

# Expert-Citizen Engineering: "Crowdsourcing" Skilled Citizens

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**Abstract**—Citizen Engineering (CE) is a concept that engages a cohort of physically dispersed citizens connected by the Internet to collaboratively solve real-world problems through massive cooperation. With advances in information technology, we can build transformative cyber-infrastructures to effectively leverage the "wisdom of crowds" [19]. Regarding the citizen engineers who function as main contributors, there is a wide spectrum of human resources that crowdsourcing system designers can harness - from amateurs/hobbyists, lacking practical experience, to experts/licensed engineers, with years of professional training. As such, we are encouraged to investigate proper approaches to design CEs that can sufficiently engage and support expert citizens who have unique needs that may be different from those of amateur citizen engineers. In this study, we focused on a system designed for engaging high-end users - expert citizens. Our experiment is based on a web site "Expert Citizen Engineering Experiment" developed to fulfill a sophisticated civil engineering task. The conclusions generated from this experiment provide guidance for future CE project designs, where skilled users are the main contributors. Based on our observations and post-experiment interviews, we believe that expert citizen engineers have higher expectations on computation platform capacity and system stability compared to average citizen engineers. Meanwhile, it should be acknowledged that in the domain of civil engineering, high reliability and trustworthiness are particularly emphasized.

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

## I. INTRODUCTION

Emerging information technologies empower us to build transformative cyber-infrastructures. Characterized by broadband networks, high performance processors, multi-user computation facilities, and super-large databases, these novel technologies have facilitated expansive collaboration among users scattered across many physical and institutional locations. As such, citizen engineering, in which dispersed users cooperatively work towards a common goal, has benefited tremendously from the new development of these engineering technologies.

Meanwhile, in the domain of civil engineering, researchers and engineers are restricted by isolated resources - the information and expertise for complex system design is often trapped inside proprietary systems [11]. Due to this compartmentalization, we are motivated to build a collaborative cyber-

infrastructure that can aggregate scattered resources, including both human brainpower and machine computational capacities.

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

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

Currently, there are several mature online marketplaces that we may utilize to crowdsource complicated tasks. Amazon's Mechanical Turk (AMT) was one of our considerations. However, the types of tasks that AMT can efficiently tackle are limited to those mutually independent, less time-consuming and cognitively non-challenging ones [13], which we do not see the best bit for fulfilling the experimental tasks. The intended tasks are embedded with intelligence challenges, and consequently indicate a highly selective workforce. Under this consideration, in the expert-citizen experiment, we use graduate students and visiting scholars from the Department of Civil Engineering and Geological Sciences at University of Notre Dame as surrogates for seasoned experts, from which we investigated user behaviors and system performance.

In this paper, we present the lessons learned and experience gained from this online experiment, which is established in a graduate level course, to provide firm design guidelines for future high-end citizen engineering system development.

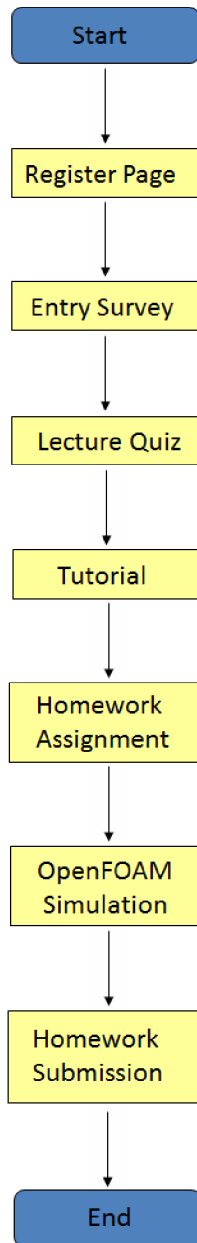


Fig. 1. Experiment Workflow

## II. RELATED WORK

In developed economies, many people enjoy more spare time than ever before. However, a large proportion of that spare time is often spent on less-productive activities. In the US alone, Americans spend around 200 billion hours watching TV every year, while the whole Wikipedia project has taken only 100 million human brain hours [17]. Because of this *Cognitive Surplus*, the approach of *Citizen Engineering* becomes feasible, where researchers are encouraged to develop well-designed mechanisms and methodologies to channel and

motivate humans to solve challenging problems that computers cannot yet handle well.

Open source software development, such as Mozilla Firefox and the Apache Web Server, serves as a successful example of crowd contribution. Mozilla Firefox, as of July 2011, is the second most widely used browser, with approximately 30% of worldwide usage share [2].

