

Contribution Attribution as the Possible Next Step for “Crowdsourced” Engineering Design and Product Development

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INTRODUCTION

Commercial websites that accept customer-generated content from a large number of users—the so-called “crowdsourcing” approach—are generating much interest from customers and researchers alike. Often, the tasks addressed by these websites can be completed by one user with a single effort. The “crowd” effect is realized by having many submissions with many individuals judging them.¹ This Article poses two questions: Can the crowdsourcing model be applied to engineering design and product development? If so, how?

Although these two brief inquiries state my research goals, to understand more completely and to see how issues related to credit attribution play a role, it is necessary to define some terms and provide some motivating examples.

Engineering design together with product development is the process by which new physical artifacts are created.² A set of characteristic sequential steps in this process can be identified. First, *need recognition*, as the name implies, identifies possible design problems. This is followed by a *search* for relevant background information, such as pertinent literature and patents. Once adequately

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1. Examples include the “namethis” project found on the Kluster website, <http://www.kluster.com> (last visited May 2, 2009), and the Threadless website, <http://www.threadless.com> (last visited May 2, 2009), that accepts user-generated designs for t-shirts.

2. See generally KARL T. ULRICH & STEVEN D. EPPINGER, *PRODUCT DESIGN AND DEVELOPMENT* (4th ed. 2007).

informed, designers can draw up more formal *specifications*. In response to these, *concepts* are generated (the “eureka” phase most people think of as “design”). A single concept is then *selected* for further development. This further development is called *embodiment*, as the concept is embodied with specific choices for materials, sizes and shapes, fastening techniques, etc. Importantly, embodiment bridges the gap between an unambiguous concept and a completely specified object that can be manufactured. Following embodiment, some number of *prototypes* are constructed and tested prior to making the commitment to mass-produce the design.

Typically, these sequential steps are done by the employees of a single company, that is, in a closed setting. This allows the design being developed to be kept secret. Additionally, a closed setting with a fairly small number of participants facilitates rich face-to-face communication.³ This helps to resolve inevitable design changes, revisions, and backtracking.

My interest is in determining if an engineering design process can be done in a more open, crowdsourced mode. Howe provides a “white paper” definition of crowdsourcing as “the act of taking a job traditionally performed by a designated agent (usually an employee) and outsourcing it to an undefined, generally large group of people in the form of an open call.”⁴ In close agreement with this, I envision a scenario in which a larger number of informal participants contribute to an engineering design process via the Internet.

I have two motivations for this inquiry. The first, perhaps obvious one, is the hope that many minds will produce more and better design ideas. This might be particularly true if the participants are target customers of the product. A major task of the specifications phase mentioned above is to obtain a set of user needs from potential users. This is a difficult and time consuming process of questionable efficacy.⁵ A crowdsourced mode, in contrast, would allow interested,

3. See Mark J. Jakiela & Wanda J. Orlikowski, *Back to the Drawing Board? Computer-Mediated Communication Tools for Engineers*, in DESIGN THEORY AND METHODOLOGY—DTM '90 127 (J. Rinderle ed., 1990).

4. Jeff P. Howe, *Crowdsourcing: Why the Power of the Crowd Is Driving the Future of Business* (Feb. 11, 2009), <http://crowdsourcing.typepad.com/>; see also Jeff P. Howe, *The Rise of Crowdsourcing*, WIRED, June 2006, at 176.

5. See Susumu Ogawa & Frank T. Piller, *Reducing the Risks of New Product*

enthusiastic users to offer explanations of dissatisfactions with current products and suggest actual design improvements. The hope is that if enough users participate in this way, formal collection of user needs will not be necessary and good ideas will be uncovered more efficiently.

