="margin-right: 10px;"><input type="checkbox"/> Rectangular</div> <div style="margin-right: 10px;"><input type="checkbox"/> Square</div> <div style="margin-right: 10px;"><input type="checkbox"/> Circular</div> <div style="margin-right: 10px;"><input type="checkbox"/> Diamond</div> <div style="margin-right: 10px;"><input type="checkbox"/> Hexagonal</div> <div style="margin-right: 10px;"><input type="checkbox"/> Fan-Shaped</div> <div style="margin-right: 10px;"><input type="checkbox"/> Multilateral</div> <div style="margin-right: 10px;"><input type="checkbox"/> Elliptical</div> <div style="margin-right: 10px;"><input type="checkbox"/> Convex</div> <div style="margin-right: 10px;"><input type="checkbox"/> Triangular</div> <div style="margin-right: 10px;"><input type="checkbox"/> Double-Barreled</div> <div style="margin-right: 10px;"><input type="checkbox"/> Irregularity</div> <div style="margin-right: 10px;"><input type="checkbox"/> Semi. Ring</div> <div style="margin-right: 10px;"><input type="checkbox"/> Arc</div> <div style="margin-right: 10px;"><input type="checkbox"/> Y-Shape</div> <div style="margin-right: 10px;"><input type="checkbox"/> Z-Shape</div> <div style="margin-right: 10px;"><input type="checkbox"/> V-Shape</div> <div style="margin-right: 10px;"><input type="checkbox"/> S-Shape</div> <div style="margin-right: 10px;"><input type="checkbox"/> L-Shape</div> <div style="margin-right: 10px;"><input type="checkbox"/> T-Shape</div> <div style="margin-right: 10px;"><input type="checkbox"/> <-Shape</div> <div style="margin-right: 10px;"><input type="checkbox"/> Select All</div> <div style="margin-right: 10px;">HELP</div> </div>		
Foundation Type	<input type="checkbox"/> Spread <input type="checkbox"/> Pile <input type="checkbox"/> Select All HELP		
Height	from: 0.0 ▼ m to: No Limit ▼ m		
Natural Frequency (1st mode)	<div style="display: flex; justify-content: space-between;"> <div> f_y: from: 0.00 ▼ to: No Limit ▼ f_z: from: 0.00 ▼ to: No Limit ▼ Torsion: from: 0.00 ▼ to: No Limit ▼ </div> </div>		
Structural Type	<input type="checkbox"/> SF <input type="checkbox"/> RC <input type="checkbox"/> SRC <input type="checkbox"/> Select All HELP		
Usage	<input type="checkbox"/> Office <input type="checkbox"/> Hotel <input type="checkbox"/> House <input type="checkbox"/> Hospital <input type="checkbox"/> School <input type="checkbox"/> Store <input type="checkbox"/> Lab <input type="checkbox"/> Select All HELP		
Test Excitation	<input type="checkbox"/> FrM <input type="checkbox"/> FoM <input type="checkbox"/> FrV <input type="checkbox"/> FoV <input type="checkbox"/> MP <input type="checkbox"/> PR <input type="checkbox"/> SW <input type="checkbox"/> Mic <input type="checkbox"/> Wind <input type="checkbox"/> EQ <input type="checkbox"/> Fr <input type="checkbox"/> Select All HELP		
Damping Estimation Method	<input type="checkbox"/> LDF <input type="checkbox"/> RDT <input type="checkbox"/> HPB <input type="checkbox"/> SHP <input type="checkbox"/> SID <input type="checkbox"/> CFT <input type="checkbox"/> CFP <input type="checkbox"/> ACD <input type="checkbox"/> PGM <input type="checkbox"/> Select All HELP		
Damping (1st mode)	<div style="display: flex; justify-content: space-between;"> <div> y: from: 0.00 ▼ % to: No Limit ▼ % x: from: 0.00 ▼ % to: No Limit ▼ % Torsion: from: 0.00 ▼ % to: No Limit ▼ % </div> </div>		

Figure F.1. Damping Interface. This is the main interface, where users can specify search conditions and parameters.

Cross-Sectional Shape			
Acronym	Meaning	Acronym	Meaning
rec	rectangular	ysh	Y-shape
squ	square	zsh	Z-shape
cir	circular	vsh	V-shape
dia	diamond	ssh	S-shape
hex	hexagonal	lsh	L-shape
tri	triangular	tsh	T-shape
ell	elliptical	cs	<-shape
arc	arc	irr	irregularity
cvx	convex	sem	semicircular ring
mul	multilateral	dou	double-barreled
fan	fan-shaped		

Figure F.2. Help Information – Shape. From this window, users can get help information about the *cross-section shape*.

Purpose	
Acronym	Meaning
off	office
sch	school
hot	hotel
hou	house
hos	hospital
sto	store
lab	laboratory building

Figure F.3. Help Information – Purpose. From this window, users can get help information about the building *purpose*.

Test Excitation	
Acronym	Meaning
FrM	Free vibration test by mechanical shaker
FoM	Forced vibration test by mechanical shaker
FrV	Free vibration test by vibration control devices
FoV	Forced vibration test by vibration control devices
MP	Free vibration test by man power
PR	Free vibration test by pull and release
SW	Free vibration test by swing
Mic	Microtremor observation (Ambient vibration)
Wind	Wind response observation
EQ	Earthquake observation
Fr	Free Vibration but unknown excitation

Figure F.4. Help Information – Test Excitation. From this window, users can get help information about the *test excitation*.

Damping Estimation Method	
Acronym	Meaning
LDF	Logarithmic damping factor method
RDT	Random decremental technique
HPB	Half-power bandwidth method using power spectrum of response
SHP	HPB using absolute frequency response function
CFT	Curve-fitting using transfer function
CFP	Curve-fitting using power spectrum
ACD	Autocorrelation decay method
SID	Microtremor observation (Ambient vibration)
PGM	Phase gradient method

Figure F.5. Help Information – Estimation Method. From this window, users can get help information about the *damping estimation method*.

Structural Type	
Acronym	Meaning
SF	Steel-framed
RC	Reinforced Concrete
SRC	Steel-framed Reinforced Concrete

Figure F.6. Help Information – Structure Type. From this window, users can get help information about the *structural type*.

APPENDIX G

STUDENT PERFORMANCE RATING SYSTEM

G.1 Background

A transformative cyberinfrastructure can help developments of other disciplinary areas, such as civil engineering. In this project, we want to build an infrastructure to facilitate civil engineering collaboration, where practitioners, researchers, academic institutions can conveniently propose, refine, evaluate and contribute. It has to be acknowledged that the fundamental challenge in civil infrastructure constructions is the high risks inherent in civil projects, which imposes strict requirements on practitioners' qualifications, which increases the barrier for keeping more citizen engineers from participating.

G.2 Concept and Methodology

In crowdsourcing projects, it is usually important to recruit a large number of participants. While this itself is challenging, it is further complicated by the reality that civil engineering projects, such as bridges, highways, and tall buildings, are often associated with high risks, where if even a small part of these civil projects fails, the society may suffer serious consequences. This challenge may be addressed through membership assignment and visibility control. For example, we set up

a system, where the more complicated the tasks are, the stronger the profile is required for the engineers to be eligible to take on the tasks.

To test the viability of this idea, we organized an undergraduate population - a Junior class from the Department of Civil Engineering and Geological Sciences at University of Notre Dame as a surrogate for a citizen engineer community. We built a prototype website for these students to act on, with the expectation that the students' behaviors may be generalized to predict the activities of a large community.

In this prototype, whose front page is shown in Fig. G.1, faculty members, acting as clients, post their questions on the portal, and students can submit their solutions to these questions. In accordance with their academic history, students are assigned into five groups, and each group has a star rating, which ranges from 1 star to 5 stars. The students who demonstrate stronger academic performance were assigned into high star rating. Students' academic performance are evaluated by their homework and exams. Our hypothesis was that the students with higher star-ratings would stand better chance to answer challenging questions correctly.

To achieve trustworthiness, we thought a plausible way may be to design a system that creates, updates and maintains citizen engineers' reputations. Depending on their star ratings, individuals can take on tasks associated with different levels of risks. This is the basic vision that motivated us to assign students into privileged star-rating groups on the OSD-CI prototype, where the students star-ratings and group assignment were adjusted over time. In next section, we will discuss the technical details.

