How Industry Can Implement Social Product Development and Innovate With The Crowd

This thesis has been submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor of Philosophy

By

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Declaration

This work has not been submitted in substance for any other degree or award at this or any other university or place of learning, nor is it being submitted concurrently in candidature for any degree or other reward. This thesis is being submitted in partial fulfilment of the requirements for the degree of PhD.

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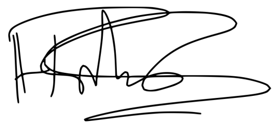

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List of Publications

List of Publications including in this Thesis

Forbes, H. and Schaefer, D., 2017. **Social product development: the democratization of design, manufacture and innovation**. *Procedia Cirp*, 60, pp.404-409.

Forbes, H., Schaefer, D., Panchal, J. and Han, J., 2019. **A Design Framework for Social Product Development**. *IEEE Transactions on Engineering Management.*

Forbes, H., Schaefer, D., Han, J. and De Oliveira, F.B., 2020. **Investigating Factors Influential on the Success of Social Product Development initiatives**. *Procedia CIRP*, 91, pp.107-112.

Shergadwala, M., Forbes, H., Schaefer, D., Panchal, J., 2020. **Challenges and research directions in crowdsourcing for engineering design: An interview study with industry Professionals**. *IEEE Transactions on Engineering Management*, pp.1-13.

List of Pending Publications including in this Thesis

Forbes, H. and Schaefer, D., 2021. **Investigating Factors Influential on the Success of Crowdsourcing Contests**.

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Glossary

Actor proximity
Actor proximity is defined is the distance in both relationship and physical space between those participating in the Social Product Development initiative.

Agile Model
Agile is a people-oriented management system, designed to make teams much more adaptable to changes.

Cloud-based Design and Manufacture
Cloud-Based Design and Manufacture is a type of parallel and distributed system consisting of a collection of inter-connected physical and virtualized service pools of design and manufacturing resources (e.g., parts, assemblies, CAD/CAM tools) as well as intelligent search capabilities for design and manufacturing solutions.

Co-creation
Co-creation is when businesses include outsiders in the ideation and development process.

Collective Action
Collective action refers to action taken together by a group of people whose goal is to enhance their condition and achieve a common objective.

Crowd Participation
Crowd participation refers to the involvement of a large group of people, normally the general public, in an activity.

Crowdsourcing
Crowdsourcing is defined as the the act of taking a job, traditionally performed by a designated agen and outsourcing it to a large group of people.

Crowdsourcing Platform
A crowdsourcing platform is a website where crowdsourcing activities are hosted and participants in crowdsourcing activities can submit their ideas.

Data Management
Data management is the practice of collecting, keeping, and using data securely, efficiently, and cost-effectively.

The Democratization of Design
The democratization of design, manufacture and innovation defines empowerment of the masses in product development.

Detailed Design
Detailed design is the process of taking on and developing the approved concept design. By the end of the detailed design process, the design should be dimensionally correct and co-ordinated, describing all the main components and how they fit together.

Digital Manufacturing
Another term for Industry 4.0 (See definition of Industry 4.0)

Digital Transformation
Digital transformation is the integration of digital technology into all areas of a business, fundamentally changing operations and value delivery to customers.

Embodiment Design
In the embodiment design phase of the product development process the arrangement of physical functions, preliminary selection of materials and the selection of final dimensions are completed.

Exploratory Research
Exploratory research is defined as a research used to investigate a problem which is not clearly defined.

Industry 4.0
The ongoing automation of traditional manufacturing and industrial practices, using modern smart technology.

Intellectual Property
Intangible property that is the result of creativity, such as patents and copyrights.

Mass Collaboration
Mass collaboration is a form of collective action where a large number of parties work together on a project. Each party makes a significant contribution to the project and all contributors are regarded as important.

Multiple Regression Analysis
Multiple regression analysis is a statistical method used to predict the value a dependent variable based on the values of two or more independent variables.

Open Innovation
Open Innovation is defined as using knowledge inflows and outflows to fuel innovation

Organisational Proximity
Organisational proximity is defined is the distance in both relationship and physical space between those participating in the Social Product Development initiative and the organisation hosting the Social Product Development initiative.

Participatory Design
Participatory design is an approach to design attempting to actively involve all stakeholders in the design process to help ensure the result meets their needs and is usable.

Portfolio careers
A portfolio career comprises a variety of roles rather than one job at a single organisation. It can be a career that combines multiple paid and/or voluntary roles.

Primary Research Question
The Primary Research Questions in this thesis are the research questions that contribute to the achieving of the thesis aim. The research presented in this thesis addresses the primary research questions.

Principle Component Analysis
Principal Component Analysis, or PCA, is a dimensionality reduction method that is often used to reduce the dimensionality of large data sets, by transforming a large set of variables into a smaller one that still contains most of the information in the large set.

Procedural Design Method
Procedural design methods have an obvious flow of data from input to output. It represents the architecture of a process as a set of interacting processes that pass data from one to another.

Requirements Analysis
Requirements Analysis is the process of defining the expectations of the users for something to be built or modified.

Secondary Research Question
The Secondary Research Questions presented in this thesis are those research questions that, when addressed, contribute to the addressing of the Primary Research Questions.

Sentiment Analysis
The process of computationally identifying and categorizing opinions expressed in a piece of text, especially in order to determine whether the writer's attitude towards a particular topic, product, etc. is positive, negative, or neutral.

Smart Manufacturing
Another term for Industry 4.0 (See definition of Industry 4.0)

SMEs
Small to Medium Enterprises

Social Product Development (SPD)
Social Product Development is defined as a group of coalescing tools and socio-technologies represented by several tenants including crowdsourcing, Internet-Based Mass Collaboration, Open Innovation and Cloud-Based Design and Manufacture.

Social Product Development Initiative
A Social Product Development initiative is the application of one or several of the Social Product Development tenants. For example, a crowdsourcing contest is a Social Product Development initiative.

Social Product Development Tenant
Social Product Development Tenants are those tools and socio-technologies that represent Social Product Development. The Social Product Development tenants are crowdsourcing, Internet-Based Mass Collaboration, Open Innovation and Cloud-Based Design and Manufacture.

Socio-Technical Systems
Sociotechnical systems in organizational development is an approach to complex organizational work design that recognizes the interaction between people and technology in workplaces.

Tertiary Research Question
The Tertiary Research Questions presented in this thesis are those research questions that, when addressed, contribute to the addressing of the Secondary Research Questions.

User-Centred Design
User-centered design is an iterative design process in which designers focus on the users and their needs in each phase of the design process.

Waterfall Model
The waterfall model is a breakdown of project activities into linear sequential phases, where each phase depends on the deliverable of the previous one and corresponds to a specialization of tasks.

Nomenclature

P_o	Organisational Proximity
P_a	Actor Proximity
N	Number of Participants
σ	Standard Deviation
IRR	Inter-rate reliability
κ	Fleiss' Kappa
$1 - \overline{\mathrm{P_e}}$	Gives the degree of agreement that is attainable above chance
$\overline{\mathrm{P}} - \overline{\mathrm{P_e}}$	Gives the degree of agreement actually achieved above chance
PC	Problem Complexity
F_j	Number of functions at level j
k	Number of levels in the function tree
E	Effort for the design problem
SR	Severity of the requirements
F	Functional design complexity
P	Probability of success
ρ	Number of unique or distinct operators appearing in the design form
N	Number of unique or distinct basic operands appearing in he design form
N_1	Total number of occurrences of the operators in the design form
N_2	Total number of occurrences of the operands in the design form
η	Number of operators and operands
L	Length of design form
H^*	The parameters of the design in the design's most compact form
A	Level of abstraction

Equations

Equation 4.4.1: Calculating Inter-rater Reliability

$$IRR\% = \frac{Agreements}{Agreements + Disagreements} * 100\%$$

Equation 6.3.1: Fleiss' Kappa Coefficient

$$Kappa, \kappa = (\overline{\mathrm{P}} - \overline{\mathrm{P_e}}) \div (1 - \overline{\mathrm{P_e}})$$

Equation 7.3.1.1: Equation for measuring problem complexity

$$PC = \sum_{j=1}^{k} * F_j * j$$

where

PC = Problem Complexity

F_j = Number of functions at level j

k = Number of levels in the function tree

Equation 7.3.1.2: Equation for measuring problem complexity

$$E = a * PC^b * SR^c$$

where

E = Effort for the Design problem

SR = Severity of the requirements

PC = Problem complexity

Equation 7.3.1.3: Equation for measuring problem complexity

$$F = log_2(\frac{1}{P})$$

where

F = Functional design complexity

P = Probability of success

Equation 7.3.1.4: Equation for measuring problem complexity

$$P = Prob[a \le r \le b]$$

Equation 7.3.1.5: Equation for measuring problem complexity

$$\begin{aligned} P &= Prob[a \le r \le b] \\ &= \int_a^b f(r)dr \\ &\Rightarrow F = log_2 \left[\frac{1}{\int_a^b f(r)dr} \right] \end{aligned}$$

where

ρ = Number of unique or distinct operators appearing in the design form

N = Number of unique or distinct basic operands appearing in he design form

N_1 = Total number of occurrences of the operators in the design form

N_2 = Total number of occurrences of the operands in the design form

Equation 7.3.1.6: Equation for measuring problem complexity

$$\eta = \rho + N$$

where

η = Number of operators and operands

Equation 7.3.1.7: Equation for measuring problem complexity

$$L = N_1 + N_2$$

where

L = Length of the design form

Equation 7.3.1.8:Equation for measuring problem complexity

$$\begin{aligned} H &= Llog_2\eta \\ &= (N_1 + N_2)log_2(\rho + N) \end{aligned}$$

where H^* denotes the parameters of the design in the design's most compact form

Equation 7.3.1.9: Equation for measuring problem complexity

$$\begin{aligned} H^* &= L^*log_2\eta^* \\ &= (2 + N^*)log_2(2 + N^*) \end{aligned}$$

Equation 7.3.1.10: Equation for measuring problem complexity

$$A = \frac{H^*}{H}$$

where

A = Level of abstraction

Equation 7.3.1.11: Equation for measuring problem complexity

$$\begin{aligned} E &= \frac{1}{A} * H \\ T &= \left(\frac{1}{S * A}\right) * H \\ &= \frac{H^*}{H * S} \end{aligned}$$

Equation 7.4.1: General Multiple Regression Equation

$$Y = b_0 + b_1X_1 + b_2X_2 + ... + b_kX_k$$

Equation 7.4.2.1: Multiple Regression Equation for Innocentive

$$\begin{aligned} S = -13344 + 9699X_1 + 1.298X_2 - 8.13X_3 + 0.00595X_4 + 13709X_5 \\ -0.000032{X_2}^2 + 0.00447{X_3}^2 - 2.55X_1X_3 - 9078X_1X_5 \\ +0.000083X_2X_3 - 0.987X_2X_5 + 6.20X_3X_5 - 0.00449X_4X_5 \end{aligned}$$

where

S = Number of Submissions

X_1 = Coupling Ratio

X_2 = Number of Employees

X_3 = Number of Words

X_4 = Total Reward Value

X_5 = Number of Stages

Equation 7.4.2.2: Multiple Regression Equation for GrabCAD

$$
\begin{aligned}
S = -111.1 + 97.3X_1 + 36.90X_2 + 5.48X_3 + 1375X_4 - 0.000582X_5 \\
-2.669{X_2}^2 + 0.1455{X_3}^2 - 907X_1X_4 + 0.000293X_1X_5 \\
-0.646X_2X_3 - 58.8X_3X_4 + 0.000009X_3X_5 + 0.001061X_4X_5
\end{aligned}
$$

where

S = Number of Submissions

X_1 = Number of Stages

X_2 = Number of Incentives

X_3 = Coupling Ratio

X_4 = Jargon

X_5 = Twitter Followers

Abstract

Imagine two companies with two similar products are fiercely competing for customers. They have both been aggressively protecting their intellectual property and stifling public user criticism, until one decides to share its design with its user community and encourage user customization. The first spends significant resources on enticing and retaining users, while the other improves their product with their users and actively involves them in their product development process. The second increases their reputation among their users, is able to innovate and address user concerns quickly and cheaply and, as a consequence, sees its sales begin to rocket. This scenario is representative of what is known as "Social Product Development".

Despite many successful examples of SPD in industry, with tangible proof of reduced development time and cost, there is a lack of implementation of SPD. The aim of this thesis is to determine why this is and to provide applicable research to support the implementation of SPD in industry. Specifically, this thesis addresses two Primary Research Questions:

1. What are the barriers for the implementation of SPD in industry?
2. How can the implementation of SPD be supported?

For the first Primary Research Question a literature study accompanied by semi-structured interviews with experts are conducted. The results of these research methods were a list of barriers to the implementation of SPD as defined by the interview participants. From these barriers, Secondary Research Questions to address the second Primary Research Question were derived. Specifically, these included research questions on problem preparation for an SPD initiative, selecting an SPD invitiative, structuring SPD initiatives, choosing incentives and making design decisions for an SPD initiative. To address these Secondary Research Questions, an expert analysis experiment and a crowdsourcing success factor experiment were conducted. The results of these methods included a expert conclusion that analysis frameworks for SPD tenants must be isolated to individual tenants as well as a series of factors that dictate the success of SPD initiatives.

In addressing these Primary Research Questions, this thesis provides original contributions to the body of work on SPD as follows:

1. The first interview study with industry practitioners revealing some of the key challenges for the implementation of SPD
2. An SPD implementation framework that allows industry practitioners to identify the most appropriate SPD initiative to solve a particular design problem
3. An SPD performance assessment tool that allows industry practitioners to, with quantitative feedback, determine how their SPD initiative design decisions and their businesses circumstances, such as the way they have framed their problem and their number of Twitter followers, impacts the participation in their SPD initiative.

Chapter 1

Thesis Introduction

Imagine two companies, with two similar products, are fiercely competing for customers. They have both been aggressively protecting their intellectual property and stifling public user criticism, until one decides to share its design with its user community and encourage user customization. The first spends significant resources on enticing and retaining users, while the other improves their product with their users and actively involves them in their product development process. The second increases their reputation among their users, is able to innovate and address user concerns quickly and cheaply and, as a consequence, sees its sales begin to rocket. This was a scenario presented by Cullen (2007), and is representative of what is known as “social product development”. Social product development (SPD) represents “a measurable shift in the ways products [are] developed” and is considered “an evolution in how people work together” (Peterson, Schaefer, 2014). It supports all disciplines in the product development life cycle encouraging designers to “go outside the traditional boundaries of the enterprise to seek advice”. It represents a change in attitude and general ways of working as well as specific social tools and technologies (Han, Yang, 2019).

Despite several successful examples of social product development (SPD) implementation in industry, there is still a lack of implementation which represents a missed opportunity for engineering design. In this thesis, the barriers to the implementation of social product development (SPD) are identified and applicable research is presented to support the implementation of social product development. In this opening chapter, the term and concept of social product development is introduced, the importance of this topic will be outlined and background information on SPD to provide context for this research is presented. Following this, the research aim and research questions this thesis addresses is presented along with a brief introduction to the research approach.

1.1 Research Background

Product development is defined as "the transformation of a market opportunity into a product available for sale" (Krishnan, Ulrich, 2001). In the specific research field of engineering design, product development defines the process from turning a concept of a product into a physical, tangible product that fulfills a set of functional requirements (Brown, Eisenhardt, 1995; Otto, others, 2003). Prior to widespread access to the internet, product development usually represented a process through which a single team within an organisation would use the resources available to them, and the people within their team, to bring a product into reality. Since the internet has enabled high speed communication, international collaboration and access to almost unlimited information, the way product development is conducted has and can be drastically different to how it once was. Several terms have emerged that in some way redefines product development for this new era. Social Product Development, however, does not represent a single framework or ideology, it is instead an overarching term representative of how every phase of the product development process can be conducted differently and enhanced with online collaboration.

1.1.1 Defining Social Product Development

Social Product Development (SPD) is defined as a group of "coalescing tools and socio-technologies" represented by several tenants including crowdsourcing, Internet-Based Mass Collaboration (IBMC), Open Innovation (OI) and Cloud-Based Design and Manufacture (CBDM) (Peterson, Schaefer, 2014).

It is the representation of both a "mindset of openness" and the specific vehicles to achieve and enable this in design, which distinguishes the term "social product development" from other concepts and frameworks such as "open innovation", "participatory design" and "user-centred design". While "open innovation" represents the blurring of traditional business boundaries and the welcoming of external involvement, social product development also represents the tools and technologies to action external involvement (Forbes, Schaefer, 2017). As a consequence, social product development is defined as being representative of four "SPD tenants"; open innovation, representing the "mindset of openness", mass collaboration, representing ways of working, crowdsourcing, representing the social vehicle for implementing early design phases and cloud-based design and manufacture, representing the social vehicle for implementing later design phases. The definitions and examples of the SPD tenants are shown in Table 1.1.

Table 1.1: Social Product Development Tenants (Forbes et al., 2019)

Tenant	**Definition**	**Example**
Crowdsourcing	Crowdsourcing is defined as the "the act of taking a job, traditionally performed by a designated agent [. . .] and outsourcing it to a [. . .] large group of people" (Howe, 2006; Panchal, others, 2015). It is most regularly used in concept generation and concept evaluation of the product development process, and social networking is used to reach the intended crowd (Forbes, Schaefer, 2018).	Organisation publishes and advertises a new product brief online and requests submissions
Internet-Based Mass Collaboration	Mass collaboration is a form of "collective action" where a large number of parties work together on a project (Elliott, 2016; Panchal, Fathianathan, 2008). Each party makes a significant contribution to the project and all contributors are regarded as important (Panchal, Fathianathan, 2008). Internet-based communication tools such as VoIP, file-sharing software and instant messaging are employed, and the number of actors must be over 25 (Elliott, 2016).	Thousands of individuals around the world contribute expert knowledge to create an online encyclopedia
Open Innovation	Open Innovation is defined as using knowledge inflows and outflows to fuel innovation (Chesborough, 2003). Web 2.0 technologies such as social networks act as channels between internal teams and external knowledge sources.	Technology organisation publishes their code for a new app in an open-source community
Cloud-Based Design and Manufacture	Cloud-Based Design and Manufacture "is a type of parallel and distributed system consisting of a collection of inter-connected physical and virtualized service pools of design and manufacturing resources (e.g., parts, assemblies, CAD/CAM tools) as well as intelligent search capabilities for design and manufacturing solutions." (Wu et al., 2012). A plethora of Internet-based communication tools are used including cloud-based software and CBDM process can include any number of actors.	CAD model is stored in cloud-based CAD software. Two mechanical engineers edit different parts of the model online and simultaneously

1.1.2 The Relevance of SPD

With the introduction of SPD tenants, the growth of the "open design" movement and the increasing dismissal of traditional business boundaries, then grew a surrounding social product development eco-system (Forbes et al., 2019). Online forums emerged, such as those on Reddit * and CAD Forum †, dedicated to supporting the iteration and improvement of products. Crowdsourcing platforms such as GrabCAD ‡ and InnoCentive § emerged to allow organisations to seek ideas from the crowd for new and existing projects. Makerspaces became more common therefore increasing access to 3D printers, CNC machines and other prototyping and manufacturing technologies. Education on engineering and design was also democratised with organisations such as Khan Academy

*www.reddit.com
†wwww.cadforum.com
‡www.grabcad.com
§www.innocentive.com

¶ and Code Academy ‖ offering rich, extensive and free guidance on product development. Manufacturing also became more accessible with 3D printer networks allowing collaboration and cheap prototyping that crossed nations and continents. This has created an environment ripe for innovation and one which allows any organisation to access talent and resource beyond their immediate surroundings.

Some organisations have embraced social product development and interacted with the growing ecosystem and external talent to support their internal projects. These examples have provided evidence for the significant opportunity social product development offers organisations. NASA is an organisation that has worked extensively with external collaborators and regularly runs crowdsourcing campaigns on both GrabCAD and InnoCentive. As Stewart (2020) describes, what began as a cost-saving initiative has, as a consequence of success, led to the founding of a Centre of Excellence for Collaborative Innovation (CoECI). NASA define crowdsourcing success through cost (Richard, Davis, 2014) and quality of solution, considering a crowdsourcing campaign a success when;

- Solutions are implemented to solve a real problem within the organisation and,
- Cost less than they would have to be solved by an internal team (Keeton et al., 2017).

Social product development projects have included outsourcing the design of a robotic arm, outsourcing the design of a toilet solution for astronauts and even outsourcing the identification of new areas of research (Gallus et al., 2019). NASA has built a large and engaged community of over two million problem solvers and has gained significant long-term success through the use of social product development. 94% of NASA's challenges are deemed a success and 80% of NASA's social product development initiatives see a cost saving of 41% or more on traditional methods. Richard and Davis (2014) state that approximately $32 million has been saved by NASA through social product development.

Procter and Gamble are another organisation that have embraced social product development and seen positive results as a consequence (Huston, Sakkab, 2006). Procter and Gamble include social product development via one umbrella initiative called "Connect and Develop". "Connect and Develop" is an "open call" platform that presents the latest trends and challenges recognised by the company and encourages external solvers to submit solutions. The recognition that the vast majority of solutions to their problems lay outside of P&G was a critical first step in the development of Connect and Develop (Dodgson et al., 2006). They focused on securing collaboration with external partners in at least 50% of cases (Agafitei, Avasilcai, 2015) to "drive innovation in the organisation". The success of Connect and Develop is recognised in both the cost savings from

¶www.khanacademy.com
‖www.codecademy.com

the initiative, the well-known products that have emerged from the programme, and the intent to continue and grow the initiative even after over 10 years of existence. Procter and Gamble now have external contribution on over 60% of their projects, have brought products such as “Febreze”, “Tide Pods” and “Olay” to market as a consequence of the programme, and have implemented over 4000 ideas from approximately 2000 solvers (Panduwawala et al., 2009). They now plan to triple the investment into Connect and Develop and continue to grow the influence of external contributors on their organisation (Panduwawala et al., 2009).

Other case studies include Boeing and their development of the Boeing 787 which saw involvement from “100 external engineers” resulting in a reduction in development time over 1 year (Afaf, 2019). DARPA also saw significant reductions in development time and cost through their “Red Balloon Challenge” (Tang et al., 2011). These case studies demonstrate the significant potential positive impacts social product development initiatives can have for an organisation. Organisations report reductions in cost, reductions in development time and proof of long-term benefits are shown by the organisations’ intent to invest significantly in continuation of the initiatives.

1.2 The Research Problem

Despite these success stories, social product development is not regularly adopted and implemented within industry (Schaefer, 2014). Only a few organisations, like those listed above, truly integrate social product development with existing practise and consider social product development part of their product development process, as opposed to an addition to it (Forbes, Schaefer, 2017). Bertoni et al. (2018) present a SWOT analysis on the use of social computing technologies in product development and state that social product development in industry is “not yet adequately supported from a knowledge perspective”. Kenly (2020) discovers that application of social product development is “new for most” and Peterson and Schaefer (2014) state that manufacturers and designers are only “taking the first step” towards implementation of social product development. This assessment is also echoed in consideration of the individual social product development tenants.

In the context of crowdsourcing, Forbes and Schaefer (Forbes, Schaefer (2018)) show the “change in sentiment” of crowdsourcing literature reflects an unwillingness of design practitioners to integrate crowdsourcing into their product development processes. Panchal (2015) states that crowdsourcing failure is common and Shergadwala et al. (2020) state that “a need for [social product development] design frameworks that are theoretically grounded and practically feasible” are needed to increase industry implementation. Furthermore, Forbes et al. (2020) show that crowdsourcing failure and lack of implementation is a consequence of “lack of case studies” and “lack of education” on application of social technologies in product development.

In the context of cloud-based design and manufacture, Elhoone et al. (2020) state that there are currently no “readily applicable system” that support the application of cloud-based design and manufacture. Furthermore, Wu et al. (2015) state that a “fully development cloud-based manufacturing system does not yet exist” and that current systems for integration do not “satisfy all the requirements” that they defined as fundamental to cloud-based design and manufacture. Furthermore Wu et al. (2012) state that there is a need to “bridge the gap” between currently existing technology and practise, with focus on integrating current “technologies, services, infrastructure and the vision” of cloud-based design and manufacture. Finally, Singh and Bhanot (2020) state that there are still “barriers for the application of social and internet-of-things technologies” in the manufacturing industry.

Open innovation is acknowledged to have been integrated more extensively into industry practise compared to other tenants but authors present several arguments that further work is needed to increase application in industry. Firstly, Liu et al. (2020) and Urbinati et al. (2020) discuss the constant evolution and complexity of open innovation practise means further work is required. Liu et al. (2020) states that “the complexity of social life has led to new problems” and that “the pattern and practise of open innovation is developing constantly”. Urbinati et al. (2020) state that “innovation processes have become more open and require greater resources and knowledge in the implementation of differing product development phases”. Bogers et al. (2017) and Yoon et al. (2016) suggest that as well as the need to update open innovation practise in industry, several sectors of industry have thus far been ignored. As suggested by Forbes et al. (2020) in the context of crowdsourcing, Bogers et al. (2017) and Yoon et al. (2016) state that “SMEs have been excluded from the mainstream open innovation discussion” and that the “SME perspective on open innovation needs addressing”. Finally, Radnejad et al. (2019) highlights the need for further insight on the application of open innovation in industry stating that further knowledge on the “suitability of different open innovation application approaches for different industry needs” is required.

In the context of mass collaboration, existing literature promotes a similar rhetoric to that presented in open innovation literature. The practise and concept of mass collaboration has existed prior to the introduction of social computing technologies but with this new and constantly changing environment, further work for the application in industry is required Reichelt et al. (2019). Li et al. (2019) state that it is “necessary to further study collective intelligence” in this modern era “due to the continual development of collective intelligence and mass collaboration”. Niazi et al. (2017) states that social computing technologies and their influence on mass collaboration is “still an emerging research area” with limited “guidance and support” for industry practitioners. Finally, Reichelt et al. (2019) states that "aspects of learning" on collaboration on a mass scale in the internet-age "requires constant reconsideration" as "the crowd is a highly complex entity".