In fact, harnessing citizen expertise to achieve a common goal has a rich collection of successful examples [22][14]: eBird [18], Galaxy Zoo [15], Foldit [6], People-Centric Sensing [10][9], Knowledge Collection [5], Stardust@home [21], Human Search Engine [4], Crowd Photo Tagging [23], Participatory Risk Management (PRM) [8], Online Team Gaming [20][16], etc.

On the other hand, a challenge system designers have to confront is the vastly diversified backgrounds of users, and the possibility of malicious users. This uncertainty raises challenges in quality control and result aggregation. 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 product quality.

Inspired by previous research on leveraging “citizen expert groups” to achieve common social scientific goals [7][3], in the engineering domain, we identify the following 3 challenges that are unique to expert citizen engineering projects.

- *Task Complexity* In expert citizen projects, tasks usually demand high human intelligence and skill level. For example, citizen experts can be asked to conduct a whole range of experiments to provide objective, insightful and trustworthy consultancy.
- *Recruitment Difficulty* Due to the complexity inherent in tasks, available human resources are limited and membership eligibility is rather selective, compared to traditional crowdsourcing tasks.
- *Resource Requirement* Complicated tasks may require sophisticated analysis tools and substantial computational resources [11]. For example, current analysis and design methods, such as nonlinear finite element analyses of complex structures, can overstress in-house computational capabilities of many firms and laboratories and far exceed the resources of most citizen engineers.

These challenges drove us to investigate more effective engineering designs that can leverage expertise and experience afforded by high-end citizen engineers. In the following sections, we introduce the methodology deployed and lessons learned in our expert citizen experiment, so as to provide more guidance for future expert citizen engineering project designs.

## III. EXPERIMENT PROCEDURES

Expert engineers used in this experiment were from a graduate level course - CE 80200 Wind Engineering, offered by the Department of Civil Engineering and Geological Sciences at Notre Dame. This senior graduate-level course covers primary design considerations under a variety of wind types. Topics include the analysis of structural response due to wind loading, modeling of wind-induced forces, and principles of



Fig. 2. Main Interface with a Brief Movie Tutorial

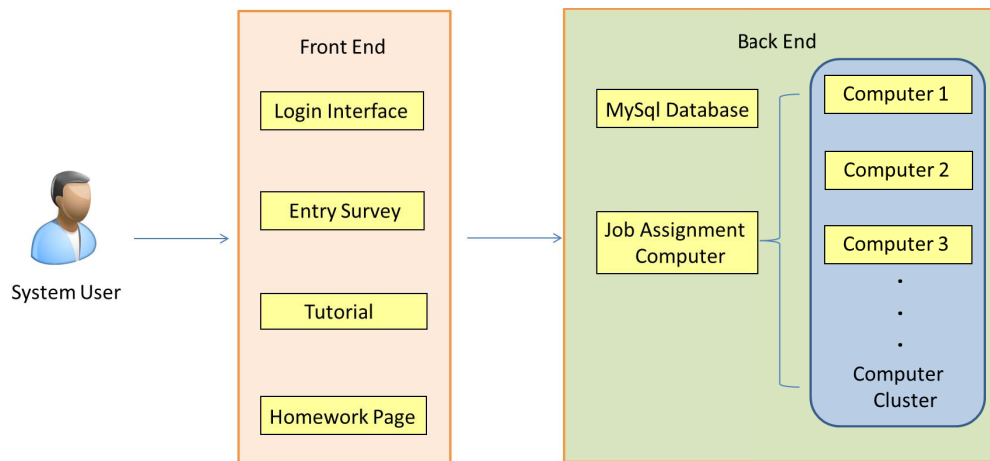


Fig. 3. Website Architecture

design to resist damage due to high wind loads. In total, 8 graduate students were formally registered, with several visiting scholars auditing the course. All of them had formal training experience in civil engineering, and knowledgeable in their professional area.

#### A. Workflow

The experimental procedure is shown in Fig. 1. Upon agreeing to a consent form, subjects were taken to a sign-up page, and asked to create their login credentials, where their campus login was verified to confirm they were registered students. If the personal information entered was valid, a new account was created, and users received the entry survey. Having completed

the entry survey, users were presented with a question set - a lecture quiz, in which questions were designed based on the class lectures, and intended to test users' understanding of the class material. After the lecture quiz, users were taken to the main interface, Fig. 2, where they could receive the work assignment, review the previous documents, logon to the simulation platform and submit their results.

#### B. Web site Design

As shown in Fig. 3, the website includes the front-end web interface and the back-end simulation platform.