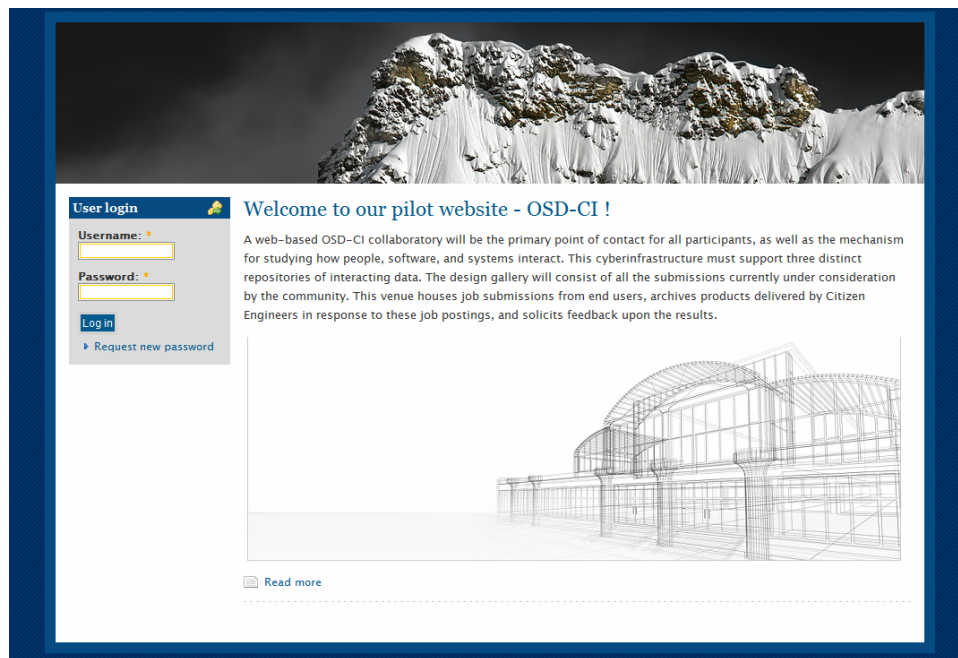


Figure G.1. Frontpage of the OSD-CI prototype

G.3 Design Goals and Considerations

G.3.1 Student Classification

To classify students into different star-rating groups, we selected a user-contributed *Drupal* module, named *Organic Group*[23], which is a tool to originate and manage private groups. Within the framework of *Organic Group*, we can create new groups, add/remove group members, pass private messages, assign questionnaires to a specific audience, etc. In practice, after setting up five private groups, we divided 23 students into these groups, each of which had 3-5 students. Within each group, students were not allowed to check their groupmates' profile.

Students were assigned 1 to 5 stars to indicate their reputations. The students with highest ranking were those coming from the 5-star group. By awarding more stars to competent students, we effectively encouraged them to vie for doing high-quality work. From Fig. G.2, we can observe the fluctuations of student group membership along the timeline.

G.3.2 Role Assignment

Different users play different roles, which can be managed by the administrator to ensure there is a fine-grained permission control on each user, and allow each role to do only what the administrator permits.

In *Drupal*, there are two default roles, which are *Anonymous User*, who does not have an account or has not logged in, and *Authenticated User*, who has a profile in the system, has logged in and has been authorized to perform tasks. Besides the default roles, to communicate with students and supervise their activities, we add two management roles: *Professor* and *WebManager*, as shown in Fig. G.3 and Fig. G.4. *Professor* is in charge of academic settings and closely works with

Date:	01/15	01/15	01/15	01/21	01/28	02/09	02/11	02/16	02/25	03/04	03/22	03/25			
student001	4*	4*	4*	4*	4*	4*	4*	4*	4*	4*	5*	5*			
student002	3*	3*	2*	2*	2*	2*	2*	2*	2*	3*	3*	3*			
student003	4*	4*	5*	5*	5*	5*	5*	3*	4*	4*	4*	4*			
student004	2*	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*			
student005	5*	5*	4*	4*	4*	4*	4*	4*	4*	4*	4*	4*			
student006	1*	2*	2*	2*	2*	2*	2*	1*	1*	1*	1*	1*			
student007	4*	4*	3*	3*	3*	3*	3*	4*	4*	4*	4*	4*			
student008	5*	5*	5*	5*	5*	5*	5*	5*	5*	5*	5*	5*			
student009	5*	5*	4*	4*	4*	4*	4*	4*	4*	4*	4*	4*			
student010	3*	3*	4*	4*	4*	4*	4*	4*	3*	3*	3*	3*			
student011	5*	3*	3*	3*	3*	3*	3*	5*	5*	5*	4*	4*			
student012	2*	2*	2*	2*	2*	2*	2*	2*	2*	2*	2*	2*			
student013	5*	4*	4*	4*	4*	4*	4*	2*	2*	2*	2*	2*			
student014	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*			
student015	3*	3*	3*	3*	3*	3*	3*	3*	3*	3*	3*	3*			
student016	2*	2*	2*	2*	2*	2*	2*	3*	3*	2*	2*	2*			
student017	4*	5*	5*	5*	5*	5*	5*	5*	5*	5*	5*	5*			
student018	1*	1*	1*	1*	1*	1*	1*	2*	2*	2*	2*	2*			
student019	4*	5*	5*	5*	5*	5*	5*	5*	5*	5*	5*	5*			

Figure G.2. Student Group Membership Variation Along the Timeline

Roles

Roles allow you to fine tune the security and administration of Drupal. A role defines a group of users that have certain privileges as defined in **user permissions**. Examples of roles include: anonymous user, authenticated user, moderator, administrator and so on. In this area you will define the *role names* of the various roles. To delete a role choose "edit".

By default, Drupal comes with two user roles:

- ⌘ Anonymous user: this role is used for users that don't have a user account or that are not authenticated.
- ⌘ Authenticated user: this role is automatically granted to all logged in users.

NAME	OPERATIONS
anonymous user	locked edit permissions
authenticated user	locked edit permissions
professor	edit role edit permissions
webManager	edit role edit permissions
<input type="text"/>	Add role

Figure G.3. Four Different Roles on OSD-CI. Four roles are *Anonymous User*, *Authenticated User*, *Professor*, and *WebManager*.

students, managing star-rating groups, releasing questions, assigning homework, etc. Compared to the role of *Professor*, *WebManager*'s responsibility is to provide technical service.

G.3.3 Question Release and Answer Aggregate

To facilitate the communication between professors and students, we need an effective tool to release questions and aggregate answers. For this purpose, another user-contributed module, named *Webform* [24] fits this need. This module can be used to post questionnaires, from which answers can be retrieved. As shown in Fig. G.5, a questionnaire on *Webform* may have closed or open questions, single or multiple options, and answer types can be checkboxes, radio buttons, select lists,

PERMISSION	ANONYMOUS USER	AUTHENTICATED USER	PROFESSOR	WEBMANAGER
admin_menu module				
access administration menu	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
display drupal links	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
advanced_help module				
view advanced help index	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
view advanced help popup	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
view advanced help topic	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
aggregator module				
access news feeds	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
administer news feeds	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
ajax_ui module				
administer ajax forms	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
block module				
administer blocks	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
use PHP for block visibility	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
blog module				

Figure G.4. Permissions/Privileges on four Different Roles

grids, etc. Upon users' submissions to the *Webform*, all data can be saved to the *MySQL* database table and then will be ready for further analyses.

G.3.4 Database Interaction

To build a robust web platform, it is important to enable smooth transmissions between the back-end database and the front-end user interface. In the prototype, after collecting students' answers using *Webform* module, the data will stored to the *MySQL* database, shown in Fig. G.6.

YOU ARE HERE Create New Assignment

Create New Assignment

Groups

Audience:

☐ 1-Star Group

☐ 2-Star Group

☐ 3-Star Group

☐ 4-Star Group

☐ 5-Star Group

Show this post in these groups.

☐ Public

Show this post to everyone, or only to members of the groups checked above. Posts without any groups are always *public*.

Webform Settings

Title: *

Description:

Text to be shown as teaser and before the form.

Figure G.5. Webform Questionnaire Interface for Professors

```

+-----+
| user_relationship_node_access |
| user_relationship_type_roles |
| user_relationship_types      |
| user_relationships           |
| users                        |
| users_roles                  |
| variable                     |
| views_display                |
| views_object_cache           |
| views_view                   |
| vocabulary                   |
| vocabulary_node_types       |
| watchdog                     |
| webform                      |
| webform_component            |
| webform_roles                |
| webform_submissions          |
| webform_submitted_data       |
+-----+
172 rows in set (0.02 sec)

mysql> █

```

Figure G.6. MySQL interface for WebManagers

G.3.5 Data Aggregation

To aggregate and analyze inputs from students, we deployed a new *Drupal* module, *FusionCharts* [22], which heavily relies on *JavaScript* to achieve dynamic visualization.

