THE IMPLEMENTATION OF CROWDSOURCING IN COMPANIES; THE CASE OF NASA

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Table of Contents:

1. INTRODUCTION AND RESEARCH QUESTION

The quick development of Web 2.0 has led to the emergence of new models for business, for communication, for learning, for personal relationships, etc.

In the field of business and open innovation, one of these models is crowdsourcing. Crowdsourcing refers to the act of outsourcing an activity to the general public, or crowd. It allows firms to bring external resources into the innovation process and reach beyond their immediate resources. This method could really revolutionize the traditional approach to R&D that firms are still maintaining in a world that instead imposes a highly flexible and dynamic mentality, detached from the old contractual models that do not belong anymore to our rapidly changing world.

This paper aims at examining and carrying out how the method of crowdsourcing can result in a winning one for companies and organizations through an in-depth analysis of the concept. The question that wants to be specifically addressed, is how and why crowdsourcing should be implemented more widely in knowledge-based industries such as NASA. After noticing a lack of extensive documentation on concrete application cases of crowdsourcing in the scientific field, the final purpose of the paper would be to support the thesis in favour of a larger implementation of crowdsourcing into these kind of organizations, thanks to empirical evidence provided by several case studies on NASA projects that show the effectiveness of using crowdsourcing in a highly specialized context.

The first section will provide the definitions, characteristics, and will define actors, typologies and differences with other similar concepts. Then the pros and cons of crowdsourcing will be explored, and the second section will follow with a focus on the implementation of crowdsourcing in the science and technology field. An examination on real case examples of crowdsourcing at NASA will be then performed, in support of the research question that wants to be answered.

2. LITERATURE REVIEW

2.1. History and definitions of crowdsourcing

The term “Crowdsourcing” was first coined in 2006 by Jeff Howe and Mark Robinson, two journalists, who indeed in that year published an article titled ‘The rise of crowdsourcing’ for

the Wired magazine. The term is composed of the two words ‘crowd’, which is the main actor, and ‘outsourcing’, the externalization of one or more activities performed by an entity . A first conceptualization of the term by Howe was “the act of a company or institution taking a function once performed by employees and outsourcing it to an undefined (and generally large) network of people in the form of an open call. This can take the form of peer-production (when the job is performed collaboratively), but is also often undertaken by sole individual. The crucial prerequisite is the use of the open call format and the large network of potential laborers.”

To be specific, the concept of crowdsourcing can be already traced back to 1857, when the Philological Society of London decided to promote the realization of a new project. They requested the general public, whoever was interested and had good english language competences, to categorize all english words and to provide an example of their use in a sentence: that is how the Oxford English Dictionary was born (Winchester, 2003).

Approaching the crowdsourcing phenomenon from a practical point of view and considering its various forms of realization, we can deduce the following general definition: Crowdsourcing is the act of outsourcing tasks which were originally performed inside an organization, or assigned externally in form of a business relationship, to an indefinitely large and heterogeneous mass of potential actors. This happens through an open call on the Internet initiated by companies for the purpose of value creation. The incentive to participate can be defined as monetary and/or non-monetary. While in most cases who initiates the open call (crowdsourcer) is a company, other project initiators cannot be excluded. It may thus be more appropriate to use the term ‘organization’, since the aim is not always profit making. As examples we can mention Wikipedia, which allows users to make changes on the website, and the reCAPTCHA-project initiated by Google, born with the aim of protecting a website from malicious softwares to perform frauds and scams and engage in illicit activity.

2.2 Characteristics of crowdsourcing

The exploitation of an indefinitely large, heterogeneous amount of users is of great importance for defining and understanding crowdsourcing. That is the necessary condition for reaching a new evolutionary level in value creation since the crowd is implicitly characterized by a collective intelligence, also called ‘wisdom of crowds’, which is the ability of people to collectively reach goals, in this case thanks to their participation via the Internet; individuals or even organizations were not able to achieve that. (Leimeister 2010, p. 240). Having access to the huge knowledge potential of the crowd allows an organization to obtain more efficient

and qualitatively better solutions than if instead the approach to a problem or task was done inside the organization, where resources are limited in quantity and quality. The opportunity of an almost unlimited integration of a broad and heterogeneous group of actors into the value creation process is what differentiates crowdsourcing from the notion of sole customer integration. Indeed, crowdsourcing goes beyond the concept of customer integration because it does not focus exclusively on customers, but instead it addresses all interested Internet users.

Another main feature of crowdsourcing is the fact that it takes place only in the online environment. The open calls as well as the implementation of crowdsourcing projects happen entirely in a digital way. This is obviously made possible thanks to the Internet, which allows to extensively address an unlimited number of recipients. In addition, the tools of Web 2.0 enable very large groups of users to communicate in a decentralized way and to cooperate for the achievement of the project goal.

A further aspect of relevance is that what is created by the crowd is left to the initiator for free creative use. This implies that crowdsourcing participants leave all rights concerning their contribution to the initiating organization. This goes along with the principle of "free revealing" typical of open source software projects, which are considered direct predecessors of crowdsourcing (Howe 2009, p. 8).

The previous definition provided above also takes into account the role of different incentives for crowdsourcing projects. This result from the fact that, as far as the potential participation in crowdsourcing projects is concerned, Internet users are driven by two basic sources of interest: on one hand the solvers may take an action for an intrinsic reason, thus attempting of doing something for its own sake, for pleasure or for the willingness to help, or on the other hand for extrinsic reasons, where the activity itself is merely a means to an end (for example to have rewards such as money or reputation). It is also possible to have a combination of the two types of motivation.

As of the definition given by Estellés-Arolas and González-Ladrón-de-Guevara, which was defined after conducting textual analysis of thirty six different crowdsourcing definitions, "Crowdsourcing is a type of participative online activity in which an individual, an institution, a non-profit organization, or company proposes to a group of individuals of varying knowledge, heterogeneity, and number, via a flexible open call, the voluntary undertaking of a task. The undertaking of the task, of variable complexity and modularity, and in which the crowd should participate bringing their work, money, knowledge and/or experience, always entails mutual benefit. The user will receive the satisfaction of a given

type of need, be it economic, social recognition, self-esteem, or the development of individual skills, while the crowdsourcer will obtain and utilize to their advantage that what the user has brought to the venture, whose form will depend on the type of activity undertaken." Estellès and Gonzàlex want to underline how this activity can always be considered to be beneficial for both parties. Indeed, while on one hand the contribution offered by the users will be deployed for the solution of a given problem, on the other hand, the solvers will be rewarded not only from the economic point of view, if planned, but also with self-esteem, social recognition and development of personal capabilities.

2.3 Actors in crowdsourcing

As previously learned, there are various actors in the scene of crowdsourcing which we can now define and deepen.

Seekers:

Seekers are those actors who use crowdsourcing platforms with the aim of issuing a challenge, an open call to obtain solutions to their proposed problem in a quicker and less expensive way compared to what would cost carrying out a R&D activity internally of the firm. Seekers are not just firms, but also public bodies and no-profit organizations.

Firms:

Nowadays firms require more and more immediate and winning ideas in order to compete in a rapidly changing environment. Thanks to the outside-in method of crowdsourcing, firms are able to access knowledge and skills of people that are external to the firm.

Source: Innocentive.com

From the graph above it appears how, although the presence of smart people employed in a firm and those who interact with it (clients, partners, suppliers, etc.), there exists a wide area composed of possible solutions to which access is possible only through the reliance on the crowd.

Public bodies:

One of the biggest issues that governments have to face is related to the limited availability of financial resources. It is key for this kind of institutions to be able to manage and exploit to the fullest their funds, avoiding unnecessary expenses. Some crowdsourcing platforms are at disposal of public bodies as a tool that allows them to develop innovative solutions at a lower cost and in less time.

Non-profit organizations:

The power and strength of crowdsourcing can be also deployed for humanitarian causes. Several software companies put some areas of their websites at the disposal of non-profit organizations, in order to allow them to make open calls that aim at solving important social issues worldwide. Not only is it possible to support the various social causes through fundraising, but also through the involvement in the development of pioneering projects and the contribution in providing efficient solutions. In these contexts, crowdsourcing platforms become also an advertising medium through which organizations

promote and publicize the challenges that millions of people around the globe have to face on a daily basis: hunger, thirst, diseases etc.
This is certainly a highly positive aspect of crowdsourcing, which allows to reach concrete goals thanks to the cooperation of the crowd.

