PRODUCT REALIZATION IN THE AGE OF MASS COLLABORATION

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ABSTRACT
There has been a recent emergence of communities working together in large numbers to develop new products, services, and systems. Collaboration at such scales, referred to as mass collaboration, has resulted in various robust products including Linux and Wikipedia. Companies are also beginning to utilize the power of mass collaboration to foster innovation at various levels. Business models based on mass collaboration are also emerging. Such an environment of mass collaboration brings about significant opportunities and challenges for designing next generation products.

The objectives in this paper are to discuss these recent developments in the context of engineering design and to identify new research challenges. The recent trends in mass collaboration are discussed and the impacts of these trends on product realization processes are presented. Traditional collaborative product realization is distinguished from mass collaborative product realization. Finally, the open research issues for successful implementation of mass collaborative product realization are discussed.

Keywords: Mass Collaboration, Decentralized design, Open design, Globalization

1 THE AGE OF MASS COLLABORATION
In his book, The World is Flat, Friedman [1, 2] defines three phases of globalization. The first phase, Globalization 1.0 is defined by countries globalizing. The second phase, Globalization 2.0, is characterized by companies globalizing. Today, we are in the third phase of globalization, Globalization 3.0, where individuals are empowered to act globally through the use of information and communications technologies. In this age of Globalization 3.0, “we are going to see the real human mosaic emerge-from all over the world, from left field and right field, from West and East and North and South-to drive the next generation of innovation” [2].

Shortly after Friedman’s description of the different phases of globalization, Tapscott and Williams [3] provide various examples to show how individuals have already started linking up in loose networks of peers to produce goods and services in a very tangible and ongoing way. They refer to this phenomenon as mass collaboration. Mass collaboration involves the collective action of large numbers of people to perform a task. The driving force for mass collaboration is the development of new Internet technologies and the evolution of the Internet as a platform. Users have evolved from passively receiving information through the web to playing an active role by forming communities, interacting with peers, sharing information, and adding value to the Internet as a result of their interactions.

The ongoing trend towards mass collaboration is already apparent in successful open source software projects such as Linux [4], Apache [5], and Mozilla [6]. The common factor for the success of all these projects is the fact that a large number of individuals with diverse expertise and varied interests work together on developing various aspects of the system. The robustness of the Linux operating system, for example, is attributed to the fact that “given enough eyeballs, all bugs are shallow” [7]. Another example of the success of mass collaboration is the free encyclopedia, Wikipedia.com [8]. Currently, about 10 million volunteers collaborate over the web to create an encyclopedia which consists of about 9.5 million articles in 256 languages. In spite of the fact that the encyclopedia is developed by a large group of people, its accuracy is comparable to that of Encyclopedia Britannica [9]. Further, the large communities on sites such as Facebook for general networking (58 million users), Flickr for photo sharing (4 million users), LinkedIn for business networking (17 million users), and soundpedia (3.5 million users) for music

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sharing show that individuals are increasingly participating in collaborations over the Internet at massive scales. Other examples of mass collaboration from different fields include Current [10] which is a global TV Network, Second Life [11] which is a 3-D virtual world created by the community, TakingITGlobal [12] which is a social projects community, and collaboratively written books such as [13]. Other examples are provided in Table 1.

Table 1 - Examples of Leveraging Mass Collaboration

<table>
<thead>
<tr>
<th>Open Source Software</th>
<th>Social Networking</th>
<th>Open R&amp;D</th>
<th>Collaborative Authoring</th>
<th>Biology</th>
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<tr>
<td>Firefox Browser [6]</td>
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<td>(e.g., [13])</td>
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Recently, there have been a few efforts on applying the concepts of open-source development to physical product development. The open source car project (OScar) [26] is an example of applying open source concepts to hardware. The goal of this project is to develop a car according to the open source principles [30]. Another example is the Open Prosthetics Project [27], where the objective is to share the CAD models of prosthetic devices as open source designs. These designs can be further developed and refined by various users. The users can also freely build the prosthetic devices based on the open source designs [31]. The open prosthetics project is being carried out by The Shared Design Alliance [32]. Adopting a similar approach, OpenMoko [33] has released the CAD files for its mobile devices into the open source domain so that people can completely customize the skin and print 3D parts.