As shown in Fig. 7, *FusionCharts* has rich options for selecting chart types and data representations. However, because of this broad spectrum of options, sometimes it was too complicated to tailor our own use. To mitigate the problem, a good understanding of *PHP* scripting language is desired. For example, when answering questions, students can provide quite diverted answers based on their own judgments. Reasonable answers normally fall into a narrow range. A challenge for us was that there are often minor differences between correct answers, usually due to the rounding choice in different steps. These distinct answers are supposed to be considered the same, and hence should be represented by the same bar in the chart. But *FusionCharts* module tends to over differentiate its inputs,

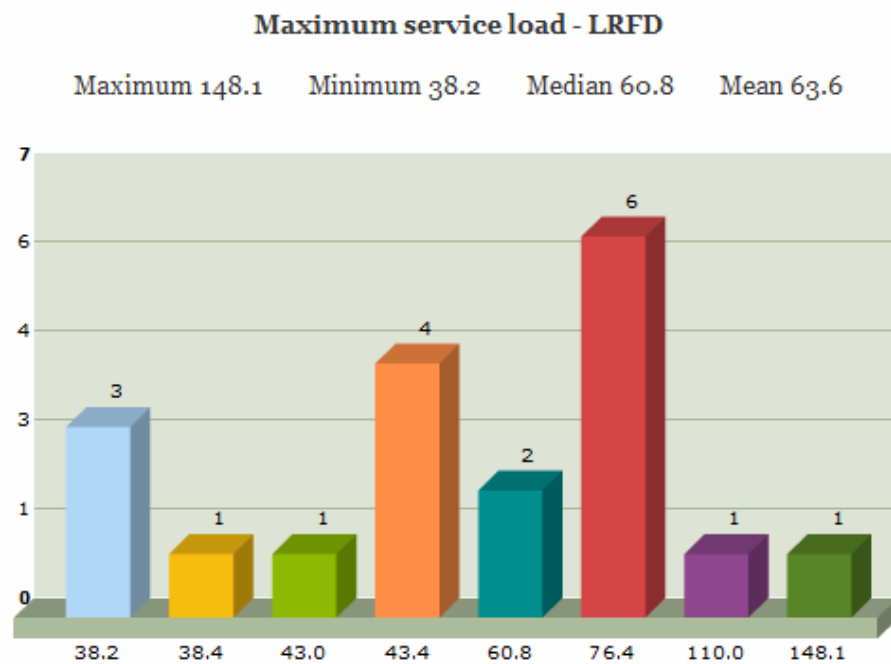


Figure G.7. Answer Aggregator on FusionCharts

even if there is only negligible distinction between them. To solve the problem, we actually hacked into *FusionCharts* module and used a *PHP* function, named *number_format()* to truncate numbers to the tenth digit after decimal point. In this manner, the answers we collected can be effectively clustered.

G.4 Experiment Results

To evaluate if students with higher ratings have more creditability to generate correct answers, we selected ten questions all all groups had answered, and listed the first five questions in Table 1-5. These questions can be considered representative, since most students did have their inputs.

An observation is that the answers from high star-rating students have a strong convergence. In other words, the more stars those students get, the closer their answers are, which is reflected by the standard deviation in each star group. Also, in each question, the standard deviations go smaller and smaller from 1-star group to 5-star group. We believe this trend has indicated that the answers coming from high star-rating groups are more stable and thus hold more creditability.

G.5 Summary and Future Work

Designing an open source system based on citizen science principles for risky projects is a complicated task, requiring a broad spectrum of expertise. With the

TABLE G.1

Q1: WHAT IS THE NOMINAL YIELD STRENGTH OF THE
CHANNEL SECTION?

Total:	Median 180.0	Mean 179.18	STD Deviation: 3.84
5* group:	Median 180.0	Mean 180.0	STD Deviation: 0.00
4* group:	Median 180.0	Mean 180.0	STD Deviation: 0.00
3* group:	Median 180.0	Mean 180.0	STD Deviation: 0.00
2* group:	Median 180.0	Mean 176.4	STD Deviation: 8.05
1* group:	Median 180.0	Mean 180.0	STD Deviation: 0.00

TABLE G.2

Q2: WHAT IS THE NOMINAL FRACTURE STRENGTH OF THE
CHANNEL SECTION?

Total:	Median 180.70	Mean 180.68	STD Deviation: 12.31
5* group:	Median 180.79	Mean 180.70	STD Deviation: 0.12
4* group:	Median 180.70	Mean 180.75	STD Deviation: 0.10
3* group:	Median 180.80	Mean 180.83	STD Deviation: 0.15
2* group:	Median 180.68	Mean 178.27	STD Deviation: 27.7
1* group:	Median 180.85	Mean 184.20	STD Deviation: 4.79

TABLE G.3

Q3: WHAT IS THE NOMINAL BLOCK SHEAR STRENGTH OF
THE CHANNEL SECTION?

Total:	Median 173.81	Mean 198.54	STD Deviation: 89.6
5* group:	Median 173.60	Mean 173.48	STD Deviation: 0.63
4* group:	Median 173.81	Mean 190.32	STD Deviation: 27.27
3* group:	Median 173.62	Mean 173.71	STD Deviation: 0.19
2* group:	Median 173.81	Mean 176.07	STD Deviation: 31.33
1* group:	Median 217.60	Mean 324.54	STD Deviation: 229.8

TABLE G.4

Q4: WHAT IS THE LRFD DESIGN(ULTIMATE) STRENGTH?

Total:	Median 130.35	Mean 131.84	STD Deviation: 3.81
5* group:	Median 130.20	Mean 129.21	STD Deviation: 1.84
4* group:	Median 130.36	Mean 132.46	STD Deviation: 3.01
3* group:	Median 130.36	Mean 131.65	STD Deviation: 2.69
2* group:	Median 130.40	Mean 132.20	STD Deviation: 2.92
1* group:	Median 134.60	Mean 135.70	STD Deviation: 8.31

TABLE G.5

Q5: WHAT IS THE ASD DESIGN(ULTIMATE) STRENGTH?

Total:	Median 86.91	Mean 87.85	STD Deviation: 2.49
5* group:	Median 86.80	Mean 86.16	STD Deviation: 1.24
4* group:	Median 88.10	Mean 88.10	STD Deviation: 1.92
3* group:	Median 86.91	Mean 87.77	STD Deviation: 1.79
2* group:	Median 87.00	Mean 88.24	STD Deviation: 1.92
1* group:	Median 90.50	Mean 89.74	STD Deviation: 5.53

ultimate goal to build a comprehensive platform to encourage and facilitate mass collaboration, we established a prototype as the first step. On this prototype, students can sign up and provide their solutions to closed or open questions. The statistics of their answers have shown that higher-rating students do demonstrate more credibility than lower-rating ones. This has supported that categorizing and membership assignment may be a legitimate solution to the question in interdisciplinary area of civil engineering and citizen science – how to balance the trustworthiness and openness.

APPENDIX H

A COMPILATION OF COMMERCIAL CROWDSOURCING WEBSITES

As discussed in Chapter II, primarily, there are three types of models that we can take advantage of to use the the “wisdom of the crowd”. Those three types are (1)Market Place, (2)Shared Interest Community, and (3)Open Competition. In this chapter, we want to provide a compilation of crowdsourcing platforms that are currently popular among the citizen workers.

H.1 Market Place

There are two levels of Market Place:

- *Micro Market Place.* Examples in this category include Clickworkers (Fig. H.4), Minuteworkers (Fig. H.9), etc.
- *Expertise Market Place.* Examples in this category include Elance (Fig. H.5), oDesk (Fig. H.2), etc.

Other examples include Fig. H.6, Fig. H.11, Fig. H.8 , Fig. H.12, Fig. H.10 , Fig. H.1, Fig. H.3 and Fig. H.7, which show applications in Market Place.

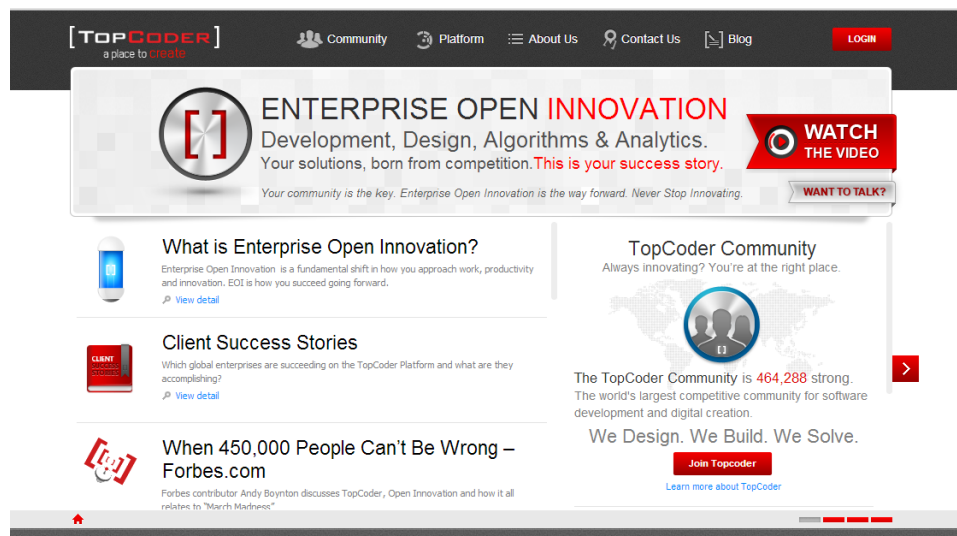


Figure H.1. Topcoder. Topcoder is a general innovation competition website. Clients' projects are broken-down by the community into small pieces that comprise the entire build. By launching a series of competitions that make up the whole project, specialists from community can register, compete, and submit solutions for each piece.