Solvers:

Solvers are the users who participate in challenges, giving their contribution through their knowledge, know-how and any skill that doesn't necessarily have to come from an academic background, but from any kind of experience. For this reason, there is no specific and exact profile or prerequisite that solvers have to satisfy. They can be anyone, come from anywhere and be highly qualified experts or just hobbyists, passionate people.

Solvers' process of recruitment:

One of the greatest challenges that have to be faced when talking about crowdsourcing is exactly the recruitment of the users, who will make available their ideas and knowledge to solve the seekers' proposed challenges. The process of recruitment can be carried out in different ways. Whenever seekers were in a dominant position of authority on the solvers, they could just ask them formally to get together in a group and participate in the challenge. In this case, because of the hierarchical relation between the parties, solvers will be 'forced' to utilize their know-how to try to solve the challenge. A concrete example could be found in the regulation issued by the European Commission to reduce the CO2 emission of cars and trucks by 2030. In this respect, automobile industries are forced to adapt to these new standards because imposed from above, and consequently some employees and engineers of the automotive industry will be asked by their boss to follow the directives and try to find a way to make cars' engines less polluting.
A second way can be to make an open call and let users decide autonomously to join the challenge, even if acknowledging that there will be no reward. This method is quite utilized since it grants seekers new knowledge and solutions without having to bear any cost. Anyhow, this solution is not exempt from complications, since on one hand, seekers can access know-how and human capital at zero cost, but on the other hand the absence of any financial reward could demotivate users in giving their contribution.

Establishing the reward:

It is essential to be able to determine and quantify the right amount of money for the final reward, in relation to the kind of proposals that will be planned by the seeker. Unfortunately it is impossible to predict the quality of solutions and know-how that participants will provide, furthermore it is also impossible to predict whether there will be any valid or hoped solutions. An open call for the translation for a text or for the implementation of new content on Wikipedia clearly will not promise the same compensation set for the creation of a commercial or for the resolution of a climate change crisis. In addition, challenges are not undertaken merely for the financial compensation; as the CEO of InnoCrowding Group stated, the reason that drives people to participate in a crowdsourcing challenge can be strictly related to earning notoriety and social recognition.
Winning a challenge, finding the right solution thanks to your own skills can be a strong incentive and motivation source. But this only happens if one is close to a certain cause, otherwise people would not waste their time and resources for something they are not fond of and devoted to.

2.4 Typologies of crowdsourcing

We can distinguish between four different types of crowdsourcing: these are crowdfunding, crowdcreation, crowdvoting and crowdwisdom. (Howe, 2008)
Crowdfunding is by definition a project's funding mechanism that works by raising smaller or bigger sums of money donated by the general public, usually through the Internet. In crowdfunding there is no single figure of the business angels, instead anyone who wishes can contribute to finance a project, starting from a couple euros.
Bright ideas that lack initial funds can come to light thanks to crowdfunding: if the crowd believes in it, the project will receive some funds.
When talking about crowdcreation, or collective creation, we are referring to the most widely implemented form of crowdsourcing. It is the collection of activities outsourced to the crowd with the aim of solving one or more issues raised by firms or organizations.
Through crowdvoting, the crowd is ultimately left with the possibility to express its own opinion. Crowdvoting is based on what is defined as the 1:10:89 Rule, according to which, out of a hundred people:

- 1 elaborates e creates something interesting and valuable;
- 10 vote and give their opinion;
- 89 make a purchase.

Those ten people who vote, are performing an act of creation as well. Voting indeed is the most convenient and less involved way to carry out market research.
Finally crowdwisdom is defined as collective intelligence, the wisdom of the crowd. According to the latter, a multitude of people is thought to be able to provide valid answers more than what a team of experts would be able to do. Later it will be discussed the difference between the concepts of crowdsourcing and wisdom of crowds.

Figure 2 illustrates different types of crowdsourcing platforms and their relative strengths and weaknesses

Crowdsourcing model	Good for	Not so good for	Examples
Crowd collaboration	• Tasks requiring the aggregate 'wisdom of the crowd' • Generating outside ideas	• Promoting individual capabilities or expertise • Predetermined outcomes	• 99Designs • X Prize • Quirky
Crowd competition	• Creating actionable solutions • Developing prototypes • Building a sense of community • Generating outside ideas • 'Gamification'	• Predetermined outcomes	• TopCoder • Kaggle • InnoCentive • Applause
Crowd labour (microtasks)	• Well-defined, everyday tasks for individuals that require general skills only • On-site manual work, such as store restocking, furniture assembly and cleaning • Large crowds • When you don't want to hire permanent employees or contractors • Real-time market intelligence or data gathering	• Poorly defined, unstructured or non-routine activities • Tasks requiring subjective judgement • Tasks requiring specialist or higher-level cognitive skills	• TaskRabbit • Amazon's Mechanical Turk • Streetbees • Gigwalk • Samasource

Crowd labour (mesotasks)	• Well-defined tasks that require specialist processing skills • Routine but time-consuming activities, such as data entry • When you don't want to hire permanent employees or contractors	• Poorly defined, unstructured or non-routine activities • Tasks requiring subjective judgement or specialist skills	• Lionbridge • CrowdFlower
Crowd labour (macrotasks)	• Poorly defined or unstructured tasks or problems, such as strategy development, research or consulting • Tasks requiring subjective judgement or specialist skills • When you don't want to hire permanent employees or contractors	• Routine tasks and activities	• 10EQS • Wikistrat • OnFrontiers • Applause
Crowdfunding	• Fundraising • Start-ups • High transparency	• Financing ongoing operations • Loosely structured initiatives • High short-term expectations	• Kickstarter • CrowdCube
Crowd curation	• Building and sharing knowledge	• Solving defined problems	• Wikipedia • TripAdvisor
User-generated content	• Building large content repositories	• Ensuring the best possible quality of content	• YouTube • iStockphoto

Source: deloitte.com

How crowdsourcing differs from other concepts

The phenomenon of crowdsourcing may be hard to define at first, and its boundaries may not be clear, but it cannot be mistaken for what it is not.

As of Larry Huston, founder of 4Inno and ex vice president of the innovation and knowledge area at P&G, on crowdsourcing he states: "People mistake this for outsourcing, which it most definitely is not. Outsourcing is when I hire someone to perform a service and they do it and that's the end of the relationship. That's not much different from the way employment has worked throughout the ages. We're talking about bringing people in from outside and involving them in this broadly creative, collaborative process. That's a whole new paradigm." (Bessant, Tidd, 2011)

2.5 Crowdsourcing vs. Open Source

Open source is a model generally and most commonly applied to the field of software development. This can be stated since some of the clearest and most evident examples of that model are found in that context, but it can be seen as a broader philosophy for product

development. To put in other words the definition for open source production given by the Open Source Initiative's official website, open source involves giving free access to the essential elements of a product (for example the source code for a software) to anyone for the purpose of providing collaborative improvement to an existing product, with its continued transparency and free distribution throughout the various stages of open development (Parens, n.d.).

In essence, all the aspects and mechanisms of a finished product are made available to the general public so that anyone who wishes may help in contributing with their modified and improved versions of the product. The driving philosophy of open source is that full transparency and free access in the design stage, together with the ability of people to develop something outside of the constraints of traditional intellectual property law will generate a product that can have increasingly better features and that is developed in a collective and democratic way. The open nature of these kinds of projects is key for overall collaboration and for bringing fresh and creative input into the design process. According to the open source philosophy, the world is seen as the best source for talent, indeed the motto is 'the more the better', because that is the only way to produce something superior than before. As successful examples of the implementation of open innovation we can cite the Mozilla Firefox web browser and the Linux operating system.

While this method can be successful and appropriate for software development, it may not be particularly suited for other applications. What drives this belief in the open source model is the concept of self-interest. Many of the people who experiment and play around with some software source code are people who would be doing this anyway, for hobby, interest or pure pleasure. The intrinsic reward for their service in producing a better version of a software may perhaps be given by the recognition among other hobbyists, and more importantly, by the pursuit of the problem and the satisfaction in finding a better solution to it (Ghosh, 1998; Hars and Ou, 2002; Hertel et al., 2003; Bonaccorsi and Rossi, 2004; Lakhani and Wolf, 2005).