Although the benefits of mass collaboration have started to surface in the software development community, the real impact is yet to be seen in the arena of product realization. The fundamental question is: “How can the collective intelligence of large groups of people be harnessed in the realization of new products?” To answer this question, there is a need for research and development of tools, and methods, and approaches for mass-collaborative product realization. In this paper, we present the key research issues in facilitating mass collaborative product realization. We first identify the differences between traditional collaborative product realization and mass collaborative product realization and discuss the opportunities presented by mass collaboration in Section 2. In Section 3, we define the key research areas and in Section 4, we present detailed research needs. Section 5 concludes the paper.

2 PRODUCT REALIZATION IN THE AGE OF MASS COLLABORATION

A significant amount of research has been conducted on understanding and facilitating product realization as a collaborative activity among various geographically distributed organizations [14-24]. However, much of the efforts have been focused on Globalization 2.0 i.e., collaboration at the enterprise level. Globalization 3.0, on the other hand, involves individuals and small groups acting globally and collaborating. The large numbers of people involved would alter the dynamics of collaborative activity. In this section, we discuss what mass collaborative product realization is based on mass collaborative activity that exists today in other fields. We define how it would differ from traditional collaborative product realization and the opportunities that the paradigm offers.

2.1 Traditional Collaborative Product Realization

Traditional collaborative product realization largely involves strategic partners working together to realize a product. Dyer [34] discusses collaboration in the automotive industry and how many companies prefer to collaborate with strategic partners. This organization of strategic partners working together to realize a product has been referred to as the extended enterprise and as a unit of business competition [34]. This implies that competition in the marketplace is between extended enterprises, i.e., one extended enterprise competing against another for market share. This in turn implies that an extended enterprise is only as strong as its weakest member. Consequently, the selection of appropriate partners in traditional collaborative product realization is an important decision that a company has to make and has a major influence on the quality, cost and lead time of a product.

![Figure 1 - Traditional Collaborative Product Realization](image-url)

The traditional collaborative product realization is depicted in Figure 1. Several characteristics of traditional collaborative product realization are depicted in the figure. It shows the decomposition of the overall product realization problem across multiple companies involved in the extended enterprise. Inherent in this decomposition is a hierarchy where the initial product realization problem is decomposed into sub-problems, which are then decomposed further. The hierarchy of the product realization problem corresponds to the hierarchy of
the companies involved in the extended enterprise. Although not all of the sub-problems involve collaboration, it depicts a relationship where a company acquires the services of another company which in turn acquires the services of other companies. Further, each sub-problem is assigned to a single company. This could take the form of completely outsourcing the sub-problem or collaborating with a partner in solving the problem. As shown in the figure, the company that seeks to outsource or collaborate in solving a sub-problem has an array of possible companies to which the sub-problem can be assigned to. Therefore, a decision has to be made on the company to collaborate with.

The figure also depicts the flow of information in the traditional collaborative product realization process. The flow of information is a directed flow that is based on the relationships between the sub-problems. The sub-problems could be related in three ways: independent, dependent, and interdependent. For interdependent activities, coordination mechanisms are necessary. Information technology for facilitating traditional collaborative product realization is developed based on this understanding of the flow of information.

### 2.2 Mass Collaborative Product Realization

Mass collaborative product realization is based on two concepts: open innovation and self organizing communities of large number of participants. Open innovation involves taking the process of innovation out of the individual organization [35]. Two models of open innovation involving communities can be defined: one that is based on competition and another that is based on collaboration. In the competition-based approach to open innovation, a design problem is made known to a community of participants. Members of the community then offer solutions to the problem and one or more solutions are selected. In this model, there is no collaboration between the members of the community. Competition is based on the offer of a reward to solutions that are selected. InnoCentive [16] utilizes the competition-based model to solve complex science and engineering problems. The key assumption in InnoCentive’s operating model is that it is very likely that someone outside the company knows the solution to the problems faced inside the company. In the collaboration-based approach to open innovation, when a design problem is made known to a community, solutions are offered and amended openly by the community. The collaboration-based approach is characterized by self organization where the evolution of the artifact to be designed is determined by the action of the community rather than a single entity. Both of these approaches collectively have been referred to as crowdsourcing. Crowdsourcing is the act of taking a task traditionally performed by an employee or contractor, and outsourcing it to an unidentified, generally large group of people, in the form of an open call [36]. The focus in this paper is on the collaboration-based approach to open innovation.