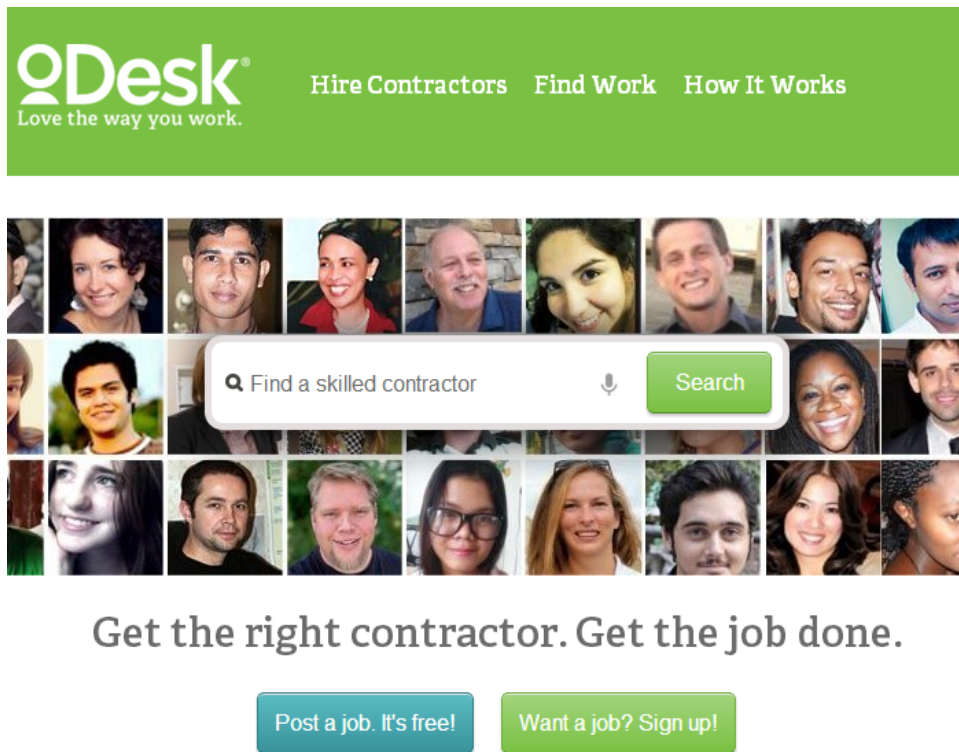


Figure H.2. oDesk. oDesk is general platform for crowdsourcing projects. It help clients find professionals to tackle various problems in a given timeline and under terms specified by the clients.

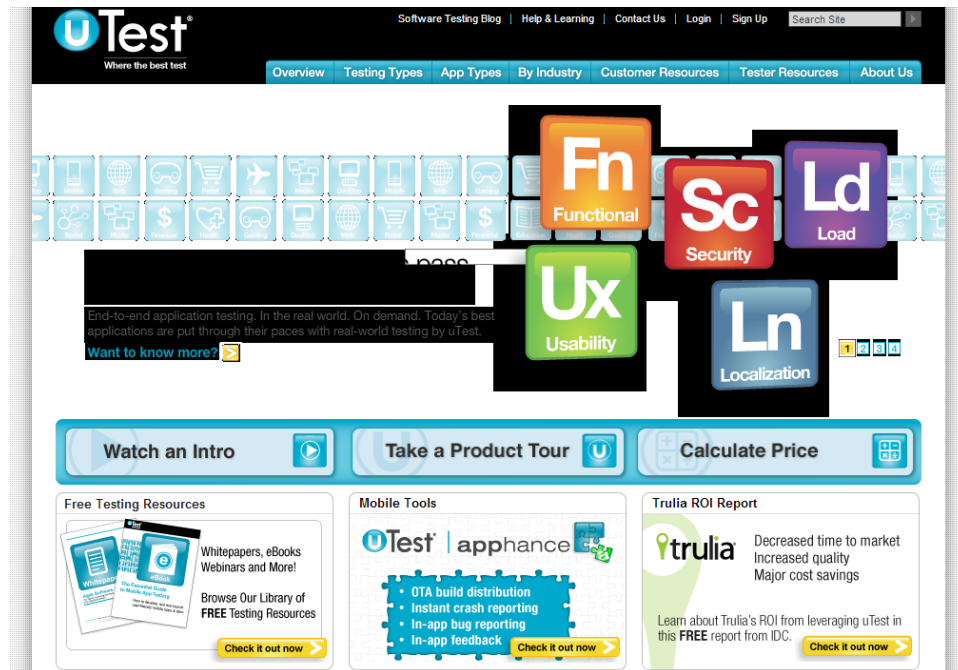


Figure H.3. Utest. Utest is a crowd-based software testing platform. The company curates a community of software testers who provide bug reports and feedback.



Figure H.4. Clickworker. Clickworker is microtask market place. Example tasks include (1) Text Creation: writing or editing of simple texts, providing unique content, or search engine optimization; (2) Translation and Keyword Assignment; (3) Image Capturing and Categorization; (4) Product Reviews and Opinion Polls Web Research

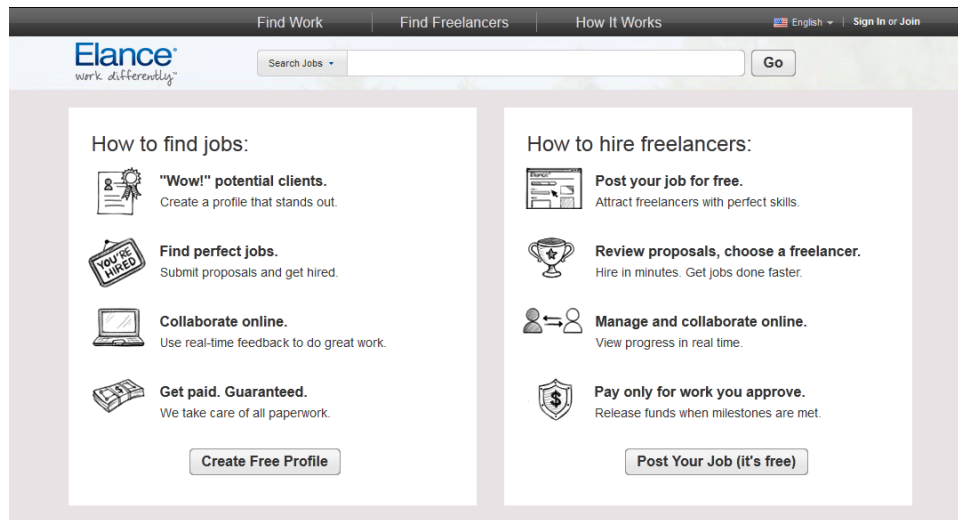


Figure H.5. Elance. General platform for online work. Elance enable clients to find, hire, manage and collaborate with online freelancers.

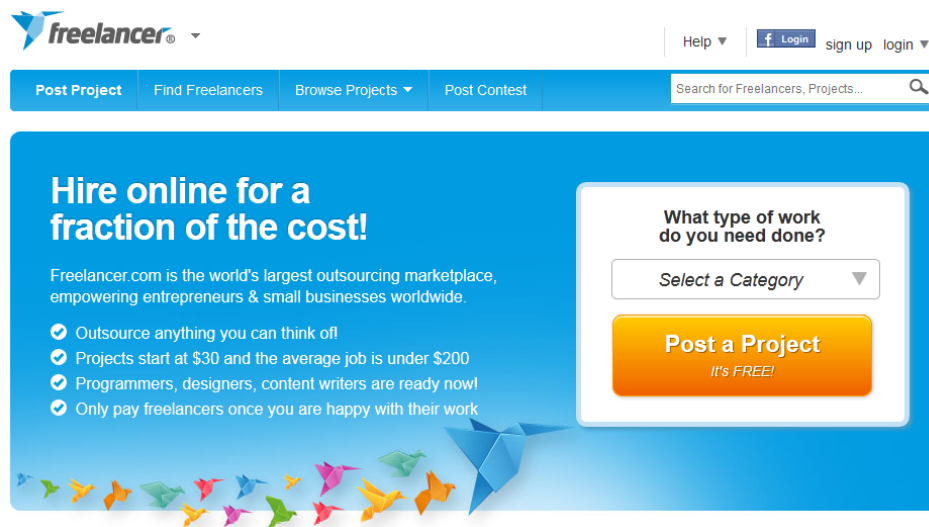
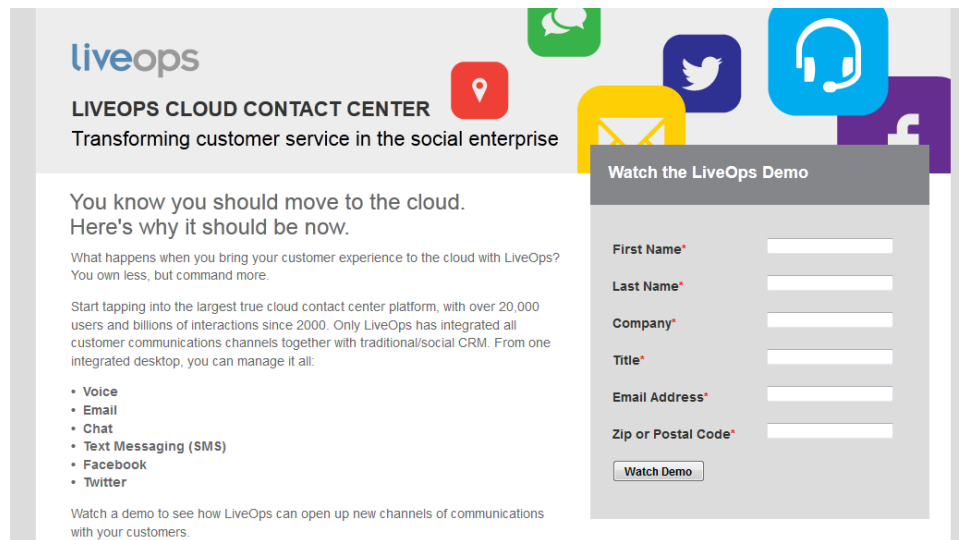