My second motivation is to administer such a scenario so that it provides a source of temporary informal employment for the participants. Imagine, as an example, farmers buying agricultural equipment. Some will buy equipment and be dissatisfied with it. Among these, some will simply switch to other suppliers for their next purchase. An important subset, however, will attempt to improve their purchased equipment by making their own modifications. As things are done currently, it is unlikely that these enthusiast users will make their ideas known to the original supplier or to other farmers. Their possibly highly innovative design work, based upon their clearly understood but unarticulated user needs, will be hidden in isolation. I want to provide these “user-customer developers,” or “UCDs”,⁶ with a profitable outlet for their design work. This raises difficult questions about how to protect their intellectual property. If they display their ideas to an open, web-based community for useful feedback, criticism, and embellishment, there must be a means to prevent others from manufacturing the design and profiting.

I leave solution of this issue to the future, and instead imagine the possibilities and questions that would arise if such enthusiast users could securely profit from their ideas. How profitable would UCD-ing be? Would general interest freelancers arise? In other words, would a class of individuals do crowd-based design work in a variety of domains? Would original equipment manufacturers release products that were somehow incomplete or easily modifiable, in anticipation of subsequent UCD-ing? How exactly would UCD-ers be compensated, and who would compensate them? One of my goals for this Article is simply to describe the potential issues to other interested researchers in order to motivate discussion and the exchange of ideas.

Development, 47 MIT SLOAN MGMT. REV. 65 (2006).

6. Termed coined by the author.

I. POTENTIAL ISSUES

When imagining how UCD-ing would work, and the capabilities required from a web-based facilitation tool, it is important to remember the sequential nature of the engineering design process. It is necessary to do more than just propose ideas: many other tasks, particularly from the embodiment phase, are needed. I envision allowing multiple other participants to do these tasks. This is in contrast to existing systems that collect user-generated design content. Threadless, for example, seeks user-generated designs for silkscreening on T-shirts.⁷ Such design content is typically done by an individual, with no revisions based upon feedback from the user community.

Assuming that a mechanism exists for the compensation of contributors, it will be necessary to have a clear and fair mechanism for credit attribution. Consider an online community of travel enthusiasts collaborating to design an improved day pack, which would hold a day's essentials (maps, lunch, sweater, camera, etc.) and be kept as carry-on luggage. This is the recognized need, and we will assume that these enthusiasts are already familiar with existing similar products, implying that a background information search need not be done. Desirable user needs would be shared among the participants. These might include that the pack (1) somehow attach to other luggage; (2) have a waterproof bottom; (3) be usable as a backpack (i.e., with two shoulder straps); (4) have a waterproof thermally insulated compartment for lunches and water; and (5) have a minimum acceptable volume. Once a list of user needs is settled upon, participants might individually generate concept designs that could be displayed to the entire community. Some type of voting procedure, perhaps a multistage runoff, could be used to pick a final winner.

Even in getting to this point, a whole host of questions related to credit attribution arise. For example, who gets credit for this outcome, and should multiple users be allowed to receive credit? Some typical approaches to answering these questions are

7. Threadless, *supra* note 1.

unsatisfactory. Winner-take-all would give all the credit to the designer of the winning design. If the odds of credit are small, might this discourage others from submitting design ideas? Credit in proportion to votes received seems to address this issue, but if two or more concepts seem equally good and get similar numbers of votes, might this fragment the community and lead to a lack of unity before the process moves forward to embodiment? What if two participants submit basically the same design? Should they be grouped together and share credit, or should the first to submit get all the credit? Is it wise to rush the creative process like this? A related issue concerns the quality of the work versus the quality of the idea. During this conceptual stage, should a beautifully rendered design idea get credit independent of its inherent quality (ingenuity, non-obviousness)? What if two participants submit basically the same idea, with one beautifully depicted and another shown as a barely comprehensible scribble? More generally, should participants get credit in proportion to the amount of time spent, assuming we can accurately measure this? Perhaps of secondary importance, should participants get credit for activities done in support of the concept generation and selection functions? Should some small amount of credit be awarded for posting commentary on others' designs? What if the commentary makes an important and unique observation? Should participants get some credit for simply voting?