There is therefore evidence and backing from existing literature that further work is required to determine *why* social product development has not fully made its way into industry and *how* social product development implementation can be supported. The literature gaps briefly outlined in this chapter and more thoroughly outlined in the following chapter (Chapter 7.2), are shown in Tables 2.1 and 2.2, and shown below for reference.

Table 1.2: Existing Literature on the Barriers to the Implementation of SPD: Literature Gaps according to SPD and SPD tenants

SPD or Tenant	Literature Gaps	References
SPD	• Very limited research on SPD in general • Papers vary significantly according how high-level the research topic is • Minimal inclusion of interviews or observations from industry • Any reference to industry focuses on how to successfully complete an SPD initiative as opposed to how to successfully implement SPD.	Forbes, Schaefer (2017), Gourdswaard et al. (2019), Bertoni et al. (2012), Bertoni et al. (2018), Kenly (2020), Peterson, Schaefer (2014), Shergadwala et al. (2020)
Open Innovation	• Very limited research on implementation of Open Innovation in industry • Larger context of open innovation implementation rarely considered from the perspective of industry professionals • Research on the implementation on Open Innovation focuses on a single organisation or a single industry with organisation types, such as SMEs, not currently considered.	Liu et al. (2019), Urbinati et al. (2020), Rogstadius et al. (2011), Radnejad et al. (2019), Chesbrough et al. (2006), Chesborough (2003)
Cloud-Based Design and Manufacture	• Very few papers explicitly investigate barriers to implementation of CBDM • Those that do so within a very focused context for a single organisation with organisation types such as SMEs, again excluded from this body of work • Any barriers to implementation or often presented at a high level. For example, "company culture" is often defined as a barrier without further elaboration on the specific aspects of company culture that may represent a barrier.	Elhoone et al. (2020), Wu et al. (2015), Wu et al. (2012), Singer, Mittal (2013)
Mass Collaboration	• A lack of empirical research in general • Any observations or case studies from industry are limited to a very specific context • Studies are very niche e.g. the study of the concept of productive friction in mass collaboration projects, or very high level e.g. mass collaboration in the social sciences.	Reichelt et al. (2019), Li et al. (2013), Niazi et al. (2017)
Crowdsourcing	• Involvement of industry case studies or interviews is very limited • Findings on the barriers to the implementation of crowdsourcing are often revealed through reviews of existing literature or through a purely theoretical approach.	Forbes, Schaefer (2018), Forbes et al. (2019), Shergadwala et al. (2018), Panchal, others (2015), Bertoni et al. (2018)

Table 1.3: Existing Literature on supporting the implementation of SPD: Literature Gaps

Literature Category	**Literature Gaps**	**References**
SPD Frameworks	• Frameworks to support implementation of SPD and/or SPD tenants are limited • The majority of literature in this sector only propose ideas for future research. • The majority of literature in this sector is exploratory in nature.	Peterson, Schaefer (2014), Forbes, Schaefer (2017), Bertoni et al. (2018), Kenly (2020), Peterson, Schaefer (2014)
SPD Success Metrics	• Definitions of SPD success are very limited • Definitions of SPD success and/or SPD tenant success are not standardized • Metrics to assess SPD success do not exist • Assessment frameworks for SPD success do not exist	Singh, Bhanot (2020), Peterson, Schaefer (2014), Panchal, Fathianathan (2008), Panchal, Fathianathan (2008), Shergadwala et al. (2020)

1.3 Importance & Relevance of the Problem

The lack of implementation of social product development represents a missed opportunity for the engineering industry for several reasons. In addressing this problem and providing actionable research to encourage implementation, there are several ways this thesis offers value to practitioners. Firstly, social product development opens the pool of problem solvers to all internet users. This allows an organisation's problem solving capacity to be increased significantly in a relatively cheap way. As shown in the examples above, this has been proven to represent savings in both cost and development time (Forbes et al., 2019). Secondly, opening the pool of problem solvers to beyond the walls of a traditional organisation significantly increases the diversity of solvers and therefore solutions (Shergadwala et al., 2020). Diversity of employees has long been shown to drive innovation (Østergaard et al., 2011; Hewlett et al., 2013; Van Beers, Zand, 2014) and social product development therefore offers both an increase in resource as well as quality of innovative solutions.

Inclusion of external contributors is in itself shown to have significant benefits for organisations (Huston and Sakkab, 2006). Abhari et al. (2019b) suggest that essential resources for innovation lie beyond the boundary of an organisation and Bertoni et al. (2012) state that "the development of technologically complex products requires a wide range of skills [. . .] which are difficult to find within a single organisation" (Bertoni et al., 2012). As well as a need for external involvement, there is also a proven benefit to looking "beyond the walls" of a single organisation. Thames and Schaefer (2016) state that "innovation projects which are largely based on external development have shortened development times and need less investment". To support this statement, Huston and Sakkab (2006) state that since the introduction of SPD initiatives at Procter and Gamble "productivity has increased by almost 60%".

The benefit of external involvement, facilitated by social product development, also offers benefits to society as a whole as well as the host organisation. Social product development initiatives represent an opportunity for individuals who may not have access to traditional education or meet hiring requirements of organisations. With increased access to education through the internet and facilities such as makerspaces and online forums, however, these individuals may have the experience and knowledge to tackle complex problems (Peppler et al., 2016). The opportunity to work with these individuals, therefore, is a benefit to the organisation but it also allows these individuals to monetize their knowledge and gain a reputation in the industry despite not meeting traditional hiring requirements. As hiring processes in traditional organisations continue to evolve (Tepšić, 2020), social product development represents an interim solution as organisations adapt to the modern talent pool. It also represents a permanent solution for individuals that cannot work internally within certain organisations due to location, lifestyle or language.

The benefits discussed above represent potential benefits of SPD implementation for all types of organisations, however, the SME sector particularly benefits from further applicable research for implementing SPD initiatives. As raised by Bogers et al. (2017) and by Yoon et al. (2016), SMEs have been "excluded from the mainstream conversation" on social product development but they have a significant amount to gain from implementation. SMEs in general have less capital to attract the best talent and less internal resource, so the opportunity that SPD represents in reducing cost, reducing development time, and driving innovation is significant for SMEs. Larger organisations have the ability to hire consultants or dedicate internal departments to social product development activities (Huston, Sakkab, 2006), while SMEs may not have this option. Therefore, tools and applicable research to support the implementation of social product development are particularly valuable to SMEs.

Adopting social product development also represents an improvement in the way organisations communicate with other organisations and as part of internally dispersed teams (Thames, Schaefer, 2016). Social Product Development seeks to facilitate the project management process by "enhancing collaboration and communication" (Wu et al., 2016a). As Wu et al. (2016a) state "most successful product development teams have high levels of communication and collaboration" and Chui and Beghin (2010) state that a "well connected design network plays a vital role [...] in design phases". The introduction of SPD tenants can therefore address this key concern in the current business climate. Furthermore, in the current business climate, competitive advantage by incremental improvement alone is no longer possible (Nazarpouri et al., 2020). Organisations must look for new ways to innovate to increase market share and satisfy "increasingly sophisticated customer needs" (Acha et al., 2004). Social Product Development is a "fundamentally new approach to innovation" (Forbes, Schaefer, 2017) that offers a route to competitive advantage for organisations. Social Product Development is therefore a new approach to thriving in the current business climate.

There is also evidence that social product development can make organisations more resilient and adaptable to change (Hackler, 2012). Having crowd and/or external input effectively integrated with internal product development processes, allows the generation of solutions to continue despite changes in employment from sickness to significant disruption due to crisis. The subject of resiliency is particularly relevant in this current era of uncertainty; a consequence of the coronavirus outbreak. Many organisations have reduced their work force and social product development offers a solution for continuous innovation. From a solver perspective, those who may be recently unemployed also have an opportunity to monetize their knowledge and grow their reputation through participation in social product development initiatives despite lack of employment.

The coronavirus outbreak also has had and will have significant implications on the world of work. Remote work or reduced working hours have been enforced for many which represents a newer, more flexible way of working. "Portfolio careers" are on the rise (Westgarth, 2020), with the coronavirus outbreak being a catalyst, of which are very conducive to participation in social product development initiatives. Social product development initiatives therefore offers opportunity for income for potential solvers and a route to recovery for organisations.

To summarise, a lack of implementation of social product development initiatives represent a missed opportunity for engineering organisations. Adopting social product development processes offers increased resource capacity and increased diversity of solvers, both proven to reduce development time and costs, and drive innovation. Furthermore, integrated social product development processes can improve communication and collaboration regardless of external involvement and offer an opportunity to gain competitive advantage in an increasingly competitive business environment. Finally, the coronavirus outbreak has and will drastically change the way organisations function. Social product development offers opportunities for potential solvers to gain income as part of "portfolio careers" and offers a route to recovery for organisations.

1.4 Research Aim, Approach and Contributions

As outlined in Table 2.1 and Table 2.2 there are several gaps in existing literature on SPD. These literature gaps can be consolidated as follows:

- There is limited empirical research in existing literature on SPD
- Research on SPD is limited and mostly exploratory
- Research on or with industry is limited
- Research studying SPD in industry is with a single organisation or industry with findings isolated to these specific cases

In section 7.2 and 1, the value of SPD in industry was demonstrated and therefore the importance of research on the implementation of SPD. The above literature gaps demonstrate the need for further research and, specifically, research on the implementation of SPD.

Specifically this means addressing the literature gaps shown above via the following research questions:

1. *Primary Research Question 1:* What are the barriers for the implementation of SPD in industry?
2. *Primary Research Question 2:* How can the implementation of SPD be supported?

These research questions are consolidated under one core aim.

The aim of this research is to provide a prescriptive framework for the implementation of SPD and a performance assessment tool to understand the effectiveness of SPD implementation

The contributions to of this thesis are:

- Empirical research, with industry professionals interviews on their experiences and insights on SPD
- Identification of the barriers to the implementation of SPD
- A framework to support the selection of an SPD tenant and launching of an SPD initiative
- An SPD initiative success assessment tool to allow industry practitioners to understand the impact of their design decisions when preparing for an SPD initiative

This thesis therefore provides an understanding as to why SPD is yet to be fully adopted by industry and two research outcomes that support overcoming of these barriers and supporting SPD implementation.

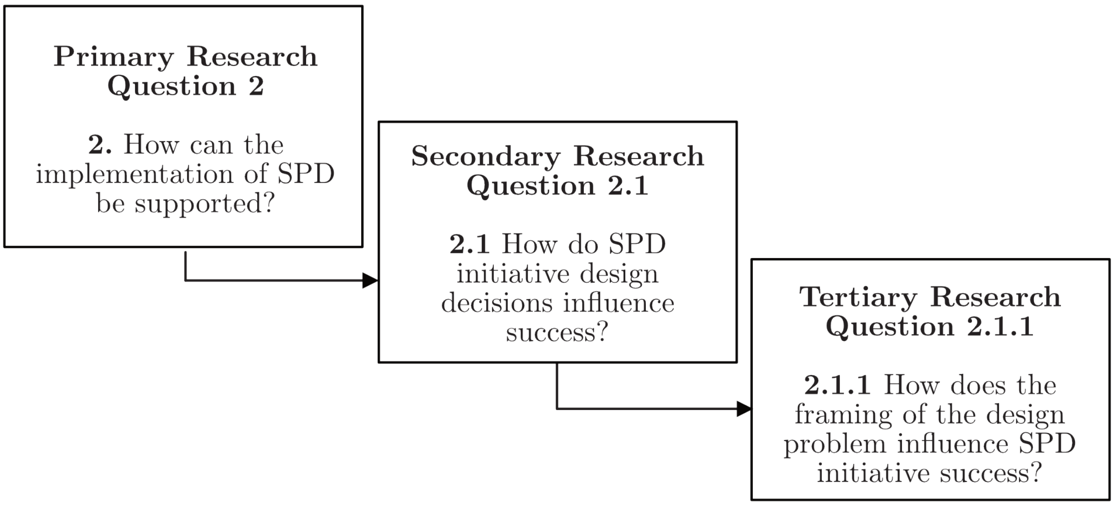

Figure 1.1: Research Question Hierarchy

There are several characteristics of these research aims that dictate the research methodology that is suitable for this addressing the research problem. Firstly, this research is centred on fulfilling the needs of a target audience. Secondly, this research aims to provide the target audience with a solution (tool, technology or product) to support the implementation of social product development. Finally, this research relies on specific research objectives emerging, after input from the target audience. The proposed research methodology therefore need to incorporate flexibility and the ability to adapt and evolve based on results from earlier stages in the methodology.

It was therefore not appropriate to dictate a methodology for all components of this thesis. Instead, in Chapter 4, the result from industry interviews is presented which dictate the further research presented in this thesis. This overall approach is defined further in Chapter 3 and methodologies for the preceding chapters are presented in Section 5.1, Section 6.1 and Section 7.3.

The research presented in this thesis addresses two *Primary* Research Questions as outlined in Section 1.4. Chapter 4 addresses Primary Research Question 1 while the following chapters address Primary Research Question 2. Chapter 4 results in the barriers to implementation of SPD and the output of this chapter is several participant-identified research questions. A selection of these is addressed in the subsequent chapters and these are referred to as *Secondary* Research Questions that divide the content presented to address *Primary* Research Question 2. Furthermore, in Chapter 6 some *Secondary* Research Questions are segmented further with *Tertiary* Research Questions addressing *Secondary* Research Questions. This hierarchy and the associated numbering is demonstrated in Figure 1.1 and for chapters addressing research questions, Figure 1.2 provides a visual representation of the organisation of the thesis.

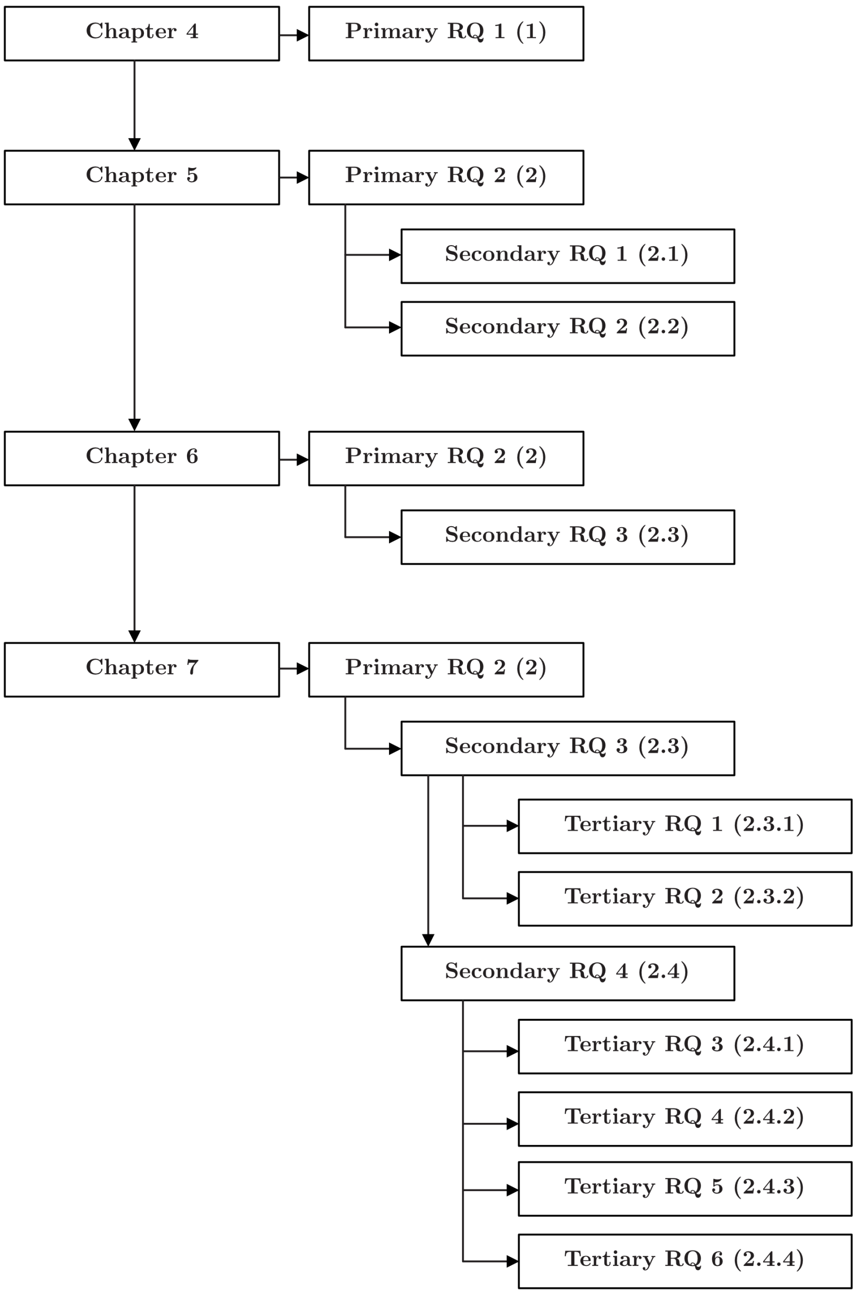

Figure 1.2: Research Question Thesis Organisation

1.5 Approach to Validation of Thesis

This thesis includes four chapters of research that each require validation. Chapter 4 includes an interview study with industry professionals, Chapter 5 includes the presentation of an SPD framework, Chapter 6 includes a expert researcher analysis study and Chapter 7 includes the presentation of a crowdsourcing success prediction tool. Each chapter includes measures for verification and validation of the research presented.

In Chapter 4, a range of interviewees of varying experiences with SPD and varying organization sizes are selected to provide a range of perspectives. The results from the interviews are yielded through a coding and analysis process. To validate this process, two coders were used to analyse the interviews and findings were not presented in the final study unless both coders could agree on inclusion.

In Chapter 5, the SPD framework is validated using the Validation Square (Seepersad et al., 2006), a method often used to validate design methods. Fundamental to this approach "is a process of building confidence in its usefulness with respect to a purpose" (Seepersad et al., 2006) consisting of four validation stages. The first two stages examine the structural validity of the design method determining whether the construction process is both effective and efficient. The latter two stages examine the performance of the design method, determining whether the design method provides effective and efficient design solutions. This validation is presented in Section 5.6.

In Chapter 6, Fleiss' Kappa (Fleiss, Cohen, 1973) is used to assess the agreement between the expert researchers and, in doing so, measures the validity of the results. Fleiss' Kappa is a generalization of Scott's pi statistic (Fleiss, Cohen, 1973), a statistical measure of inter-rater reliability and works for any number of raters giving categorical ratings, to a fixed number of items.

Finally, in Chapter 7, the validity of the prediction equations yielded by the experiment are tested by running them on crowdsourcing contests that were not included in the original sample. The outcome of this validation experiment is shown in Section 7.5.

1.6 Chapter 1 Summary

In Chapter 1, an introduction to this thesis is presented, with the scope and relevance of the research problem defined.

Firstly, Social Product Development (SPD) and the tenants of SPD are defined and the distinction between SPD and other terms such as "user-centred design" and "participatory design" are clarified. The growth and relevance of SPD is then presented. The open design movement and the growing number of online tools is democratising access to design and allowing anyone with an internet connection to learn and earn from product design. In this chapter, successful examples of SPD such as NASA's use of InnoCentive and Procter and Gamble's Connect and Develop initiative are presented, and provide evidence for the value of implementing SPD in industry.

Having provided evidence for the value of implementing SPD, the research problem is presented. Despite success stories, SPD is not regularly adopted and implemented within industry with only a few organisation truly integrating social product development into their product development process. A brief overview of existing literature provides evidence for this problem and in Table 2.1 (Page 38) the literature gaps in this area are outlined.

In the next section, the importance and relevance of the research problem is presented. The lack of implementation of social product development represents a missed opportunity for the engineering industry for several reasons. Firstly, using SPD initiatives allows access to a vast and global talent pool allowing an increase in resource at a low cost. Secondly, involving problem solvers from outside the organisation often increases diversity of solvers which has long been related to driving innovation. SMEs are shown particularly to benefit, gaining access to the time and knowledge of solvers that they ordinarily may not be able to afford. Furthermore, adopting SPD represents an enhancement in collaboration and communication and an ability to innovate more rapidly, a key to creating a competitive advantage. Finally, using SPD can help businesses adapt and be flexible to the changing world of work, a world that has been forced to change even more rapidly as a consequence of the coronavirus outbreak.

The contribution of this thesis is then presented with reference to the literature gaps presented in Table 2.1 (Page 38). The contributions are summarised as:

- Results from empirical research involving industry professionals
- Identification of the barriers to the implementation of SPD for industry
- A framework to support the selection of an SPD tenant and launching of an SPD initiative
- A success performance tool to allow industry practitioners to understand the impact of their design decisions when preparing for an SPD initiative

Following outlining of the contributions the research aim and questions are outlined as follows:

The aim of this thesis is:

To provide applicable research to support the implementation of social product development

Specifically this means addressing the literature gaps shown above via the following Primary Research Questions:

1. Primary Research Question 1: What are the barriers for the implementation of SPD in industry?

2. Primary Research Question 2: How can the implementation of SPD be supported?

To complete Chapter 1, the research approach is briefly described and the organisation of the thesis, as shown in Table 1.4, is presented.

In Chapter 2, a literature review is presented to demonstrate gaps in existing literature and to provide further evidence of the importance and relevance of this research.

Table 1.4: Thesis organization in Relation to Research Questions

Chapter	**Page**	**Primary Research Question or Purpose**	**Secondary Research Question(s)**	**Tertiary Research Question(s)**
2	19	Present existing literature and literature gaps		
3	47	Present overall approach to addressing research questions		
4	56	**1** What are the barriers to the implementation of SPD in industry?	Secondary Research Questions identified in this chapter	
5	82	**2** How can the implementation of SPD be supported?	**2.1** How to prepare a problem for SPD initiatives? **2.2** How to determine which type of SPD initiative to choose?	
6	107	**2** How can the implementation of SPD be supported?	**2.3** How do structural decisions of an engineering design SPD initiative influence its design outcomes?	
7	119	**2** How can the implementation of SPD be supported?	**2.3** How do structural decisions of an engineering design SPD initiative influence its design outcomes? **2.4** How do design decisions of an engineering design SPD (crowdsourcing) initiative influence its outcomes?	**2.3.1** How does company reputation influence SPD success? **2.3.2** How does the number of stages in an SPD initiative influence success? **2.4.1** How does framing of engineering design problems in competitive scenarios influence its solutions? **2.4.2** How can SPD initiative designers effectively decompose an engineering design problem? **2.4.3** How can optimal incentive structures be formulated for SPD initiatives? **2.4.4** How does the complexity of a problem influence SPD success?

Chapter 2

Literature Review

This literature review provides evidence for the literature gaps being addressed by this thesis. This chapter presents an overview of the existing literature on Social Product Development.

The chapter begins with an explanation of the literature searching, synthesisation and review process in section 2.1. The literature relating to the two Primary Research Questions are then presented separately with literature pertaining to the barriers to implementation of SPD presented in section 2.2 and literature pertaining to the implementation of SPD presented in section 2.4.

Existing literature discussing barriers to implement SPD is relatively rich compared to literature addressing the second Primary Research Question. As a consequence, literature discussing barriers to SPD are categorised according to the SPD tenant being discussed. Literature on the implementation of SPD is relatively scarce and therefore literature is discussed according to the two topics presented in existing literature; frameworks supporting the implementation of SPD and defining success of SPD initiatives.

Published Work Included in the Chapter

Literature from the following published work is included in this chapter:

Forbes, H. and Schaefer, D., 2017. **Social product development: the democratization of design, manufacture and innovation**. *Procedia Cirp*, 60, pp.404-409.

Forbes, H., Schaefer, D., Panchal, J. and Han, J., 2019. **A Design Framework for Social Product Development**. *IEEE Transactions on Engineering Management*.

Forbes, H., Schaefer, D., Han, J. and De Oliveira, F.B., 2020. **Investigating Factors Influential on the Success of Social Product Development initiatives**. *Procedia CIRP*, 91, pp.107-112.

2.1 Literature Collection Process

The purpose of this literature review was to identify and review any existing literature that replicated or intersected with the investigations and findings presented in this thesis. Specifically, the aim was to determine whether existing literature addressed the two Primary Research Questions:

1. *Primary Research Question 1:* What are the barriers for the implementation of SPD in industry?
2. *Primary Research Question 2:* How can the implementation of SPD be supported?

With regards to Primary Research Question 1, intersecting literature would present barriers for the implementation of SPD and literature addressing Primary Research Question 2 would present methods, processes or frameworks to support the implementation of SPD.

For both Primary Research Questions, literature databases such as Elsevier Scopus [*], Google Scholar [†] and The Lens [‡] were searched using various search terms as follows:

[*] https://www.elsevier.com/en-gb/solutions/scopus
[†] scholar.google.com
[‡] https://lens.org

- For barriers to SPD implementation: "social product development challenges", "social product development barriers", "social product development hurdles"
- For SPD implementation" "social product development implementation", "social product development integration", "social product development adoption"

The papers found were then reduced for detailed review according to the following criteria:

1. The paper had to specifically use the term "social product development" as opposed to one of the tenant terms i.e. "open innovation" or "mass collaboration"
2. The paper must have been published by an academic outlet as opposed to self-published
3. The paper must have been written in or translated to English
4. The paper must have been published within the last five years

On the final point, only papers published within the past 5 years are included in this study to ensure the literature gaps identified in this study are drawn from only the most recent research in this area. Furthermore, the term Social Product Development, as defined in this thesis, is a relatively new term. Papers predating 2015 sometimes use Social Product Development to refer to product development for social inclusion. This process provided only five papers addressing, or intersecting with the intended findings of, Primary Research Question 1 and only one paper addressing, or intersecting with the intended findings of, Primary Research Question 2.

There was therefore a need to widen the literature search and, by doing so, recognise that the term "social product development" is still used interchangeably with terms such as "collective action", "mass collaboration" and "co-creation". Furthermore, to ensure a breadth of literature, work on the individual SPD tenants was included as part of the review. The final literature count was 34 papers for Primary Research Question 1 and 27 papers for Primary Research Question 2. The following sections present the key findings from existing literature and categorises the literature according to whether the paper discusses SPD as a whole or an individual tenant. This process is illustrated in Figure 2.1.