As previously stated, not all problems outside of software development are well suited for the open source model. To term it in simple economics, the production of software can be done with basically no overhead costs. The Linux or Mozilla programs exist virtually, thus occupying no shelf space in a brick-and-mortar store; there is no use of raw materials, waste products' emission, and the distribution is free since it consists of a download from a website. Is it evident that not all products are in a digital form; in fact the vast majority of what exists in our world is made from actual materials, it requires a physical production process, it has

real-world costs, and so on. Any firm that produces physical products has to incur in costs and investments for the development of those. Considering that these investments will eventually be recovered and generate income, the core issue that wants to be raised on open source is to what extent a user would continue to be interested in improving/inventing a product, for hobby or passion, for free and with no financial reward as for the open source method. Since humans, because of their nature, have by default some degree of self-interest, would they be performing that kind of activity, donating their time and energy without claiming any financial reward? This question brings some doubt on the open source model as a supreme model for product development.

Crowdsourcing, on the other hand, is designed to overcome these limitations of the open source model by providing in the first place a definite format for the compensation of contributors. It can be considered a hybrid model that blends the open source features of transparency and democratization into a feasible model that includes the business aspects, and it is all enabled through the web. In addition, the monetary value of winning crowdsourced solutions is relative to the potential for firms to maximize profits from those solutions. Firms indeed can rely on them to partially offset the costs of material production, since the ideas of the crowd can yield profits, and once obtained, ideas also need to be protected and owned by the seeker firm, to prevent others from copying or implementing them. In capitalist societies, for material objects to have cultural importance as commodities, the idea behind the object itself must be novel, rare, desired. It is clear that open source production works exactly against this concept by making things available to anyone. At the same time though, it is evident that open source production yields superior products compared to those of closed development. But material goods do not make themselves and are not free from cost, risk and processes. The open source philosophy of giving free and uncontrolled access to code does not find a wide practical use; a society that values the quality and innovation of open source production, but at the same time is locked into a capitalist system of ownership and capital, can instead have and accomplish both needs with the method of crowdsourcing.

2.6 Crowdsourcing vs. Wisdom of crowds

As it often happens with innovative theories, they can quickly generate new related concepts and applications. The original idea is enriched with additional elements and it can make it harder to draw a clear line between the original theory and its offspring concepts. This is the case with the two concepts of crowdsourcing and the related wisdom of crowds.

As we have learned so far, crowdsourcing refers to the practice of outsourcing a job to undefined agents who are external and unknown to the issuer of the open call. The wisdom of crowds concept can even be traced back to the times of ancient Greece, with Aristotle's theory of collective judgment presented in his work *Politics*. He described it in the context of a banquet dinner, explaining how a group of individuals that come together can create a more satisfying feast as a whole compared to what one individual might provide.
The wisdom of crowds idea, differently from crowdsourcing, was defined in 2004 by journalist and writer James Surowiecki as a decision-making process that leverages the collective knowledge of a group rather than relying on the knowledge of a number of experts. Both concepts open up the process of value creation to a "crowd" – usually an unspecified group of people – in order to enhance the overall effectiveness of the process. The crowd thus represents a crucial element of both concepts. The user-centered Web 2.0 technology has drastically reduced the costs of gathering and involving a crowd, so we can say that both concepts are ubiquitous on today's internet. So how to differentiate between the two ideas? The core difference lies in the extent to which the crowd's contributions are combined.
In a crowdsourcing process, the input of the whole crowd isn't necessarily aggregated into a final output. In Surowiecki's theory of wisdom of crowds, on the other hand, aggregation plays an important role. Indeed, what is necessary to make use of the wisdom of a crowd is the aggregation, the combination of their individual contributions into a suitable output through a proper mechanism. The term "wisdom" is central to Surowiecki's point of view. According to his theory, collective decisions are not only considered more efficient but also overall superior. By contrast, the key element of Howe's crowdsourcing theory is the idea of outsourcing. His main focus is on increasing efficiency that crowdsourcing can encompass. Individual steps in the value creation process are outsourced to the crowd to save time and money, thus improving the overall productivity. In conclusion, the general focus of crowd wisdom is on increasing quality, whereas crowdsourcing demands for increasing efficiency. The two concepts therefore do not differ in the engagement of the crowd but rather in the emphasis of different aspects of involvement of the participants: The quality of the outcome or the efficiency of the process leading up to it.

According to Surowiecki, the key characteristics of a wise crowd are the following:

1. the crowd should have a diverse range of opinions.

2. one person's opinion should remain independent of others (it should not be influenced by anyone else around them).
3. anyone in the crowd should be able to express their own opinion based on their individual knowledge.
4. the crowd should be able to merge individual opinions into one collective decision.

2.7 Pros and cons of crowdsourcing

In order to determine how and when firms should adopt the method of crowdsourcing, it first should be weighed up by its positive and negative aspects or issues that can arise with its implementation into organizations' processes. Sometimes not all that glitters is gold, indeed we can identify some critiques that have been moved against crowdsourcing. Outsourcing to the crowd implies having to face unplanned situations, the crowd is in fact unpredictable by definition. The relation between seekers and solvers is not a typical work relationship and for this reason inconvenients can sometimes happen and can exceed the benefits.

Negative aspects

We will now take into analysis the negative aspects of crowdsourcing that should be taken into account before implementing it and their possible solutions.

Unemployment and wage reduction:

The main issues of outsourcing to the crowd emerge in the article called "The Dark Side of Crowdsourcing", namely the increase in unemployment and the destruction of jobs for highly qualified potential employees. Jeff Howe himself describes how a Manhattan-based freelance photographer, Mark Harmel, lost an important job for the Washington National Health Museum because of the IStockphoto crowdsourcing platform. High quality pictures offered by the photographer for $100/150 could be easily replaced by those on the online platform for only $1. Competing with the crowd will always end up with a loss until users will be willing to be rewarded with a few dollars, few cents or even no money at all in exchange for some notoriety. If one one hand solvers allow and accept very modest payments, on the other hand, by doing so they will offer their service for such a low cost to companies that in turn could decide to rely more extensively on those cheap services and fire qualified employees thus contributing to unemployment.

It is also to say that whenever a firm would not be satisfied with the performance of online

solvers, it would seek for external skills and qualities reaching to SMEs or freelancers. Crowdsourincg prevents this from happening by destroying these businesses (Morphy, 2009).

Consequences of an economic recovery:

An economic crisis, because of unemployment, makes available to crowdsourcing platforms a relevant number of highly skilled qualified people that have temporarily lost their job. If on one hand it can be favourable to companies, on the other hand, as soon as the economy recovers those people will most likely be unavailable because employed elsewhere, so companies that exclusively rely on crowdsourcing would run the risk to end up without human capital which would impact their performance (Morphy, 2009).

Lack of total control:

Another downside of crowdsourcing is related to the impossibility to thoroughly control contest participation. It is possible in fact that some users decide to participate in the contest and to propose solutions which are not in line with the ethics of the challenge. We can take as an example a challenge for a company's advertisement in which solutions are sent privately to the seeker. In that case there would be no problems, but if solutions are instead submitted on a public space with full visibility to others, in that case the company could be highly damaged in its public image. It is in fact common that solutions are elected through public voting on the platform or on social networks, and who gets the most votes wins the challenge. A possible solution to this problem would simply be to take precautions in the selection process by performing a first checking procedure by the company itself before publicly posting the ideas received from users, or to ban from future challenges those who behaved incorrectly, or even to set the requirement to have references in order to be able to participate in the challenge.

Solvers' exploitation:

Jimmy Wales, one of the founders of Wikipedia, is one that goes against crowdsourcing for the lack of respect towards users; in his idea, firms that outsource a whole complex task are not just using crowdsourcing, but much more than that. Crowdsourcing in fact is considered just one part of the "Open Authority" process, which refers to a mix of skills, experiences and discussions within a smaller or bigger audience (Phillip, 2012), and much more.

Source: innocentive.com

The other elements that constitute it are Community Sourcing and Participatory Interpretation. The intermediary phase, Community Sourcing, includes a more collaborative approach between participants reached thanks to ideas sharing, communication and shared knowledge. Finally, to conclude the Open Authority process it is necessary a final stage in which qualified users work together to develop the project in all its aspects, which coincides with the final phase of Participatory Interpretation. (Wales, 2014). According to Wales definition, Wikipedia cannot be defined as Crowdsourcing but to be more correct as Community Sourcing. We have already seen how different people had different interpretations of the term Crowdsourcing, indeed Jeff Howe himself, inventor of the term, reports Wikipedia as an example of Crowdsourcing, which gives us an additional proof of the fact that an agreement on the topic has yet to be reached and analyzed.