Figure H.6. Freelancer. General platform that can crowdsource various projects.



The image shows a landing page for LiveOps. At the top left is the 'liveops' logo. To its right is the text 'LIVEOPS CLOUD CONTACT CENTER' and 'Transforming customer service in the social enterprise'. Above this text are several social media and communication icons: a red location pin, a green speech bubble, a blue Twitter bird, a blue headset, and a purple Facebook 'f'. Below the header, the main text reads: 'You know you should move to the cloud. Here's why it should be now.' This is followed by a paragraph: 'What happens when you bring your customer experience to the cloud with LiveOps? You own less, but command more.' Then another paragraph: 'Start tapping into the largest true cloud contact center platform, with over 20,000 users and billions of interactions since 2000. Only LiveOps has integrated all customer communications channels together with traditional/social CRM. From one integrated desktop, you can manage it all:'. Below this is a bulleted list: '• Voice', '• Email', '• Chat', '• Text Messaging (SMS)', '• Facebook', and '• Twitter'. At the bottom left, a small line of text says: 'Watch a demo to see how LiveOps can open up new channels of communications with your customers.' On the right side of the page is a grey box titled 'Watch the LiveOps Demo'. Inside this box are input fields for 'First Name*', 'Last Name*', 'Company*', 'Title*', 'Email Address*', and 'Zip or Postal Code*'. At the bottom of this box is a button labeled 'Watch Demo'.

liveops

LIVEOPS CLOUD CONTACT CENTER
Transforming customer service in the social enterprise

You know you should move to the cloud.
Here's why it should be now.

What happens when you bring your customer experience to the cloud with LiveOps?
You own less, but command more.

Start tapping into the largest true cloud contact center platform, with over 20,000 users and billions of interactions since 2000. Only LiveOps has integrated all customer communications channels together with traditional/social CRM. From one integrated desktop, you can manage it all:

- Voice
- Email
- Chat
- Text Messaging (SMS)
- Facebook
- Twitter

Watch a demo to see how LiveOps can open up new channels of communications with your customers.

Watch the LiveOps Demo

First Name*

Last Name*

Company*

Title*

Email Address*

Zip or Postal Code*

[Watch Demo](#)


Figure H.7. Liveops. Via Liveops, a company specialized on crowdsourcing customer services, clients can route their customer interactions to proper channels and agents.




Figure H.8. Rapidworkers. A specialized platform. It helps clients create low cost publicity and marketing campaigns to increase sales.



Figure H.9. Minuteworkers. A microtask Platform. To earn small amount of money, workers need to complete simple jobs online which are created by employers. Typically, these short jobs take minutes to complete.



work & earn or offer a micro job



[Existing user Login](#)
[New user? Register for free](#)

Employers, post a micro job

Employers, ask people to...

- Vote for your photo
- Help you promote on Facebook
- Rate your Video
- Sign up to a website
- Follow you on Twitter
- Bookmark your website
- and much more...

Workers, get paid to do micro jobs

Workers, sign up and...

- Browse micro jobs
- Select jobs you like
- Finish tasks & submit proof
- Earn money

Basic Jobs - Any Worker can participate

Your Page Name

Like

Promote your Facebook page!

Its simple - Run a Campaign and ask Workers to help you promote your page!

Increase your website Page Rank
and get better placement in Google, Yahoo! and Bing

Get more inbound links to your website
and drive more traffic to your website

Get bookmarked at digg, delicious, twitter...
and make your website seen


Ask for Comments, Posts, Reviews and Ratings
and get popular quickly



6/10

Google

Alexa



#13,396



Microworkers - how it works?

[Frequently asked Questions](#)
[Guidelines](#)

Predefined Groups

You want to hire best Workers but you don't have time to look for Workers? Use predefined Groups in "Hire Group" Campaigns.

Results in CSV

Employers can download results in CSV file

"Hire Group" campaigns - Hire only Workers of your choice, Pool of best Workers, HM Campaigns with same or different description, CSV-spreadsheet support for complex tasks (different tasks per Workers), Groups of Workers, Best Workers, Workers' Reputation (Stars), Rating of Employers, Mass add Workers to Groups from your previous Campaigns, Profile pages, Basic Campaigns can be restarted and more...

Exclude up to 7 countries, Campaigns can be moved to "Archive", Geo-target popular countries, Extend a campaign - add positions, Adjust Campaign speed,...

Inside Microworkers

Available jobs	Payment	Time
Youtube: Vote for this video	\$0.10	1 min
Follow me on Twitter	\$0.12	1 min
Insurance Form: Sign up	\$1.50	5 min

Figure H.10. Microworkers. A microtask market place. Typical tasks are voting for photos, promoting on Facebook, rating videos, signing up to a website, following on Twitter and bookmarking websites.

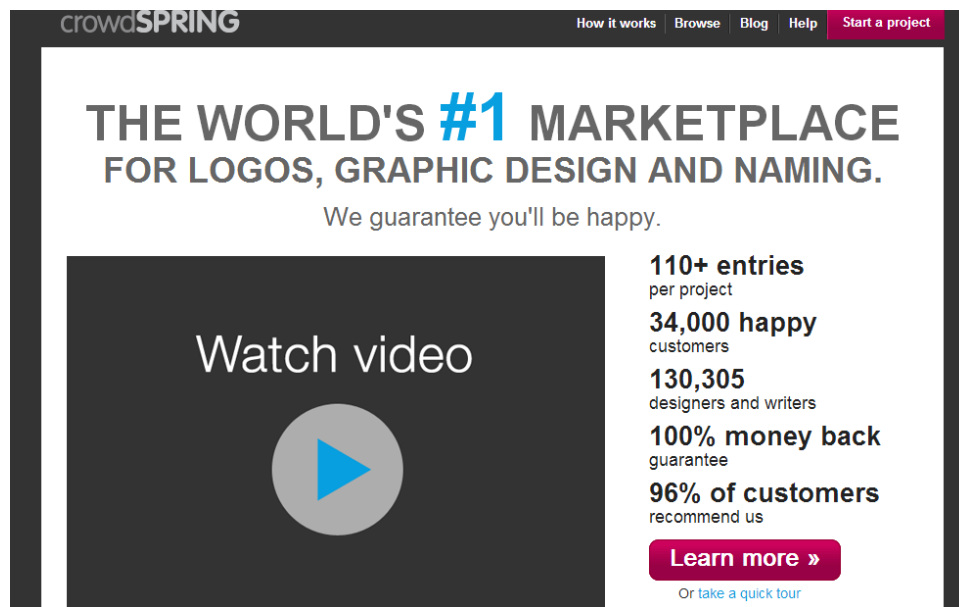


Figure H.11. Crowdspring. A specialized market place, providing service related to designing business identifications, such as logos, graphics and T-shirts.



Figure H.12. Mobileworks. A microwork market place whose goal is to match tasks with qualified workers in the virtual workforce.



Figure H.13. Ponoko. Ponoko is a shared interested community, where users can exchange digital photos, music, movies, and other downloadable products.