2.2 Existing Literature on the Barriers to the Implementation of SPD

While several large product development organisations have proven the potential benefits of social product development, it is yet to fully make its way into industry. One key

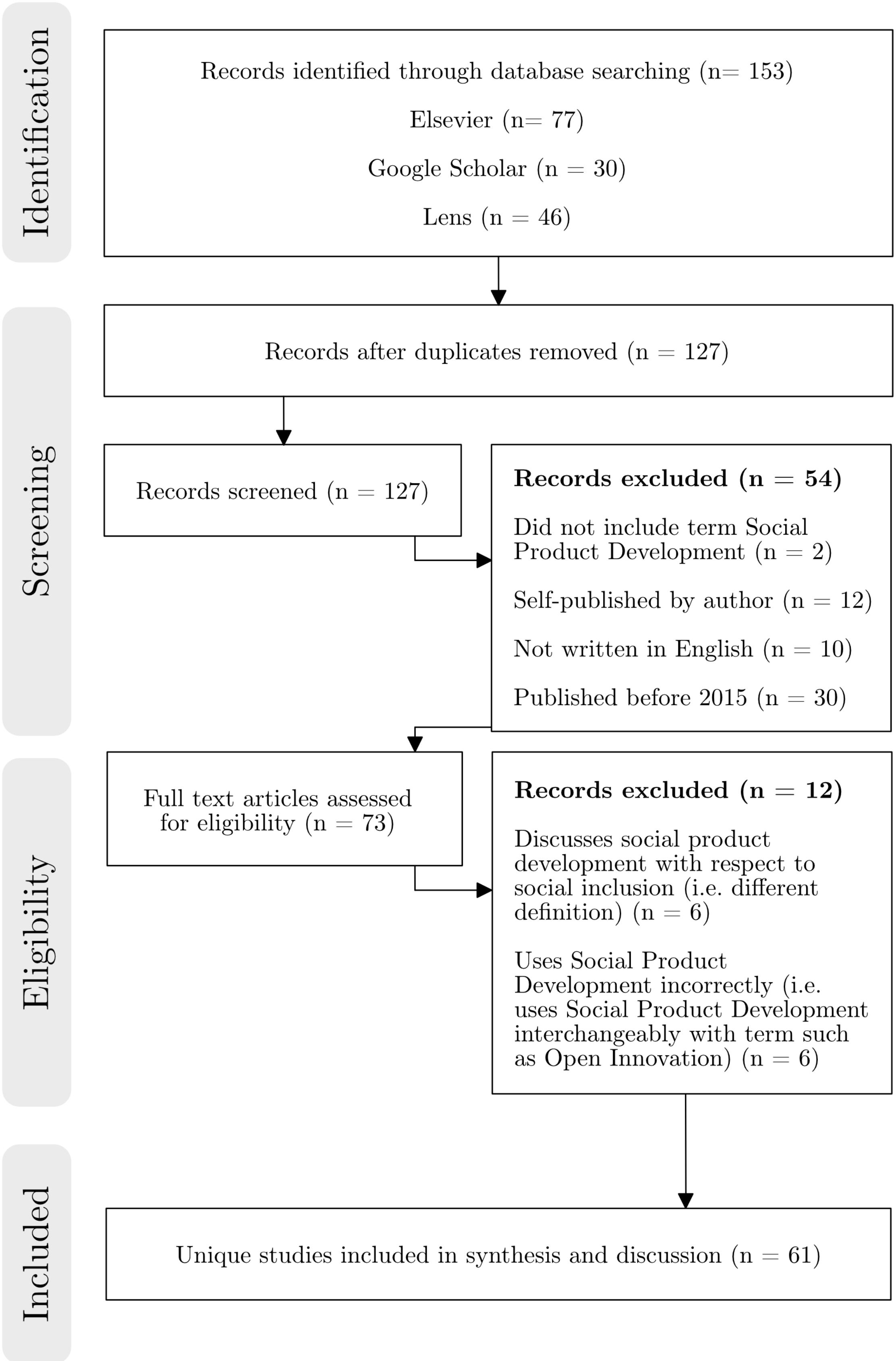

Figure 2.1: PRISMA Flow Diagram of Systematic Literature Review Process

contribution of this thesis is to provide an understanding as to why SPD is not regularly implemented in industry. In this section of the literature review, existing literature on the implementation of social product development in industry is presented. In the context of the following Primary Research Question:

What are the barriers for the implementation of SPD in industry?

The aim is to determine:

1. Does an answer to this question already exist in literature?
2. Has anyone investigated the implementation or lack of implementation of SPD in industry?

Literature that refers explicitly to social product development is presented in section 2.2.1. As is shown, this sector of literature is limited. Existing literature on the implementation of each individual tenant is therefore presented in section 2.2.2, 2.2.3, 2.2.4 and 2.2.5.

2.2.1 SPD Implementation Challenges

Literature reviewed in this section includes those that explicitly discuss social product development, as a whole. Literature in this sector is limited and therefore is not categorised or segmented. The individual papers are instead discussed with individual literature gaps identified. The overall literature gaps in this section are then consolidated in the final paragraph.

Wu et al. (2016b) investigates communication and collaboration in social product development using social network analysis. They specifically investigate the implementation of social product development in dispersed engineering teams in industry and seek to determine how information is transformed in socio-technical systems. They use a theoretical approach to generate a framework to measure communication by "transform(ing) an implicit design network into an explicit and formal social network based on specific indices of tie strengths".

Wu et al. (2016b) provide "a generic framework for investigating communication and collaboration mechanisms in SPD settings" and therefore provide an understanding of how SPD may function in an industrial setting. It is the case, however, that the "application examples were not conducted in the context of real industry environments but in a graduate level engineering design course". This literature therefore does not offer an insight into the barriers that industry practitioners face in implementing SPD. Furthermore, it provides an insight into how SPD processes operate in industry but not how they are initially adopted and integrated.

Annosi et al. (2020) provide insight into "how organizations can acquire, maintain, and use different sources of knowledge [..] to sustain social product development". They state that "pertinent extant literature has stressed how an organization should practice social product development" but does not indicate how to maintain social product development practise. They conduct semi-structured interviews and observations in a Dutch food company providing a real-world insight into social product development in industry. They specifically aim to determine how research-based and practise-based knowledge on SPD is implemented in industry. By interviewing practitioners and observing SPD in industry, Annosi et al. (2020) provide insights directly from practitioners. However, as discussed by Ameri et al. (2008), this work is limited by the inclusion of only one organisation in this study. Furthermore, while some of the challenges of SPD implementation are provided by this work the barriers to SPD implementation are not provided, since the company observed are already actively implementing SPD. As a consequence, while this work provides one of the first considerations of the industry perspective on SPD, the insights are limited by the use of only one organisation.

Abhari et al. (2019a) investigate the experience of "co-creators" in social product development. In this case, "co-creators" refer to the actors in social product development which could refer to the solvers in a crowdsourcing context as well as an external contributor to an open innovation initiative. Abhari et al. (2019a), in general, aim to determine the common factors in social product development that dictate experience for all types and level of involvement. The main contribution of this work is "a conceptual model to theorize and operationalize co-creation experience in SPD networks" and the ultimate conclusion that the experience of a co-creator is a key influencer on the decision to participate in SPD networks as well behaviour within SPD networks. Similarly to Wu et al. (2016b), Abhari et al. (2019a) use a theoretical approach to determine behaviour in SPD networks. With the absence of organisations actively participating in social product development, theoretical models provide valuable insight. It is the case, however, that in order to understand the barriers to SPD implementation and how to support the implementation of SPD in industry, further experimental work with industry involvement is required. Furthermore, this paper again focuses on improving existing implementation of SPD as opposed to understanding the barriers to implementation of SPD.

Abhari et al. (2020) "critically assess the viability and paths forward for SPD" by examining "social innovation processes, technologies, and platform governance". Their focus is on how SPD platforms operate, engage and communicate with communities and how this, in turn, impacts implementation of the SPD model. The main contribution of the paper is a "holistic model [that] provides a new framework for systematic investigations of SPD for further theorization and empirical study".

Abhari et al. (2020) provide "six different functions that firms can explore and exploit to integrate external actors into NPD" whereby allowing the integration of SPD in industry.

These insights are yielded through case study analysis of two SPD platforms; Quirky and Edison Nation. The literature gap therefore remains with regards to the collection of direct experiences by existing practitioners from a variety of organisations. This work again provides valuable insight on the improved implementation of SPD but does not provide insight on why organisations, in general, are not open to implementing SPD.

This chapter presents existing literature that considers the implementation of SPD in industry. The literature in this sector, representative of an emerging field, cannot be easily categorised with some authors, for example, considering user experience on SPD platforms and others considering the motivation of SPD participation. Existing literature is considering various different problems within the implementation of SPD and at various levels of abstraction. The literature gaps that emerge are as follows:

1. Existing literature has minimal presentation of interviews or observations with industry.

Annosi et al. (2020) have conducted semi-structured interviews and observations, but of a single company. Further industry insight, from a range of types and sizes of organisations is required to gain an understanding of the barriers for SPD implementation.

2. Any consideration of the perspective of industry on SPD is in reference to the successful implementation of SPD as opposed to the possible implementation of SPD.

With very few companies having implemented SPD, a pressing question is why they are yet to implement SPD prior to how to implement SPD successfully. While the latter is important, and will be investigated in this thesis, an understanding of the barriers to entry is important in increasing the implementation of SPD in general. The following sections present existing literature for the implementation of the individual SPD tenants.

2.2.2 SPD Implementation Challenges in Open Innovation Literature

In this section existing literature that discusses the barriers to the implementation of open innovation is reviewed. Insights from this literature may provide insights on the implementation of SPD as whole as well as further evidence for literature gaps in the overall sector.

Literature that discusses the barriers to the implementation of open innovation can be categorised as follows

1. Case studies on specific industry to yield insight on the implementation of open innovation

2. Expertise and culture of the team and how this influences open innovation adoption
3. Existing processes or business models used by the organisation and how this influences open innovation adoption

Studies on the approach a specific industry takes to implement open innovation are most numerous in this sector of literature. For example, Ettabaa et al. (2019) presents "an exploratory review" that provides insight into how open innovation "manifests" itself in the automotive industry. Martinez (2013) conduct case studies on open innovation in the food and beverage industry, Wikhamn et al. (2016) considers open innovation implementation in SMEs by studying the Swedish pharmaceutical industry, Del Vecchio et al. (2018) consider the tourism industry and Elia et al. (2020) investigate the implementation of open innovation in the semi-conductor industry. Consolidating the findings of this literature to provide overall insights from the sector is difficult as conclusions are very diverse. Ili et al. (2010) find that open innovation is "more adequate to achieve a better research and development productivity" than closed innovation in the automotive sector and find that "sustainable support" from management is the most important factor for effective implementation. While Del Vecchio et al. (2018) find that defining user experiences is the most important factor for open innovation in the tourism industry and that "social big data" is vital for "opening up innovation". On the other hand, Chiaroni et al. (2009), in the context of the pharmaceutical industry, find that understanding the "risk pattern" and the "management of intellectual property" is most important for open innovation implementation. Finally, after studying the implementation of open innovation in Italian small to medium enterprises (SMEs) in technology, Santoro et al. (2019) determine that SMEs select open innovation processes according to "specific internal resources and capabilities" with three factors being most important; human resource management, resource allocation and experience with open innovation. The only consistent findings from across literature, and therefore industries, was the requirement for further research into the implementation of open innovation and the acknowledgement that open innovation offered new opportunities for the specific sector above closed innovation processes.

The next sector of research on the implementation of open innovation is investigations into how culture influence open innovation practise. Lee et al. (2019) discuss "how project expertise and complexity jointly impact the decision to adopt open or closed innovation". It therefore investigates both the decision to implement open innovation as well as the "openability" of problems according to their complexity. Lee et al. (2019) theoretical propose and empirically test the impact of complexity on "the relationship between project expertise and open innovation adoption". They do so in the single context of the US pharmaceutical industry and the experimental method focused on the development of drugs. Lee et al. (2019) find that for large companies conducting

		Complexity	
		High	**Low**
Project Expertise	High	Open innovation (Science-based OI/Network OI)	Closed innovation
	Low	Open innovation (Coopetition OI)	Open innovation (Crowdsourcing OI)

Figure 2.2: Lee et al. (2019)'s Recommendations for Large Firms (OI = Open Innovation)

highly complex projects "science-based open innovation" and "network open innovation" are recommended for high project expertise and "coopetition open innovation" for low project expertise. The full recommendations are shown in Figure 2.2.

Lee et al. (2019) provide insight on the appropriate open innovation model for large companies according to data from the US pharmaceutical industry. While it gives an indication of the decision-making process, this is again refined to a single context; the US pharmaceutical industry. Findings therefore cannot be applied to SMEs, start-ups are larger organisations outside of the pharmaceutical industry. Furthermore, the definition of project expertise and complexity may vary according to industry and organisation size. Further research is therefore needed to expand on these findings and determine whether they are generally applicable for product development.

Offering further insight on organisation culture and open innovation implementation is Parveen et al. (2015). Parveen et al. (2015) argue that implementation of some form of open innovation is inevitable for competitive organisations and considers how this impacts organisational culture.

Parveen et al. (2015) find that "organizational culture has a positive relationship with commitment towards open innovation" demonstrating the importance of organisational culture as a factor for effective implementation of open innovation. These findings are also echoed by Kankanhalli et al. (2017) after investigating open innovation in the public sector and Waiyawuththanapoom et al. (2013) in the construction of a "open innovation readiness assessment model". Overall, this sector highlights the importance of organisational culture in open innovation implementation and that, without culture change, open innovation implementation may not be possible. Furthermore, even with change to organisational culture, the implementation process of open innovation is unique to each organisation.

The third sector of literature on the implementation of open innovation referred to models and frameworks to support implementation. For example, Virlee et al. (2015) provide an open innovation framework for the implementation of open innovation for service-based firms, Grönlund et al. (2010) present a revised new product development process based on the stage-gate model that incorporates a process for open innovation implementation and Podmetina et al. (2018) develops a competency model for open innovation implementation from an individual to an organisational level. This literature provides some insight into the challenges that organisations face when implementing open innovation. For example, Virlee et al. (2015) finds that service-based SMEs are more likely to use closed innovation processes due to a lack of knowledge and Grönlund et al. (2010) find that some organisations struggle to implement open innovation due to "the challenge of sustaining internal commitment over a sufficient period of time". It is the case, however, that literature in this sector focuses predominantly on supporting implementation, as opposed to determining reasons for a lack of implementation. This literature is therefore explored more thoroughly with regards to the second Primary Research Question of this thesis;" Having determined the barrier to SPD implementation, how can organisations be supported in the implementation of SPD?" This review can be seen in section 2.4.1.

Overall, the majority of literature on the implementation of open innovation in industry is focused on a single industry and in some cases and single industry within a single country. Bogers et al. (2019) attempt to consolidate these findings in their paper "Strategic management of open innovation: A dynamic capabilities perspective". The output of this paper is "some key attributes and an initial framework for the strategic management of open innovation" in industry. In general, Bogers et al. (2019) find that industry has issues with "coopetition", selecting problems that are truly "openable" and lack an understanding of how the ability to implement open innovation changes with problem complexity and experience. However, they state that these insights are yielded from organisations that exclusively see open innovation as an add-on to the research and development strategy, as opposed to integrated into their product development processes. Industry focus is on "leveraging external capabilities" as opposed to "enhancing internal capabilities". Overall, Bogers et al. (2019) determine, through consolidation of literature examining a number of industries, that further research "to provide a better understanding of the benefits and limits of open innovation" is required to understand how best to manage and implement open innovation.

Investigations into the implementation of open innovation is a relatively rich field. It is the case, however, that the vast majority of research focus their investigation on a single organisation or a single industry. As a consequence, papers that aim to consolidate and synthesise these findings suggest that further research is required to offer general insight into the barriers to implementation and management of open innovation in industry.

2.2.3 SPD Implementation Challenges in Cloud-Based Design and Manufacturing Literature

In this section, literature that discusses the barriers for the implementation of cloud-based design and manufacture (CBDM) is reviewed. The majority of literature in this sector present implementation tools or frameworks as opposed to explicitly presenting the barriers to implementation. However, in describing the importance and need for their implementation framework, authors present barriers to implementation that is included in this section. Discussion of the frameworks presented in this work is reviewed in Section 2.4.1.

It should also be noted that, as defined by Thames and Schaefer (2017), CBDM is often discussed alongside Industry 4.0 and synonymous terms such as Smart Manufacturing and Digital Manufacturing. These terms were therefore included in the literature search with papers recognised to be discussing CBDM (despite not explicitly including the term) included in this review. Several barriers for the implementation of cloud-based design and manufacture were discussed in this literature sector, these are presented in this section.

Several barriers for the implementation of CBDM can be categorised as barriers relating to company context or culture. Ghobakhloo (2020) aim to identify and analyse factors that determine the implementation of technology for smart manufacturing. They find that the majority of challenges related to implementation are a consequence of a firm's "minimal capacity to innovate". Ghobakhloo and Ching (2019) also echo this stating that the implementation of their framework is limited by "environmental challenges" both physical i.e. manufacturing line setup and cultural i.e. company culture. Zhang et al. (2019) state that "contextual differences in the way companies implement cloud technologies" can limit the effectiveness of existing implementation support and represent a barrier to implementation. Furthermore, Frank et al. (2019) state that a lack of flexibility to allow adaptation as a consequence of company culture represents a barrier to the implementation of CBDM. Company culture was presented as an implementation barrier in the majority of papers in this sector as is therefore deemed to be the most significant barrier for the implementation of CBDM.

The second-most numerous barrier, mentioned by existing literature, was the lack of support available to organisations for the implementation of CBDM. This includes a lack of support for specific types of organisations such as SMEs and a lack of support related to factors such as stakeholder communication. Thames and Schaefer (2017) state that organisations have trouble finding the information they need to implement CBDM and Ghomi et al. (2019) states that this breeds an "unwillingness to adopt" CBDM technologies. Habl et al. (2017) discuss the difficulties organisation have in deploying CBDM and state that "knowledge transfer within or across organisations" is limited which represents a barrier to implementation. Furthermore, Milisavljevic-Syed et al. (2020) states, with regards to barriers to digital transformation in the manufacturing industry, that “the main challenges in delivering a digitally savvy workforce of tomorrow are rooted in today’s outdated and inflexible education”.

Further to a lack of support available for organisations, a lack of knowledge by stakeholders and business leaders is cited as a barrier to implementation by several authors. Liu et al. (2019) state that there is a lack of knowledge and confusion over definitions of CBDM and what it means to implement CBDM, a sentiment echoed by Thames and Schaefer (2017). Ghomi et al. (2019) also state that there is a lack of “knowledge and trust management” that spans organisations and departments within organisations. Furthermore, Ghomi et al. (2019) cites “knowledge and trust management” by senior leaders as a barrier to implementation, Habl et al. (2017) states “common leadership” on topics of digital transformation is lacking, Yue et al. (2020) states that “entrepreneurs are willing but worried and confused” and Mittal et al. (2020) state that a lack of “(Smart Manufacturing) awareness of SME leadership and staff” is an issue when trying to implemented CBDM.

Further barriers to the implementation include low levels of company maturing (Mittal et al., 2020; Thames, Schaefer, 2017; Zhang et al., 2019; Piorkowski et al., 2013), access to capital (Mittal et al., 2020; Evans et al., 2015a) and poor data management (Thames, Schaefer, 2017; Mittal et al., 2020; Babiceanu, Seker, 2019; Wang et al., 2017; Han, Yang, 2019; Evans et al., 2015a) are also defined as key challenges. Finally, technological challenges, most significantly, security and privacy are defined as notable challenges for the implementation of CBDM by Thames and Schaefer (2017), Babiceanu and Seker (2019) and Habl et al. (2017).

This literature review shows that literature on the implementation of CBDM, specifically, is not lacking and while only a few papers explicitly investigate the barriers to implementation, research on this topic does exist. Despite this, several literature gaps emerge the suggests further research is required in this area. Firstly, knowledge on specific contexts for implementation such as within companies at a high level of maturity or low level of maturity (SMEs). Furthermore, “company culture” or “contextual factors” are listed as barriers to entry but further insight on what specific aspects of company culture cause limitations are lacking. Finally, barriers to implementation presented by this sector are predominantly drawn from papers presenting implementation frameworks as opposed to conducting investigations on the barriers specifically. Further insight from real organisations may help provide further insight on broader implementation barriers and from organisations in circumstances different from the norm (SMEs).

2.2.4 SPD Implementation Challenges in Mass Collaboration Literature

In this section, literature on mass collaboration is reviewed to determine whether barriers to the implementation of mass collaboration have been investigated. Literature in this sector is varied and papers specifically investigating barriers to implementation are limited. It is the case, however, that challenges for the implementation of mass collaboration arise in varied types of papers, as follows:

- Implementation frameworks for mass collaboration
- Existing literature that uses mass collaboration as a method
- Investigating implementation of mass collaboration in a specific context or field
- Existing literature on activities to support mass collaboration (such as the management of big data)

Papers representing each of these types will be discussed in this section with literature gaps identified and consolidated.

The richest sector of those outlined above is existing literature that provide implementation frameworks for mass collaboration. Through describing the importance and relevance of the presented work, authors describe the challenges to the implementation of mass collaboration. One instance of this type of research is "Intelligent Group Structuring for Mass Collaboration within Engineering Design" by Ball (2020). In this thesis Ball (2020) proposes a framework for structuring groups and organising individuals to provide effective outcomes to mass collaboration projects. Using social network analysis they also are able to predict performance from the organisation of a group partaking in a mass collaboration activity. Challenges for the implementation for mass collaboration by Ball (2020) refer exclusively to the organisation of individuals. Ball (2020) suggest that issues such as unreliable knowledge, disorganised process and poorly managed knowledge can be addressed by organisation of individuals. The main challenge highlighted is therefore the difficulty in organising individuals in a mass collaboration activity. A challenge that Ball (2020) addresses in their thesis. While Ball (2020) could therefore be said to provide a solution to a key challenge, as discussed by Senghore (2016) the dynamics of a group are varying and unpredictable suggesting organisation of a group for mass collaboration may require approaches that regularly change.

Herrmann (2016) similarly present a method to facilitate mass collaboration for creative e-participation. They also discuss the challenge of facilitation and coordinating large groups for the implementation of mass collaboration as well as raising the importance of technology for the implementation of mass collaboration. Ball and Lewis (2018) also provide recommendations for mass collaboration in design and in doing so provide some challenges for the implementation of mass collaboration including the difficulty in selecting appropriate projects for mass collaboration. Furthermore, there is a challenge in matching the right collaborators to the right mass collaboration project. Other challenges raised in this sector include the difficulty in scaling mass collaboration by Elliott (2016), managing differing distances and diversities by Fischer (2016), motivating collaboration by Fischer (2016), tracking progress by Fischer (2016) and managing community by Winkler et al. (2020). Furthermore, Reichelt et al. (2019) discusses the complexity of the crowd stating that "the crowd is a highly complex entity with an emergent nature and inner momentum that is primarily fuelled by the affectedness of its participating individuals". Reichelt et al. (2019) therefore supports the notion that approaches to manage the crowd need to adapt to the unpredictable nature of mass collaboration. Similar literature gaps emerge from these examples; challenges to the implementation of mass collaboration are raised through a lack of empirical research involving industry or, challenges that are raised through empirical research are within only one industry or one type of organisation.

Insights into the barriers for the implementation of mass collaboration were also provided by existing literature using mass collaboration as a method. In description of the methodology, challenges and limitations for the implementation of mass collaboration were presented. Zamiri and Camarinha-Matos (2018) discussed the use of mass collaboration for learning, specifically the opportunity for increasing knowledge in participation of mass collaboration projects such as Wikipedia. Several challenges were presented by Zamiri and Camarinha-Matos (2018) including the impact of organizational structure. Zamiri and Camarinha-Matos (2018) state that "organisational structure has a profound impact on whether mass collaboration is possible" and suggests that large hierarchical organisations struggle to implement mass collaboration effectively. Further challenges raised by Zamiri and Camarinha-Matos (2018) include the challenge of evaluating the quality of generated knowledge, the availability of adequate technology and the assignment of such technology for appropriate use for mass collaboration. Furthermore, for the context of learning, Zamiri and Camarinha-Matos (2018) suggest that mass collaboration can result in the "dissemination of unreliable knowledge" and building a process of prevention is a challenge to the implementation of mass collaboration. Of all literature on the barriers to implementation of mass collaboration Zamiri and Camarinha-Matos (2018) offer the greatest number of challenges. It is the case, however, that the challenges presented are yielded from literature and the single experience of Zamiri and Camarinha-Matos (2018) for the specific context of learning using mass collaboration. This suggests a further need for investigation with increased case studies and interaction with industry to validate the challenges presented.

Senghore (2016) also use mass collaboration as a method to investigate innovation drivers. Barriers to implementation are therefore presented by Senghore (2016) through the use of mass collaboration as a method. Senghore (2016) states that “despite the interest and adoption rate of this type of innovation [...] the scholarly and empirical research on mass collaboration networks are limited”. They also state that mass collaboration networks are dynamic and that the most effective way to implement mass collaboration is constantly changing as a consequence. They conclude that a key challenge to the implementation of mass collaboration is the dynamic and unpredictable nature of a large network of workers. Salganik et al. (2020) also yield challenges for the implementation of mass collaboration through the use of mass collaboration as a method. Specifically, Salganik et al. (2020) provides a template for using mass collaboration as a method for social science research. They state that similar literature is limited but that “progress [in mass collaboration research] might reveal other social research problems that we can solve better collectively rather than individually”. They state that challenges for the implementation of mass collaboration include “the need for patience” which makes mass collaboration most suitable for longitudinal studies with large resource. Building on this, they state that mass collaboration within the social sciences requires extensive content and ethical practises which requires significant resource. While both Salganik et al. (2020) and Senghore (2016) provide challenges for the implementation of mass collaboration they do so within small and specific contexts. Senghore (2016) studies international hackathons while Salganik et al. (2020) study mass collaboration for the social sciences drawing conclusions on minimal empirical research. A lack of empirical research is one clear research gap in this sector as well as the investigation of mass collaboration in contexts of varying levels of abstraction (i.e. engineering design hackathons vs. social sciences in its entirety). This makes comparison and validation of the challenges for the implementation of mass collaboration difficult.