Many believe that with Crowdsourcing users are exploited as they are underpaid or even unpaid, and for this reason critics have been moved even against Facebook admins who in 2008 asked their users for the platforms' translation with no monetary reward. However we have to highlight how users not always take part in challenges merely for money, but also for personal gratification and enrichment.

Real costs:

In the case where a solution proposed to and chosen by the seeker would result incomplete, there would be additional costs for refinement and adjustments. Sometimes these costs, summed with those to launch the challenge and to reward the users, can end up being much higher than what would cost performing internal R&D. Crowdsourcing requires time and money, especially when an organization decides not to rely on existing platforms and to build its own; in that case, there would also be added costs for the programming and development. Even if the organization would choose to make use of an existing crowdsourcing platform like Innocentive or Innocrowding, it would have to face costs related to the development and launch of the challenge, but also costs to maintain the platform and to attract new potential solvers. Once solvers submit their solutions, these have to be analyzed and filtered, which requires effort and time in order to find the best suitable solution.

Lack of motivation:

As we have learned so far, there can be cases of crowdsourcing platforms and/or challenges that do not provide a significant remuneration to users, or do not provide a reward at all. In addition, it could also happen that users won't even have social or public recognition, which can generally be one of the reasons for which solvers take part in these online challenges. In all these cited cases, it is evident that users are not stimulated nor motivated to join challenges since they will not get anything back, and they would be merely used by companies as a means to an end. This negative factor could bring platforms or projects to their failure because of consequent lack of participants, lower work quality, lack of personal interest in the project.

Definition of intellectual property:

Once the seeker identifies the winning solution for its challenge, an issue that may be raised is on who will own the intellectual property between the seeker and the solver. The definition of who legally owns the idea and the work done can vary from case to case; usually, contrary to what one could think, the seeker is considered to be the owner. The issue may be raised not only when considering the winning project, but also for all the solutions discarded. In order to avoid ambiguous and confusing situations, the users will be able to consult the "Terms and Conditions" section for each given challenge proposed, in which it will be defined who will have the intellectual property over the chosen solution and all the other necessary rules. Thus by accepting the "Terms and Conditions" the solver will also

accept the transfer of his idea to the seeker even in the case the project will not be a winning one.

Data confidentiality:

When launching a challenge, seekers put at disposal of participants a document that introduces the challenge and gives all the general information, fundamental for users. In the case in which the seeker company has a competitive advantage given by the knowledge of confidential data, it would be counterproductive to disclose it just for the purpose of facilitating the solvers' job, even if essential for the challenge resolution. For companies that own this kind of knowledge, crowdsourcing could represent a double-edged sword thus the decision whether to implement it or not has to be pondered very carefully.

Language barriers:

One last factor to be considered when adopting crowdsourcing, given its wide diffusion and accessibility from all over the world, is the unavoidable existence of language barriers for some users. Open calls, challenges or simply voting procedures are mainly in English, but this problem can be overcome in most cases through the use of online translation websites or better through the rising attention given to the teaching of the English language.

Positive aspects:

After having thoroughly analyzed what are the cautions that firms and organizations should consider before adopting the crowdsourcing method, we can now continue with the analysis of its benefits, in order to understand why it has been growing in popularity in the latest years all over the world.

Low research costs:

Crowdsourcing represents a typology of outside-in Open Innovation and as such it is characterized by some distinctive features. One of these is certainly the opportunity to access people's skills and know-how at a very low cost or even at no cost. A firm that only needs to pay a few cents of dollars instead of thousands of dollars benefits from a great advantage; in this way a huge amount of money will be saved instead of being spent for employing new personnel or for outsourcing processes. The area of firms that benefits the most from Crowdsourcing is surely R&D, because thanks to it a substantial amount of expenses can be

avoided; consequently by facing lower costs, firms will have higher profit margins. Even in case a firm decides to make use of its internal R&D, by sustaining a minimal expense in crowdsourcing it will have the availability of a much higher number of qualified experts than those working for the firm itself.

Accessing new knowledge:

By reporting Chesbrough's sentence "Not all the smart people work for you", it can be highlighted how crucial it can be for firms to reach outside of their closed boundaries and disrupt their traditional ways of working. We can bring an evident example to support this concept. In 1989 an oil tanker spilled over 10 tons of petrol in the Alaskan sea; the greatest scientists, professors and scholars of all times were asked to find a quick and efficient solution to separate petrol from water even if the latter was freezing and solidifying. After years of studies and research, in 2007 the Oil Spill Recovery Institute (OSRI) launched an open call on the InnoCentive platform in order to find a solution to the disaster, which was later found by John Davis, a construction worker from Illinois. He exploited his personal construction know-how to compare the Alaskan sea to concrete, which is kept in a vibrating machine to prevent it from solidifying. His intuition was a winning one, and it granted him a $20,000 reward.

Thanks to this example it is clear how the use of external minds can bring value inside an organization, thus reaching to the crowd can imply obtaining a faster and more efficient result. This can be vital sometimes for firms to survive in the competitive market because thanks to the contribution of users, new and fresh ideas can be obtained and exploited, which would not be possible instead by adopting a Closed Innovation mindset.

Higher degree of confidence in users:

It has been already mentioned how technology deeply impacted the spread of Crowdsourcing, as the Web is used to launch challenges, ask for help and opinions; anyone can be easily reached through web portals and that is why we can talk about 'open network'. Studies have shown that users that interact with a computer screen feel more at ease, and more keen to share their thoughts and opinions. That is because they tend to ignore, totally or partially, that their work is under the judgement of someone else; in fact those who join online crowdsourcing challenges gain more confidence from not being face-to-face with others, and not having anyone to interact and confront with. This is an advantage that allows online users to eliminate any fear and thus perform a higher-quality job (DeVun, 2007).

Humanitarian aid:

Crowdsourcing can be an optimal tool that, when used properly, can provide great support for the current world's biggest problems like hunger, poverty, illiteracy, pollution and so on. It would be a mistake to consider Crowdsourcing merely a financial tool for firms; in the latest years, it was brought to life the concept of "Open Green Innovation", born from a blend of the need to preserve the Earth and the concept of Open Innovation invented by Henry Chesbrough; its aim is to develop an innovative approach in order find valid solutions for issues related to the environment (Ronco, Pelosi, 2013). Also thanks to crowdfunding platforms not only is it possible to ideate and carry out new interesting projects, but also to donate money for humanitarian causes (in this case we can talk of "Fundraising"). In Italy we can count about 5-6 billions of euros raised through fundraising, but if we think of the United States the numbers are much higher, around 400 billions dollars[1], both because of the bigger population but also and most importantly because of the greater awareness and adoption of the method.

A brand marketing tool:

Another point to be highlighted is the opportunity for firms to use Crowdsourcing as a marketing tool to promote their brand, attract new clients and to build customer loyalty. By engaging with the crowd, firms can directly understand consumers' needs and wants, since by participating in Crowdsourcing activities users express their opinions and points of view in a voluntary marketing research, thus collaborating in the process of product refinement and adjustment. When users participate in contests and develop projects for firms, there is a great opportunity for the latter to build a strong customer loyalty, particularly considering projects or challenges that stimulate users' interest in the matter, which can bring unexpected external engagement and visibility. An example is the advertising campaign for the Super Bowl in 2011, when Doritos involved its fans into a contest to ideate an advertisement to use for the event; the winners of the contest, besides feeling accomplished for seeing their creation on the screens of all the United States and more, received a 25 thousand dollars reward. Four of these advertising spots were placed in the USA Today top ten ranking, giving Doritos huge visibility for free.

[1] Source: Il sole 24 ore http://www.ilsole24ore.com/art/impresa-e-territori/2014-05-15/in-italiafundraising-vale-gia-sei-miliardi-ma-europa-e-ancora-lontana112509.shtml?uuid=ABd1SRIB

Versatility

Crowdsourcing can be considered a very versatile tool with respect to its wide spectrum of uses. It can be implemented in bigger firms that have more funds to invest, but it also mostly fits smaller firms or start-ups that have restricted access to funds thus can find a solution to some of their problems on crowdsourcing platforms. Not only can it be used to retrieve valid ideas, but also to temporarily outsource certain tasks of firms during busy working seasons or periods. Many are the activities that can be carried out through crowdsourcing, and it can be quite hard to define boundaries of applicability. Its uses span from natural disasters, to personal opinions on given issues, to development of whole projects (Jichcliff, 2009).