Returning to our story, assume that a single concept has been chosen and the embodiment phase has begun. Similar sub-scenarios will ensue, all with suggested solutions and voting used to choose the solutions that will be implemented. These might involve the specific choices of materials, colors, buckles, shoulder straps, and fabrication techniques. Consider a case in which a participant, let's call her "Jane," suggests using a soft faux suede material on one side of the bag to facilitate using it as a pillow.⁸ In her life outside of the web community, Jane works as a costume designer and hence is interested

8. I give credit for this story to St. Louis public television station KETC and events witnessed during one of its pledge drives. Celebrated travel author, Rick Steves, in the local studio as a guest, offered such travel bags, complete with soft outer surface, as an incentive gift for making a pledge. Prior to this, this case study would have dealt with a college book bag. *KETC Pledge Drive* (KETC television broadcast Mar. 2008).

in the material choices and manufacturing aspects of the bag. This basic idea, using the bag as a pillow, was considered during concept generation and was championed by “Joe,” who submitted a concept design that included an air chamber and hand-actuated pump. Others had designs with secondary pillow functionalities that used foam or packed clothing as the padding material. None of these did well in the voting, and the winning design had no explicit pillow capability. But now Jane’s idea of providing an inviting surface material has ignited a vigorous discussion, with several calls for the community to revisit the concept selection process. If they do, and Joe’s concept, embellished with Jane’s embodiment detail, is favored by a majority, what is the fate of “Dick” and his design, which was the winning concept before the upheaval? Is the design “dethroned,” with Dick losing the credit he has earned?

Or, consider a less ominous version of this scenario. What if, during concept generation, a sizable minority emerges in support of Joe and his pillow idea? This group vigorously promotes the idea to the community and urges some attention to it in the final design. Dick magnanimously takes this to heart and incorporates a rudimentary version of it in his final submission. Should Joe get some credit for leading the charge? Continuing on, Jane again enters the scene at a later stage and suggests the faux suede, which now is easily integrated into Dick’s design. Should Dick now get even more credit for being prescient? Is the importance of Joe’s earlier leadership rarefied? How do we keep track of all this?

This example may seem fanciful, but in industry this type of back-to-the-drawing-board flip-flopping happens constantly. Indeed, when it doesn’t happen, inferior products often result. In a conventional small-group, closed setting, credit attribution is more easily managed. There may be an “all for one, one for all” approach that is palatable given the small team size, or a project manager may receive most of the cumulative credit. Group members might take turns serving as project manager. Difficulties tend to arise when there are a larger number of participants overall, when the participants are not collocated, or when a larger number of participants are potentially contributing to a single task that usually is done by far fewer. These are exactly the conditions of a crowdsourced mode.

II. RELATED WORK

In this section, I give examples of possibly related research. This discussion is not intended to be exhaustive: there may be a large body of work related to each example. I only hope to give illustrative examples of other efforts. My search for research efforts addressing similar issues has found studies that address specific pieces of our bigger picture or other similar bigger pictures. Though interesting, none of these provide specific guidance on how to configure the dynamic, multi-level credit attribution system required.

A. *Similar Situations*

A scenario related to crowdsourcing that has received significant attention is mass authorship of scientific publications.⁹ These are cases in which everyone ever associated with a large-scale project is named as an author on resulting articles. No formal effort is made to distinguish who did what. Birnholtz focuses on the worldwide community of high energy physics researchers and suggests some important characteristics of these situations.¹⁰ He notes that projects intended to produce a single working prototype (such as a particle collider) that are massive in scale and require very long lead times tend to encourage a “one for all” mentality.¹¹ Getting it done at all is the most important task. In this regard, those who traditionally would not be considered scientific contributors, such as technicians who devised clever hardware design solutions, are also commonly given credit.¹² Additionally, it is evident that, unlike in engineering design and product development, the participants themselves are the customers. Once the physical apparatus is completed, the same scientists will use the equipment to collect data. In this context, the desired credit attribution is professional recognition among the large number of researchers involved and the larger physics research

9. See, e.g., Jeremy P. Birnholtz, *What Does It Mean to Be an Author? The Intersection of Credit, Contribution, and Collaboration in Science*, 57 J. AM. SOC'Y FOR INFO. SCI. & TECH. 1758 (2006).