Mass collaborative product realization is depicted in Figure 2. Unlike traditional collaborative product realization, the participants in the mass collaborative product realization process are not necessarily organized in a hierarchical manner. Participants can offer solutions, amend solutions and offer comments on solutions at various levels of the design problem. Participants do not have to be assigned a particular sub-problem of the overall product realization problem and are free to work on sub-problems that they want to contribute to. Mass collaborative product realization therefore allows for the customer to be involved in the product realization process. It provides opportunities to implement concepts such as design-by-customer and design-with-customer. Further, in mass collaborative product realization multiple independent participants work on a single sub-problem, unlike traditional collaborative product realization where a sub-problem is assigned to a single company.

![Figure 2 - Mass Collaborative Product Realization](image)

The information flow in mass collaborative product realization adopts a ‘publish and subscribe’ model. In this model, all participants of solving the product realization problem ‘subscribe’ to the problem. Whenever a change is made to the information pertaining to the problem are made, every subscribed participant is notified of the change. Participants then react to the change that has occurred. Based on this information flow, information technology for facilitating mass collaborative product realization should facilitate:

a) formation of the community,
b) online description of product realization problem,
c) online submission of solutions and comments, and
d) notification of changes.

The differences between traditional and mass collaborative product realization are summarized in Table 2.

### Table 2 – Differences between traditional and mass collaborative product realization

<table>
<thead>
<tr>
<th>Factor</th>
<th>Traditional Collaboration</th>
<th>Mass Collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product Realization Process</strong></td>
<td>Top-down, Hierarchical</td>
<td>Self Organization</td>
</tr>
<tr>
<td><strong>Team Members</strong></td>
<td>Strategic partners</td>
<td>Members of a community</td>
</tr>
<tr>
<td><strong>Team Organization</strong></td>
<td>Hierarchy and one to one relationship between sub-problem and company</td>
<td>Ad hoc and many to one relationship</td>
</tr>
<tr>
<td><strong>Information flow</strong></td>
<td>Directed flow</td>
<td>‘Publish and subscribe’</td>
</tr>
<tr>
<td><strong>Collaborative Computing Environment</strong></td>
<td>Facilitate directed flow of information.</td>
<td>Platform for ‘publish and subscribe’ information flow.</td>
</tr>
</tbody>
</table>
2.3 Opportunities Provided by Mass Collaborative Product Realization

Realizing successful products in the marketplace requires various different types of competencies. Often a single organization and more certainly an individual do not possess the necessary competencies to successfully realize a product in the marketplace. Organizations have traditionally dealt with this through the formation of partnerships with other organizations. Single individuals, on the other hand, rarely have the opportunity to be involved in the product realization process as individuals, other than through an organization. Mass collaborative product realization as a paradigm offers opportunities to organizations as well as single individuals. These opportunities are at the root of the consequences of Globalization 3.0, i.e. the ability of individuals to act globally. Organizations can now tap the collective intelligence of large groups of people to successfully realize products and single individuals can now collaborate with other individuals or organizations and be involved in the realization of products. Specific opportunities provided by mass collaborative product realization are discussed in the rest of this section.

2.3.1 Turning ideas into products

One of the consequences of the ability to utilize competencies on a network is the ability to turn ideas into products. While many good ideas are generated daily, few are successfully brought into the marketplace [37]. Reasons for this include the lack of a proper team and the lack of resources. In a mass collaborative environment, individuals with ideas now have the opportunity to form teams with appropriate competencies and also utilize the resources that members of a network might possess to turn their ideas into products.

2.3.2 Turning technologies into products

New technologies are constantly being invented. A key problem in utilizing new technologies is identifying areas in which the technology may be utilized. Often a technology is not utilized in as many areas as it could appropriately be used in because inventors are unaware of the application areas. Mass collaborative product realization provides an opportunity for organizations and individuals to make known or offer their new technologies to large groups of people who could identify new applications.

2.3.3 Solving difficult problems

Organizations and individuals are limited in the knowledge that they possess. Mass collaborative product realization provides the opportunity to take difficult product realization problems that the individual entity is unable to solve and open it up to large groups of people. The probability of solving the difficult problems is hence increased as a result of many minds trying to solve it.

2.3.4 Identifying what the market wants

A key aspect of product design is identifying the design requirements, which involves identifying the needs of the customer. While various methods exist for customer needs finding, mass collaboration provides the opportunity for large groups of people to voice their opinion in what they want in a product. It provides a new means of including the voice of the customer in the design of the product.