3. CONCEPTUAL ANALYSIS

3.1 Crowdsoucing in science

Our broad and general analysis of crowdsourcing will now move to the core theme of this paper by targeting one specific area of application: science and science-based innovation. This section will aim to provide a better understanding on if and how crowdsourcing can be successfully implemented in a highly specific sector, and it will be focused on scientific methods for open science through crowdsourcing, also by including possibilities and risks in this specific field. Two major aspects of online crowd creation are firstly being part of a crowd by contributing to a challenge proposed on a crowdsourcing platform and secondly presenting to the crowd a question to be solved. Specialists, scientists in particular, will now be the subject of closer inspection; in this respect how can scientists and more specifically scientific institutions take part in an open innovation path by opening up science projects, and how can they establish a collaboration with companies?

How Scientists Exploit Crowdsourcing

The use of crowdsourcing not only makes it possible to merge and aggregate data but also to categorize and classify it. We have seen that crowdsourcing can involve literally any person in the resolution process, with no requirements on academic background or qualifications. In the science field though, it can be stated with a quite high degree of confidence that the more specific the challenge proposed, the more important it becomes to refine the research for specialists out of the participating crowd. Scientists can adopt four main forms of crowdsourcing:

1. They can reach individuals and interest communities in order to collect data or to perform a set of easy tasks, such as measurements.
2. They can use the Internet to communicate with other scientists or partner research labs to collaborate for posing scientific questions on equal terms.
3. They can contribute in answering scientific questions themselves.
4. Firms and companies often adopt the second and third choice above cited as a means of open innovation, most of the time combined with monetary rewards for the participant.

From what just stated above, we can conclude that there are two major forms of crowdsourcing in the sciences: contributing towards a solution and requesting a solution.

Perspective 1: Contributing to a Crowdsourcing Process

One form of open innovation through crowdsourcing in the sciences is given by the contribution to research questions by providing ideas, often free of charge. In particular in the fields of mathematics, biology and medicine, open science is a well-known and strongly appreciated method of scientific collaboration.

One relevant example is the U.S. “Human Genome Project”, coordinated by the American Department of Energy and the National Institutes of Health and completed two years ahead of schedule in 2003, thanks to rapid technological advances. It was the first large scientific undertaking to address ethical, legal and social issues and implications arising from project data. The federal government promised to grant private companies licences for technologies and to award grants for innovative research; the project catalyzed the multibillion dollar U.S. biotechnology industry and fostered the development of new medical applications. This project was so successful that it generated a second one: the “encode project”. In September 2003 a public research consortium named ENCODE was launched, which was the Encyclopedia of DNA elements and had the aim of identifying all the functional elements in the human genome sequence.

Collaborating in the online context of open science can be achieved using a multitude of tools that can work for scientists but also for any other type of researchers. In example it can be done with a digital workbench, where users can collaborate by means of online tools (network.nature.com); they can also build communities (open and closed) or workshop groups consisting of worldwide peers exchanging information and insights (Openwetware.org; DiagnosticSpeak.com); researchers can also create social networks, pose questions and get them answered by colleagues from all over the world (ResearchGate.com).

Perspective 2: Obtaining Support (Citizen Science)

The second aforementioned aspect of open innovation through crowdsourcing in science is to ask a community for help. This approach to "human computation" implies numerous people carrying out numerous small tasks (which cannot be solved by computers so far). The practice of asking a community for help can be successfully applied in "citizen science", which we can define for the sake of simplicity as the inclusion of non-experts in the research process, whether it is a matter of data collection or more specific problem-solving. As we have learned, crowdsourcing is a well-known form of "citizen science". As the website scientificamerican.com explains, "research often involves teams of scientists collaborating across continents. Now, using the power of the Internet, non-specialists are participating, too." Several examples can show scientists operating in this manner and obtaining solutions by asking the crowd. This form of crowdsourcing can be also found in the media: scientific media bodies have established dedicated websites for citizen science projects like http://www.scientificamerican.com/citizen-science where readers are invited to take part in a list of projects. In view of the strategy "Ask the public for help", to these social media websites, scientists can appeal to the public for participation and help. Exemplifications of research areas or assignments could be to count animal species in the rain forest or underwater, or those that visit plants to pollinate them, such as in "The Great Sunflower Project". A striking example is the "Galaxy Zoo" project. In brief, the task to be performed is to help classify galaxies. From the analysis of the work done by users, it turned out that the classifications provided by the website http://www.galaxyzoo.org are as good as those from professional astronomers. The results are also useful to and at disposal of a large number of researchers. Citizens interested in these subjects, together with scientists working in this field of knowledge, can be considered as contributors.

3.2 Innocentive platform

There exist several platforms dedicated to crowdsourcing activities, each with its purpose, but we can highlight the most widely used and well known one, Innocentive.com, founded in 2001 in the USA by the pharmaceutical company Eli Lilly. Nowadays, this platform hosts more than 500 millions solvers from all over the world, but considering also partnerships, the number of solvers increases to 12 millions, all with different skills, qualities and knowledge. Over 40 million dollars have been paid out to winners, with rewards ranging from $500 to $1 million, depending on the task's complexity. Challenges can be either addressed to the external public community, or to a restricted group of people such as

employees of a company. Users registered on Innocentive have very broad and diverse backgrounds, with several fields of interests; in contrast, platforms like Topcoder gather users with verified skills that share a common interest and that are driven by passion for a specific subject. Topcoder in particular is widely used by NASA for the resolution of some of its highly specific crowdsourcing challenges, which will be now analyzed in detail.

3.3 Crowdsourcing at NASA

In a strongly interconnected and networked world, NASA (National Aeronautics and Space Administration) is one of the most active organizations for the recognition of the value of the crowd, employed as a strategic partner for the resolution of some of the most urgent challenges. The ultimate aim of the agency is to effectively exploit the expertise and ingenuity of individual members of the public through open innovation approaches, specifically crowdsourcing. Reporting what stated by NASA Deputy Chief Technologist Jim Adams, "NASA recognizes that these methods present an extraordinary opportunity to inspire the development of transformative solutions by offering a means to engage with nontraditional sources of innovative ideas, all in a remarkably cost effective way". At NASA, traditional problem solving approaches are complemented by prizes, challenges and crowdsourcing to create a robust set of innovation methods for a variety of programs. For quite some time in the U.S. NASA has retained leadership in the implementation of prize competitions and it has been recognized by the White House in 2011 as the most suitable example to show results from the use of these methodologies. We will analyze some recent case studies from NASA challenges to underline what to expect from Federal agencies and other similar companies in the science sector as they start implementing methods for open innovation. Not only is NASA considered to be a leader in space-related matters, but also as the one setting the pace for future experimentation. In November 2011 NASA launched the Center of Excellence for Collaborative Innovation (CoECI) which helps US Federal government programs, in addition to NASA centers, run first challenge-driven open innovation activities.