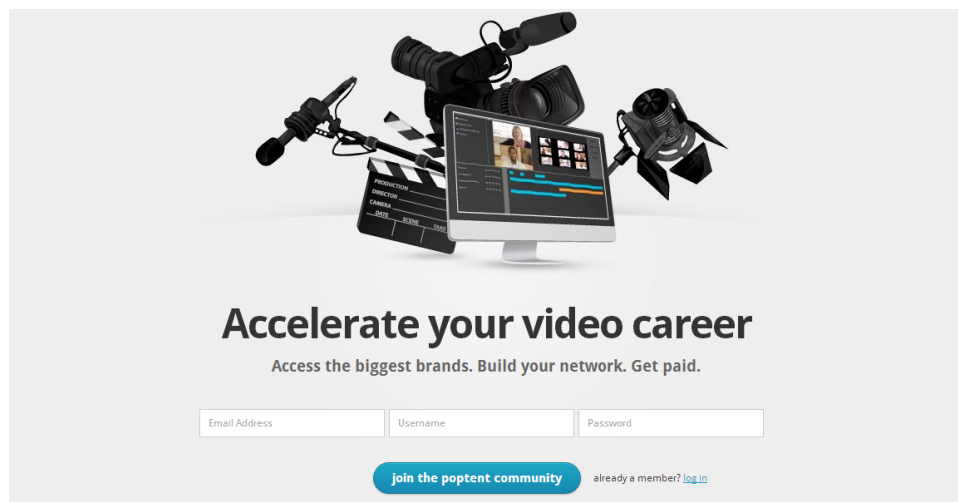


Figure H.14. Poptent. Poptent is a specialized market place, where video seekers can network with other video professionals and enthusiasts, and video producers have opportunities to earn money producing commercials for established companies.



Figure H.15. BusinessLeads. BusinessLeads is a market place that is specialized on business consulting.

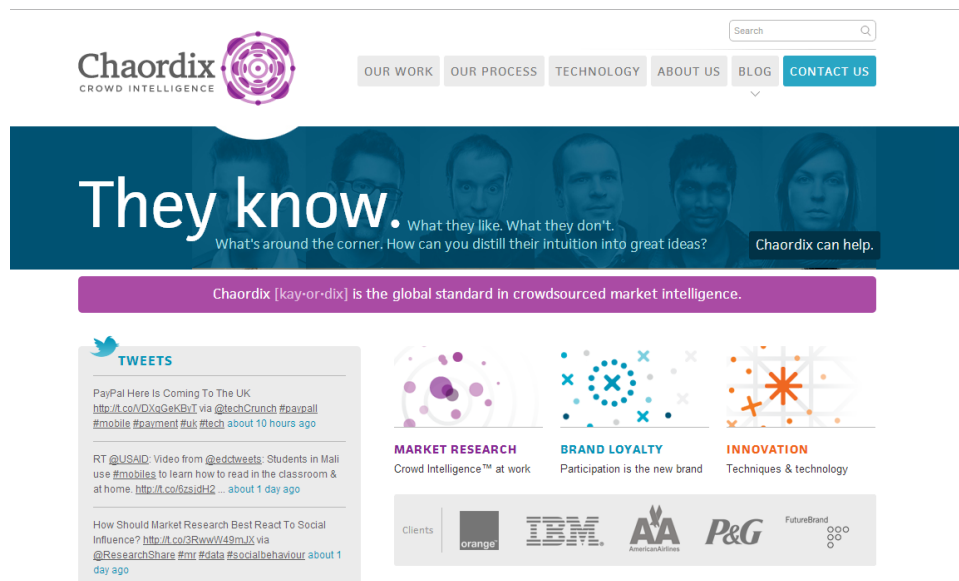


Figure H.16. Chaordix. Chaordix is an idea incumbent for social initiatives.



Figure H.17. Agent Anything. Agent Anything is microtask market place that can complete non-virtual tasks, such as walking dogs, running to the pharmacy, and picking up a last minute gift, whatever.

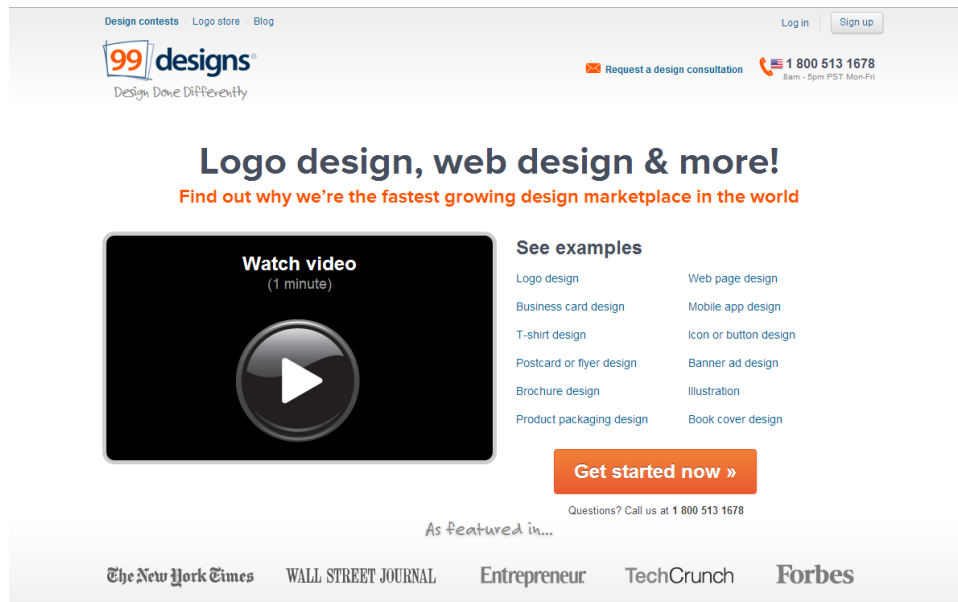


Figure H.18. 99Design. 99Design is a market place specialized in crowdsourcing graphic design.

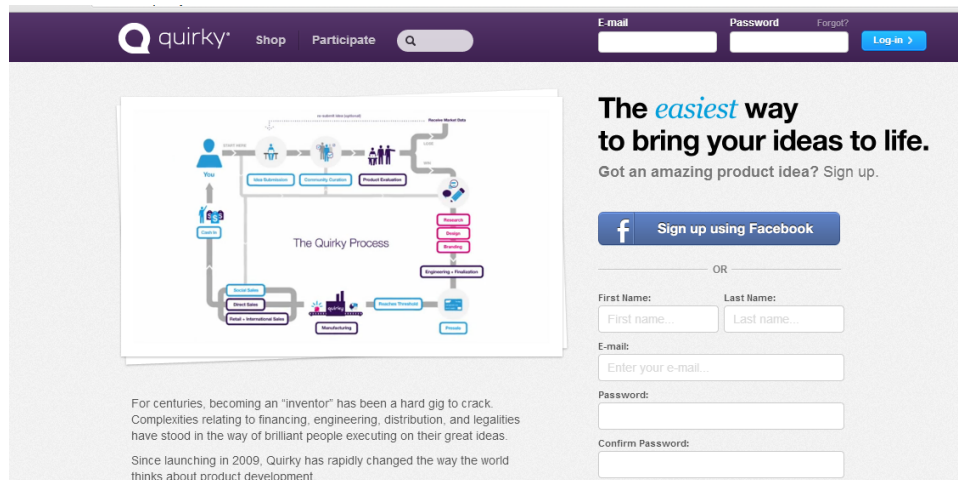


Figure H.19. Quirky. Quirky is a shared-interest community, where people trade inventive ideas and new gadgets.



The banner features the IdeaScale logo on the left, which includes a lightbulb icon with a green plant growing inside. To the right of the logo is a navigation bar with links: Home, Features, Pricing & Signup, Contact Sales, and Blog. Below the navigation bar is a screenshot of the IdeaScale web application interface. The interface shows a 'Your Feedback Community' page with a 'How does it work?' section, a 'Welcome to our community!' message, and a list of categories including 'Less paperwork' (217 ideas) and 'Simplify registration' (194 ideas). A large green play button icon is overlaid on the screenshot. To the right of the screenshot, the text 'Empower innovation' is displayed in large white letters, followed by a description: 'Bring out the best ideas from your customers and stakeholders by giving them a platform to share, vote and discuss feedback.' Below this text is a blue button that says 'Get started for free'.

Empower innovation

Bring out the best ideas from your customers and stakeholders by giving them a platform to share, vote and discuss feedback.

[Get started for free](#)

Watch video How IdeaScale Works

Figure H.20. Ideascade. IdeaScale is a market place for soliciting and collecting of feedback and ideas.

H.2 Shared-Interest Community

Fig. H.24, Fig. H.23, Fig. H.21 and Fig. H.22 show applications in Shared-Interests Community.

H.3 Innovation Center

Fig. H.27, Fig. H.28 and Fig. H.29 show applications in Innovation Center.