As well as direct discussion of mass collaboration, barriers for the implementation of mass collaboration were also presented in papers that investigated activities supporting mass collaboration. The first example of this type of literature is by Holtz et al. (2018). Holtz et al. (2018) “discuss several methods that can be applied to analyse the dynamic nature of knowledge-related processes in a mass collaboration environment”. They present three challenges associated with the implementation of mass collaboration; the challenge of consolidating knowledge in the still unpredictable dynamics of collective action and the challenge of the organisational adaptation that is required. This paper is specifically on the relatively niche topic of “productive friction” and how to ”operationalise productive friction” in mass collaboration. Slivko et al. (2016) presents similar research on the study of causal effects in the context of mass collaboration. They specifically study how the actions of one participant may impact another in an attempt to counter the “complex nature of crowds”. Both of these examples represent the key challenge presented by this sector; managing the complex crowd. While challenges are presented, the barriers to implementation are not specifically investigated and specific concepts are instead explored in order to create an approach to knowledge management in mass collaboration.

The final sector of literature that presents challenges to the implementation of mass collaboration include investigations into the implementation of mass collaboration in a specific context or field. Cress et al. (2016) offers challenges to the implementation of mass collaboration from a purely research perspective through an investigation not mass collaboration in the specific context of education. For example, challenges such as " integrating multiple concepts and theories" and "explaining mass collaboration as a means to overcome the digital divide". This paper therefore does not provide significant value for industry practitioners seeking a guide for the implementation of mass collaboration. Scuotto et al. (2017) presents an investigation into mass collaboration in SMEs proposing that mass collaboration and the use of social media can enhance productivity in SMEs. They find that a lack of technology or effective implementation of technology is the most significant challenge SMEs face in the implementation of mass collaboration. Despite conducting empirical research to yield these findings, Scuotto et al. (2017) acknowledge that a limitation to their research is the use of only one case study which means the challenges identified through this work may not be applicable for all types of organisations.

Across all literature discussing the challenges for the implementation of mass collaboration, several challenges are repeated. First and foremost, authors identify the crowd as complex and unpredictable emphasising the need for any guidance for the implementation of mass collaboration to be flexible and adaptable to varying organisations and organisational structures. Furthermore, challenges such as the poor use or lack of use of technology, the managing and consolidation of knowledge and the management of output quality are also challenges by several authors in this sector. Overall, several literature gaps emerge. Firstly, there is a distinct lack of empirical research on this topic with investigations involving industry being limited or limited to a specific context. Comparison for implementation in different types of organisations is not possible and therefore findings are distinct for specific fields and not generally applicable. Furthermore, studies are often either very niche, e.g. the study of productive friction in the context of mass collaboration for engineering design, or very high level e.g. investigating the use of mass collaboration for social sciences. This again limits the value of outputs form this sector as a consequence of varying findings from varying contexts. Ultimately, further empirical research comparing findings across organisational types and industries is required.

2.2.5 SPD Implementation Challenges in Crowdsourcing Literature

In this section literature that investigates barriers to the implementation of crowdsourcing in a social product development context are reviewed. Similarly to literature on the previous tenants, there are few papers that directly investigate barriers to implementation for industry practitioners. Many authors, however, discuss the challenges to implementation while providing background and relevance to their research. The literature in this area can therefore be categorised as follows:

- Factors for encouraging participation crowdsourcing initiatives
- Crowdsourcing platform management
- Crowdsourcing success factors and frameworks for crowdsourcing initiative design

Research on crowdsourcing is a relatively rich field and crowdsourcing is implemented in many sectors. Literature in this review refers explicitly to crowdsourcing used in product design and development i.e. representative of social product development processes.

The first sector of literature that discusses barriers to the implementation of crowdsourcing includes investigations into factors that encourage participation. Motivating participation is considered a challenge by existing literature and through literature review and interviews with potential participants, authors provide clarification on the barriers that exist that may limit participation and therefore implementation of crowdsourcing. For example, Wu et al. (2017) aim to determine the optimal level of community involvement in crowdsourcing initiatives by conducting a case study on crowdsourcing platform Threadless [§]. Furthermore, Acar (2019) raises the challenge of evaluating a large number of poor submissions and aims to determine, by consulting the crowd, the ideal project for high quality submissions. Acar (2019) also proposes challenges to the implementation of crowdsourcing include the management of scale and diversity of participants as well as the difficult process of implementing crowdsourced ideas. Kavaliova et al. (2016) also investigates increasing motivation for participation in crowdsourcing initiatives. They specifically seek to determine how the use of gamification on Threadless encourages participation. These papers, and the sector they represent, raise many barriers to the implementation of crowdsourcing by organisations, specifically associated with motivation for participation. A key literature gap, however, is minimal direct discussion with industry practitioners. Any investigation is focused on interviewing potential participants or reviewing existing literature to determine why potential participants do not participate as opposed to why organisations struggle to increase participation. For example, while participants may cite various reasons for not participating in a crowdsourcing initiative, those reasons may be different depending on the actions and status of the host organisations. It should also be noted that while papers in this sector use industrial case studies they do so from the same platform; Threadless, which suggests results could be biased towards crowdsourcing initiatives focused on Threadless.

[§]https://www.threadless.com/

Barriers to the implementation of crowdsourcing in product development are also discussed by literature examining effectiveness of crowdsourcing platforms. Blohm et al. (2018) conducts interviews with 26 executives of crowdsourcing platforms to provide insight on how crowdsourcing platforms can be improved. In doing so challenges for crowdsourcers i.e. organisations hosting a crowdsourcing initiative are discussed such as the challenge in setting an appropriate incentive, task framing and defining submission requirements. Niu and Qin (2017) also considers the functional aspects of crowdsourcing platforms through a review of crowdsourcing technology for product design and development. They find certain mechanisms such as assigning the right project to the right participant and crowd communication mechanisms are poorly managed by platforms and represent a challenge to organisations. Also in this sector, Coelho et al. (2018) investigates the impact on crowdsourcing participation by studying the functionality of crowdsourcing platform Quirky [¶]. They state that platforms could do more to motivate participation and create an accessible and enjoyable user experience. Focus is again on the challenges to potential participants as opposed to the challenges for organisations to implement crowdsourcing.

Barriers to the implementation of crowdsourcing are also presented in existing literature on crowdsourcing implementation frameworks and investigations into crowdsourcing success factors. Ketonen-Oksi et al. (2017) present an analysis of different factors that increase the likelihood of crowdsourcing success. Crowdsourcing success, in this case, is defined as the ability of the model to output high quality solutions according to the expectations of the host organisation. Ketonen-Oksi et al. (2017) conduct interviews with crowdsourcing platforms to reveal factors that may influence crowdsourcing success. Schemmann et al. (2016) raises the evaluation of ideas as a key challenge for host organisations and aim to find a way to "match" potential participants with appropriate "crowdsourcable problems". Schemmann et al. (2016) draw their conclusions from data on a single crowdsourcing campaign on a single crowdsourcing platform and therefore do not consult industry professionals on the difficulties of crowdsourcing implementation. Also in this sector are papers that present frameworks for crowdsourcing initiative design including "Using crowds in engineering design: towards a holistic framework" by Panchal et al. (2015). Panchal et al. (2015) uses a theoretical approach to comprise a three stage framework to support the implementation of crowdsourcing in engineering design. As shown in other sectors, barriers to the implementation of crowdsourcing are not derived from empirical methods involving industry professionals. They instead use purely theoretical methods or consult potential participants or consult crowdsourcing platform executives.

As for existing literature that directly investigates crowdsourcing challenges, there are two types of papers. Firstly, papers including that from Forbes and Schaefer (2018)

[¶] https://www.quirky.com/

discusses the challenges posed as a consequence of key literature gaps shown in academic work on crowdsourcing. Forbes and Schaefer (2018) state that a lack of a clear crowdsourcing definition, a lack of standardisation on the types of crowdsourcing, a lack of guidance on the implementation of crowdsourcing for industry practitioners and a too focused examination of crowdsourcing in early-design phases represented a challenge to industry professionals seeking to implement crowdsourcing. These challenges are derived exclusively through a literature review and present only those challenges posed to industry professionals as a consequence of a lack of academic research.

Literature on the barriers to the implementation of crowdsourcing platforms is, as demonstrated with the other SPD tenants, limited. Similar literature gaps have emerged such as the minimal inclusion of industry professionals in existing research. Interviews are conducted with crowdsourcing platform professionals to understand how crowdsourcing platforms can be improved, interviews are conducted with users to understand what entices potential participants to crowdsourcing but interviews with businesses are limited with no investigation into what barriers may limit the implementation of crowdsourcing by a range of businesses. Specifically, discussion of the implementation of crowdsourcing in the context of the product development process and how it can be integrated with existing product development processes is minimal.

2.3 Literature gaps for Industrial Implementation of SPD

Table 2.1 provides an overview of the literature gaps revealed from literature on the barriers to implementation of SPD.

Overall, there is shown to be a lack of involvement or understanding of how industry practitioners approach the implementation of SPD and the barriers that industry practitioners face. Any research addressing this gap is focused on a specific context that means insights are not validated for general use across industries or types of organisations. There is a need for increasing empirical research in this area involving industry practitioners from a range of industries and types of organisations.

Table 2.1: Existing Literature on the Barriers to the Implementation of SPD: Literature Gaps according to SPD and SPD tenants

SPD
• Very limited research on SPD in general • Papers vary significantly according how high-level the research topic is • Minimal inclusion of interviews or observations from industry • Any reference to industry focuses on how to successfully complete an SPD initiative as opposed to how to successfully implement SPD.
Open Innovation
• Very limited research on implementation of Open Innovation in industry • Larger context of open innovation implementation rarely considered from the perspective of industry professionals • Research on the implementation on Open Innovation focuses on a single organisation or a single industry with organisation types, such as SMEs, not currently considered.
Cloud-Based Design and Manufacture
• Very few papers explicitly investigate barriers to implementation of CBDM • Those that do do so within a very focused context for a single organisation with organisation types such as SMEs, again excluded from this body of work • Any barriers to implementation or often presented at a high level. For example, "company culture" is often defined as a barrier without further elaboration on the specific aspects of company culture that may represent a barrier.
Mass Collaboration
• A lack of empirical research in general • Any observations or case studies from industry are limited to a very specific context • Studies are very niche e.g. the study of the concept of productive friction in mass collaboration projects, or very high level e.g. mass collaboration in the social sciences.
Crowdsourcing
• Involvement of industry case studies or interviews is very limited • Findings on the barriers to the implementation of crowdsourcing are often revealed through reviews of existing literature or through a purely theoretical approach.

2.4 Supporting the Implementation of Social Product Development

Having determined the barriers to the implementation of SPD, this thesis will continue to determine how the implementation of SPD can be supported. Therefore, in this section of the literature review, existing literature that provides research outputs to support the implementation of SPD is reviewed. In the context of the following Primary Research Questions:

How can the implementation of SPD be supported?

The aim in this section is to determine:

1. Does an answer to this question already exist in literature?
2. What currently exists in existing literature to support the implementation of SPD?

There are two kinds of existing literature that provide support for the implementation of SPD. Firstly, there is literature that supports the design and implementation of SPD initiatives (shown in section 2.4.1). Secondly, there is literature that supports the assessment of SPD initiative performance to allow improved implementation for future SPD initiatives (shown in section 2.4.2).

As shown in the previous section of this literature review, a review of literature explicitly discussing SPD implementation will be included as well as findings from literature on the SPD tenants. Only key papers, representing the state of literature will be discussed in section 2.4.1 and section 2.4.2.

2.4.1 Frameworks to Support the Implementation of SPD

The aim of this literature review is to identify Social Product Development frameworks and provide evidence for research gaps. The term "framework" is used to describe an instructional set of principles or steps that guide the inclusion of Social Product Development tenants in the product development process (Forbes et al., 2019). Existing literature could therefore include a Social Product Development framework in its entirety or a framework to guide the inclusion of a single tenant.

The term Social Product Development is sometimes used to describe the development of social products that generate social impact. Any literature relevant to this understanding of Social Product Development is not included in this body of work (Forbes et al., 2019; Evans et al., 2015a). To search for relevant literature, terms such as "Social Product Development framework" and "Social Product Development design framework" were used. In this relatively young field, however, the number of results were expectantly low. "Open Innovation framework" was therefore used as a search term to widen the search field. This term yielded literature presenting frameworks for individual tenants as well as frameworks for the application of Social Product Development as a whole. The authors therefore recognised that this fragmentation of SPD and the formulation of frameworks on a lower level of abstraction is more common (Forbes et al., 2019). As a consequence, this literature review includes first a consolidation of overall Social Product Development frameworks and then looks at literature that discusses frameworks for individual Social Product Development tenants. It concludes with identification of the gaps within these individual sectors, as well as literature gaps at a higher level of abstraction.

The search term and variances of the term "Social Product Development framework" yielded only one result. In this paper, Forbes and Schaefer (2017) introduce the idea of a Social Product Development framework which presents the potential impact each SPD Tenant may have on the product development process. It is designed, however, to be a precursor to a more refined SPD framework and does not provide any detailed instruction to the inclusion of SPD in the product development process.

Existing literature, for individual tenant frameworks, includes the "Distributed Team Innovation" by Larsson et al. (2003) for the use of Internet-Based Mass Collaboration in product development. This framework is for ensuring product development, education and research are given equal precedence in the product development process (Larsson et al., 2003; Forbes et al., 2019). Bartl et al. (2010) present a similar framework for the "co-creation" of products. They suggest three aspects of the product development process require equal consideration; methods and tools, organisation and culture (Bartl et al., 2010; Forbes et al., 2019; Evans et al., 2015a). While both of these frameworks, offer insight into the management of the entire product development process, they are not instructional, nor detailed enough to effectively guide the implementation of SPD.

As has been previously discussed, a large amount of insight on the implementation of open innovation is provided through case studies within a single context. Virlee et al. (2015) represents this type of literature, providing a framework for the implementation of open innovation for service-based firms, as shown in Figure 2.3.

The framework shown in Figure 2.3 is representative of similar frameworks that are at a high-level of abstraction and do not provide a prescriptive and detailed approach to application. Peterson and Schaefer (2014), however, suggest that an "open innovation culture" is required to foster social product development. This suggests that Open Innovation frameworks could act as a precursor to a Social Product Development framework and ensure an industrial environment is prepared to conduct an SPD approach (Forbes et al., 2019).

The existing literature on crowdsourcing frameworks for product development is rel-

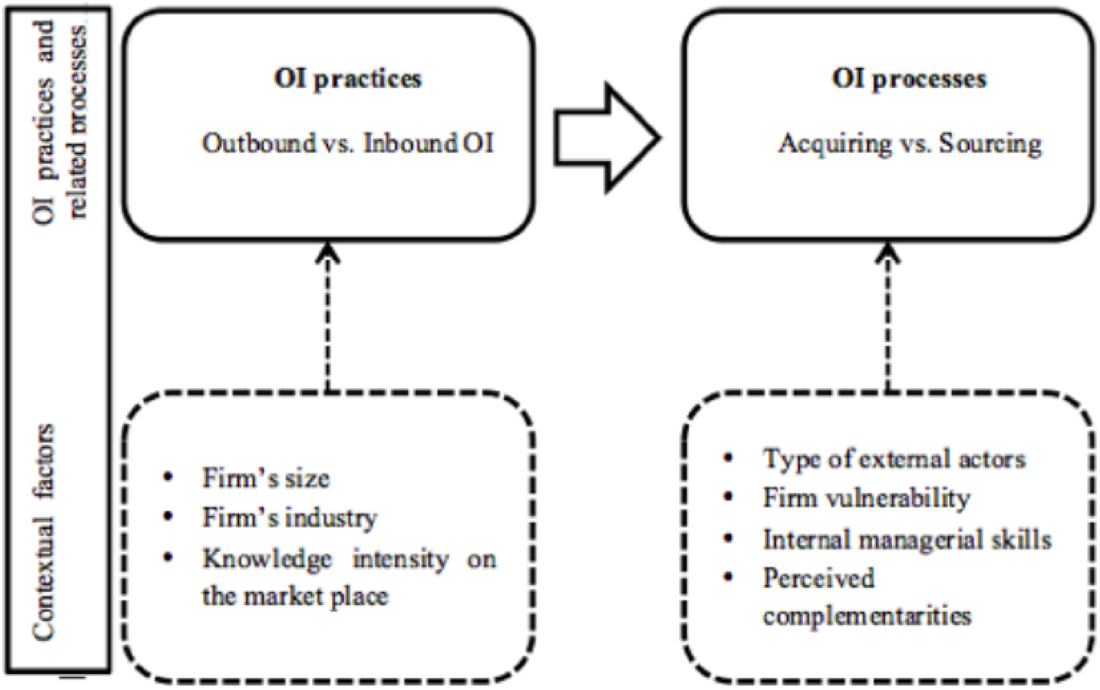

Figure 2.3: Open Innovation Implementation Framework for Service-Based firms (Virlee et al., 2015)

atively extensive and provides several insights into both high level and detailed requirements for a Social Product Development framework. Niu et al. (2019) present a framework for the application of crowdsourcing in product development, guiding the user through important crowdsourcing decisions. Panchal et al. (2015) also presents a framework for the use of crowdsourcing in product development, providing a four-step approach to crowdsourcing application. This framework includes three key steps; selecting crowdsourcing initiatives, making design decision and incentive design. Panchal et al. also provides further detail regarding "incentive design" by presenting a game-theoretic model for managing crowd participation. Similarly, Abrahamson et al. (2013) present an "Incentives Mix Framework" for understanding crowd participation and Cullina et al. (2016) and Gerth et al. (2012) provide in depth research on finding the "qualified crowd" in crowdsourcing contests. Finally, Kittur et al. (2011) consider the crowdsourcing of Human Intelligence Tasks (HITs) and "provide a systematic and dynamic way to break down tasks into sub-tasks and manage the flow and dependencies between them". While a relatively rich field of research, these crowdsourcing frameworks predominantly refer to "low-level" aspects of crowdsourcing application. For example, Cullina et al. (2016) discusses the need to understand crowd motivation in contests which is a single factor contributing to the successful implementation of crowdsourcing. Crowdsourcing, however, is a single tenant of Social Product Development and further high-level research is required to understand the place of crowdsourcing in this overall framework (Forbes et al., 2019).

Overall, frameworks to support the implementation for SPD and SPD tenants is limited with existing literature mostly being exploratory. Frameworks are proposed using existing literature or through purely theoretical methods. Frameworks built on the basis of industry requirements do not exist in this body of work and therefore more is required to support the implementation of SPD.

2.4.2 Defining Success of SPD Initiatives

Improvement and understanding of SPD initiatives relies on the ability to assess existing initiatives and determine what went wrong, what went well and how SPD implementation can be improved. Unfortunately an assessment process for SPD does not exist in current literature representing a clear gap in current research. This section presents existing literature that discusses SPD success to demonstrate this literature gap.

To identify existing literature on SPD success, search terms such as “Social Product Development success”, “SPD performance” and “SPD effectiveness” were used. This yielded only twelve papers. They are described in this section.

Annosi et al. (2020) “investigates how organizations can acquire, maintain, and use different sources of knowledge [...] to sustain social product development” using a case study of a Dutch food-service company. They find that the success of SPD is hinged on the management of knowledge and the management of in flows and outflows of knowledge. Similarly, Wu et al. (2016a) identified two common enablers for a successful SPD initiative as follows:

- The existence of touch-points between organisations and stakeholders
- The presence of paper knowledge-management processes (Wu et al., 2016a; Annosi et al., 2020; Evans et al., 2015a)

Wu et al. (2016a) therefore also focus on knowledge management. Also, providing these similar insights are Martini et al. (2017) who suggest that “internal and structured routines and procedures play a critical role in the effective integration” of social product development. These papers therefore discuss SPD success at a high level, not providing any specific assessment processes, but indicating the aspects of SPD that should be assessed for overall performance.

The other key aspect of SPD that existing literature associates with success is “actor experience”. This refers to the experience that all stakeholders in the SPD process have. This could mean, for example, public participants in a crowdsourcing initiative or two organisations participating in an Open Innovation initiative. Abhari et al. (2019b) states that “the success of SPD processes highly depends on the coordination of

1. Social engagement and participation in ideation
2. Exchange of experience, information, and knowledge (experiential communication and social validation)
3. Actors' direct contribution to new product development and commercialization" (Abhari et al., 2019b)

There is therefore again an emphasis on knowledge sharing but this time, in the context of how this influences actor experience.

Further in regards to actor experience, Abhari et al. (2019b) presents a "classification model to predict social actors' co-innovation behaviour in social product development". They suggest that classifying and organising social actors is "beneficial in expanding (Social Product Development) for practical application" (Abhari et al., 2019b; Forbes et al., 2020). Similarly, Markopoulos et al. (2019) present the "structure, concepts, methods and operations of a proposed framework that addresses" this new approach to improve product development experience. They describe SPD as "co-evolution of a democratic industry-society relationship between the large or small organizations and individuals"(Markopoulos et al., 2019; Forbes et al., 2020). Abhari et al. (2019a) also focus on actor behaviour as a key to defining SPD success stating that "predicting co-creators' behavioural intentions" is critical for understanding the co-creation experience.

Finally, on actor experience, Abhari et al. (2017) in the context of SPD cites the importance of "co-innovation" and states that "the success of co-innovation depends on many factors, including the quality of co-innovation experiences (MacGregor, 2007; Abhari et al., 2017). Gaining insights into actor experience is more critical than ever before as companies' investments in co-innovation community are dramatically growing (Füller, 2010; Han et al., 2012; Abhari et al., 2017). The importance of actor experience is therefore emphasised by literature and provides direction for future assessment frameworks. This literature does not, however, provide any prescriptive guidance for assessment of SPD initiatives.

Definitions and assessments of success are also presented in existing literature of individual SPD tenants. For example, with regards to crowdsourcing, Panchal et al. (2015) defines "modes of crowdsourcing failure" including poor quality of solutions and cost exceeding that of an in-house team. With regards to open innovation, Westergren (2011) defines success according to the strength of "inter- organizational relationships" and for cloud-based design and manufacture, Bohlouli et al. (2011) defines "availability and access to knowledge" as a mark of success. Despite definitions, general metrics of success are omitted. While individual tenants are ultimately considered to represent SPD, definitions and assessments of individual tenant success cannot be expanded to provide useful assessment of SPD initiatives as a whole i.e. An assessment for crowdsourcing success cannot be used to assess the success of a Open Innovation initiative. Authors have included metrics of success when SPD tenant outcomes can be directly compared to outcomes of traditional product development practises, however, these are specific to the application. Existing literature therefore fails to provide metrics for SPD success.

Existing literature therefore provides useful indications of how SPD success could be assessed but there are no existing frameworks or specific criteria to allow quantitative or qualitative assessment of SPD initiatives.

2.5 Literature gaps for Implementation Support for SPD

This section has provided an overview of the two key sectors of literature relating to the implementation of SPD; SPD frameworks to guide the implementation of SPD initiatives and literature on the assessment of SPD initiative success or performance.

With regards to SPD frameworks, single tenant frameworks are far more numerous than frameworks guiding the implementation of SPD as a whole. However, these tenant frameworks are exclusively exploratory and authors propose them as part of an emerging literature area, as opposed to with an intent to provide guidance to practitioners. A literature gap therefore emerges:

- There a minimal SPD and SPD tenant frameworks that guide the implementation of SPD

Furthermore, the frameworks proposed, such as Panchal et al.'s (2015) crowdsourcing framework, are developed purely through theoretical methods. Experimental work, involving industry experience, is not used to design and propose SPD frameworks.

- Existing SPD and SPD tenant frameworks are exclusively developed using theoretical methods

With regards to the assessment of SPD initiative success and performance, the available literature is incredibly limited. At both an SPD level and an individual tenant level, existing literature only provides indications of what should be assessed in a future SPD assessment process. For example, good actor experience and effective knowledge management are presented as fundamental aspects for SPD success but no consolidated process for assessing these in an SPD context are provided. The key literature gap is therefore as follows:

- Existing literature provides no assessment process or specific criteria for determining whether an SPD initiative has been successful or not and to what extent

These literature gaps in existing literature supporting the implementation of SPD or SPD tenants is consolidated in Table 2.2

Table 2.2: Existing Literature on supporting the implementation of SPD: Literature Gaps

SPD Frameworks
• Frameworks to support implementation of SPD and/or SPD tenants are limited • The majority of literature in this sector only propose ideas for future research • The majority of literature in this sector is exploratory in nature
SPD Success Metrics
• Definitions of SPD success are very limited • Definitions of SPD success and/or SPD tenant success are not standardized • Metrics to assess SPD success do not exist • Assessment frameworks for SPD success do not exist

2.6 Chapter 2 Summary

Chapter 2 reviews the existing literature associated with the Primary Research Questions of this thesis. To start this review process, terms such as "social product development challenges" and "social product development implementation" were searched in peer-reviewed literature databases. The result of this search, however, provided only five papers related to Primary Research Question 1 and only one paper related to Primary Research Question 2. There was therefore a need to widen the literature search and, by doing so, recognise that the term "social product development" is still used interchangeably with terms such as "collective action", "mass collaboration" and "co-creation". In doing so 34 papers for Primary Research Question 1 and 27 papers for Primary Research Question 2 were identified.