##### 1) Front-end User interface:

- *Welcome Page* Introduces the motivations and concepts of this experiment.
- *Entry Survey* Investigates students' background information such as their GPA, gender, year, etc, as shown in Fig. 4.
- *Lecture Quiz* Tests users' understanding of course materials, as shown in Fig. 5.
- *Tutorial* Explains how to use the computation platform to run simulations.

#### 2) *Back-end Simulation Platform:*

- *Database* Keeps profile information of students, such as their academic background and lecture answers, etc.
- *Computer Cluster* Takes parameters submitted by users, generates data sets, presents mesh grids and runs simulations.

Users logged into our web site, reviewed the tutorial, accessed the simulation task, ran their simulations, and submitted reports to the database through a designated web page.

Starting on Apr. 25 and ending on May 3, 2011, in total, we received 9 complete simulation reports. This small sample is a reflection of the high selectiveness of the user base.

## IV. SIMULATION TASKS

### A. *Task Introduction*

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 can refer to the article [12]). Turbulence flow simulation is a complex process, and it normally takes several hours to generate the results if the simulation is set up correctly. In this expert citizen project, students are encouraged to try multiple experiment configurations and plot their results, by which they can better interpret the influence of the grid density (discussed in detail in Section V.B).

### B. *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 general submission, there are several areas we may evaluate for quality.

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

The criteria listed above are rather subjective and qualitative, mostly depending on reviewers' personal judgments. To evaluate the quality of complicated job submissions, we traditionally resort to help from well-trained professionals. In future research, one of the feasible metrics that can mechanically assess simulation quality was the deviation of the curve from an ideal curve that has been thoroughly tested by previous research, as shown in Fig. 8. If there is an unacceptable difference between the two curves, we reasonably lower our confidence in the submissions of this particular citizen engineer.

**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

Fig. 4. Sample Questions from Entry Survey

## V. SIMULATION TOOLKIT

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

However, two additional considerations complicate matters. First, the idea of citizen engineering is to collect inputs from online contributors. As such, we, the project organizers, must provide hardware and software support, with a web interface, to allow contributors to access the underlying simulation software. Second, in spite of the higher level of experience of the expert contributors, many software tools, including most CFD, are complex and domain-specific with a very steep learning curve. Therefore, we must provide a layer of user-friendliness between the raw software tool and the expert contributor.

## 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.

Fig. 5. Sample Questions from Lecture Quiz

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

- CFD package: An underlying software framework.
- Web-based front-end: Gateway to OpenFOAM software.
- Distribution System: Dispatch controller to send simulation jobs to hardware resources.

### A. OpenFOAM Package

In this experiment, students were expected to take advantage of the CFD platform to conduct flow analysis for a channel flow situation. The basic simulation tool was the OpenFOAM (Open Field Operation and Manipulation) CFD Toolbox developed by OpenCFD Ltd [1], which is a free, open source software package, licensed under the GNU General Public License (GPL).

As open source software, the OpenFOAM package's ability to simulate complex fluid flows of turbulence, and its openness to allow users to customize and extend its existing functionality were the main reasons that we used it as a major simulation tool on our platform. Also, OpenFOAM is one of most popular CFD simulation tools, widely deployed by practitioners around the globe, and has been validated and verified intensively [1]. In this regard, our design goal of providing users a functional and robust simulation platform can be satisfactorily met. Lastly, OpenFOAM has an embedded meshing utility, which helps users better visualize their results.

### B. Web-based Front-end

CFD is highly complex however, so rather than distribute the software package for users to download, install and use on their own computers, we installed it on our own system and

produced an easier-to-use web-based front-end that allowed users to access specific software features.

This front-end restricted the users to producing and simulating channel-flow cases, which were the only ones needed to answer the problems posed. However, the system gave the users the flexibility to specify the mesh parameters and simulation time step. The users also had the ability to browse case files and download results.

We found three main challenges related to providing such a system:

- User-friendliness had to be carefully tuned. If the system was too complex, users could get frustrated and confused. If the system was too restrictive, then there was little point to a crowdsourcing study, since we would have already done the work to specify what simulations the contributors should run.
- Since these simulations could run a long time, we had to design our interface to account for the fact that procedures did not happen instantly when a user clicked. In multiple cases, impatient users initiated multiple replicate simulations because 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 generation affected job duration.

In CFD, "meshing" is used to define a finite number of elements to represent the geometric structure, in which the denser the mesh, the more accurate the data generation is, but at the expense of a greater computational time/memory. In other words, more elements and thus finer grids lead to higher accuracy, but consume more computational time to complete a simulation. The platform provided ways of visualizing meshes after they were generated, but users still had to experiment with how meshes affected simulation time. Fig. 6 shows a portion of the front-end in our system dealing with mesh generation.