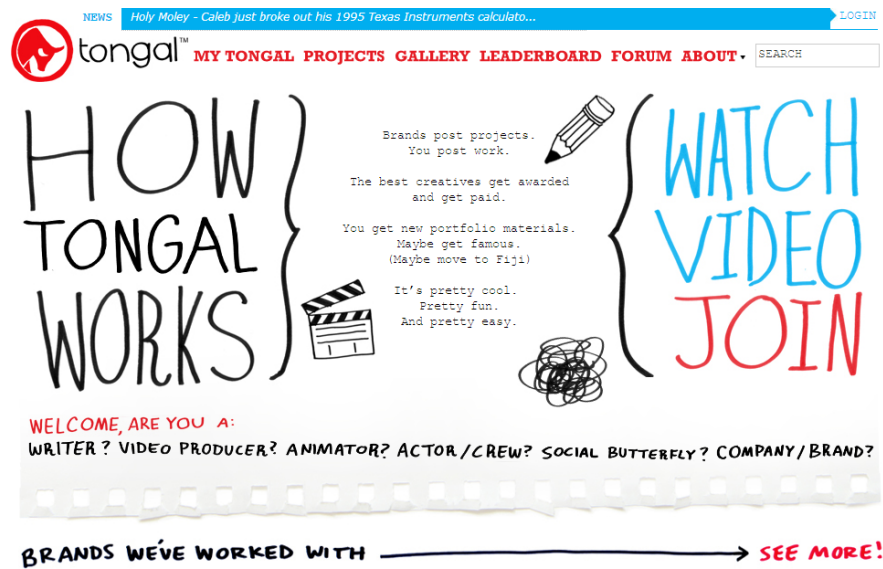


Figure H.21. Tongal. Tongal offers users opportunities to work with brands and companies that need new and original video content.

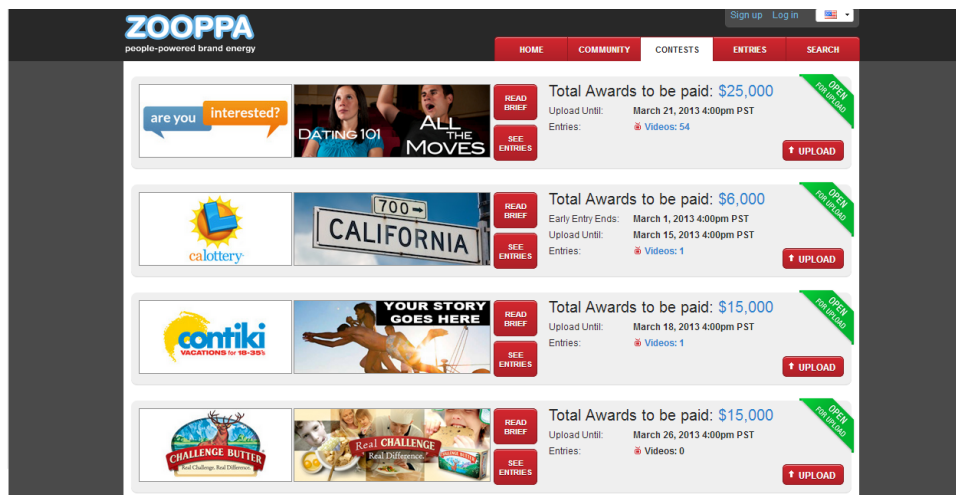


Figure H.22. Zooppa. Zooppa enables users to submit their own entry to brand-sponsored video contests and graphic design contests for cash rewards.

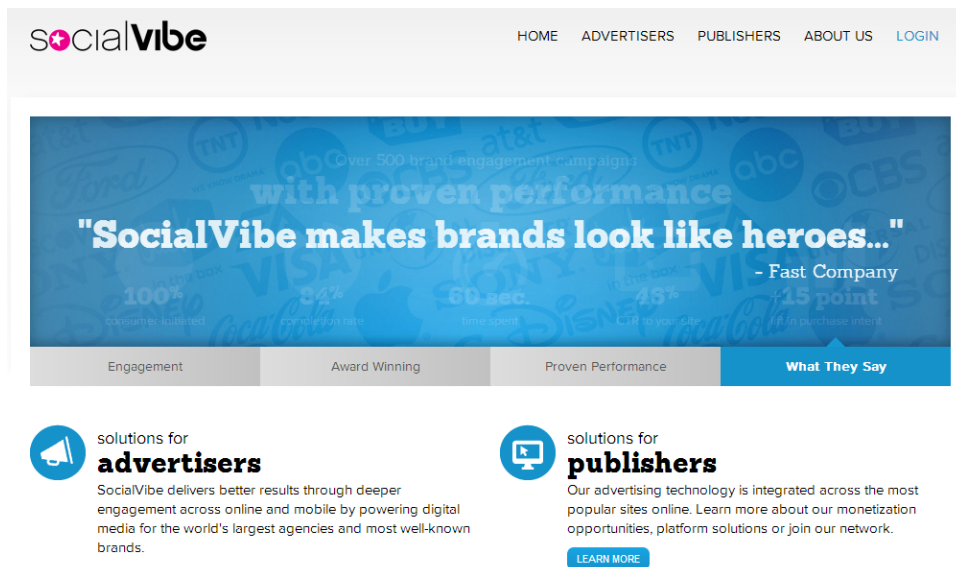


Figure H.23. Socialvibe. SocialVibe is a crowd-based advertisement consulting company that helps advertisers to reach consumers.

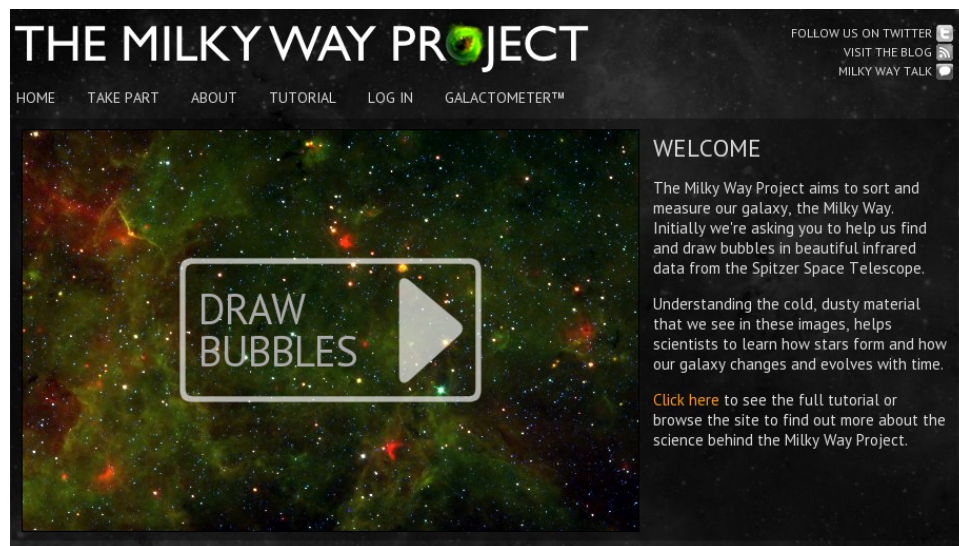


Figure H.24. Milk Way Project. It hopes to map star formation in the galaxy. Using the bubble-drawing interface on the platform, users can find bubbles and identify important or unusual characteristics.



Figure H.25. Challenge Government. It tries to engage regular citizens to contribute ideas to solve challenging problems which governments confront.



Figure H.26. IdeaConnection. IdeaConnection is an open innovation platform, which aims to solve problems teams of diversified experts collaborate to solve clients' technology development challenges.

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Where the world innovates

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	Humanitarian Air Drop Deadline: 05/02/2011 318 active solvers	\$20,000 USD
	The Economist-InnoCentive Healthcare Information Economy Challenge Deadline: 03/30/2011 645 active solvers	\$10,000 USD
	Upload Your Compound Libraries! Deadline: 01/20/2013 92 active solvers	See details
	Remote Human Demographic Characterization Deadline: 05/02/2011 140 active solvers	\$20,000 USD

NEWSFLASH

Prize4Life Awards \$1 Million Prize for InnoCentive ALS Challenge

"For InnoCentive, the Prize4Life Challenge has been our 'walk on the moon,'" said Dwayne Spradlin, CEO of InnoCentive. "Together, InnoCentive and Prize4Life set a wildly ambitious goal, knowing that to reach it would be a monumental achievement. Now, after five years, we've achieved that goal. And we can say without question that harnessing bright and passionate minds from every discipline and every walk of life can indeed change the world in the most profound ways."

Figure H.27. InnoCentive. InnoCentive is an open innovation and crowdsourcing platform that aims to solve problems by connecting organizations to diverse sources of innovation, such as employees, customers, partners, and other problem solving marketplaces.