For those papers relating to Primary Research Question 1 i.e. they discuss or provide relevant discussion related to the barriers to implementation of SPD, key aspects of the literature are discussed according to whether they relate to SPD as a whole or an individual SPD tenant. The majority of literature related to the barriers to the implementation of an individual tenant as opposed to SPD as a whole. Sections 2.2.1, 2.2.2, 2.2.5, 2.2.3 and 2.2.4 all provide key findings from literature related to the barriers to the implementation of SPD. The key literature gaps for these sections are shown in Table 2.1.

With regards to literature relevant to Primary Research Question 2 i.e. provided or discussed support for the implementation of SPD, this was significantly more limited. As a consequence the literature was synthesised and analysed in two sections;

1. Frameworks to support the implementation of SPD
2. Defining success of SPD initiatives

The literature gaps related to Primary Research Question 2 are shown in Table 2.2

The contributions presented in Chapter 1 are derived from these literature gaps and through the addressing of the two Primary Research Questions, these literature gaps are also addressed.

In Chapter 3, the research methodology designed to address these literature gaps is presented.

Chapter 3

Methodology

As will be discussed further in this chapter, a key contribution of this thesis is to gain direct insight from industry regarding the implementation of social product development to identify the barriers that exist. As a consequence, creating support mechanisms to overcome the barriers to implementation is highly dependent on the insight provided by industry. It is therefore the case that while an overall approach was used to guide this research, a detailed description of the methods used was developed after determining the barriers to the implementation of social product development. This chapter therefore outlines the overall approach to this research while individual methods are described in more detail alongside the results and discussion of individual chapters.

The aim of this thesis is to address two overarching research problems:

1. What are the barriers to the implementation of social product development?
2. How can the implementation of social product development be supported?

There are several characteristics of these research aims that dictate the research methodology that is suitable for this addressing the research problem. Firstly, this research is centred on fulfilling the needs of a target audience. Secondly, this research aims to provide the target audience with a solution (tool, technology or product) to support the implementation of social product development. Finally, this research relies on specific research objectives emerging, after input from the target audience. The proposed research methodology therefore need to incorporate flexibility and the ability to adapt and evolve based on results from earlier stages in the methodology.

For the first step in determining an appropriate methodology, existing design methods were reviewed. For each of these requirements an existing sector of design methodology emerges. For research centred on fulfilling the needs of the user, user-centred design is most appropriate. For research centred on creating a product, product development frameworks such as Pahl & Beitz (Pahl et al., 2013) is most appropriate. For a research approach that adapts both requirements and the process according to emerging results, agile methodologies are most appropriate (McCormick, 2012).

3.1 Design Method Review

User-centred design, meso-procedural design and agile methodology is reviewed for their appropriateness for use as a research methodology.

3.1.1 User-centred design

According to Bevan and Curson (1999), user-centred design "describes how a human-centred design process can be used to achieve usable systems". Where usability is a high level quality objective defined by the solution's effectiveness, efficiency and satisfaction (Bevan, Curson, 1999). The "adherence to iterative, user-centred design process, instead of the common, technology and market driven one", according to Buurman (1997), "leads to more useful and usable products". Norman and Draper (1986) depicts user centred design through an illustration of a human at the centre of a series of circles, demonstrating the interaction of the user with every aspect of the design process and solution (Buurman, 1997). Noyes and Baber (1999) also define user-centred design this way stating that fundamentally "humans are at the centre of the design process", leading and influencing every design phase. Unlike Pahl and Beitz (2013) (see Figure 3.2), user centred-design is not a procedural methodology and it is a macro methodology (Wynn, Clarkson, 2018). This means prescribing to a user-centred methodology ultimately describes the relationship to the user as opposed to a specific series of instructions. Several authors do present prescriptive user centred methodologies however, such as the one shown in Figure 3.1 by Bevan and Curson (1999).

Buurman (1997) also presents a series of steps as follows:

1. Know your users
2. Incorporate current knowledge of users into process
3. Confront users repeatably in early design phases
4. Redesign based on user feedback if necessary

Monk (2000) also presents specific methods that should be used to yield user requirements including focus groups, interviews and observations. In determining whether user-centred is appropriate to fulfill the research aim, several discussion points are raised.

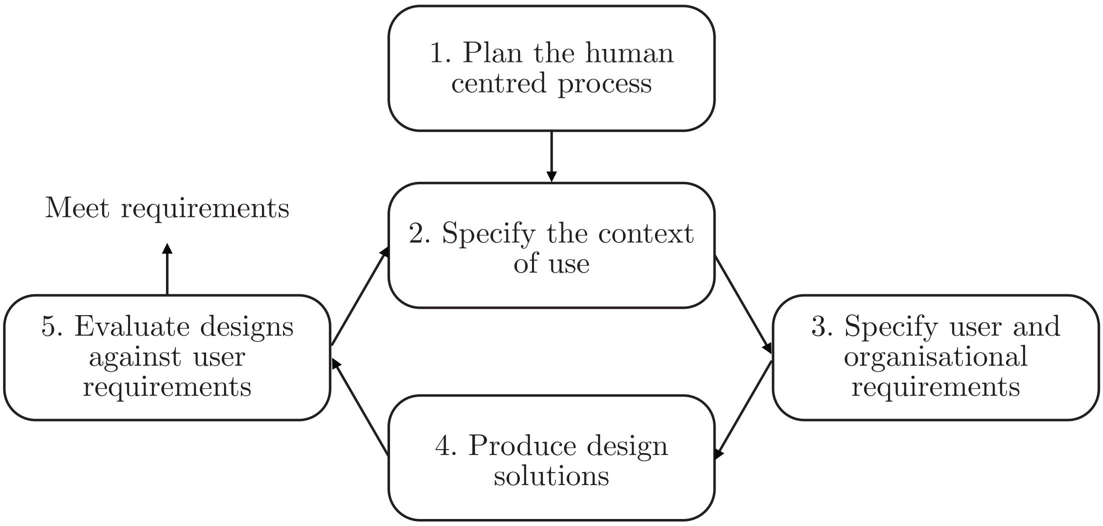

Figure 3.1: User Centred Design Process (Bevan, Curson, 1999)

Firstly, as presented in Section 1.2, the understanding of social product development is limited among industry practitioners. This raises the issue of whether products or, in this case, research, should be crafted *for* users of *by* users Eason (1995). There is an argument that in an area of knowledge where the user is not the expert, any suggestions could offer less value as a consequence. As Henry Ford famously exclaimed "if I'd asked my customers what they wanted they would have said faster horses" Alizon et al. (2009). A second issue with the exclusive use of user-centered design is the lack of procedural methodologies within the sector. Furthermore, those that are procedural, such as that presented by Bevan and Curson (1999), are at a high level of abstraction and therefore provide minimal specific guidance for structuring research. On the other hand, the research problem is framed entirely in the context of the needs of the target audience; engineering practitioners. The first research aim is fulfilled only by a deep understanding of the users' perception of social product development and the second research aim can only be fulfilled with user input. It is therefore the case that while user-centred design is not appropriate to guide the full research process, elements of user-centred design must be included in the research process.

3.1.2 Meso-procedural Design Methods

Meso-level procedural design methods correspond to the research requirement to deliver applicable guidance (representative of a product) to the user. Meso-procedural design methods "offer guidance throughout the whole design process and provide information and guidance for each design phase" (Forbes et al., 2019). They therefore provide both breadth and depth (Forbes et al., 2019). There are six meso-level procedural design methods according to Wynn and Clarkson (2018); Evans' Design Spiral (Evans, 1959), Pahl and Beitz' Stage Model (Pahl et al., 2013) (shown in Figure 3.2), French's Stage Model (French et al., 1985), VDI2221 Stage Model (Richtlinie, 1993), Hubka's Stage model (Hubka, Eder, 1992) and Ullman's Stage model (Ullman et al., 1988). These methods are nuanced according to the depiction of a systematic design process but for the purpose of guiding this research, they can be considered identical with regards to their appropriateness.

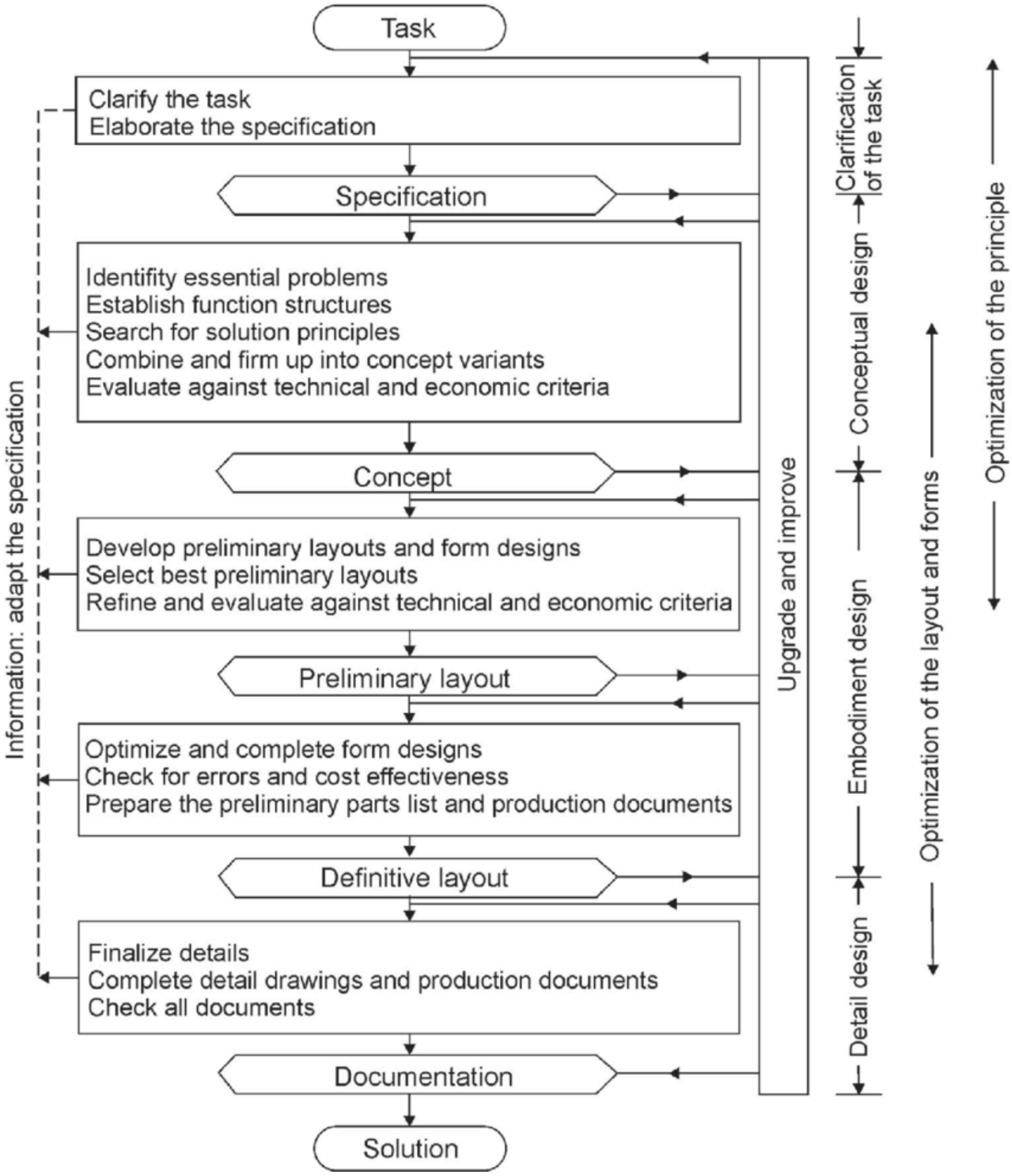

Figure 3.2: Pahl and Beitz Product Development Process (Pahl et al., 2013)

Meso-procedural methods offer a structured approach to product development and the fulfillment of user requirements (Pahl et al., 2013). As shown in Figure 3.2, opportunities for reflection and repeating tasks are incorporated but the process is ultimately mono-directional towards completion and delivery of a product (Evans, 1959). This is aligned to the research aim of this thesis as it guides the creation of applicable research that can be used by practitioners and accounts for the needs of the user. It is the case, however, that there is only opportunity to adjust the *design outcome* as opposed to the *design process* as a consequence of user input. In the case of this research, where the key contribution is achieved by meeting the research needs of the user, this lack of flexibility means a meso-procedural method alone, is inappropriate to guide this research.

3.1.3 Agile Methodologies

The final product development methodology reviewed for appropriateness to guide this research was agile. Agile is a methodology that was developed for the realm of software development but is becoming increasingly adopted for a flexible approach to product development (Karlström, Runeson, 2006). Agile is deemed an "alternative to 'heavy' traditional methods" and "suitable for an increasingly competitive world" (Nishijima, Dos Santos, 2013). It "makes space for continued customer input" and is fundamentally focused on "correcting errors as they happen" as opposed to creating a perfect product on the first attempt (Duka, 2013). Yau and Murphy (**?**) summarise agile but the phrase "faster, cheaper, better" emphasising agile as not only as a "collection of practises" but also as "a frame of mind" (**?**). McCormick (2012) describes agile in the context of traditional "waterfall" processes as shown in Figure 3.3.

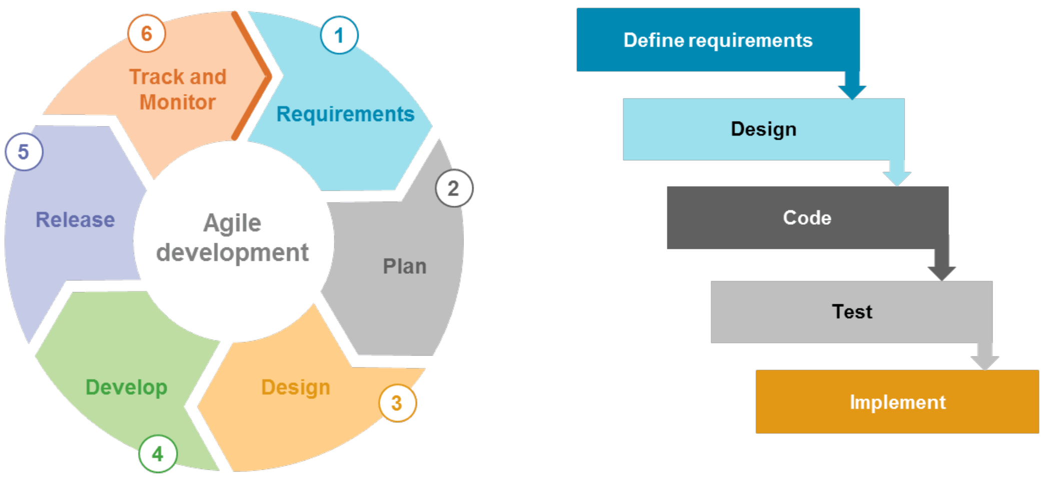

Figure 3.3: Agile vs. Traditional Waterfall Process (Pham, 2009)

McCormick (2012) describes agile as a “breaking away” from traditional “structured, systematic, bureaucratic” processes and allows more “flexible development”. Duka (2013) states that the focus of agile is to “empower cross-functional teams” to allow “rapid iteration”.

Agile was reviewed as part of methodology selection due to the emphasis on flexibility and iterative improvement. In this case where flexibility is important to adapt to user needs, it potentially provided a solution. It is the case, however, that “iterative improvement” in the context of agile is focused on errors recognised predominantly by the organisation as opposed to the customer. In existing agile literature the key benefits to agile focus more on ways of working (such as with cross-discipline teams) as opposed to superior fulfilment of customer needs and customer involvement. It is the case, therefore, that while it offers flexibility in adapting the research process, it does not centre the process change on the needs of the user.

3.2 User-Centred Exploratory Research Methodology

Two key issues arise from the design methods explored; the lack of flexibility and, in the case of appropriate flexibility, not enough emphasis on user input and its impact on the research process. This ultimately was considered to be as a consequence of the nature of the two research problems proposed. The first research aim was to determine why SPD has not made its way into industry while the second aim focuses on providing practical guidance to encourage the implementation of SPD. The first aim is more conducive to exploratory research while the second aim is more conducive to a structured approach. It is the case, however, that the structure of the approach to fulfill the second research aim is highly influenced by the user input provided in fulfillment of the first research aim.

As a consequence, the research methodology to explore the first aim is described as following a “user centred exploratory methodology” incorporating methods of user-centred research (as raised by Monk, 2000) in an exploratory approach. The output of this exploratory research is a user-dictated research approach that ensures the actionable research (fulfilling the second research aim) is truly centred on the needs of the user. The process that resulted from this approach is shown in organisation of thesis shown in Figure 3.4. The first method in addressing Primary Research Question 1 is described in the following chapter.

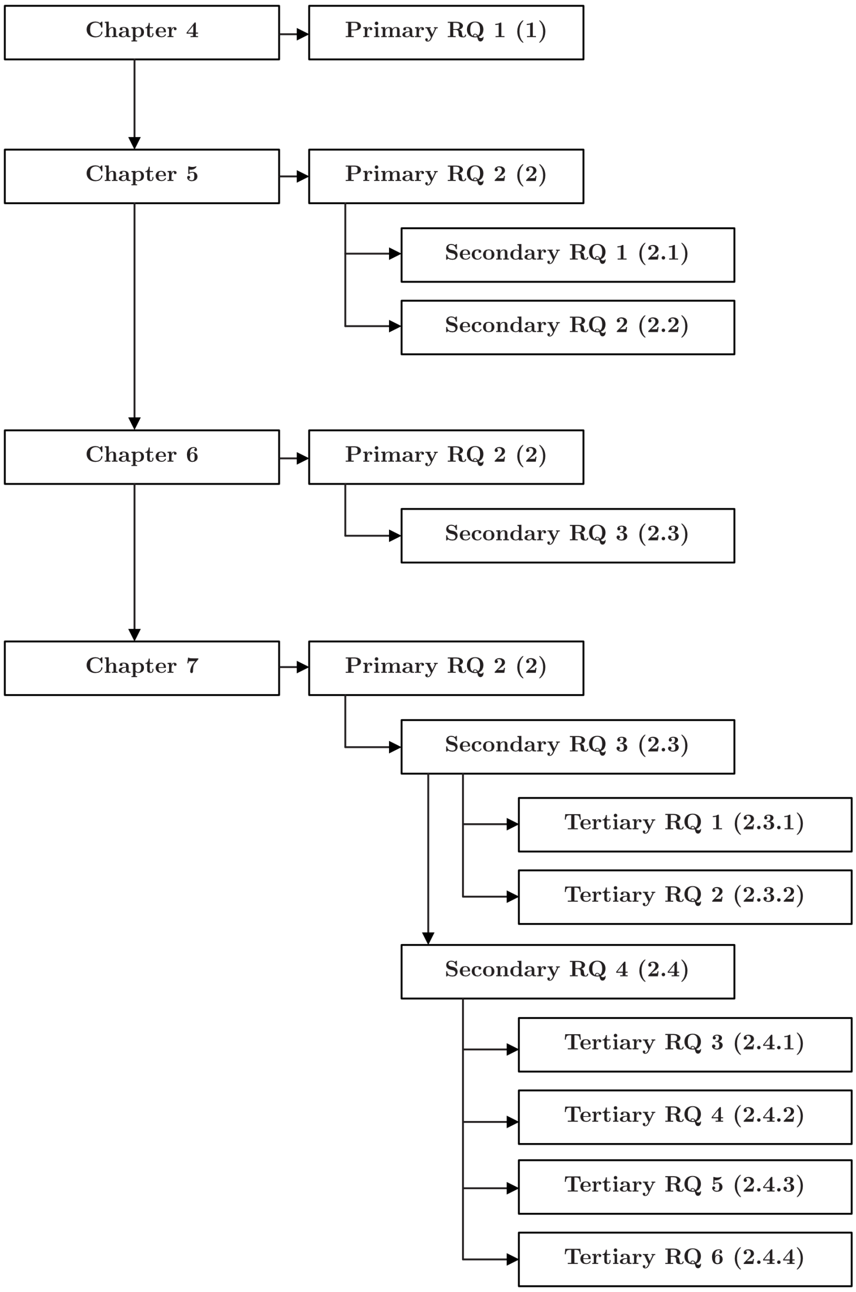

Figure 3.4: Thesis Organisation

3.3 Chapter 3 Summary

In this thesis, the results from the first research method (interviews with industry shown in Chapter 4) provide more detailed requirements for the following research chapters. As a consequence, this thesis does not include an exhaustive methodology chapter and instead, in Chapter 3, includes an overall approach to this research supplemented with methodology sections related to each individual research method. An overall approach to addressing Primary Research Questions 1 and 2 was determined, however, and this is outlined in Chapter 3.

Several characteristics of the Primary Research Questions dictate the kind of overall methodology this research requires as follows:

1. This research is centred on fulfilling the needs of a target audience (industry practitioners)

2. This research aims to provide the target audience with a solution (tool, technology or product) to support the implementation of social product development

3. This research relies on specific re-search objectives emerging, after input from the target audience

The proposed overall methodology was therefore required to be flexible and adapt and evolve based on results from the first research method (presented in Chapter 4).

To fit these requirements, three potential types of methodologies are identified; user-centred design methodologies, procedural product development frameworks (like Pahl and Beitz *) and agile methodologies. In the following sections of Chapter 3, each type of methodology is reviewed for its appropriateness to guide this research.

It is found that two key issues arise from the design methods explored; the lack of flexibility and, in the case of appropriate flexibility, not enough emphasis on user input and its impact on the research process. This ultimately was considered to be as a consequence of the nature of the two Primary Research Questions proposed. The first Primary Research Question was to determine why SPD hasn't made its way into industry while the second Primary Research Question focuses on providing practical guidance to encourage the implementation of SPD. The first Primary Research Question is more conducive to exploratory research while the second aim is more conducive to a structured approach.

As a consequence, the research methodology proposed for the first Primary Research Question is described as following a "user centred exploratory methodology" incorporating methods of user-centred research in an exploratory approach. The outcomes of

*Pahl et al. (2013)

this initial research (presented in Chapter 4) then provides structure to addressing the second Primary Research Question. The methodologies for which are presented in the relevant chapters.

Chapter 4

Interviews with industry

As discussed in the Methodology (Chapter 3) to address the first Primary Research Question (What are the barriers for the implementation of SPD in industry?) there was a need to learn directly from the user i.e. industry practitioners operating within product design and development. Key literature gaps, as shown in Table 2.1, for both SPD as a whole and for individual SPD tenants are as follows:

- There is minimal use of experimental methods and specifically those including the opinions of industry practitioners
- Any case studies or interviews conducted with industry are with single organisations or industries and do not cover a range of industry experiences

This chapter not only addresses these literature gaps by presenting the results from an experimental method, involving a number of and range of industry practitioners, it also informs further research presenting in this thesis.

The following section (Section 4.1) outlines the methodology for this experiment and why this experimental method was chosen to fulfill the research requirements. The data collection, analysis and coding process are then outlined in sections 4.2. The challenges associated with SPD initiatives as well as the beliefs associated with the use of SPD initiatives are presented in section 4.4 before a discussion of the results in section 4.5. The discussion presents the interview caveats and observations along with, most significantly, the key challenges raised by interviewees. Challenges raised by interviewees are discussed in the context of existing literature to ensure the research directions presented, to inform the further research presented in this thesis, had not been extensively discussed already in literature.

The final result of this chapter is barriers to the implementation of SPD, identified by industry practitioners, and research opportunities, presented in Table 4.4 to overcome these barriers. In Section 4.7, the specific Primary Research Questions addressed by this thesis are clarified, with reasoning for their selection. Section 4.7 informs the continued approach of the rest of this thesis, as defined by the user-centred approach discussed in Chapter 3. In Figure 4.1 the research questions addressed in this chapter are highlighted.

Published Work Included in the Chapter

Literature from the following published work is included in this chapter:

Shergadwala, M., Forbes, H., Schaefer, D., Panchal, J., 2020. **Challenges and research directions in crowdsourcing for engineering design: An interview study with industry Professionals**. *IEEE Transactions on Engineering Management*, pp.1-13.

4.1 Interview Experiment Design

One-on-one semi-structured interviews were conducted with four industry Professionals who have discipline-specific work experience with product design processes. An interview study was conducted as opposed to an observational study due to, firstly, the small number of organisations actively conducting SPD initiatives. Of those that were conducting SPD initiatives, several were in highly secure environments that would not allow for observational study with results publishable in the public domain. Secondly, interviews were chose over an observational study to allow the researchers to learn from several companies of varying sizes and industries in a relatively short time frame, compared to observational studies which, in general, take longer to yield useful results from fewer numbers of organisations. Semi-structured interviews were chosen in order to enable us to investigate the challenges, opportunities, and research directions on the implementation of various types of SPD initiatives. There was also a motivation to capture the interviewees' state of belief about the feasibility of the implementation of SPD initiatives in their respective domains. No incentives were provided to the interviewees, and it was conducted based on their desire to contribute to this research.

Table 4.1 lists the discipline-specific experience of the interviewees, and the size of their organisation. Two of the Professionals, labelled as Professional 1 and Professional 2, have experience with designing SPD initiatives. Whereas, Professional 3 and Professional 4 do not have such experience. Professional 1 has experience with open innovation and crowdsourcing for a big government organization. They have conducted "prize competitions" which are considered to be crowdsourced engineering design contests.