### C. Distribution System & Hardware Back-end

For this project, we needed to provide computational resources to allow CFD jobs to run. For this, we used an experimental project on dispatching and managing jobs to cloud-based resources. Our computing back-end was several virtual machines run on an on-campus private cloud computing environment. Our task manager was designed to take queued tasks from the front-end and dispatch them to the back-end, and we intend to make considerable enhancements and additions to this software project, and expect to publish details on this software component at a later date.

## VI. RESULTS AND DISCUSSION

Most students submitted high quality reports. Fig. 7 shows a participant's mesh generation, while Fig. 8 shows a sample velocity curve.

# ND CFD Computation Workbench

Instructions
Manage Cases
See Running Tasks
Logout

Case Folder: home/newCase  
[Go Back](#)

Below, step by step functions are available for running standard CFD tasks on this template:

**Stage 1: Mesh Generation:**

The first step is to generate a grid of cells that will be used as the basis of the simulation. It is recommended that you view the mesh before proceeding.

Specify the basic parameters of the mesh:

Nx:	40
Ny:	25
Nz:	30
Upper y-ratio:	0.0984
Lower y-ratio:	10.7028

Note: If your mesh has too many elements, the simulation will take too long to run, too few and the simulator might fail. Also the max courant numbers should always be less than 1.

Generate Mesh

While the mesh is being generated, you can check on progress by clicking: [Mesh Generation Task Status](#)

Once the mesh is generated, you can look at the mesh: [Visualize the Mesh](#)  
 (Note that this can take a few moments to load.)

Fig. 6. Simulation Platform Entry Page - Parameters for Mesh Generation.

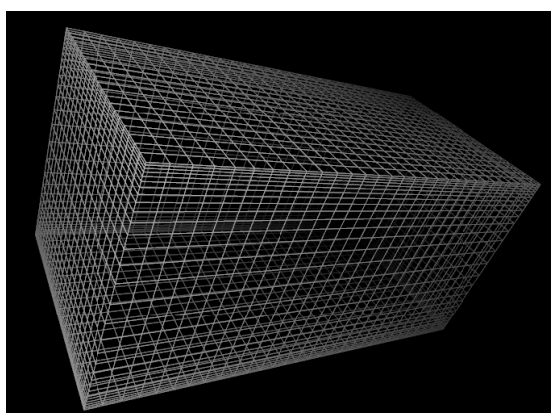


Fig. 7. Mesh Visualization of the Channel Flow. This screenshot is from one student's report.

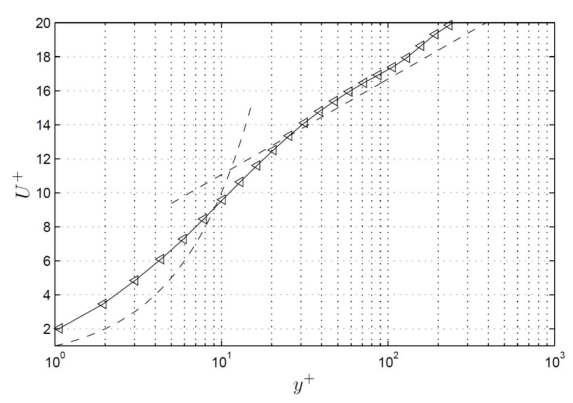


Fig. 8. Velocity Profile from One Participant's Report. The solid line marked by triangles is the simulation curves generated by the student, and the dashed line is the ideal curve.

### A. Simulation Quality vs. Lecture Quiz

The simulation reports were graded by the professor who lectured the class, 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), the thoroughness of result analysis and discussion, etc.

As shown in Fig. 5, the lecture quiz was intended to measure citizen engineers' expertise level, aiming to test the correlation between students' understanding of course material and accuracy of their simulation results. In this experiment, we did not halt a user's participation simply because of his/her low score on lecture quiz, since the quiz questions, expected as simulation quality indicators, were experimental. But in future CE system design, the quiz/questionnaire performance could be leveraged as one of the references that may help project organizers match jobs with proper users.

In our prototype, counter-intuitively, as demonstrated in Fig. 9, there was no statistically significant correlation between quiz scores and simulation qualities. In Section VI.E, we further discuss this observation.

### B. Uneven Workload

As illustrated in Fig. 10, 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.

In the extreme, in the evening hours before the deadline, May 3, 2011, system records showed that all 9 users were simultaneously running tasks on the platform. As such, in practice, project organizers should prepare a system robust enough to support bursty workloads.