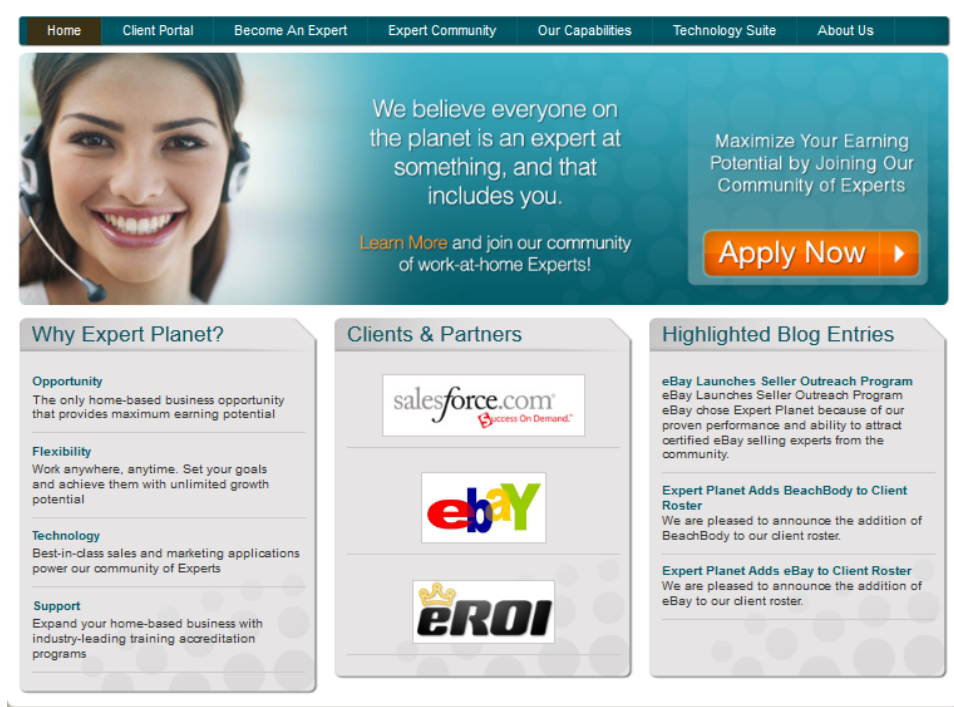


Figure H.28. Expertplanet. Expertplanet aims to provide a sales and marketing channel that matches skilled sales consultants with customers. Experts on the platform are required to have experience in consultative sales, marketing tools and decent practices.

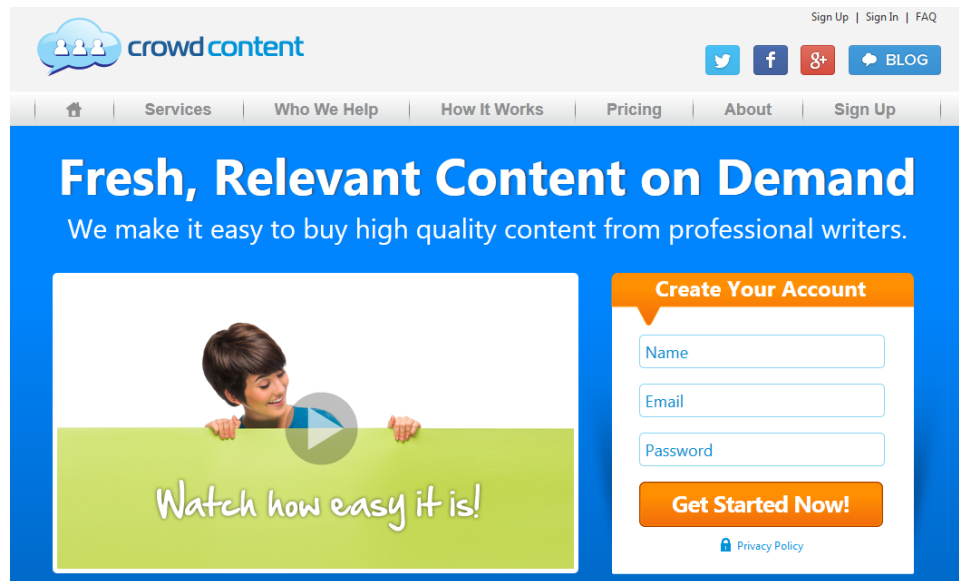



Figure H.29. Crowdcontent. Clients specify their content requirements, and Crowdcontent uses this information to create a brief that communicates to writers in the crowd. Based on the brief, the client's order will be claimed by a group of interested writers, who subsequently create the content.

 CrowdFlower

SolutionsContributorsCompanyBlogDocs

Login

The World's Largest Workforce

Instantly hire millions of people to collect, filter, and enhance your data.

Business Data
Data collected at scale
The accuracy of in-house teams,
the cost advantage of the crowd

Senti
Sentiment Analysis
Fast, accurate human review of
user-generated social media
content.

**Contributors
& Channels**
Interested in completing
microtasks or displaying a task wall
to your user base?

Real-time Crowd Labor



2 judgments/sec
current velocity

855,922,379
total judgments

On-Demand
Pay for only what you
need when you need it.

Accurate
Guaranteed quality with
rich analytics.

Fast
100x faster than
traditional methods.

Experienced
Creating crowdsourcing
solutions since 2007.


Figure H.30. CrowdFlower. Regular users can become labor providers for CrowdFlower's platform. They can monetize their work by completing CrowdFlower tasks.

Fig. H.30 and Fig. H.35 show applications in the media.




CrowdSource™

HOW IT WORKS SOLUTIONS ABOUT US CONTACT US BLOG

500,000 WORKERS ON DEMAND



We deliver...


-  SUPERIOR QUALITY
-  COST-EFFECTIVE RESULTS
-  UNPRECEDENTED SPEED

[View Solutions](#)

Managed Crowdsourcing Solutions

CrowdSource provides full-service crowdsourcing solutions to accomplish labor-intensive tasks with unprecedented speed and superior quality.

Figure H.31. CrowdSource. CrowdSource is a general micro task market place.

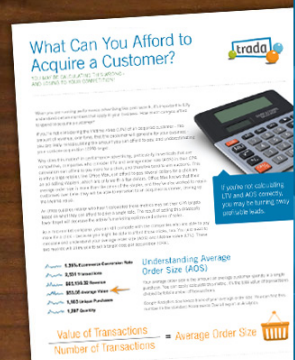


[HOW TRADA WORKS](#)
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Whitepaper: What Can You Afford to Acquire a Customer?

If you're not calculating LTV and AOS correctly, you may be turning away profitable leads/sales!

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What Can You Afford to Acquire a Customer?

When you're running an online business, one of the most important things to understand is how much you can afford to spend to acquire a new customer. This is where Lifetime Value (LTV) and Average Order Size (AOS) come in. LTV is the total amount of money a customer will spend with you over their lifetime. AOS is the average amount of money a customer will spend per transaction. By understanding LTV and AOS, you can determine how much you can afford to spend to acquire a new customer and ensure that you're not turning away profitable leads/sales.

Understanding Average Order Size (AOS)

Your average order size is the amount of money a customer spends in a single transaction. This can vary significantly based on the products or services you offer, the marketing channels you use, and the time of year. To calculate your average order size, you need to know the total value of your transactions and the number of transactions. The formula is:

$$\text{Average Order Size (AOS)} = \frac{\text{Value of Transactions}}{\text{Number of Transactions}}$$

[Click Here for a FREE Demo >](#)

Figure H.32. Trada. Trada is a specialized market place for online advertising management. It motives a community of workers to boost advertisers' paid search campaigns.



Figure H.33. DesignCrowd is a specialized microtask market place, which has crowdsourcing services related to web, logo and graphic design.

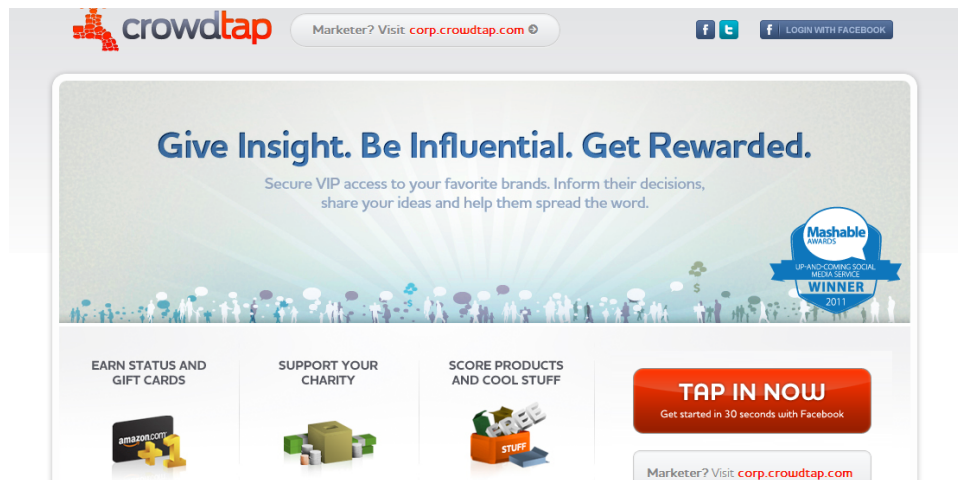


Figure H.34. Crowdtap. Crowdtap is a specialized marketing platform, which provides communication channels between companies and their influential consumers for real-time insights and peer-to-peer marketing.



Figure H.35. Samasource. "Samasource delivers enterprise digital services through a unique micro work model that harnesses the untapped potential of the world's poor." It connects poor women and youth to training and employment in the digital economy. As a premier provider of digital services, they deliver a steady flow of micro work to people around the world.

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