Through the analysis of several case studies, we will highlight the diversity of purposes and impacts of open innovation in stimulating space-related activities, which include:

1)Detecting cost savings and promote the development of better products "on demand"

2)Discovering out-of-discipline perspectives to increase the number of minds tackling NASA's problem

3)Triggering the development of new markets and new opportunities for business and jobs

Challenge programs and definitions

The Federal Government of the United States has been urged to come up with improved and modern practices of innovation implementation by using open innovation tools and platforms that are either existing or emerging. NASA has embraced strategies to foster the use of challenges and crowdsourcing activities to expedite tasks at all organization levels. In this section it will be provided NASA's own definitions for nomenclature such as prize, challenge, and crowdsourcing, which have different interpretations across sectors; the organization and relationships of NASA's challenge programs will also be covered. NASA's Policy Directive 1090.1 defines and illustrates the terms “challenges”, “prize competitions”, and “crowdsourcing” as follows. Taken together, we mainly refer to these methods as “Open Innovation” :

- Specific problem-statement approaches are used in challenges to receive suitable solutions from a wider, indefinite public rather than a closed group of individuals. Crowdsourcing and prize competitions are specific modes for Challenges implementation .
- A challenge carried out through a prize competition is aimed at stimulating innovation in a way to potentially boost NASA's mission by offering a competitive award. NASA or a third party allied organization typically administer these challenges that are introduced to the public through a direct channel. (Gustetic, 2015)
- A challenge carried out through crowdsourcing is aimed at soliciting products, services, ideas, or content contributions from a wide range of people, usually (but not necessarily) through the Internet, and they may or may not grant awards (e.g., NASA Innovation Pavilion and NASA Tournament Lab). An award is meant as a recognition of any kind given to the winner contributor of a challenge, and it can vary from cash payment, value different from cash (e.g., payment of travel expenses, accommodation on a launch vehicle) or other types of reward (e.g., recognition, invitation to an event). The crowdsourcing may involve either NASA employees or external communities, and its purpose may be for idea generation, education/outreach, product or service construct, or to repurpose NASA technologies for earth-space benefit. Challenges of this kind are typically run using existing communities, often organized or curated by commercial companies, but they tend to be open to anyone in the public who desires to join and participate. (Gustetic, 2015)

Various departments and programs at NASA have been making use of crowdsourcing to tackle arduous and unsolved problems. NASA's OCT (Office of the Chief Technologist) is in charge of coordinating the manifold open innovation projects, by providing strategy and

policies for open innovation. Since 2005, through prize competitions NASA's Centennial Challenge Program has directly engaged the crowd in the development of advanced technology, considered valuable to NASA's missions and to the aerospace community. The Space Technology Mission Directorate (STMD) has made the Centennial Challenges Program part of it.

In 2011, as previously seen, NASA established the CoECI (Center of Excellence for Collaborative Innovation) to coordinate the challenges implemented through crowdsourcing and in general to promote the use of open innovation methodologies. The CoECI is Government-led, and it administers the NASA Tournament Lab, the NASA Innovation Pavilion, and NASA@Work which are platforms used to run challenges both for NASA internal projects and other government agencies, with the purpose to infuse open innovation methods across all federal agencies. In addition, several NASA offices have supported individual projects such as education challenges including the Robotic Mining Challenge (known as Lunabotics) and the Annual International Space Apps Challenge, which is a thriving example of crowdsourcing and citizen science. The NASA International Space Apps Challenge, known as "the world's largest global hackathon," is a 48 hours event that takes place on a yearly basis, where users around the world gathered in teams can make use of NASA's open data and from those, develop pioneering solutions to challenges in Earth and space science. The Space Apps challenge has a small global infrastructure but relies on the strong commitment of local organizers around the world that, through the use of tools and information provided by NASA, can develop, fund, and manage these events. The theme of the events is different every year; in 2020 the theme was “Take Action”, which wanted to be a critical reminder that a difference can be made even from the comfort and safety of home. Over 26,000 people from nearly 150 countries joined together for the ninth annual event in 2020. In response to the COVID-19 pandemic, NASA and the Space Apps Global Organizing Team took the decision to launch an all-virtual hackathon event. 23 challenges were launched, and more than 3800 teams submitted over 2300 projects. The next hackathon will take place in October 2021, celebrating its tenth year anniversary. This initiative, thanks to its global network, succeeds in fostering collaborations across borders and populations, as diverse teams of coders, scientists, software developers, technologists, and more come together to collaborate on open-source solutions to the challenges of the year. Participation is growing worldwide: in 2018 approximately 18,000 people across 75 countries participated, and the hashtag #SpaceApps on social media had a reach of over 49 million people. Needless to say, the outcomes are extraordinary as they include new science applications, the creation of

collaboration communities, workforce development, and growing engagement of women. Users' solutions, thanks to NASA's open data, among the various benefits they bring in terms of increased knowledge, also foster a better understanding of Earth and space science allowing the generation of new positive and impactful outcomes in the science field.
According to the authors of the article "Outcome-driven open innovation at NASA" (2015), reports of the Federal Government of the United States have focused mainly on the benefits of open innovation methods, listing many such as: paying only for end results, not for upfront investments; establishing a goal without determining who and how has to reach it; increasing the diversity of the team, leading to a wider spectrum of possible solutions; stimulating private sector investments; changing the crowd's perception of what is possible.
At NASA instead, much more important are the end results and outcomes provided by challenges. In addition, a clearer understanding of the intended outcomes could be much more useful and valuable for the solution process rather than only considering the benefits of the method itself, thus outcomes should be prioritized as guiding design factors and should be well clarified from the beginning; outcomes should not be an afterthought, but the main driving factor of challenge design. With 15 years of challenge design experience, challenge managers at NASA have come to understand that the primary outcome that a challenge is seeking to further is what can lead the design to take one or another direction. Based on this experience with nearly 400 projects[2], including several partnerships, NASA listed the types of outcomes that have been achieved through the wide variety of challenges conducted: (Gustetic, 2015)

- Research advancement: The solutions submitted identified information not previously known by the challenge sponsor. This broadened the comprehension of the solution range for a definite problem area, allowing NASA to analyze the technical adequacy of its current approaches.
- Operational integration: Winning solutions were directly incorporated into or used in the NASA operational environment (e.g.implementing code into a system, testing techniques into a lab, etc..).
- External use: External entities (non-NASA) exploit the solutions submitted to NASA (e.g. open source code or other government or commercial buyers)
- Education/public outreach: Submitted answers were elaborated for the purpose of education or to raise awareness.

[2] Source from 2020

- Proof of concepts: The illustration of solutions submitted was a confirmation of an idea and/or a turning point for the potential of technology progression. In this case the goal was not gaining the solution itself, but rather illustrating the potential advance of the prior state.
- Bring products to the market: Either the solutions themselves or closely related derivative products were proposed on the market by competitors.
- Aerospace companies creation: In the field of open innovation, competitors merged into new businesses, becoming new vendors for NASA and others, thus diversifying and expanding the marketplace.

Though its challenges, NASA aims to achieve at least one of the above mentioned results, which happened indeed in a substantial number of cases between over 50 successful challenges[3] pursued. An important thing to note is that even though NASA is one of the leaders in open innovation, there are still some types of challenges not yet handled, so the types of results sought through challenge-driven methods could expand as experience with supplementary types of challenges and crowdsourcing platforms increases. Learning from the expertise given by past challenges, NASA challenge owners are encouraged to explicitly identify outcomes desired at the very beginning, in order to facilitate to shape the challenge structure, design, and operational approach. Earlier NASA challenges were not explicitly developed with a specific outcome-driven design approach, which now instead portrays a more complete way in which NASA designs challenges through its Centennial Challenges Program and CoECI. It can happen that challenge creators have different unstated expectations and opinions on the kinds of results that would lead a challenge to be successful. According to some opinions, challenges would be most effective when they boost markets, instead, for others, when they prove better technologies than the existing previous ones. Others consider challenges a powerful tool if their process serves to educate the participants. It is thus becoming increasingly relevant for prize designers to determine the most crucial outcomes of a challenge at the earliest possible. This outcome driven prize design philosophy is currently in use at NASA and will be iterated on as challenge managers learn more about how well designing for outcomes affects the results of a challenge.

4. EMPIRICAL ILLUSTRATION

[3] Source from 2015

The following section will discuss crowdsourcing activities in six case studies described at the 65th International Astronautical Congress, which fall within NASA's outcomes list described above; they exhibit the broad range of outcomes obtained as well as those they can help achieve. (Gustetic, 2015)

4.1 Astronaut glove challenge:

The Astronaut Glove Challenge conducted by NASA's Centennial Challenges Program from 2007 to 2009, was a dual level competition aimed at improving gloves' design in a way to improve the durability and reduce the effort needed by astronauts to perform tasks. Among all the components of the pressure suits that astronauts must wear in space, the gloves are one of the hardest parts to design since the fingers of the gloves counteract the attempt to bend them, so that pressure has to be fought by astronauts with the strength of their hand, which is certainly tiring and can result in injuries. Additionally, the junctures of the glove are subject to erosion and can provoke life-threatening leakages. Competitors of the challenge in question presented their idea by using the glove to perform a series of tasks in an evacuated chamber similar to use in space, assensing gloves' leaks resistance. To obtain a reward, all the requirements had to be met and also outperform the elasticity of the NASA spacesuit glove in use. For the 2007 competition, the only required layer was the pressure-restraining one. For the 2009 Challenge instead, teams had to ideate a complete glove equipped with the outer, thermal-micrometeoroid-protection layer that protects the pressure-restraining one from the space environments. As with most of NASA's Centennial Challenges an unfunded agreement had to be underwritten with the non-profit space education organization Volanz Aerospace Inc.. For the 2007 competition, for teams demonstrating a better inner glove the prize reward was set at $250 thousands. Five teams enrolled to compete, and eventually three of them presented their new glove ideation. The final winner happened to be an unemployed aerospace engineer, who invested the reward to launch his space glove company, Flagsuit LLC, which is now a gloves supplier to NASA spacesuit retailers. In the 2009 competition two teams competed in displaying the finished glove; one was Peter Homer, the winner from the previous edition, and the other one was composed by Ted Southern and Nik Moiseev, two people competing also in the 2007 challenge. They won second place obtaining $100 thousand, while Peter won $250K for first place.