10. See *id.*

11. *Id.* at 1767.

12. *Id.*

community. Such credit could be meaningful in tenure and promotion decisions.¹³

Birnholtz also makes interesting comparisons with film production, where the role of each contributor has typical expectations.¹⁴ The important idea here is that there are “standard roles,” such as “gaffer” and “key grip.”¹⁵ The expected tasks for each are well known, and presumably their significance to the overall film production process is reflected in their level of compensation. Similar roles exist in conventional (small numbers of collocated participants) engineering design and product development. The titles “designer,” and “chief engineer” are more likely to indicate creative work output. “CAD operator” is likely to refer to a responsibility to document the designs finalized by others. Identifiable tasks requiring no creative input might not benefit from a crowdsourcing approach as envisioned here. Why have many compete to create CAD models, when the results will be the same regardless of the source? In many industries, this line is less clearly drawn than one might think: design decisions *are* made in the final documentation and prototype fabrication stages, sometimes to correct errors that occurred upstream. Again, one can imagine that these late-stage “fixer uppers” will deserve some credit.

Lastly, Casati et al. suggest a dramatic overhaul of the scientific publication process, replacing published papers with “liquid papers” that are evolvable and admit contribution from many in the manner of open source software and wikis.¹⁶ This overall enterprise would have many similarities (credit attribution for partial contributions, etc.) to our proposed approach. A facilitating factor might be that most contributions to liquid papers could be text-based.

13. *Id.* at 1763–68.

14. *Id.* at 1768 (citing the analyses of film production done by Beth A. Bechky, *Gaffers, Gofers, and Grips: Role-Based Coordination in Temporary Organizations*, 17 ORGANIZATIONAL SCI. 3 (2006), and HOWARD S. BECKER, ART WORLDS (1982)).

15. Birnholtz, *supra* note 10, at 1768.

16. Fabio Casati, Fausto Giunchiglia & Maurizio Marchese, *Liquid Publications: Scientific Publications Meet the Web* (Univ. Trento, Dep’t of Info. & Comm’n Tech., Technical Report DIT-07-073, 2007), available at <http://eprints.biblio.unitn.it/archive/00001313/01/073.pdf>.

B. Similar Subprocesses

Models and formulas for types of credit attribution do exist, but do not seem to allow the kind of dynamic updating that we describe. The notion of bookmarking, for example, has arisen as a way to “remember” world-wide-web locations that one finds interesting.¹⁷ Counting the number of times that a website has been bookmarked can be considered as a measure of its significance. One could imagine a similar approach being imposed in a crowdsourced engineering design scenario. Contributors would bookmark other submissions they have seen prior to making a contribution, with the idea being that these other submissions have influenced the contributor in some manner. It is possible, however, to imagine cases in which the other seen submissions are not actually significant. Perhaps the contributor has simply confirmed that their present idea has not yet been submitted. The fact that there is no easy way to record and reason about the rationale for making a bookmark seems to limit the utility.

Additionally in a design setting, it would seem that a mechanism for noting a bookmark when the contributor has not is necessary. What if a contributor submits a design idea that, knowingly or inadvertently, is similar to previous submissions? If we cannot rely on submitters to note the significance or influence of previous efforts, some type of automated system for doing so would be required. A similar situation has been recognized in the patent application process. An “examination support document,” among other things, attempts to identify the prior art most closely related to each proposed claim.¹⁸ A software provider called PatentCafe advertises that they already have automated the creation of examination support documents using artificial intelligence techniques.¹⁹

Additional measures of significance exist in other broader domains. Hirsch’s “h index,” for example, is intended to provide a

17. See Tony Hammond et al., *Social Bookmarking Tools (I): A General Review*, D-LIB MAGAZINE, April 2005, <http://www.dlib.org/dlib/april05/hammond/04hammond.html>.