2.3.5 Arriving at innovative solutions

Mass collaboration provides an opportunity to solicit ideas and solutions from large groups of people. Concepts and alternatives generation are important aspects of the design process. The quality of the final design is often limited by the quality of concepts and alternatives generated for design problems. Involving large groups of people provides an opportunity to increase the quality of concepts and alternatives to arrive at innovative solutions to design problems.

2.3.6 Arriving at sound solutions

The design process also involves analyzing alternatives generated from multiple perspectives and making sound decisions. The kinds of models utilized, the perspectives considered and how decisions are made play an important role in the final quality of the design. Mass collaboration has a self-correcting characteristic brought about by large numbers of people amending or commenting on the quality of solutions and the decisions made, thus allowing sound solutions to be arrived at.

3 ENABLING MASS COLLABORATIVE PRODUCT REALIZATION

As discussed in the preceding section, the emerging paradigm of mass collaboration offers organizations and individuals new opportunities to utilize the collective intelligence of large groups of people to realize innovative new products. However, achieving this ultimate vision necessitates developing a foundation for mass collaborative product realization that will form the basis for facilitating mass collaborative product realization and how organizations and individuals can take advantage of the opportunities present. In this section, we discuss the enablers for realizing the vision of mass collaborative product realization. An overview of the enablers of mass collaborative product realization is provided in Figure 3. A discussion follows.

Figure 3 - Enablers of Mass Collaborative Product Realization

Product Realization Process: The product realization process defines how products will be realized in the mass collaborative environment. A vast amount of research has been conducted on design methods, but the mass collaboration paradigm...
Involves a fundamentally different environment for realizing products where large numbers of people are involved and where self-organization could play a greater role than traditional top-down design methods. While self-organization could be beneficial, it also could result in negative effects when bad solutions dominate and greatly influence the convergence to a solution. To facilitate product realization in the mass collaborative environment requires an understanding of product realization with large numbers of people. A key enabler of mass collaborative product realization is an understanding of the product realization process in a mass collaborative environment and tools that will aid organizations and individuals manage the process effectively.

Information and computation: Mass collaborative product realization involves collaboration among geographically distributed participants. Communication between participants is based on the exchange of information. Computational environments to facilitate mass collaboration are a key enabler of mass collaborative product realization. This would require understanding the nature and flow of information between participants in a mass collaborative environment and developing the appropriate environment for collaboration to occur. Further, as with current collaborative engineering environments, information models for seamless exchange of information between people working on different aspects of the product realization process are essential.

Business and Legal Aspects:
As discussed by Tapscott and Williams [3], the business paradigm to leverage mass collaboration is different from the traditional paradigms. Companies based on traditional paradigms innovate, differentiate, and compete with each other. They gain competitive edge by protecting their intellectual property fiercely. In contrast, the enterprises that leverage mass collaboration paradigm are based on openness, peering, sharing, and acting globally [3]. The structure of the enterprise is also different. Instead of a hierarchical organizational structure with a central control, a flat and decentralized structure is required for mass collaboration to be successful [38]. The business models for such enterprises are also different [39]. West [40] discusses the role of intellectual property in the context of open innovation, which has similar impact on the mass collaborative environment. Openness of intellectual property also raises a number of legal issues. The questions such as “who owns the intellectual property?”, “what kind of new intellectual property laws are required?”, “who owns the responsibility if a product fails?” become more important. Significant efforts in the business and management research community under the umbrella of open innovation [35] are important in understanding how businesses can utilize mass collaboration.

Social and Psychological Aspects: The success of mass collaboration is based on openness and sharing. The fundamental question that arises is “how can collaboration and openness be encouraged when in the short term it is economically rational to be closed and to compete?” Significant research is currently being carried out in the social sciences to address this question. Alexrod and co-authors [31-34] have presented their research on the evolution of cooperation. Other social aspects important in mass collaboration include trust between people in the community, motivation to contribute, crowd psychology, and collective behavior.

In this paper, the focus is mainly on the product realization process, and information and computing. We have discussed the business, legal, and social aspects briefly because these aspects are equally important in the success of a mass collaborative product realization enterprise. Collaboration between researchers from all these aspects is important for gaining a holistic understanding of mass collaborative product realization. Having discussed the enablers, we focus on the key research issues associated with product realization process, and information and computation in Section 4.