4.2 Lunar lander challenge:

The Lunar Lander Challenge conducted from 2006 to 2009 by NASA's Centennial

Challenges Program required constructing and flying a rocket-powered vehicle, reproducing a vehicle's flight on the Moon. This machine had to depart vertically, move horizontally and finally land at a specific spot; then it had to depart again and go back horizontally to the initial starting point where it had to land successfully. The Lunar Lander challenge involved a $2 millions incentive prize program with the final purpose to build an industry of American companies that owned rocket vehicles able to routinely and safely fly vertically, take-off and landing, used for lunar exploration and further uses. Along with the Google Lunar X Prize, this prize was thought to kickstart the "Moon 2.0" project for sustainable lunar exploration. In this challenge as well, NASA conducted the challenge through an unfunded agreement with the XPrize Foundation. The reward was divided into two levels, a relatively easier one and a more difficult one, and each had a first and second place prize: respectively $350 thousands and $150 thousands for level one and $1 million and $500K thousands for level two. Time flight requirements on each flight for the first level was of at least 90 seconds and for the second level of at least 180 seconds. Furthermore, for the second level challenge, one of the landing attempts had to be made on an artificial lunar surface with rocks and craters. Eleven teams joined the competition during the 4 years, and those that had met all of the requirements would be ranked according to the landing accuracy of their two flights. Masten Space Systems won first place and Armadillo Aerospace won the second place prize. After the win, both teams received contracts from NASA to develop vehicles to provide suborbital flight opportunities to conduct microgravity science. Furthermore, in 2014 Masten Space Systems entered into a partnership with NASA to propel commercial cargo transportation ability to the surface of the moon. Several private companies were involved as well, which not only developed skills that could result in a commercial robotic spacecraft landing on the moon but they could also possibly allow exploration tasks of interest to NASA and to enlarge scientific and academic communities.

4.3 International Space Station (ISS) longeron shadowing challenge:

This challenge launched in 2012 by the Center of Excellence for Collaborative Innovation (COECI) consisted in developing a novel algorithm that showed an efficient way to place solar arrays on the International Space Station to generate as much energy as possible throughout the most delicate orbital positions. This challenge also included a promotion element for the main challenge; a T-Shirt design contest. The fact of pointing the solar arrays directly at the Sun can be quite straight forward, but the ISS also has to consider the loads stressing the longerons supporting the arrays. The problem comes if these support structure

materials are exposed at the same time to extreme heat from the Sun on one side and to the cold of deep space on the other side, because that can provoke physical dilatation and contraction of the materials, ruining the structure. The algorithm has to assure power-catching maximization of the solar arrays while avoiding or mitigating conditions with potential shadows. Energy is vital for the success of ISS operations and research, so handling this issue meets both the need to enable the operations and research and to lengthen the duration of the solar array systems. NASA's CoECI launched the challenge on the NASA Tournament Lab (NTL) which, under a NASA contract with Harvard University, could be run on the TopCoder platform. The formulation of the challenge took several months to wholly specify the full intricacy of the issue . In January of 2012, TopCoder launched a 3-week challenge that paid out over $40,000 in prizes to develop this new algorithm; the challenge attracted over 4000 solvers and in the end there were 2185 submissions, which broke a new record for the NTL, from which 10 winners were selected. The final algorithms were proven to be as good as the ISS current ones for core operations and some brought significant improvement in many ways. The ISS mainly used this contest as a pilot to comprehend challenges in general and thus did not plan to take the results into full operations, it has in fact been demonstrated in multiple challenges that unless the challenge issuer has plans, resources, and authority to operationally implement the challenge winning solution, regardless of its quality, it will likely not be integrated into operational systems. This does not mean that crowdsourcing challenges are useless, on the contrary, they give great inspiration for new innovations and developments and as we have learned, they are also cost-effective. The total cost of this challenge including awards and operational expenses amounted to$109,600, while NASA estimates that a similar internal research process would have cost over $240,000.

4.4 Kevlar and Vectran strain measurement challenge:

This challenge conducted in 2012-2013 by the CoECI had the purpose to find a new measurement method for the strain on Kevlar and Vectran synthetic fiber straps in the 25-125 C° degrees range. Traditional measurement by contact extensometers has caused damage and failure, while non-contact methods have worked well with certain samples at room temperature, but at elevated temperature range some fibers cannot be measured, so a new technique was needed to accurately measure the strain in those samples. NASA's Langley Research Center (LaRC) worked with the Innocentive platform, posting a $20,000 reward challenge that attracted 347 users from 45 different countries around the world. 71 were the solutions submitted from 19 countries and in the final evaluation, 3 winners were

chosen (awarded $10 thousand, $5 thousand, and $5 thousand). The winning solutions involved adding a strip of rubber strap on which to take measurements that would then be correlated back to the fabric strap. These solutions were considered useful right away by the analysis team and applicable to multiple projects besides Lightweight Materials and Structures. The solution was defined as “extremely elegant, simple and repeatable”. Again, by approaching this problem through crowdsourcing, NASA could save a huge amount of dollars by not contracting out an extended research program to find a solution.

4.5 Non-invasive intracranial pressure measurement challenge:

The challenge was conducted in 2012-2013 by the CoECI and it aimed at finding a non-intrusive procedure to measure intracranial pressure. NASA reports show how during spaceflight, the astronaut's body is subject to short and long term changes in physiology, which especially during long missions results in permanent changes to tissues and organs. Some astronauts, after long duration missions, go through changes in visual acuity and in eye anatomy. There are suspects that these alterations relate to increased intracranial pressure so there is the need to monitor this pressure over time in a non-invasive way since current measurement technologies are either invasive or too inaccurate to be considered acceptable for repeated measurements. According to market surveys, the state of technology at that time was insufficient to meet NASA's research needs, so NASA's Human Research Program decided to take care of it and to solve this problem using multiple approaches. The challenge was first run on NASA's internal challenge platform, NASA@WORK, which resulted in 3 winners whose inputs lead the team to contemplate developers that were not previously taken into consideration. The challenge was then run on both the Innocentive and Yet2.com platforms. On Innocentive, the challenge was presented as a theoretical question with a $15,000 reward and resulted in 636 submissions with two solutions being selected as winners. One winner was UCLA's Non-invasive Intracranial Pressure Calibration Framework algorithm, developed from a database of cerebrovascular parameters and Inductively Coupled Plasma (ICP) measurements. The second winner was named “Thinker: An Intelligent Intracranial Pressure Monitor” which was a physiological data acquisition system in miniature with an algorithm able to predict ICP from digitized pressure waves, based on a commercial digital technology. This technology seemed promising, but the algorithm instead required improvements. The team also published the challenge on Yet2.com, a tech scouting firm. This challenge generated 3 solutions of high interest, 6 other appealing ones and 6 potential complementary technologies. Overall, the outcomes emerged led the team to a

broader understanding of the various aspects of the available technologies and helped it identify a much clearer path to a final usable implementation.