18. See Gerry J. Elman, *Editorial, Automated Patent Examination Support—A Proposal*, 26 BIOTECHNOLOGY L. REP. 435, 435 (2007).

19. See Benefits of PatentCafe’s Patent Classification and Search Automation Tools, <http://www.37cfr.com/benefits.asp> (last visited Feb. 15, 2009); PatentCafe, <http://www.patentcafe.com/> (last visited Feb. 4, 2009).

quantification of a researcher's scientific output.²⁰ Consider "h" as the number of an author's published papers that have been cited that number or more times. The Hirsch index "h" is the maximum value of that number.²¹ An interesting aspect of this metric is that it is a function of a recognized atomic activity unit: the published paper. I suggest that an analogous activity unit in the domain of engineering design and product development is the "design change," which could represent anything from suggesting a new design to making slight modifications to any designs currently under consideration. Clearly, however, some design changes are more significant than others, independent of how many times they may be bookmarked. I would also like to include input that does not directly alter the artifact under consideration. Posted comments, for example, might be extremely significant.

So far I have been concerned with ensuring that a credit attribution system is fair and allows dynamic revision. Another aspect is making it motivational. Can it be designed so that it optimally encourages participation? Can it encourage the participants to be sincere, to not attempt to plagiarize and infringe? Birnholtz recognized that this is an example of an economic mechanism.²² Designing these "rules of the game"²³ has often been cast as designing incentives for particular behaviors.²⁴ Recently, these have been designed automatically for specific situations.²⁵ I would hope, for example, to design credit attribution mechanisms that motivate contributors to report truthfully how their submission might be derived from previous ones.

20. J.E. Hirsch, *An Index to Quantify an Individual's Scientific Research Output*, 102 PNAS 16569, 16569 (2005).

21. *Id.* at 16569.

22. Birnholtz, *supra* note 10, at 1769 (citing Theodore Groves, *Incentives in Teams*, 41 ECONOMETRICA 617 (1973)).

23. Tuomas Sandholm, *Automated Mechanism Design: A New Application Area for Search Algorithms*, in PRINCIPLES AND PRACTICE OF CONSTRAINT PROGRAMMING 19, 20 (F. Rossi ed., 2003).

24. *See* Theodore Groves, *Incentives in Teams*, 41 ECONOMETRICA 617 (1973).

25. *See, e.g.*, Sandholm, *supra* note 23.

III. SYSTEM CAPABILITIES FOR CROWDSOURCED ENGINEERING DESIGN

I conclude by suggesting a set of requirements for a web-based system for crowdsourced engineering design and product development. This set is based upon the issues examined above, as well as J. Zheng's and my own experience with an initial implementation using a web forum format, titled "WeDesign," that did not allow backtracking and did not use credit attribution.²⁶

A. General System Requirements

1. Text and Graphical Input

Initial experience with our "WeDesign" system allowed a crowd to perform concept generation and selection using a web forum-based implementation.²⁷ Any text or scannable input was allowed; no active CAD models were used.²⁸ For these two tasks, this was adequate for design problems addressing personal protection devices and camping equipment. We predict that sophisticated physical models, such as those for solid modeling and engineering analysis, will only be necessary when the task at hand is to create them for their own purposes.

2. Selection Using Voting

In our initial implementation using a web forum, a simple polling capability was used in the concept selection process. For example, in a situation in which fifty participants submitted fifty concept sketches (as .pdf files), a runoff vote was held to attempt to narrow this down to four. This typically resulted in a lack of consensus with no clear winners, and a broad distribution of votes across many of the designs.