4 OPEN RESEARCH CHALLENGES IN MASS COLLABORATIVE PRODUCT REALIZATION
This section details the open research challenges in facilitating product realization in a mass collaborative environment.

4.1 Product Realization Process
Understanding how products may be realized in a mass collaborative environment and the nature of the products that could be realized in such an environment are central to facilitating product realization in a mass collaborative environment. This sub-section discusses the open research challenges in these two aspects.

4.1.1 Process Related Research
Product realization process and coordination
Given that an entity, an organization or a single individual, has access to a large number of potential designers, a key challenge is defining a product realization process that will allow the designers to work together in the realization of the product. When groups of people are involved in the product realization process, it is important that their actions be coordinated. Accordingly, the research question that arises is “what should the structure of the product realization process be and how should designers be coordinated?”

A number of product realization processes based on different coordination mechanisms may be defined. These include:

- **Uncoordinated product realization process**: An uncoordinated product realization process would involve designers reacting to new information and taking actions as they deem. No rules are present to limit or govern the behavior of designers in the environment.

- **Central coordination of the product realization process**: Central coordination would involve a central manager who decides how the product realization process proceeds. The manager decides on allocation of tasks to individual designers or design teams and decides on the sequence of design tasks.

- **Coordination based on opinion polling**: This process would involve design process and product decisions being made based on the collective opinions of the group of designers involved. This coordination mechanism is similar to house-hunting in social insects [41].
Set-based product realization: Set-based product realization would involve concurrent development of multiple concepts [42-44]. This could involve a scenario where multiple design concepts are explored concurrently by different groups of designers in response to a posed design problem.

Addressing the challenge of defining a product realization process and appropriate coordination mechanisms necessitates understanding how effective the above and other product realization processes are for a mass collaborative environment. This requires modeling these processes and examining the emergence of the product. One means of modeling the action of individual agents and examining the effects of their actions is through agent based modeling (ABM) [45]. An agent-based model is a computational approach for simulating the actions and interactions of autonomous individuals in a network. Bonabeau [46] explains that the ABM approach focuses on “how processes evolve over time and how policies might be changed to affect the outcomes of an evolving system.” ABM would therefore allow defining policies for product realization in a mass collaborative environment. It should however be noted that ABM simulations are not designed to perfectly recreate the design environment, but are used as a tool for examining and understanding emergence of patterns.

Nature of product realization teams

Surowiecki [47] discusses how a large group of people could be better at solving problems as compared to a small group of experts under certain conditions. One of these conditions is the diversity of the group of people involved in solving the problem. Accordingly, another important research question in mass collaborative product realization is “how would the size, diversity and competency of the designer group affect the product to be designed?” Answering this question would allow one to understand the nature of the product realization team that is necessary for product realization in the mass collaborative environment. Necessary measures can then be adopted to ensure a greater probability for successful product realization. The research challenge is therefore in identifying the appropriate organization of designers in terms of size, diversity and competence for successful product realization. Similar to understanding the product realization processes, understanding the nature of teams for product realization necessitates modeling different numbers of product designers with diverse expertise and different levels of competencies. Agent-based modeling would also be useful in this respect as it allows modeling of individual agents and their interactions. ABM can therefore be utilized to model and understand the emergence of a product based on design groups with different sizes, competencies and interests.

Collective learning and evolution

Participants in a mass collaborative product realization environment may work on multiple projects either concurrently or in a sequence (i.e. one project after another). Individual participants learn certain behaviors and knowledge based on their involvement in a project. These behaviors and knowledge are then brought with them to other projects, which in turn influence other designers. As a result, collective learning and evolution of the entire society of designers could occur. An example of this could be in the spread of technology. An organization could introduce its technology into a certain design project. Its success or failure in the project would cause designers to build an impression of it to other projects, increasing or decreasing the technology’s chances of adoption. While such behavior is evident today in the marketplace, a mass collaborative environment provides a platform for rapid transfer of information. The research challenge here is to understand the effects on the overall design environment as a result of the action of individuals. This would involve studying not only effects within a project, but also across projects. This would involve modeling the relationships between projects in the environment. This understanding is necessary for the identification of overall mechanisms or policies for the mass collaborative product realization environment.

**Incentives to Participants (Individuals and Organizations)**

The current design research is mainly focused on top-down design, where the design process starts with a requirements list and the system level requirements are progressively decomposed into subsystem requirements and assigned to design teams. The design process is hierarchical with design requirements flowing from top to down. The design objectives of each design team are determined by the higher level design requirements, and the overall goal is to satisfy the requirements as closely as possible. Each designer’s decisions are driven by the higher level objectives.