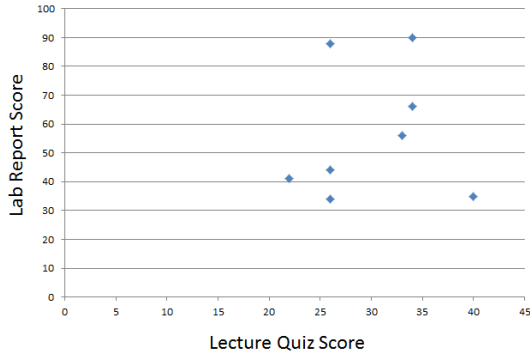


Fig. 9. Scattered Plot of Lecture Quiz Score vs. Lab Report Score (No Statistically Significant Correlation). The lecture was intended to measure the citizen engineer’s expertise level.

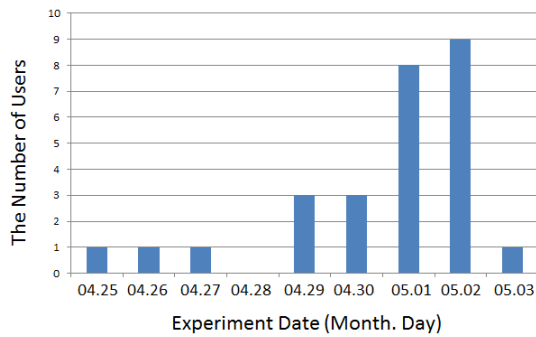


Fig. 10. Variation of the Number of Users Working Simultaneously on the Simulation Platform.

### C. Simulation Time

Another category of information is students’ simulation time. System data shows that the time durations students spent on the simulation platform completing their tasks were rather random. In other words, there was significant variations among the lengths of time periods that different users used to fulfill their tasks. Examining the log data further, we also found there was no statistically significant correlation between the time that a given student spent on simulation task and that student’s simulation quality.

One of the reasons which 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, when a large number of users were running their tasks simultaneously, significantly slowing down the system. When this happened, some impatient users repeatedly submit their jobs, which deteriorated the situation, and artificially prolonged the simulation time. We actually have observed from the system log files that one user continually pushed the same job to the system more than 10 times in a very short period of time.

In the real development of an expert citizen engineering system, deadlines on tasks could be imposed, and the computation

platform could experience bursty workloads. In this regard, a recommendation for future system design is that the designers should take account into this situation, supporting users with enough computation capacity, but meanwhile equip protection mechanisms that can throttle some users’ job submission, preventing them from overloading the system.

### D. Post-experiment Interview

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

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

Users’ concerns show that when our web site has provided basic functionalities, expert citizens especially emphasize the reliability and stability of the system that can help them to fulfill complicated tasks. In this sense, the retention of expert citizens, when competitive sources available, to a large degree depends on the satisfaction of their high expectations on user experience. “Being usable and being likable are two different goals” [24]. Easiness and smoothness may play a more primary role for professional users than it does for average users.

### E. Experiment Limitations

We acknowledge that there are some limitations on this expert-citizen experiment that need to be addressed:

1) *Lecture Quiz Design*: As stated in Section VI.A, when analyzing user submissions, we did not observe significant correlation between the quiz score and simulation performance. We believe the reason for this is that most questions in the lecture quiz were designed for investigating participants’ theoretical understanding of simulation concepts rather than their practical simulation skills.

2) *User Population*: Because of the highly selective user base, this prototype system only engaged 9 users in total, including both upper level graduate students and visiting scholars. To generate reliable inferences from the experiment, we need to engage more users, by which we can provide more convincing arguments for the generalization of the conclusions we derived from the prototype.

3) *Result Evaluation*: In this experiment, the professor who gave the lecture worked as a “super expert”, who evaluated expert users’ submissions. However, if we want to scale up the system and enlarge the user base, the “super expert” will consequently become a scarce resource, so we need to develop new approaches to effectively automating part or all of the evaluation processes. As discussed in Section VI.A, the curve deviation could serve as a plausible candidate.

## VII. CONCLUSION AND FUTURE WORK

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 high level users. In this study, through an expert-citizen engineering system prototype, we illustrate our considerations and approaches in the process of achieving a successful CE design.

We believe this paper is one of the first that focuses on tapping high-end expert citizens to solve sophisticated civil engineering tasks. We present the lessons we learned and experience we gained from our pilot project. Undoubtedly, there are more challenges waiting to be answered. For example, how can we present a well-structured interface, without compromising site functionalities, to improve platform understandability and consequently user performance? How should we properly group individual contributors, and make them collaborate complementally? When it comes to citizen engineer recruitment and retention, how do we attract experienced users to come and perform high-quality work? These questions drive us to further our understanding of the design principles of citizen engineering system.

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