26. Mark J. Jakiela & J. Zheng, *WeDesign: A Forum-Based Tool for Managing User-Generated Content in Engineering Design and Product Development*, in PROCEEDINGS OF THE 2008 ASME DESIGN ENGINEERING TECHNICAL CONFERENCES AND COMPUTERS AND INFORMATION IN ENGINEERING CONFERENCE: VOLUME 4, 20TH INTERNATIONAL CONFERENCE ON DESIGN THEORY AND METHODOLOGY 711 (2008).

27. *See id.*

28. *See id.*

It will be necessary to design (possibly iterative) voting procedures that force the group quickly and clearly toward unanimity. More generally, we envision systems configured to drive the process to a single design, both overall and for each stage. One design should result from concept selection, embodiment, and prototyping and testing. It would seem to be easy to allow communities to subdivide into multiple design processes if consensus cannot be reached.

3. Backtracking

Even given this desire for a single result, the system should facilitate the type of backtracking described in the imagined scenario above. Contributors should not have to restart the process, and the completion of tasks that would follow the revision should be automated as much as possible.

B. Requirements Related to Credit Attribution

1. “Annotated Scrapbooking”

I suggest this term for the case in which a contributor notes that a previous submission has been influential to the submission he or she is currently making. Designers often keep scrapbooks, sometimes annotated, of previous designs that were in some way meaningful. Comments from the designer on why the prior submission is currently pertinent should be facilitated.

2. Identification of Related Previous Submissions

Another issue arises when a contributor does not note influential previous submissions. The system must have the capability to review prior submissions to determine if any should be cited. I would hope that this process could be automated to some degree using computation,²⁹ but in simpler implementations one can envision groups of “watchdog” participants that earn credit by performing this function. This would be similar to the goal of the Amazon.com

29. See *supra* note 19.

Mechanical Turk system, which uses “artificial artificial” (i.e., human) intelligence to complete simple tasks that defy easy automation.³⁰ This requirement—the immediate identification of lacking attribution and copying—seems to suggest several interesting research questions. For example, will a randomly picked group of individuals agree that two designs are similar, or, in a different context, that one design is derived from the other? Will the aggregate finding of a group differ from the opinions of the designers of the two artifacts? How does making these comparisons depend upon the domain of the design? It might be easier, for example, to notice that the same portion of electrical circuit has been used than it would be to tell if two mechanical machines use the same approach. J. Zheng and I are currently conducting a literature review of these topics.

3. Credit Attribution Networks

Should credit propagate? If a submission is found to be influential, should the earlier submissions that influenced it also receive additional increments of credit? In an engineering design scenario, this would seem to cause the chosen concept design to get stronger as more work is done to refine it into a working prototype. This capability would require some type of quantification of the amount of credit attributable to the predecessor, in contrast to a simple binary (either/or) indication of attribution.

4. Credit as a Function of Amount of Completion

An opposing trend in cumulative credit should be related to the extent of completion of the overall sequential engineering design process. For example, if concept design has been completed, any reward available could be claimed by the contributors to that concept. If the design process moves forward to a concluded embodiment, the reward would then have to be shared by all contributors to both processes, thereby decreasing the amount of credit available to the contributors to the winning concept. The more the design is

30. Amazon Mechanical Turk, <https://www.mturk.com/mturk/welcome> (last visited Feb. 11, 2009).

completed, the more the total available credit must be shared. This could be augmented in a variety of interesting ways, such as retaining credit in anticipation of possible backtracking. In our earlier travel bag example,³¹ at the end of the concept phase, Dick and Joe might share credit in proportion to the number of votes their concepts received. Intuitively, Joe's credit should decrease as Dick's design is more fully developed. Joe's credit would swell when the community decides to backtrack and reconsider his idea with Jane's embellishment.

CONCLUSION

I have described how issues of credit attribution arise when considering the design of a computer-based system for the facilitation of a multistage engineering design process. A review of previous literature shows related attention in other disparate domains but no direct preceding work that provides specific guidance on how to proceed. In response to this, I have suggested necessary system capabilities. I hope that this Article will encourage discussion of this issue among other researchers.

31. See Part I, *supra*.