In contrast to the traditional design, in the case of open and mass collaboration each individual is driven by his/her personal objectives that may not be directly derived from the system level objectives. Every participant has his/her own intrinsic interest in contributing to the overall effort. The overall design emerges based on the interactions of these self-interested individuals. In such a scenario, the key objectives from the systems perspective are to: a) understand the motivation of individuals in participating in the mass collaborative product development process and to provide appropriate incentives for them to collaborate synergistically, and b) to orchestrate the interactions between the self-interested individuals for efficient and effective achievement of design objectives.

One of the questions that arise in mass collaborative product development is: why would an individual contribute his/her efforts? The understanding of motivation is important to utilize mass collaborative product development into a viable business approach. The motivation of participants in the open source software development projects has been studied to some extent in the business literature. Lerner and Tirole [48] characterize the motivation as either extrinsic or intrinsic motivation. Examples of intrinsic motivations include intellectual stimulation and philosophical beliefs, whereas the examples of extrinsic motivations include career advantages due to experience gained by participating in open source projects, and reputation benefits [49, 50]. From an economic perspective, if the benefits of participating in open source development project are greater than the cost (i.e., time and energy invested), individuals would be willing to participate in such projects. In the context of physical product development,
We believe that significant research on modeling mass communities. Co-authors [56] study the emergent behavior in open source impact on system behavior is by Schelling [55]. Valverde and community. Related work has been performed in the social design literature. However, models for bottom-up design processes have been presented in the engineering domain. The basic research question is: "What is interested participants is necessary for mass collaborative design processes as interactions between self-interested participants. The key question is "What should the architecture of the product be to facilitate mass collaboration?" Some products such as software are amenable to mass collaborative design. Other products such as multidisciplinary and multifunctional products are highly coupled and may not be directly suitable for mass collaborative design. Whitney [67] discusses that mechanical design cannot be like a VLSI design which is highly modular. Research on designing product architectures in the context of mass collaborative product development is critical for (a) identifying types of products that are suitable for such development strategy and (b) designing new architectures for systems that are not highly modular. The modularity of the product is also related to the design processes. It helps in achieving independence in design tasks.

**Product Co-Design**

Seybold [68] presents various examples of how many product development companies have started working closely with their customers for designing their products. The relationships between companies and their customers are not limited to one-way feedback anymore. Instead, the customers are co-designing products with them creating a vibrant ecosystem. Seybold [68] discusses how Lego leverages customer co-design in their Mindstorms product kit. Customers not only help design the products but also advertise the products. The collaboration between customers takes place through online communities, and live competitions.
In such a customer co-design scenario, the key question from the business standpoint is “how can companies utilize the knowledge and capabilities of their customers to foster innovation in their products?” Answering this question requires designing products such that customers get enough freedom to extend (and augment) the products’ functionality to satisfy their desired objectives. The two essential aspects of this statement are a) ability to extend the functionality, and b) ability to satisfy a wide variety of needs. Hence, the resulting question from the design research standpoint is: “how can products be designed in a flexible manner to provide opportunities to extend the functionality for a wide range of needs?” The design objective here is significantly different from traditional design where the emphasis is on achieving desired requirements as closely as possible. Openness and flexibility are the key characteristics for successful co-design of products.

Product – services systems
Product-Service Systems represent a combination of products and services [69]. Manzini [70] defines it as an innovation strategy where the focus is not only on designing physical products but a system of products and services that are jointly capable of satisfying clients’ needs. Various companies are moving from just providing products to the customers to providing a host of services that accompany the product. Examples of such services include installation, maintenance, customization, maintenance, and recycling. For the state of the art in product-service systems, please refer Baines and co-authors [69].

Current research on product-service systems only focuses on products and associated services that can be provided to the customers by the company. In the context of mass collaborative product development, we believe that companies have much to gain by developing products and opening up the service component to the individuals outside the company. The knowledge outside the company has a potential to build a strong infrastructure around the product that enhances the success of the product itself. The key research issue from the design standpoint is “how can a product-service system be designed to leverage mass collaboration between individuals outside the company?” Design research in this area is essential for developing strong product – service ecosystems.