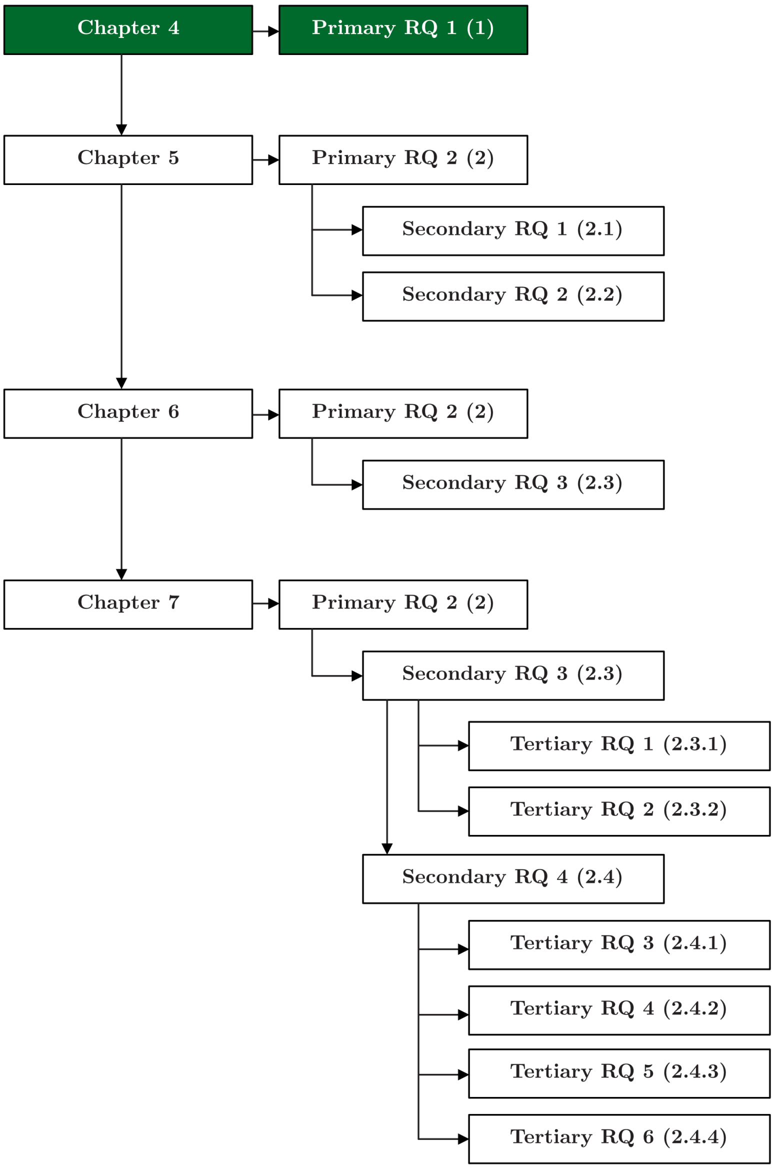

Figure 4.1: Research Question Organisation for Chapter 4

Professional 2 is a co-founder of a start-up in Silicon Valley. The start-up is founded on providing services for data labeling and annotation through crowdsourcing raw data in the form of microtasks. Professional 3 and Professional 4 have experience with design consultancy to design products in various domains such as pharmaceutical and consumer goods. None of the Professionals were aware of the identities of the other interviewees. To the best of knowledge, the interviewees do not know each other.

The interviewees are considered expert interviewees and this study is considered an expert interview study. Professional 1 works at a national organisation in the aerospace sector and specifically worked to frame problems for SPD contests with the public. Professional 1 was able to achieve the organization's design objectives via a public contest

Table 4.1: Professional background of the interviewees

Interviewee Label	Industry	Profit or Non-profit	Size of Company	Length of Experience with SPD	Time in Industry
Professional 1	Aerospace	Profit	17000 employees	5	12
Professional 2	Technology	Profit	10	2	10
Professional 3	Design	Profit	50	0	7
Professional 4	Design	Profit	100	1	7

1 year quicker and with 10% of the budget of an internal team. Professional 2 is a a Co-Founder of a technology start-up that has SPD activities as a core aspect of their business activities. Specifically, Professional 2 specialises in crowdsourcing for the completion of human intelligence tasks i.e. tasks that are hard to automate but easy for humans to complete. Professional 3 and 4 are design experts having worked for 5+ years in design consultancy.

4.2 Data Collection for Industry Interviews

The interviews were conducted via teleconferencing, which was audio-recorded and then transcribed manually. Interview questions were formulated based on the former SPD experience of the interviewees. Teleconferences lasted for an average of 16 minutes.

The structure of the interviews are shown in Table 4.2. In all the interviews, the first question asked to the interviewee was to describe their discipline and work experience. Then, they were asked about their knowledge and experience or interest in SPD initiatives. Based on their response, they were either asked to describe their experience or interest in SPD initiatives. If they did not have experience with SPD, they were asked what aspects of their work they believed could be implemented as part of an SPD initiative. A question was asked related to the challenges they faced or would face in implementing SPD initiatives. A requirements question was asked to understand what tools or state-of-the-art would be required for the interviewees to overcome the discussed challenges in implementing SPD initiatives. Additional follow up questions were asked, if necessary, in order to acquire context-specific information from the interviewees about the SPD initiatives, challenges, and research perspectives.

Table 4.2: Interview structure based on interviewee's SPD experience

Investigation Topic	**Motivation**	**With SPD Experience**	**No SPD Experience**
Interviewee's domain and experience.	To understand the context of their responses towards SPD practices.	*Please describe your Professional background and work experience.*	*Please describe your Professional background and work experience.*
Interviewee's interest and/or experience with SPD.	To categorize interviewee's interest and/or experience	*Could you please describe the type of SPD initiative(s) you have used?*	*What do you understand by the term Social Product Development? Which SPD initiative do you believe would be appropriate to utilize for your work?*
SPD Benefits	To understand the perception towards the advantages of SPD initiatives.	*Why did you choose that initiative and what are its advantages?*	*What do you believe are the advantages of such SPD initiatives?*
SPD Challenges	To investigate the challenges faced by industry Professionals.	*Could you please describe the challenges in implementing the initiatives you described?*	*Why have you not implemented these SPD initiatives yet?*
Research Directions	To formulate research directions and avenues for further study for effective implementation of SPD initiatives for engineering design.	*What would you require to overcome these challenges? Are there any research directions you might suggest that can help improve the state of the art?*	*What would you require to implement SPD initiatives?*

4.3 Data Analysis for Industry Interviews

The transcribed responses of the interviewees' are analysed through content analysis (Krippendorff, 2018). Throughout the analysis, words and sentences were coded to identify the product design context, the type of SPD initiative used or mentioned for future implementation, the perceived SPD advantages, challenges, limitations, and the state-of-the-art requirements as stated by the interviewees.

For the content analysis, a coding scheme was developed to categorize words and sentences using four main criteria. These criteria are 1) Challenges, 2) Advantages, 3) Caveat, and 4) Research Directions. The "challenges" and "advantages" criteria are self explanatory and they are analyzed from the perspective of the challenges and advantages of SPD as described by the interviewee. However, "caveat" and "research directions" are inferred by the researchers and not necessarily explicitly mentioned by the interviewee. Thus, the comments from the experts were coded verbatim to investigate just two categories of codes, namely, "advantages" and "challenges" of SPD. A purely inductive approach was utilized to do so (Krippendorff, 2018).

The instances of the other two codes, namely, "caveats" and "research directions" were identified through an abductive approach (Krippendorff, 2018) where the authors' domain knowledge as well as the background of the experts was taken into consideration to draw a conclusion. The "caveat" criterion was formulated by the researchers in order to identify the context, limitations, and/or the discipline-specific conditions based on which an interviewee perceived the benefits, limitations, and challenges to the SPD initiatives. Also, the "research directions" were formulated as Secondary Research Questions by the researchers based on the challenges described by the interviewees. Table 4.3 tabulates the details of each of these criterion and provides a coded example. The coding scheme is agnostic to the length of a particular coded instance. This implies that if the interviewee elaborated on a particular instance such as a "challenge", it was considered as a single coded instance in the transcript.

In order to ensure content analysis reliability, the transcribed interviews were coded several times by the researchers. The inter-rater reliability (IRR) was calculated by taking the ratio of the number of agreements amongst coders for labeling each instance of the "advantages" and "challenges" to the overall sum of agreements and disagreements (Miles et al., 1994). A coded instance is considered as an agreement if no clarification was requested amongst the coders towards identifying that instance and its relationship to the coding scheme. The IRR is given by,

$$IRR\% = \frac{Agreements}{Agreements + Disagreements} * 100\%$$

Equation 4.4.1

The disagreements were resolved by the researchers through discussions, and the consensus of the results are presented. However, the IRR scores include the disagreements amongst the coders prior to the discussion aimed towards reaching a consensus. Thus, the IRR score quantifies the reliability of utilizing the coding scheme, as illustrated in Table 4.3. The results of the content analysis as well as the IRR scores are provided in Section 4.4.

In the following sections, the interview results are presented and discussed. In section 4.4, the advantages and challenges of SPD initiatives, as stated by the Professionals is presented. In section 4.5, research directions and caveats as inferred by the researchers from the interviews, are presented and discussed with existing literature.

Table 4.3: Coding Scheme

Criterion	**Details**	**Coded Example**
Challenges	This criterion refers to the challenges that the Professionals state that they need to overcome in order to successfully to implement a SPD initiative. Instances of this category are coded verbatim from the transcripts.	• *"[trust] is a problem, so, for example, it's the same problem that Uber faces – how do you trust a completely new driver, who's picking you up"* • *"how to balance when you want to decontextualize but when you also want to make sure you can target well enough so you want to broaden your pool but you don't want to make it so vague that people don't see it as their problem"*
Advantages	The perceived benefits of SPD initiatives as stated by the interviewee. Instances of this category are coded verbatim from the transcripts.	• *"we got real engineering solutions that are good and much better than what the expert solution is. "* • *"totally business point of view, there's the efficiency it brings in like for example today you have some small microtask like data entry or classifying some images you would outsource it to a BPO "*
Caveat	The conditions and/or limitations identified by the researchers to the described challenges and advantages of SPD initiatives as described by the interviewees. Instances of this category are inferred by the researchers and not coded verbatim.	• *The interviewee does not identify time and lack of resources as a challenge because they belong to a big government organization* • *State of belief of the Professional 2 is that any problem can be crowdsourced*
Research Directions	The knowledge gaps that need to be addressed based on the challenges as described by the interviewees. Instances of this category are inferred by the researchers and not coded verbatim.	• *How do we define expertise when the crowd can belong to seemingly unrelated domains but still provide effective solutions?* • *What are the geopolitical policy implications of providing monetary incentives to the crowd?*

4.4 Interview Analysis: Challenges and Advantages

In this section, the challenges and advantages of SPD initiatives as identified by the Professionals are presented. The results presented in this section are coded verbatim from the transcripts. The IRR score for the initial content analysis of the interviews conducted with Professional 1 is 86% with 13 agreements (3 instances of advantages and 10 instances of challenges) and 2 disagreements over the instances of challenges. The IRR score for the initial content analysis of the interviews conducted with Professional

2 is 100% with 15 agreements (5 instances of advantages and 10 instances of challenges) and 0 disagreements. The IRR score for the initial content analysis of the interviews conducted with Professional 3 is 87% with 7 agreements (3 instances of advantages and 4 instances of challenges) and 1 disagreement over a challenge instance. The IRR score for the initial content analysis of the interviews conducted with Professional 4 is 100% with 8 agreements (4 instances of advantages and 4 instances of challenges) and 0 disagreements. After a discussion regarding the interpretation of the codes, any disagreements were resolved and the results were consolidated and are presented in the following sections.

4.4.1 Insights on the advantages of SPD initiatives

Professional 1

Professional 1 states that SPD has traditionally focused on *"crowd as more of a layman"*. However, they believe SPD initiatives can be utilized to *"find expertise outside of the organization"*. They believe that conducting SPD initiatives is both cost and time efficient as compared with hiring an in-house team. They mention that, *"we were faster than [the internal team]. We beat them by three times with the solution from the crowd"*.

Professional 2

Professional 2 states that *"we are believers of remote work in general"*. They mention that microtasks as an SPD initiative is a good starting step as the crowd can be trained on demand to do simple tasks. They believe that SPD is increasing the efficiency of achieving targets by disrupting traditional administrative processes and directly reaching to the crowd for task completion. They also highlight the significant cost reductions via such initiatives.

Professional 3

Professional 3 believes that SPD is a *" collaborative approach to design and using most people's ideas and using [their] experience [gets] the optimal solutions"*. Professional 3 referred to SPD benefits for *"the early ideation stages"*. Professional 3 also stated that *"there are lots of people out there who are not necessarily in the field we are in and have good ideas and [its] important to take them on board"*.

Professional 4

Professional 4 states that SPD offers value for idea generation and customer-centric design. They state that gathering a *"diverse group of opinions, problems and issues from consumers"*, would be a great benefit of using SPD. They particularly value the access to diversity of thought that SPD offers, stating *"I think as a single organization in the U.K., the teams we have in the project aren't necessarily in the target demographic of our product"* and that *"opinions, expectations, and customer needs vary throughout the markets we operate in"*. They acknowledge that *"being able to tap into knowledge and experience from all over the world is an important part in global product design"*.

4.4.2 Challenges in conducting SPD initiatives

Professional 1

Professional 1 identifies five themes with respect to the challenges with SPD initiatives. The themes are 1) Problem framing, 2) Openness of problems, 3) Notion of expertise, 4) Design of initiatives, and 5) Future of work. They discuss the potential questions that need to be addressed for each of these themes.

Professional 1 discusses the time associated with formulating a problem. They state, *"It took us three years to figure out what we were actually going to do and then it took us another year and a half to actually write the challenges"*. They also discuss the need to mentor Professionals on problem formulation for domain-specific expertise utilization. They mention that *"there isn't good theory about how to decontextualize [a problem] ... but you also ... want to broaden your pool"*. Also, Professional 1 recognizes the need to identify the characteristics of a problem that determine its feasibility. They mention that, *"I think there's a ton of value to trying to characterize, what about a problem makes it more openable or not."*

Professional 1 highlights the lack of clarity about the notion of expertise for SPD initiatives with respect to characterizing the crowd. They discuss how disruptive innovation examples of the past have illustrated that individuals from seemingly unrelated domains can make significant contributions to innovation. Professional 1 believes that *"a reformulation of a problem instead of making it context-less"* would not only be easier but could also reveal connections between seemingly unrelated domains.

Professional 1 discusses the challenge of incentivizing SPD initiatives and the complex connections between incentives, behavior, and problem framing emerge. There is a challenge in designing the right incentives in order to ensure motivation, participation, and quality of design solutions. The interviewee believes that intrinsic incentives such as personalization of a problem to a problem-solver is connected to problem-framing.

Professional 1 also discusses the impact of the changing ways of working and the role of Open Innovation in this change. From a US policy perspective this represents a challenge to SPD initiatives. They state that *"right now federal agencies don't let you send the money overseas for winning so anyone in the world can participate but only an American can win."* Professional 1 highlights that boosting innovation by seeking expertise of the crowd across the globe can have strong implications for industrial policies. They also highlight the effect of the trend of outsourcing design tasks on design firms and consultancies *"losing their core competency"*. They discuss the trade off involved with utilizing SPD initiatives and maintaining an organization's status quo.

Professional 2

Professional 2 discusses challenges within four themes. The themes are 1) Openability of the tasks, 2) Quality of solutions, 3) Crowd management, and 4) Lack of case studies.

Professional 2 discusses how complexity aspects of a task affect the openability of such tasks. They state that, *" [when task complexity increased] people could no longer use mobiles and needed laptops...we needed people to have better RAMS in their laptops and as a small company we couldn't provide that"*. They believe that the openability of expertise-related tasks need to be further understood.

Professional 2 discusses challenges for quality control. They discuss the need to develop trust with the crowd. They give an example of a mechanism implemented by Uber and state *"How do you trust a completely new driver, who's picking you up, you don't know anything about them?"*. They discuss that Uber implemented a "rating" mechanism for both the drivers and the riders and draw parallels to microtasks for their domain where they implemented a similar ratings mechanism for their crowd. By doing so, however, a further challenge emerged. They discuss that by providing ratings to the crowd, their state of belief about the worker's own value for executing a particular task increases. Consequently, they demanded for greater incentives. The challenge that is raised is how does ensuring quality influence the utilization of resources?

Professional 2 discusses the issue of crowd management. They discuss the challenges associated with finding the right experts, ensuring communication to the participants regarding the prerequisites for executing microtasks, and worker retention. When their SPD initiatives witnessed an increase in participation, they switched from finding participants to retaining them through effective management. To ensure worker retention they needed to update their incentive structures as well as assign managerial roles to individuals within the crowd.

The interviewee also describes the lack of crowdsourcing literature that is easily accessible to industry Professionals. The interviewee discusses the need for case studies that should include details such as *" what things were used for SPD, how those things were implemented, how did people think of DARPA [crowdsourcing initiatives] and what were the after-effects of it, how did people think of finding that airplane that was lost, how they found the debris and how people solved it, right. I need those case studies, which are missing"*.

Professional 3

Professional 3 discusses four main themes associated with SPD initiatives which are 1) Management of Intellectual Property 2) Incentive structures 3) Future of Work 4) Lack of case studies.

Regarding, intellectual property (IP), Professional 3 discusses the value that their organization offers clients and how intellectual property is an important service offering for their organization. Professional 3 stated *"when we do something new, a large part of that is IP"*. If Intellectual Property is created as part of an SPD initiative, Professional 3 suggested concern at how this would be managed.

Professional 3 also raised the challenge of selecting incentives for SPD initiatives. They recognize the importance of good incentive structures but stated *"I don't know what we could offer back as a reward"*. They also stated that creating incentives that appeal to a range of participants is difficult.

A lack of education and a lack of case studies was raised as a challenge by Professional 3. Regarding education, they stated *"it's a fairly new concept even for younger employees"*. Regarding a lack of case studies, Professional 3 states *"there's not much of that in our sector"*. Professional 3 states that case studies from similar organizations would increase their knowledge on SPD and give them more confidence in using SPD.

Professional 4

Professional 4 raised challenges associated with four themes. These were 1) Crowd Management 2) Resources and Big Data Analysis 3) Problem Framing and 4) Education and Case Studies.

With respect to crowd management, the key challenge was how to direct crowd conversations to elicit customer requirements. They state that facilitation is vital to existing requirements elicitation activities and were concerned this could not be replicated with SPD. They state that there *"tends to be a lot of noise if there's nobody to control the discussion"* and *"it's a worry that it would be too hard to filter out the useful things"*.

Professional 4 raised the challenge of lack of resources for analysis of crowd interactions. The interviewee states *"there could be some software tools that could help us do this"*. The interviewee then specifically states the need for *"keyword filtering and sentiment analysis"* to aid submission management and collection.

Regarding problem framing, Professional 4 discusses the challenge in selecting information to share with the crowd. They also speak about the challenge in protecting

IP when framing problems. Regarding the presentation of information in SPD initiatives, the interviewee states *"One of the problems we have as a company that in the focus groups customers don't really know what they want unless you present something to them"*. This draws in the interviewee's experience with existing requirements and idea elicitation processes. Regarding IP, Professional 4 emphasized the importance of confidentiality stating *"We operate under very strict confidentiality procedures for our clients so it would definitely need their approval [to do an SPD initiative]"*.

A lack of education and case studies is raised as a challenge by Professional 4. They state that their clients need convincing of the value of SPD and that a change in attitudes could come with education. They state that education is needed to show that *"SPD [is] becoming less of a niche or a gimmick but more of a well-defined business tool"*. They also suggest case studies could accelerate this change in attitudes. The interviewee states that *"if there are a number of case studies or examples or tools that could be shown"* to clients, they would *"be more willing to use SPD in business"*.

4.5 Research Opportunities in SPD Initiatives for Engineering Design: A Discussion

In this section, research opportunities that emerge from the challenges of SPD initiative design are discussed. Table 4.4 shows the Secondary Research Questions that have emerged from the interviews categorised according to the design phase of SPD initiatives.

In the following section these Secondary Research Questions are discussed in more detail and existing literature is examined to determine whether a solution to these Secondary Research Questions has yet to be proposed. Table 4.4 also notes whether this research direction is explored in this thesis. The reasoning for this decision is described in Section 4.7.

Table 4.4: Research opportunities identified in the interviews.

Category	Potential Research Directions	Explored?
Determining whether to use SPD	What characteristics determine the openability of a problem?	Yes
	How does implementation of SPD initiatives influence the perception of an organization's expertise and core competency?	No
	What are the characteristics of successful engineering design SPD initiatives of the past and how can it be utilized for effectively designing SPD initiatives in the future?	No
Selecting an SPD Initiative	How to determine which type of SPD initiative to choose?	Yes
Designing an SPD Initiative	How do the structural decisions of an engineering design SPD initiative influence its design outcomes?	Yes
	How does framing of engineering design problems in competitive scenarios influence its solutions?	Yes
	How can we quantify the influence of design expertise on the outcomes of a SPD initiative?	No
	How can SPD initiative designers effectively decompose an engineering design problem?	Yes
	How can optimal incentive structures be formulated for SPD initiatives for engineering design?	Yes
	How can we predict the influence of design decisions for an engineering design SPD initiative on its outcomes?	Yes
Post-SPD Initiative	How can the crowd be effectively managed for engineering design initiatives?	No
	How can an organization ensure sustainability of an SPD initiative?	No
General Implications of SPD	What are the geopolitical policy implications of conducting SPD initiatives for engineering design?	No
	How is SPD for engineering design influencing the future of work?	No
	How can future workforce be effectively mentored to design SPD initiatives for engineering design?	No

4.5.1 Interview Caveats and Observations

The caveat with the interviews were as follows. Professional 1 did not recognize management of resources such as cost and time as a challenge possibly because they worked for a big government organization where resource limitation was not an issue. Professional 2 did recognize management of resources such as cost and time as a challenge probably because they belong to a start-up where unsuccessful initiatives could heavily influence their business. Both Professional 3 and 4 recognize the need for further education and training on the topic of SPD. However, with current state of the art, they were not convinced that their organizations would adopt SPD.

Based on the interviews with the Professionals, it was observed that the Professionals with experience in SPD described greater variety of challenges associated with SPD initiatives and to a greater detail than the Professionals who lacked such an experience. It was noted how the state of belief about the challenges of conducting SPD initiatives can drive a Professional's decision and by extension an organization's decision to use SPD or not. To influence such state of beliefs about SPD initiatives for engineering design I believe that research needs to be pursued that addresses the challenges associated with designing and executing SPD initiatives. In the following section, the potential research directions based on the analysis of the interviews.

4.5.2 Investigating Design Decisions for SPD Initiatives

The interviews highlight the challenges associated with making design decisions for SPD initiatives. Research opportunities to overcome challenges associated with each category of decisions is discussed.

Structural Decision Making

Professional 1 suggests that currently there is a lack of understanding of how structural decisions influence the outcomes of a SPD initiative in an engineering design context. For example, it is currently not known how the decision of choosing a single-stage versus a multi-stage contest impacts the quality of engineering design outcomes.

Existing literature in economics and management sciences have studied the influence of a contest structure on contest outcomes (Taylor, 1995; Fullerton et al., 2002; Moldovanu, Sela, 2001; Corchón, 2007; Camerer, 2011; Archak, 2010). However, current models of contests need to be further developed to study engineering design outcomes. Structural decisions influence activities unique to design such as concept generation, analysis, and experimentation. For example, the decision to allow team formation can heavily influence how design analysis and experimentation is conducted. Current models of contests do not account for such design activities. Therefore, research is required to quantify and incorporate the influences of structural decisions on design activities in such models.

Within the engineering design community, the importance of SPD in engineering design has been highlighted by Gerth et al. (2012), Chaudhari et al. (2016), Burnap et al. (2015), Panchal et al. (2017) and Sha et al. (2015). The studies range from theoretical models to behavioral experiments that test modeling assumptions. Such studies have provided a starting step towards developing theoretical foundations of designing SPD initiatives for engineering design. However, further research is required to account for the complexity of decision making in real design scenarios that involve interconnected activities carried out by multiple agents. Thus, research opportunities exist towards quantifying and understanding influence of structural decisions on complex design activities and design outcomes.

Problem-related decision making

Professional 1 raises a relevant question for problem-related decision making, that is, how to formulate a problem to motivate participants from different disciplines and domains? Problem formulation propels innovation because it enables people to contribute to the same problem in different ways (Schon, 1983).

Theoretical frameworks for problem framing exist such as Minsky's frame system theory (Minsky, 1975), Entman's theory of framing (Entman, 1993), and Framing theory in political science (Chong, Druckman, 2007). With respect to design studies, extensive work has been done on understanding problem framing as an integral activity of design thinking (Kahneman, Tversky, 2013; Klabbers, 1996; Buchanan, 1992; Schön, 1987). Such works have described problem framing across a wide range of contexts and activities. The consensus that remains is that by considering design as a search process in the problem space (Simon, 1996), problem framing essentially allows a reformulation of problem space that allows for the discovery of novel solutions to the same problem. In engineering design context, problem framing research directions need further refinement such as the need to understand the effects of framing engineering design problems in competitive scenarios.

Professional 1 raises another relevant problem-related decision which is to decide how to effectively decompose a problem? Problem decomposition refers to dividing a problem into several sub-problems (Newell et al., 1972). It is an effective technique in design domains to solve ill-structured problems (Simon, 1973). Existing literature on problem decomposition for SPD initiatives has presented problem decomposition strategies (Jiang, Matsubara, 2014; Garcia-Molina et al., 2016) that make assumptions about the overall quality of task as an aggregate quality of the sub-tasks. In context of engineering design, such assumptions may not be valid. Ineffective problem decomposition could lead to lower quality and even unfeasible design solutions. Recent work in systems engineering has theoretically explored the trade-offs between problem-decomposition and solution-feasibility in SPD (Szajnfarber et al., 2014). Such studies are necessary to develop theory of problem framing for open innovation contexts. Further research is required to experimentally understand 'decomposibility' of problems and the effectiveness in solution generation.

Incentive Related Decision Making

All the Professionals discuss the importance of formulating the right incentives for the SPD initiative. Literature on designing incentive structures for SPD initiatives is vast (Singer, Mittal, 2013; Karger et al., 2014; Zhang et al., 2015; Gao et al., 2014; Horton, Chilton, 2010). It is known that incentives heavily influence crowd motivation, perception, and behavior, thereby, determining the success of an SPD initiative (Silberman et al., 2010).

Complex connections between incentives, behavior, and initiative design decisions are further compounded in design scenarios. It is shown that performance based financial incentives can improve the quality of tasks (Harris, 2011). Also, mechanisms have been suggested to prime crowd behavior (Morris et al., 2012) to influence the quality of solutions. However, what constitutes as quality of a design task may be difficult to determine a priority in engineering design contests. For example, the novelty or creativity of a design solution in a design innovation contest is difficult to estimate before the solution is submitted. This in turn can affect a prior quantification of performance which can hinder the decision to set up performance based incentive structure. Research is required to understand how determining what constitutes as quality in design problems can influence incentive related decisions.