4.6 Strong tether challenge:

The challenge conducted from 2005 to 2011 by NASA's Centennial Challenges Program aimed at ideating a material that is at the same time strong and light enough to support a 96560 kilometer long tether, that would thus need to be almost 25 times better than the best commercially available tether. The purpose of this challenge is driven by the idea of a space elevator that allows access to low earth orbit, mainly constituted by a ribbon-like cable (a tether) anchored to the Earth surface and that extends into space, designed to permit vehicle transport directly into space without the use of rockets. Achieving the required tether strength-to-weight ratio can be considered the most difficult task in building a Space Elevator. A possible solution to that could also revolutionize the engineering of down-to-earth structures including aircraft bodies, sporting equipment, and even bridges and buildings. The Centennial Challenges Program conducted the challenge together with the non-profit organization Spaceward Foundation in Mountain View, California, by signing an unfunded agreement. The reward for the development of a tether that met the requirements for length, weight, and strength was set at $2 millions. More than ten teams competed in the years from 2005 through 2011, but eventually none of them was able to ideate a tether satisfying those requirements by outperforming the commercial products already available on the market. After observing consecutive failures and five years later, the challenge was cancelled due to lack of technology improvement. This negative outcome still gave a positive contribution to deepening knowledge on open innovation activities and taught a lesson: when fundamental research and development to advance technology is still substantially lacking, an incentive prize may not be the best method for technology development and demonstration challenges. In this current technological historical context, a more effective and viable way to use crowdsourcing challenges would be to exploit existing technologies in original ways to create disruptive and innovative methodologies rather than attempting to ideate new and unknown technologies.

4.7 Challenge adoption choice

It has been shown how challenges can deepen research and knowledge in many areas, but sometimes the competitors are required to perform research and make demonstrations that are too advanced for their capabilities, compared to the current state of technology. In this

respect, to address this issue, the Centennial Challenge Program has chosen to carry out specific challenges that require a lower effort in fundamental research and development compared to that required for the Strong Tether Challenge.

The adoption of open innovation by NASA has been increasingly growing, also thanks to the exponential advance of technology in the scientific field. Challenge design is also an important aspect that is gaining greater attention as it is becoming more sophisticated thanks to a broader knowledge and experience. The results obtained in crowdsourcing challenges and described above are a clear indicator of how open innovation approaches can foster scientific discovery, hence closer attention should be directed towards this scope. It is fundamental to note that open innovation methodologies should be implemented with a precise action plan, determining ahead the types of outcomes that want to be achieved so that the definition of the challenge will result in a more precise and efficient process. It is also a hard but important task for companies to identify which kind of problems are suitable for open innovation, and develop a set of metrics to conduct performance management and resource allocation.

4.8 Statements of Deputy Manager of NASA's Center of Excellence for Collaborative Innovation

In an interview with Steve Rader, Deputy Manager of NASA's Center of Excellence for Collaborative Innovation, which was conducted in March 2020, it can be evidently deduced that crowdsourcing is a highly appreciated and strongly suggested method of innovation in the scientific and technological field because of its numerous applications and potential. NASA's Center of Excellence for Collaborative Innovation is a department that works across the entire agency to promote open innovation through challenges carried out with the so called "curated crowds", which are groups of users that share a common interest or passion. These crowds, brought together by companies, are divided into subgroups depending on the area of interest which can span from problem solving to coding to algorithms and so on. These specialized communities are employed to solve complex problems whose solutions may bring great advantages and progress to NASA's objectives. From research and literature it can be concluded that the most significant aspect in the development of innovative technologies is and will always be diversity; reaching to diverse team components and sources is key for having a broader range of solutions and for eventually finding the most suitable one. The most valuable ideas gathered during NASA challenges in fact have been proven to be the ones that lie outside of the problem's specific domain, and have rather emerged from knowledge from a different field applied to the one specific to the problem, by looking outside the box and connecting the dots. A technology

used for a specific scope, even if at first sight could not seem to be useful in other fields of applications, it could instead be tweaked and used for a totally different purpose than what it was originally thought for. To make an example, a farming technology could be adjusted and modified to find a new useful application for NASA, that operates in a totally different field. There is plenty of evidence on challenges solved by somebody whose knowledge does not belong to the same domain of the challenge and they often bring to the table solutions that exist already. That provides a much advanced starting point to then build fruitful ideas on that technology and generate amazing outcomes. The reason why solutions come often from outside the principal domain, according to Steve Rader, is that usually teams that try to solve these problems all have the same base knowledge and assumptions, using tried and tested methods which impedes them from looking for solutions somewhere else and to connect the dots to other domains. In this regard, crowdsourcing truly represents an enabler for innovation. When asked about possible failure of the method, Rader pointed out that while doing R&D internally leads to unavoidable upfront costs in order to initiate any kind of activity, regardless of its outcome, through use of crowdsourcing firms only get the good side because they select only valuable ideas discarding the others for which they don't have to pay, so expenses will only be directed to creditable solutions.

Following Rader's interview, one basic but fundamental step in the ideation of a challenge is determining what a firm is trying to achieve and how, through the choice of the crowd depending on the type of challenge; the so called "curated crowds" have proven to be very efficient and a famous example is Topcoder, a platform that users spontaneously join just for sake of interest and passion for software and data science; its users are not there just trying to win some economic reward, they are there because truly driven by passion, so they join challenges to connect with others, upgrade their skills and reputation among the community. This underlying ground allows for the creation of a rich and profitable space characterized by a more substantial participation. Going back to the importance of determining the desired outcome of a challenge, another underestimated but crucial aspect is the formulation of the problem; from a case described by Rader, a failing challenge turned into a successful one just by making a subtle change to the phrasing of the request, which can really be determining in the type of crowd that will decide to join it, thus affecting the success or failure of the problem. Other types of challenge are better carried out through the employment of a broader and unconstrained crowd, that can be recruited through platforms such as Innocentive, Ninesigma or HeroX in which users are simply driven by the will to solve problems. This wider class of solvers, that can perform any kind of profession and have any kind of academic

background, is the one suitable for problem-solving in its most general conception. A NASA real case described in the interview by Rader was about improving prediction time on solar flares which can be very dangerous for astronauts when they are outside the space station. After struggling with a solution, a group of scientists, precisely heliophysicists, posed that question and received many solutions, among which one from a retired cell phone engineer who had a never used undergraduate degree in heliophysics. Thanks to his experience in communication engineering, the man managed to connect the dots and generate an algorithm to predict solar flares which improved by four times the previous method in use.

The scientific world has to acknowledge that technology is evolving at a constantly faster rate, and it is becoming harder even for top organizations to keep up with the pace. The standard model involves hiring and bringing experts inside the firm, but times have changed and it is no longer sustainable to work in that way since considering a limited budget, the options are either to cut out people or to find more budget. This relatively new method of conducting research and innovation that involves the sporadic use of external experts is in line with this new environment that does not allow for the quite stationary and non-dynamic mindset that characterizes the majority of firms at the moment. For employees of organizations like NASA, it could be frustrating having to see others do the job for them and not feeling useful enough, but a new approach should be implemented because especially in these highly specialized sectors, knowledge is either obtained from previous experience or it is otherwise necessary that somebody else connects the dots for you, and the best available way to do that is through crowdsourcing. It is however important to note that organizations engaging in crowdsourcing are using it to support and not to replace other approaches to accomplish work. NASA in fact has largely relied on its internal R&D while at the same time exploiting crowdsourcing as a complementary tool to gather ideas. This to show that they can become an additional expense therefore, before undertaking a crowdsourcing journey, firms should carefully examine how that fits into its strategic goals and what to expect from it.

5. CONCLUSION

Throughout this paper, we analyzed in detail the concept of crowdsourcing and all of its aspects, its actors and its forms. By trying to focus on the benefits that greatly outweigh the negative sides, we have learned that crowdsourcing truly has the potential to reshape the future of firms, also of those highly specialized and with apparently closed boundaries.

Changes are happening not only at firm level, but also at user level: curated and specialized crowds are starting to overlap with freelance crowds, which together with the advancements inside firms, are starting to redefine the future of work. A phenomenon which is not emphasized yet in the job world is the slow but evident transition of workers from full-time employment to the freelance workforce, especially during the last period characterized by the COVID-19 pandemic, which contributed to accelerate this trend. The literature can give light to the numerous beneficial outcomes of crowdsourcing from several points of view, but still the adoption of this method remains the hardest part since there can be skepticism from firms that are still attached to a more traditional way of thinking; that conception though is short-lived in the long run because technology advancements will be too disruptive and evident that even having the most extraordinarios internal employees will not be enough to satisfy the market's changes.

An incredible aspect of crowdsourcing is its versatility, indeed when even the most extremely specialized company decides to open some of its projects to the public, it means that it is relying on the crowd and on its ideas. That involves also creating a communication flow between a very "closed" and qualified environment, and the external public, which even if not as educated as internal skilled employees, can still make a relevant contribution to firms. This shows that no matter the educational background of a person, everyone will always have to learn from others, creating a sort of reliance and trust on others.

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