4.2 Information and Computation
Facilitating mass collaboration in product realization necessitates the development of a platform where individual designers and organizations can offer services and participate in the product realization process. The term service is used generally to mean any resource that could aid in the product realization process. This would include the ability of the human designer to perform a task or a computational tool that could perform a task. While a platform is necessary for designers and organizations to join the community and offer services, the bigger issue is the integration of the various services offered by the participants of the community, specifically the computational tools. The research challenge to be addressed here is “how can computational tools be integrated on the fly as and when needed to facilitate collaborative product realization?” The issue of information exchange between participants is also related to this question.

Current Product Data Management (PDM) systems and Product Lifecycle Management (PLM) systems are focused on enterprise level information management. The emphasis is on application integration and customization for the extended enterprise. However, in the mass collaborative environment where individuals work together to design and manufacture products, integration of diverse software and hardware tools is a challenge of much greater magnitude. Development of standards for information exchange between various applications is critical. There is a large variety of open source analysis applications available on the Internet. Examples of such applications include Finite Element Modeling tools, Computer-Aided Design tools, manufacturing process planning tools, optimization tools, etc. However, the integration between these applications is extremely weak. Further, the applications should be sufficiently open so that different individuals can contribute their expertise towards extending the functionality. The frameworks developed by commercial vendors support good integration across applications but lack the openness that is needed for mass collaboration.

A vast amount of research has been conducted on the development of frameworks for systems integration [71]. However, systems integration is still largely manual today. New approaches need to be developed that allow automated and dynamic integration [72]. Service oriented architecture [73, 74] is a philosophy that could fulfill this vision of dynamically integrating systems to facilitate collaborative product realization. Service oriented architecture is an approach to developing systems based on the use of services as fundamental elements. Services are entities that perform a certain task and can be described, published and discovered. Systems are synthesized dynamically to support processes through the composition of services found on a network. Fulfilling the vision of a service oriented computing environment necessitates research at three levels as shown in Figure 4, service foundation level, service composition level and the service management level [73]. Each level defines functionality that the next level relies upon. The service foundation level involves developing the functionality for describing, publishing and discovering services. The service composition level provides the necessary roles and functionality for aggregating services. Aggregated services could either be used as higher level services or as applications. Service composition also involves coordination of the services to control the execution of the services. The service management and monitoring levels provide the functionality to ensure that the service oriented computing environment is functioning effectively.

Technologies are rapidly developing at all of these levels. At the service foundation level, web services and grid computing provide the necessary middleware to not only exchange information, but also utilize distributed computational resources on a network to create virtual organizations [75]. At the service composition level, various standards have been developed for service orchestration. Service orchestration
refers to “how services can interact with each other at the message level, including the business logic and execution order of the interactions from the perspective of a single endpoint” [73]. Service orchestration languages for business processes include the Business Process Modeling Language (BPML) [76] and Business Process Execution Language for Web Services (BPEL) [77]. Facilitating mass collaborative product realization would require extending these standards and technologies.

![Figure 4 - Levels of a Service Oriented Computing Environment [73](image)](image)

We envision that the product realization environment would itself be co-created by the masses of individuals who use the framework for product realization. The architecture of the framework should be open so that it can be developed through mass collaboration.

5 CLOSURE

In this paper, our objective is to present the product realization environment in the age of mass collaboration. The trend towards mass collaboration is clear from recent developments, particularly the success of open source software development, online communities, web-based social networks, and innovative business models adopted by various companies. Based on these developments, we present our vision of product realization and distinguish it with the current product realization approaches.

There are significant differences in the product realization environments, particularly in the manner the design processes are structured, the types of products developed, and the computational infrastructure required for mass collaborative product realization. Two of the key enablers for product realization in such a collaborative environment are a) product realization process, and b) information and computation. These are discussed in detail in this paper because they relate closely to the research in the engineering design research community.

We present specific research issues that need to be addressed for successful implementation of mass collaborative product realization. These research issues include a) product realization process and coordination, b) nature of product realization teams, c) collective learning and evolution, d) self interested participants, e) product architectures, f) product co-design, g) product-service systems, h) collaborative engineering environments, and i) product lifecycle management for mass collaborative design. All these aspects are associated with fundamental research issues that are of potential interest to the design community.

Linux and Wikipedia just represent a starting point of the age of mass collaboration. This new age has the potential to completely revolutionize the way we realize products, services and systems.

6 REFERENCES