4.5.3 Implication of SPD on the Notion of Expertise

Crowds have been traditionally considered as non-experts. Engineering design problems on the other hand require domain-specific expertise making them seemingly unfeasible for SPD. However, all Professionals agree that SPD can be utilized for engineering tasks which suggests the notion of expertise for engineering tasks is changing. It has been shown that the crowd can exhibit expert-level performances (Staffelbach et al., 2015). Moreover, SPD has been utilized for engineering tasks by organizations such as Proctor & Gamble and InnoCentive. All the Professionals also agree that SPD can be utilized for engineering tasks. It is clear that the notion of expertise and who constitutes as experts is changing. Research opportunities exist for revisiting the notion of expertise in context of SPD for engineering design.

Research on expertise in engineering design is vast, however, the majority of research on expertise has focused on qualitative studies resulting in subjective definitions of expertise. In context of SPD for engineering design, there lies a need for an objective measurement of expertise in order to quantify its impact on design outcomes. Such quantification would enable analytical models of contest to make better predictions about the quality of outcomes. Such predictions would enable designers of SPD initiatives to make better initiative design decisions. Towards quantification of expertise, Herling (Herling, 2000) argues that expertise should be defined by performance and consistency. Such a consideration towards expertise focuses the discussion on questions such as what constitutes performance, how is performance effectiveness and efficiency measured. Such an argument for objective measurement is also supported by other design studies (Hoffman et al., 1991; Shergadwala et al., 2016). They argue that objective measurements should not rely on subjective behaviours but on performance. Shergadwala et al. (Shergadwala et al., 2018) quantify domain knowledge on the basis of the requirements and performance criteria in an engineering design problem. Such studies are a starting step towards objective quantification of expertise but further quantitative and qualitative research is required to understand this change in attitude.

Similarly, identification of experts using such criteria can also be a challenge when consensus of good performance is formulated by the crowd itself (Burnap et al., 2015). Further research is required towards understanding design performance, its quantification, and relationship with expertise. From a design organization standpoint, research is required towards understanding how SPD can influence belief about the expertise of an organization and thus its reputation. The question that needs to be addressed from a business and management research perspective is, how does the implementation of SPD initiatives influence the perception of an organization's expertise and core competency? Such questions can have implications towards an organization's decision to use SPD or not. Huston and Sakkab (2006) briefly discuss the need to promote changes in attitudes at Proctor&Gamble to redefine the perception about their research and development organization. However, research on this topic is very limited.

Further research is required towards understanding attitudes of organizations, their employees, and customers towards SPD initiatives and its influence on the belief about the expertise of an organization and thus its reputation. I believe that conducting qualitative research through surveys and interviews would provide valuable results towards investigating public opinions about the expertise and the reputation of various organizations utilizing SPD initiatives. Such surveys could ultimately help inform an organization's decision to use SPD or not.

4.5.4 Investigating Openability

Both Professional 1 and Professional 2 raise the concept of openability and suggest there is value in conducting further research on this topic. Both speak of the broader challenge of determining openability and Professional 2 raises further Secondary Research Questions regarding the specific characteristics of a task that make it openable for SPD.

The concept of openability is discussed in existing literature. Thuan et al. (2016) discuss factors that influence the decision to crowdsource, Knop and Blohm (2016) discuss the task characteristics of crowdsourcing and Buecheler et al. (2010) conducted a state of the art review on the openability of tasks. The synthesization of this literature revealed a significant disparity between the challenge described by the interviewees and the agreed research priority stated in existing literature. Professional 1 specifies the need to determine the aspects of the problem that make it openable. However, existing literature emphasizes value in, not just openability in relation to the problem, but all factors relating to the decision to use SPD. Knop and Blohm (2016) provide a comprehensive list of the factors influencing the decision to use SPD or not. They state that task complexity is a key factor in this decision process, which is a statement supported by Professional 2.

Thuan et al. (2016) state that determining whether or not to use SPD initiatives "is a complex decision making process, where multiple contingency elements should be considered". They suggest that an organization's capability to use SPD must be examined, as well as the openability of a problem. To support this notion, Knop and Blohm (2016) list a series of factors that influence the decision to use SPD which includes "strategic perspective". This "refers to the strategic level of SPD with regards to the competitive advantage" and covers issues such as "the availability of internal resources". Therefore, this research challenge should be redefined as, not just the difficulty in determining the openability of the task, but instead the difficulty in determining whether or not to use SPD. The openability of a problem is one aspect of this "multi-faceted" and "complex" decision (Thuan et al., 2016; Buecheler et al., 2010).

4.5.5 Investigating Crowd Management

The term crowd management refers to several considerations associated with managing external participants in SPD initiatives. Both Professional 2 and 4 talked extensively about the challenges of managing SPD participants, and it is therefore regarded as a significant aspect of the initiative design process.

Professional 4 talks specifically about managing the contributions from SPD participants. They mention the need to replicate existing requirements elicitation processes *"[where] we can define exactly what we want to get out of it"*. Professional 4 suggests that without being able to *"guide participants towards useful responses"* SPD initiatives would offer limited value. It could be said that Professional 4's perspective is unique to their client-focused organization. Regardless of this, however, it raises the issue of whether there should be facilitation in the SPD process or whether this stifles the benefit in external involvement.

Forbes and Schaefer (2018) also discuss the challenge that some organizations see in balancing diversity and frequency of perspectives with deemed quality of solutions. Burnap et al. (2017) suggest that all ideas should be compared to "the true objective" and Brambilla et al. (2015) judge the success of an SPD initiative on the number of "correct" and "precise" responses. There is a suggestion, however, that submissions that are guided towards an "ideal solution" may not be as novel as those created with minimal organization intervention (Forbes, Schaefer, 2018). This is especially the case if the "ideal solution" is defined by an existing in-house team. In support of this notion, Howe (2006), credited as first coining the term crowdsourcing, a key SPD tenant, suggests that methods designed to decrease diversity in the crowdsourcing process will reduce the value of the crowdsourcing initiative. Despite this countering argument, it is clear from current literature and from Professional 4's contribution, that receiving an excess of unsuitable solutions is considered a challenge. Therefore, it is suggested, that the SPD initiative design process (Panchal, others, 2015) should accommodate organizations that aren't willing to negotiate on their idea of a "high-quality solution" (Forbes, Schaefer, 2018).

Professional 2 raises the challenge of managing the amount of participation from the crowd. Panchal also raises these challenges stating that SPD initiatives are vulnerable to failure when "an initiative fails to attract a crowd with a suitable number of participants" (Panchal, others, 2015). Furthermore, Zheng et al. (2011) state that in order to receive "optimal solutions from [SPD] participants, firms need to improve task design and motivate contest solvers' participation" (Zheng et al., 2011). Several academics have offered a solution to this problem. For example, Zheng et al. (2011) suggest that if an SPD initiative requires solving a problem that is "highly autonomous, explicitly specified, and less complex, as well as require a variety of skills", the crowd will be motivated to participate (Zheng et al., 2011). Despite these solutions, interviews with practitioners demonstrate a lack of knowledge in this aspect of crowd management. Further research is therefore required to transfer this knowledge to industry.

Professional 2 also raises the challenge of managing worker retention in SPD initiatives. They describe having difficulty in retaining participants, stating that after a worker has participated in a *"certain type of [initiative] for a long time, that person expects a hike or progression in their career"*. Existing literature supports this challenge. Difallah et al. (2014), Gadiraju et al. (2015) and Feyisetan et al. (2015) all describe the difficulty in retaining workers. Difallah et al. (2014) suggest that pricing schemes and incentive structures can be adjusted to improve retention while Feyisetan et al. (May, 2015) suggests SPD initiatives should be gamified. While existing literature has considered the challenge of retention, work in this area is limited. The author therefore acknowledges this as a research direction for supporting practitioners.

The challenge of worker retention, also highlights the difficulty of creating sustainable SPD initiatives. Sustainability, in this context, is defined as the continued effectiveness of SPD initiatives. Organizations need to ensure they are adjusting incentive structures, effectively framing design problems and managing other key factors to ensure the crowd remains motivated to participate. As Lin et al. state "the success of any [SPD] approach relies on strong and long lasting motivation to attract enough crowd" (Lin et al., 2010). Existing literature on this topic is very limited and the author therefore promote creating sustainable SPD initiatives as another valuable research direction.

4.5.6 Implications of SPD on the Future of Work

The relationship between SPD and the future of work is a topic discussed by all Professionals. Challenges related to this theme are all consolidated under the Secondary Research Question; How would widespread implementation of SPD change the future of work and what are the challenges associated with this?

Professional 1, 3 and 4 offer a pessimistic view of SPD's influence on the future of work while Professional 2 takes a more optimistic viewpoint. This section considers both perspectives and the realm of experience of all Professionals that led to these differing attitudes.

Regarding the future of work and the future of SPD, Professional 1 raises the issue of geopolitical policy. Regarding industrial policy and SPD, existing literature is very limited. Taeihagh et al. (2018), Mureddu et al. (2012) and Brabham (2013) discuss using SPD as a tool for creating policies but not how SPD demands policy change. Should SPD become a more popular way to procure services, further implications for industrial policy may also emerge. For example, a greater proportion of workers may choose to participate on a full time capacity, contributing the "rise of the gig economy" (Abraham et al., 2019). As Johnes states "the creation of a spot market changes the nature of interaction between demand and supply sides of the labour market in fundamental ways [...] which presents challenges of relevance to businesses, workers and policy-makers" (Johnes, 2019). The implications of widespread use of SPD on industrial policy is therefore an important research direction in this field.

Professional 2 takes an optimistic view point on SPD and its implications for the future of work. They state their belief that *"remote tasks are going to be the future"*. SPD is also defined by Gourdswaard et al. (2019) as an important way to democratize design, manufacture and innovation by enabling “more ‘non-designers’ to become involved in idea generation, development and production of products, services or processes” (Fleischmann, 2015; Gourdswaard et al., 2019). For example, Professional 2 discusses how popular their company became in India, due to offering individuals *“an opportunity for a second source of income”*. Therefore, SPD cannot only benefit organizations but also allow engagement and involvement for the benefit of the external contributors.

4.5.7 Need for Case Studies and Education

Professional 2 and 4 state a need for case studies that demonstrate the use of SPD initiatives in design. Forbes and Schaefer also recognize this as a challenge stating that “availability [of case studies] for the implementation of SPD in product development, is limited” (Forbes, Schaefer, 2018). They suggest that case study literature is siloed with authors presenting knowledge based on only specific examples without decontextualizing advice for supporting other SPD initiatives. For example, Koch et al. present a case study on crowdsourcing for design of government initiatives (Koch et al., 2011), Brabham et al. present a case study for transit planning design (Brabham et al., 2010) and Dubey and Rameshwar present a case study for disaster relief (Dubey, 2019). Furthermore, terminology used to present SPD case studies is not yet standardized. Professional 2 expresses a need for case studies on microtasks, yet existing literature that present case studies do not explicitly define their SPD initiative. This makes searching and accessing case studies, to aid application, difficult for practitioners. A valuable outcome from future research is therefore the presentation of SPD case studies that are categorized according to both their application and the specific SPD initiative they represent. Case studies could also be grouped according to influential factors for SPD success such as the budget of the initiative and the time frame of the initiative. This would make case studies more accessible for practitioners and aid the design of crowdsourcing initiatives.

4.6 Conclusions for Industry Interviews

In this study, the barriers to the implementation of SPD and therefore the research opportunities to build theoretical foundations towards designing and conducting SPD initiatives were identified in context of engineering design. Research gaps were identified by interviewing four industry Professionals about the challenges experienced by them while implementing SPD initiatives. The barriers and therefore the research opportunities are tabulated in Table 4.4 by categorizing them based on their relevance to the SPD initiative design process.

The coding units in the transcripts were mainly sentences and paragraphs as opposed to single words. Thus, the identification of 15 coded instances, as in the case of Professional 1, implies 15 recognized advantages and challenges from the interview with Professional 1 alone. It is important to mention that the expectation by the author was about 3 to 5 advantages and challenges from such short interviews (15 minutes). Moreover, it was intuitive to identify greater instances of coding for challenges/advantages from Professionals 1 and 2 with SPD experience as compared to the Professionals 3 and 4 who did not have that experience. Overall, more than 40 instances were identified of barriers to the implementation of SPD initiatives in engineering design contexts which were utilized as a basis along with corroboration from existing literature to discuss potential research opportunities.

Overall, this interview study allowed the identification of barriers to the implementation of SPD from a range of industry practitioners with differing experience with SPD. While the research directions identified in Table 4.4 are not claimed to be exhaustive they do provide the first exploration of barriers, from an industry perspective, and provide the foundation for the further research presented in this thesis. By structuring the remaining research according to the user (industry practitioners) identified barriers, the outcomes of this thesis may provide value to the user themselves.

4.7 Implications for Chapter 5

As shown in Table 4.4, the research directions identified by the industry practitioners, and not addressed in existing literature fall into five categories:

1. Determining whether to use SPD
2. Selecting an SPD initiative
3. Designing an SPD initiative
4. Post-SPD Initiative
5. General implications of SPD

Category 5 references research directions that relate to the future of SPD implementation and general implications of SPD. Category 4 refers to challenges associated with post-implementation and sustaining SPD initiatives after initial implementation. Categories 4 and 5 do not relate to the research directions and therefore outside of the scope of this thesis.

The following chapters therefore relate to Categories 1, 2 and 3 in providing support to overcome barriers to SPD and support implementation of SPD. In Chapter 5, Category 1 and 2; determining whether to use SPD and selecting an SPD initiative are addressed by the development of an SPD initiative selection framework. In Chapter 6, the components of the SPD initiative selection framework are used to attempt to build an SPD initiative selection framework to allow practitioners to determine how structural decisions influence SPD initiative outcomes (as presented in Category 3). It is the case, however, that Chapter 6 instead demonstrates the need for individual tenant assessment frameworks which is explored in Chapter 7, therefore addressing Category 3 and the second Primary Research Question. This is summarised in Table 4.5.

4.8 Chapter 4 Summary

Chapter 4 presents the research method that allows barriers to the implementation of SPD to be identified, and therefore provides focus for addressing Primary Research Question 2. Specifically this chapter aims to understand why industry is yet to fully adopt SPD and address the following literature gaps:

- There is minimal use of experimental methods and specifically those including the opinions of industry practitioners
- Any case studies or interviews conducted with industry are with single organisations or industries and do not cover a range of industry experiences

To do so, one-on-one semi-structured interviews were conducted with four industry professionals who have discipline-specific work experience with product design processes. Semi-structured interviews were chosen in order to enable the investigation of challenges, opportunities, and Secondary Research Questions on the implementation of various types of SPD initiatives. The professionals had a variety of experience with SPD initiatives and were from a range of types of organisations. Interviews lasted an average of 16 minutes and were transcribed as part of the data collection process.

The interviews were analysed through content analysis (Krippendorff, 2018) with words and sentences coded according to the following criteria:

- Challenges
- Advantages
- Caveats
- Research Directions

Table 4.5: Thesis Organisation

Chapter	Page	Primary Research Question or Purpose	Secondary Research Question(s)	Tertiary Research Question(s)
2	19	Present existing literature and literature gaps		
3	47	Present overall approach to addressing research questions		
4	56	**1** What are the barriers to the implementation of SPD in industry?	Secondary Research Questions identified in this chapter	
5	82	**2** How can the implementation of SPD be supported?	**2.1** How to prepare a problem for SPD initiatives? **2.2** How to determine which type of SPD initiative to choose?	
6	107	**2** How can the implementation of SPD be supported?	**2.3** How do structural decisions of an engineering design SPD initiative influence its design outcomes?	
7	119	**2** How can the implementation of SPD be supported?	**2.3** How do structural decisions of an engineering design SPD initiative influence its design outcomes? **2.4** How do design decisions of an engineering design SPD (crowdsourcing) initiative influence its outcomes?	**2.3.1** How does company reputation influence SPD success? **2.3.2** How does the number of stages in an SPD initiative influence success? **2.4.1** How does framing of engineering design problems in competitive scenarios influence its solutions? **2.4.2** How can SPD initiative designers effectively decompose an engineering design problem? **2.4.3** How can optimal incentive structures be formulated for SPD initiatives? **2.4.4** How does the complexity of a problem influence SPD success?

In order to ensure content analysis reliability, the transcribed interviews were coded several times by the researchers. The inter-rater reliability (IRR) was calculated by taking the ratio of the number agreements to the number of coded instances.

The results section provide the caveats identified as well as the advantages of SPD initiatives and challenges of SPD initiatives as identified by each professional. In the discussion section the barriers to the implementation to SPD, as identified as the interviewees, were discussed alongside existing literature whereby providing evidence of a literature gap or future research direction. The main outcome of this chapter is a list of Secondary Research Questions, as identified by the interviewees and corroborated by individual literature reviews, that offer insight into how barriers to the implementation of SPD can be overcome. This is shown in Table **??** and below for reference.

Chapter 5

SPD Initiative Selection

This chapter represents the start of the research addressing Primary Research Question 2:

Primary Research Question 2: How can the implementation of SPD in industry be supported?

It also represents the first areas of research addressing the Secondary Research Questions in order to support SPD implementation, as shown in Table 1.4. These specifically are:

1. How to prepare a problem for SPD initiatives
2. How to determine which type of SPD initiative to choose

With reference to the Literature Review (Chapter 2), this section is addressing the literature gaps pertaining to Primary Research Question 2 as follows:

- Frameworks to support implementation of SPD are limited
- The majority of literature in this sector only propose ideas for future research as opposed to providing applicable outcomes
- The majority of literature in this section is exploratory in nature as opposed to providing applicable outcomes

To address these literature gaps, a Social Product Development Initiative Selection Framework was developed to support practitioners in preparing to launch a Social Product Development initiative. A framework was chosen since it allows the user to organize the SPD process and orient SPD initiative development by intended outcomes rather than in an exploratory sense, as has been done in previous literature.

The following section, Section 5.1 details the methodology to conceiving this framework. The next sections show the framework realisation process followed by Section 5.4 which presents the full SPD Initiative Selection Framework. This includes further description of the tenant selection phase and an example of the framework in use. Finally, this section finishes with a validation process in Section 5.6 and conclusions in Section 5.7. The research questions addressed in this chapter are shown visually in Figure 5.1

Published Work Included in the Chapter

Literature from the following published work is included in this chapter:

Forbes, H., Schaefer, D., Panchal, J. and Han, J., 2019. **A Design Framework for Social Product Development**. *IEEE Transactions on Engineering Management.*

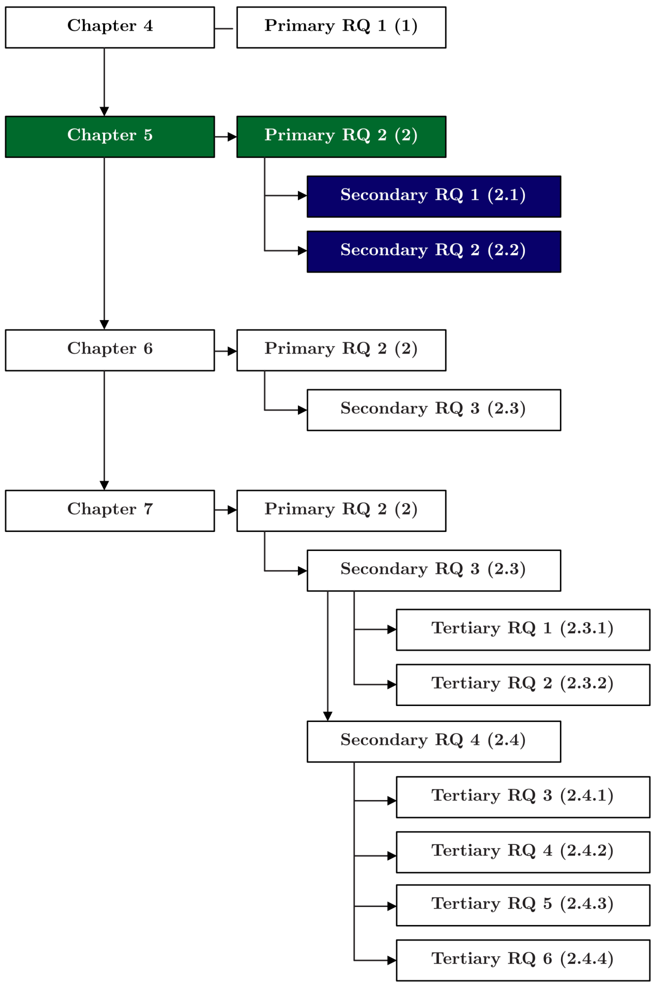

Figure 5.1: Research Question Organisation for Chapter 5

5.1 Initiative Selection Framework Methodology

To construct the methodology for conceiving a Social Product Development framework, the authors sought literature for “designing a design framework”. It was found, however, that the conception process of design frameworks was rarely documented. For example, Panchal’s (2015) framework for the design of crowdsourcing contests presents a framework as a “step towards addressing this research gap” and the conception process is not described. Larsson et al. (2003) present a framework for developing products with distributed teams that was conceived using an ethnographical study of practitioners. While the results of the ethnographical study are presented and analysed in this literature, the specific process of using the experimental findings to conceive the presented framework is not described (Larsson et al., 2003; Evans et al., 2015b). In an attempt to find a described and validated framework conception process, the authors looked beyond the field of design, using search terms such as “conceiving a framework” and “designing a framework”. Mior et al. (2005) discuss the process taken to conceive a framework for the “delivery of collaborative musculoskeletal care”. The process taken was user-centric, with several rounds of requirements analysis including different stakeholders. Boydell et al. (2004) also followed a similar approach described as a “multi-stage user consultation” for the conception of an “evaluation framework” for paediatric telepsychiatry. In both processes, the outcome of this in-depth requirements analysis were key themes that were carried into the conception of a design framework. In both circumstances, however, how the “key themes” were processed to form a framework, was not described. Finally, Reeves et al. (1998) design a framework for the professional development of school leaders and managers by analysing and synthesising literature in their field. Existing literature, therefore, does not provide a prescriptive approach for the complete construction of a design framework. In the absence of a methodical approach to the conception of a design framework, the authors choose to adapt an existing design approach. In the following sections, existing design methods are compared and selected for use in this context. The selected method(s) are then adapted to produce a high-level Social Product Development framework.

5.2 Design Method Selection

In this section, established design methods are examined, selected and compared for use as an SPD initiative selection framework.

5.2.1 Narrowing the Design Method Pool to Procedural Methods

Wynn and Clarkson (2018) present extensive and comprehensive literature on design methods. Their organizational framework, shown in Figure 5.2 categorises all development and design methods according to the method's scope and the type of method.

Figure 5.2: Wynn and Clarkson Design Methods (Wynn, Clarkson, 2018)

In order to reduce the design method pool the authors began by considering which of the categories, presented by Wynn and Clarkson (2018) would be appropriate for an SPD framework.

It was first determined that a procedural design method would be required. This is due to statements by Wynn and Clarkson and other academics on its suitability, above other types, for actual implementation. Wynn and Clarkson state procedural methods "convey best practices intended to guide real-world situations" (Wynn, Clarkson, 2018) and Harmsen and Saeki (1996) state that procedural methods are "most relevant to practical situations". Furthermore, analytical methods are described as "better positioned to provide support in specific contexts" (Wynn, Clarkson, 2018) while abstract methods are "not able to provide insights for implementation" (Wynn, Clarkson, 2018). Social Product Development tenants are used to solve a breadth of design problems which means methods designed for specific circumstances are not appropriate.

Having now refined the design method pool to procedural methods, the authors looked further into the distinction between micro, meso and macro-procedural methods and which was most appropriate for an SPD framework. As stated by Wynn and Clarkson (2018), micro-level, meso-level and macro-level, in this context, are defined as the following:

1. Micro-level: Focuses on individual process steps and their immediate contexts
2. Meso-level: Focuses on end-to-end flow of tasks as the design progresses
3. Macro-level: Focuses on project structures and/or the design process in context

Micro-level procedural methods offer a step-by-step process that can be easily applied to a variety of contexts. They do not, however, provide adequate guidance for the full design process and are instead useful for application in individual design phases or tasks. Macro-level procedural methods offer high-level guidance for the design process and beyond, providing step-by-step guidance for organisational and managerial tasks as well as design tasks. As a consequence, however, neither provide adequate nor detailed information on how to conduct the design phases. Meso-level procedural design methods, however, offer guidance throughout the whole design process and provide information and guidance for each design phase. They are therefore the most suited for this context, providing both breadth and depth in design process support.

5.3 Selecting a Meso-Level Procedural Method

With reference to Figure 5.2, there are six meso-level procedural design methods. These are Evans' Design Spiral (Evans, 1959), Pahl and Beitz' Stage Model (Pahl et al., 2013), French's Stage Model (French et al., 1985), VDI2221 Stage Model (Richtlinie, 1993), Hubka's Stage model (Hubka, Eder, 1992) and Ullman's Stage Model (Ullman et al., 1988). To select between them, the authors consulted design method selection literature. Both López-Mesa and Thomspon (2003) and Braun and Lindemann (2003) suggest comparing the elementary tasks of the approach with the elementary tasks of the design task to determine compatibility. In order to conduct this comparison, the authors first identified tasks vital for the application of SPD. These were identified using a combination of existing literature on SPD initiatives and form the industry interviews presented in Chapter 4.

These are presented in Table 5.1.

Table 5.1: Elementary tasks for an SPD framework

Elementary Task	**Description**
Problem Clarification	Users are required to clarify and de-contextualise the design task they are interested in solving with an SPD tenant.
Requirements Analysis	Users are required to identify why existing practises aren't working, and why.
Concept Generation	Users should have an understanding of which SPD tenants are available to them.
Concept Evaluation	Users then need to evaluate the available SPD tenants and select one to solve their design problem.

Following Concept Evaluation, the user will need to conduct a detailed design phase for the selected SPD tenant. The specific steps required as part of this process, however, are likely to be dictated by the chosen SPD tenant. They are therefore not included in Table 5.1. Studying each of the proposed design methods alongside Table 5.1 provides further insight into the compatibility of each design method. The design methods are distinguished in three key ways:

1. By the way in which they guide the design realisation process
2. By their level of detail
3. By their content

First, Evan's Design Spiral (Evans, 1959) is not appropriate for this design task due to the process of design realisation. Unlike the other five design methods, Evan's Design Spiral requires an initial identification of "the overall arrangement" (Evans, 1959; Evans et al., 2015b) before developing the design through the realisation of relationships between the constituent components of the design. This process is not appropriate for the selection of design of SPD tenants because very little is known about the overall format or structure of the SPD tenant prior to use. The design realisation process of Evan's Design Spiral in comparison to the other five methods, is illustrated in Figure 5.3.

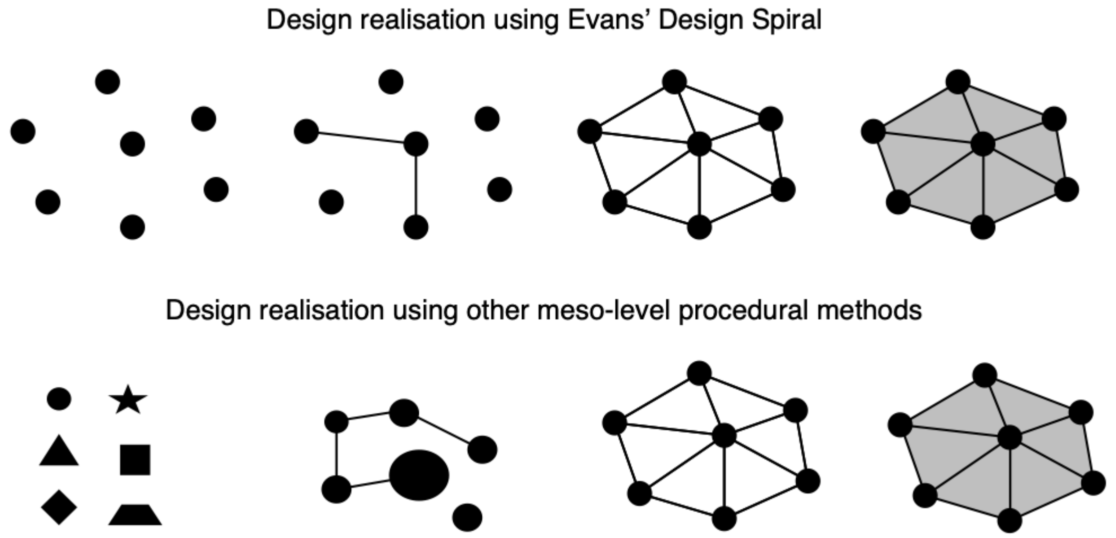

Figure 5.3: Design realisation in meso-level procedural methods

French's stage model (French et al., 1985) was deemed inappropriate for this design task because of its lack of detail relative to the other design methods. Furthermore, some important elementary tasks, as shown in Table 5.1, such as requirements analysis and concept generation are not included in French's model. Hubka's model is also deemed inappropriate for this reason. The first step in Hubka's model is "Given Design Constraints" (Hubka, Eder, 1992) which means important steps including problem clarification and requirements analysis are omitted.

The design method pool was therefore refined to three methods; Pahl and Beitz (Pahl et al., 2013), VDI 2221 (Richtlinie, 1993) and Ullman's Stage Model (Ullman et al., 1988). While each of these methods provide slightly different content and are presented in slightly different formats, it was deduced that, especially in the case that the final method would be adapted, choosing between them was not necessary. The next section therefore demonstrates how a combination of these methods was created and selected for use.

5.4 The Social Product Development Initiative Selection Framework

An adaptation of these three meso-procedural design methods are used to create the SPD framework. The elemental tasks, as described in Table 5.1, are incorporated and represented as Task Clarification, Requirements Specification, and Tenant Selection and Evaluation. For SPD tenant application, the early design phases are focused on the selection of an SPD tenant. Detailed Form Design then prompts decision-making on the content and structure of the selected SPD tenant. The final design phases prompt the launch of the SPD tenant and a Results Processing phase to determine whether the SPD tenant produced an appropriate solution to the design problem. The framework is designed to support design team leads and product designers to incorporate the SPD framework. It is therefore designed with the expectation that the user understands and uses design processes. The SPD Framework is shown in Figure 5.4. In the following sections the tool used for the Tenant Selection and Evaluation Phase is presented.

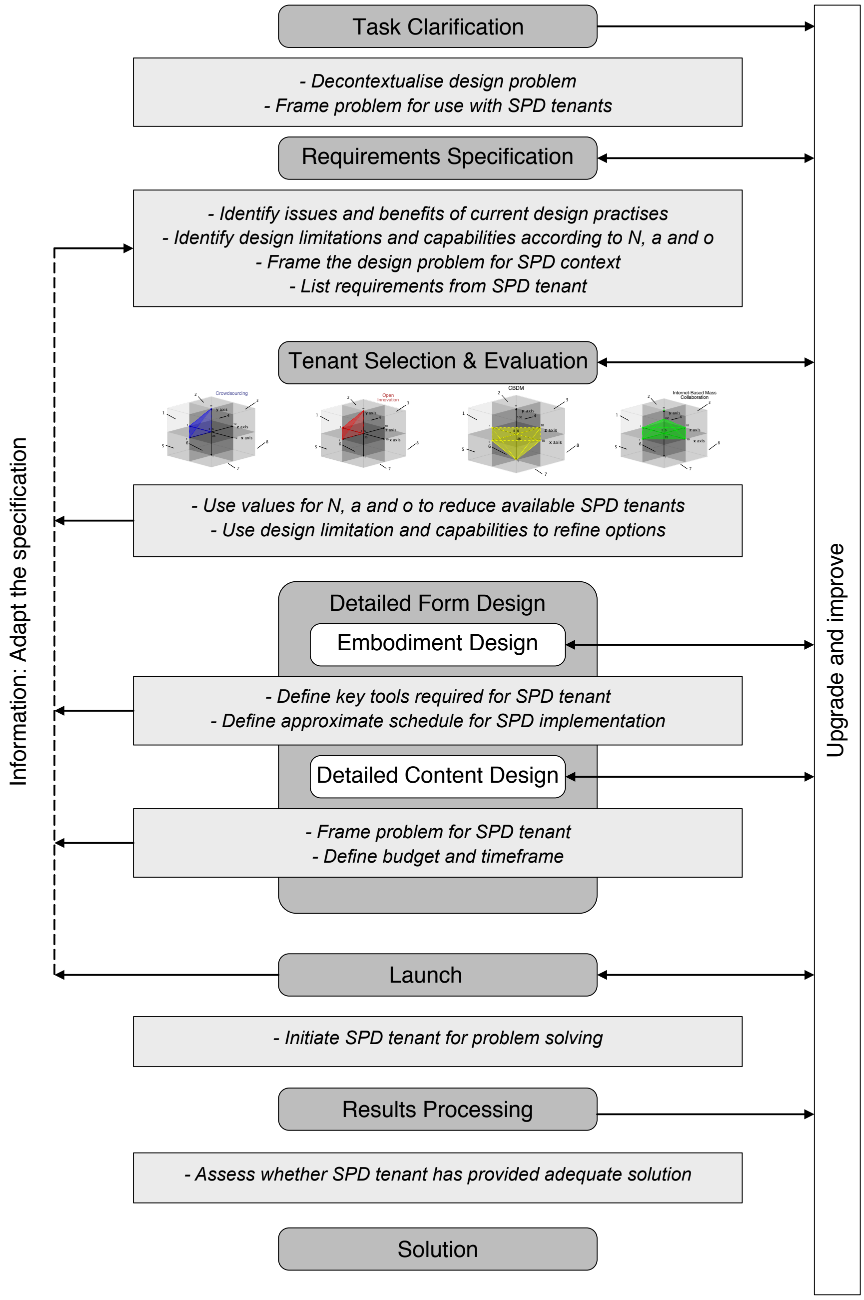

Figure 5.4: Adapted design method for SPD tenant selection

5.4.1 Tenant Selection and Evaluation

A key task in the early design phases of the application of SPD, is the selection of an SPD tenant. Social Product Development is represented by a group of tenants, as defined in Table 5.2, which are united by their use of Web 2.0 technologies. As individual tenants, however, they are applied to product development in different ways. For example, Open Innovation is defined as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation" where "external knowledge plays an equal role to [..] to internal knowledge" (Chesborough, 2003; Chesbrough et al., 2006; Evans et al., 2015b). IBMC, however, is defined as the collective action of members of a large group (Fathianathan et al., 2009). Actors in IBMC, therefore, could be within the same organisation while Open Innovation specifies the involvement of knowledge external to the organisation.

Table 5.2: SPD Tenant Definitions

SPD Tenant	Definition	Example
Crowdsourcing	Crowdsourcing is defined as the "the act of taking a job, traditionally performed by a designated agent [. . .] and outsourcing it to a [. . .] large group of people" (Unterberg, 2010; Panchal, others, 2015). It is most regularly used in concept generation and concept evaluation of the product development process, and social networking is used to reach the intended crowd (Forbes, Schaefer, 2018).	Organisation publishes and advertises a new product brief online and requests submissions
Open Innovation	Open Innovation is defined as using knowledge inflows and outflows to fuel innovation (Chesbrough et al., 2006). Web 2.0 technologies such as social networks act as channels between internal teams and external knowledge sources.	Technology organisation publishes their code for a new app in an open-source community
Cloud-Based Design and Manufacture	Cloud-Based Design and Manufacture "is a type of parallel and distributed system consisting of a collection of inter-connected physical and virtualized service pools of design and manufacturing resources (e.g., parts, assemblies, CAD/CAM tools) as well as intelligent search capabilities for design and manufacturing solutions." (Wu et al., 2012; Piorkowski et al., 2013). A plethora of Internet-based communication tools are used including cloud-based software and CBDM process can include any number of actors.	CAD model is stored in cloud-based CAD software. Two mechanical engineers edit different parts of the model online and simultaneously
Mass Collaboration	Mass collaboration is a form of "collective action" where a large number of parties work together on a project (Elliott, 2016; Panchal, Fathianathan, 2008). Each party makes a significant contribution to the project and all contributors are regarded as important (Panchal, Fathianathan, 2008). Internet-based communication tools such as VoIP, file-sharing software and instant messaging are employed, and the number of actors must be over 25 (Elliott, 2016).	Thousands of individuals around the world contribute expert knowledge to create an online encyclopaedia

5.4.2 Selecting SPD Tenants According to Three Common Variables

To select between the SPD Tenants their similarities and differences were identified. They are united through their use of social computing technologies Peterson, Schaefer (2014) and their involvement in the product development process, as defined in Table 5.2. They differ, however, through the method they facilitate communication in the product development process. Specifically they differ through the number of participants they connect, the distance of those participants from each other and the distance of those participants from the organisation Forbes et al. (2020). The differences between the SPD tenants can be represented by three core variables, outlined in Table 5.3. Proximity is defined as “nearness in space, time and/or relationship” (Stevenson, 2010).

Table 5.3: SPD Variables: Scale and definitions

Variable	Scale	Definition
Organisational Proximity, P_o	1 - 10	1 = the actor or involved party is an external organisation that has minimal knowledge beyond what is in the public domain 5 = the actor or involved party is within the same industry as the organisation 10 = the actor or involved party is within the same organisation but not within the same location as the project lead (Web 2.0 technologies are therefore required for involvement)
Actor Proximity, P_a	1 - 10	1 = the actors or involved parties do not have a relationship and do not collaborate with each other 10 = the actors or involved parties are within the same organisations each other and have at least professional relationships with each other
Number of Participants, N	1 - ∞	This refers to the number of people involved in the activity or the number of people with the opportunity to be involved in the activity

The main SPD tenants are assigned a variable range in Table 5.4. These numbers have been derived from the definitions of the SPD tenants given above.

Table 5.4: SPD Tenants and Variable Values

SPD Tenant	P_a	P_o	N
Crowdsourcing	1 - 5	1 - 5	25 - ∞
Open Innovation	1 - 5	1 - 5	25 - ∞
Cloud-Based Design and Manufacture	1 - 10	1 - 10	1- ∞
Mass Collaboration	1- 10	1 - 10	25 - 100

To illustrate this, the scales given in Table 5.4 are represented as three axes. The

Number of Actors is assigned the y axis, Organisational Proximity is assigned the x axis and Actor Proximity is assigned z axis. Placing the assigned values shown in Tables 5.3 and 5.4 on these axes yields Figures 5.5, 5.6, 5.7 and 5.8.

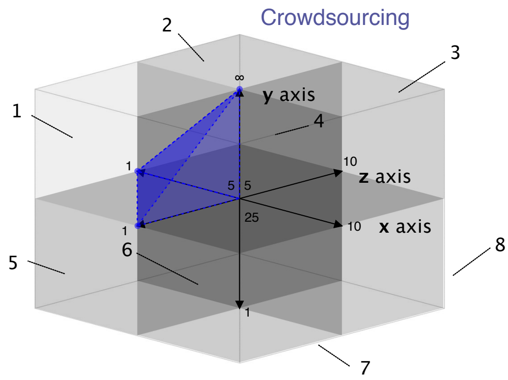

Figure 5.5: Illustration of crowdsourcing in the context of the three SPD Variables

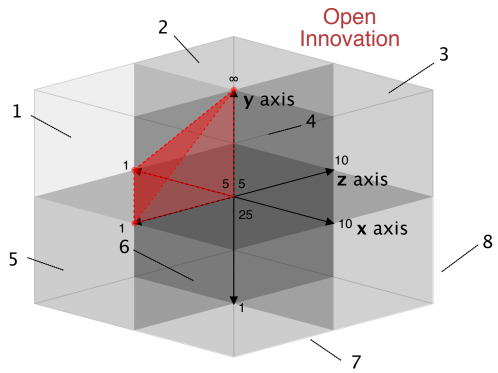

Figure 5.6: Illustration of Open Innovation in the context of the three SPD Variables

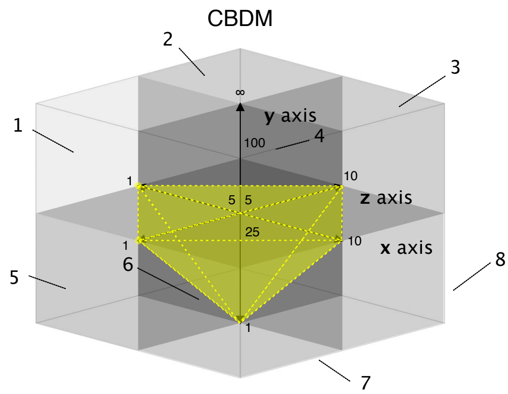

Figure 5.7: Illustration of CBDM in the context of the three SPD Variables

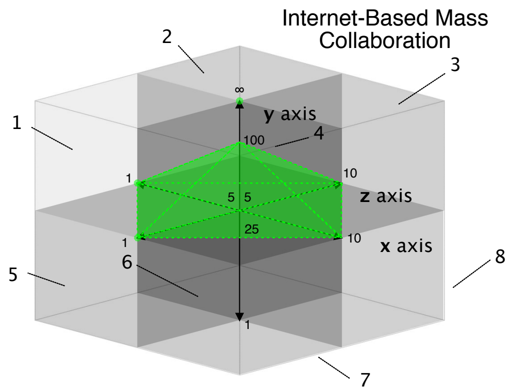

Figure 5.8: Illustration of Mass Collaboration in the context of the three SPD Variables

5.4.3 The Quadrants of Social Product Development

Figures 5.5, 5.6, 5.7 and 5.8 present the eight quadrants of Social Product Development. What these quadrants mean, beyond the context of the graphical representation, is described in Table 5.5.

Table 5.5: The SPD Quadrants

	Quadrant 1	Quadrant 2	Quadrant 3	Quadrant 4
Org Proximity	1 - 5	1 – 5	5 - 10	5 - 10
Actor Proximity	1 - 5	5 - 10	5 - 10	1 - 5
Number	25 - ∞	25 - ∞	25 - ∞	25 - ∞
Value Flow	External to Internal	Between external and then to Internal	Between external and then to internal	Familiar External to Internal
Description	Access to large and diverse crowd. Minimal collaboration between contributors.	Crowd work together to create solutions that are then provided to organisation. Project ownership is more decentralized	Crowd work together to create solutions but organisation is more involved. Project ownership is more central to the organisation.	External parties provide value to organisation but do not collaborate with each other
Main Web 2.0 tool used	Social networking	Instant messaging	Instant messaging	Instant messaging, VoIP, file sharing
Also known as	Crowdsourcing	Wikipedia	Mass Collaboration	Large scale Outsourcing
	Quadrant 5	Quadrant 6	Quadrant 7	Quadrant 8
Org Proximity	1 – 5	1 - 5	5 - 10	5 - 10
Actor proximity	1 - 5	5 - 10	5 - 10	1 - 5
Number	1 - 25	1 - 25	1 - 25	1 - 25
Value Flow	External to internal	Between external to internal	External to Internal to External	External to internal
Desc.	Value to the company is created by non-collaborative parties and then provided to the organisation	Value to the company is created in a community without the organisation's input, it is then provided/bought by the organisation (University IP)	Actors collaborate with each other and are close to the organisation	Expert actors provide and collaborate with the company but not with each other
Main Web 2.0 tool used	SaaS	SaaS	VoIP, instant messaging	VoIP, instant messaging
Also known as	Individual agencies/inventors	Think Tanks	Mass Collaboration	Small scale outsourcing

5.5 Using the Tenant Selection Tool as part of the SPD Framework

In the Task Clarification and Requirements Specification phases, the user derives the values for N, P_a and P_o representing their preferences and capabilities relating to their design problem. The user then maps these variables on the axis, as shown in Figures 5.5 to 5.8, allowing their SPD Quadrant to be revealed. The case study shown in Table 5.7 below, demonstrates this process. As shown, the framework is followed by the design team lead. Such individual also makes the decision to move onto the next phase of the framework when the requirements of the phase have been fulfilled.

Table 5.7: Using the SPD Framework and Tenant Selection Tool

SPD Design Phase	Description	Case Study Context
Task Clarification	What is the problem to be solved?	My in-house design team is struggling to present a novel concept for an off-road wheelchair design.
Requirements Specification	What do we need to solve this problem?	My team is lacking in diversity and have limited experience of using or designing wheel chairs. We are also a small team of five and so require a greater number of perspectives to generate ideas. We also have limited time available and need new ideas within the next few months.
	N	Greater than 5
	a	Less than 5
	o	Less than 5
Tenant Selection and Evaluation	Use the SPD Quadrants to determine which SPD tenant to use.	According to the definition model, SPD tenants with high number of participants that are detached from each other and the organisation in proximity includes crowdsourcing and Open Innovation.
	Make decision on which SPD initiative	Crowdsourcing allows ideas to be gained from a large number of people with varied perspectives in a relatively short amount time. Open Innovation, on the other hand, requires the construction of formalised knowledge sharing channels. Crowdsourcing is therefore most suitable for this case.
Detailed Form Design	Make decisions on the structure, performance and content of the chosen SPD tenant	In the case of crowdsourcing, due to time constraints a crowdsourcing contest will be promoted using existing platforms such as Facebook and Twitter. The contest will be open for two months, allowing the remaining time to be used for submission evaluation. The prize money will be calculated according to the available budget factoring in the cost to evaluate submissions.
Launch	Apply the SPD tenant	In the case of crowdsourcing, this stage is the launch of the crowdsourcing contest
Results Processing	Determine whether SPD tenant has produced appropriate an appropriate design solution	In the case of crowdsourcing, this process includes the evaluation of submitted ideas according to the defined quality criteria
Documentation	Document the process to reveal learning outcomes for future application	

5.6 Validation of the Social Product Development Framework

Validation of engineering research has traditionally demanded formal, rigorous and quantitative validation (Seepersad et al., 2006). There are some areas of engineering research, however, that rely on subjective statements which makes quantitative validation problematic (Munzner, 2009). The SPD framework presented in this thesis exists within this realm of engineering research. The authors, therefore sought validation methods that offered rigorous and formal validation of design methods.

Seepersad et al. offer one such validation approach defined as The Validation Square (Seepersad et al., 2006), as shown in Figure 5.9.

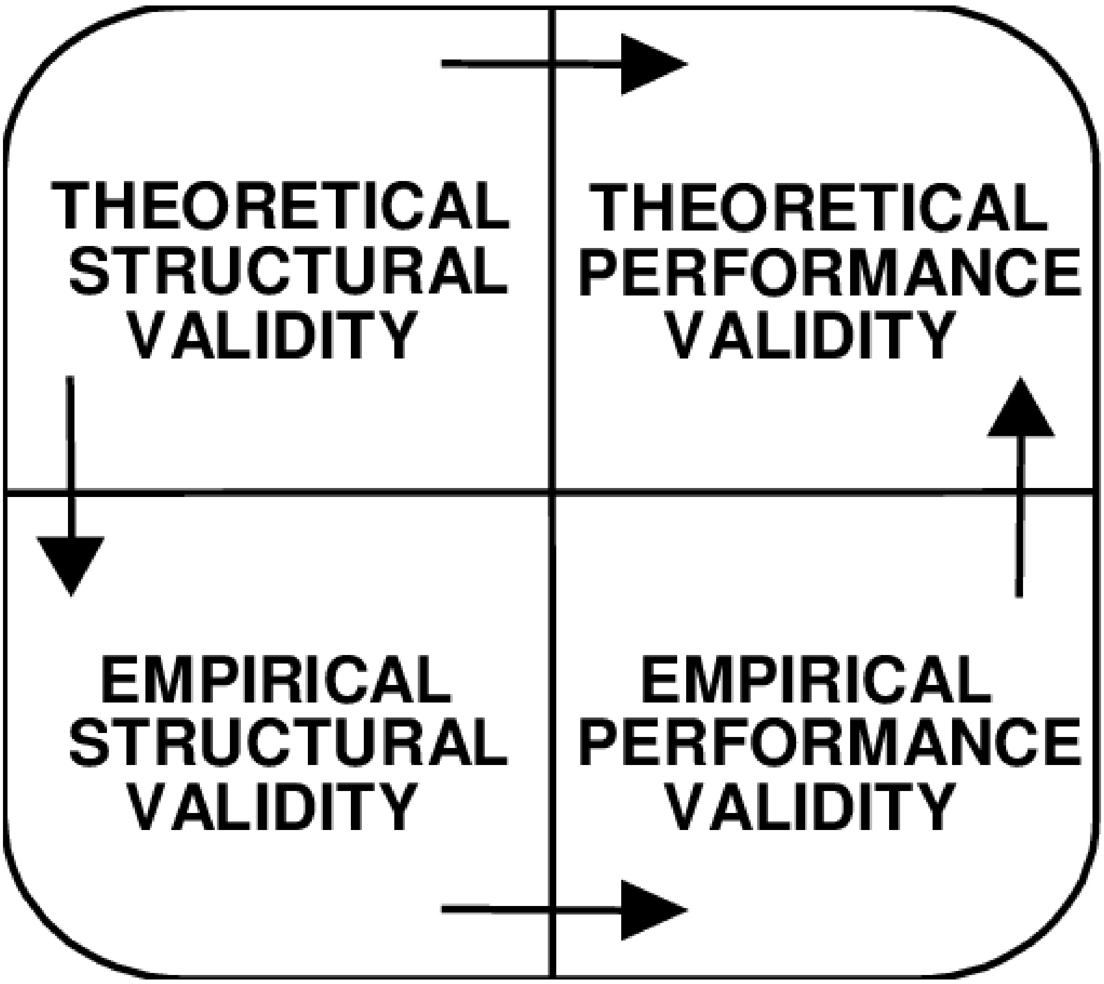

Figure 5.9: The Validation Square

Fundamental to this approach "is a process of building confidence in its usefulness with respect to a purpose" (Seepersad et al., 2006) consisting of four validation stages. The first two stages examine the structural validity of the design method determining whether the construction process is both effective and efficient. The latter two stages examine the performance of the design method, determining whether the design method provides effective and efficient design solutions. How these validation stages are defined in the context of the validation of the Social Product Development framework, is shown in Table 5.9.

Table 5.9: The Validation Square in the context of validation of the Social Product Development Framework

Validation Stage	**Definition**
Theoretical Structural Validity	Has a rigorous and methodical application of theory been used to construct the framework?
Empirical Structural Validity	Has the theory used to construct the framework been proven to offer effective design solutions?
Theoretical Performance Validity	Demonstrate that the design method can provide a design solution in an efficient way.
Empirical Performance Validity	Use the design method to demonstrate that the design method can provide effective design solutions.

Theoretical Structural Validity

The validity of the SPD framework, in this stage, is judged according to the process chosen to construct the SPD framework. In the absence of an existing construction method, the authors chose to use an existing design method. Existing design methods were chosen from a recent, "detailed and comprehensive" presentation of design methods, as provided by Wynn and Clarkson (2018), and design methods were rejected over a series of detailed evaluation stages.

Empirical Structural Validity

The validity of the SPD framework, in this stage, is judged on the validity of the underpinning theory to provide useful design solutions. In this case, the design methods most similar to the SPD framework are prescriptive design methods such as Pahl and Beitz (Pahl et al., 2013), Ullman's Stage Model (Ullman et al., 1988) and VDI2221 (Richtlinie, 1993). Each of these design methods, as described by Wynn and Clarkson, "convey best practices intended to guide real-world situations" (Wynn, Clarkson, 2018) and have been rigorously validated by the design community.

Theoretical Performance Validity

To demonstrate theoretical performance validity of the Social Product Development framework, a case study was presented in Table 5.7. This demonstrates the framework's use for the theoretical generation of a design solution.

Empirical Performance Validity

Within the time constraints of this research, it was not possible to conduct an empirical performance validity. This form of validation would have required industry practitioners to commit to launching an SPD initiative and allocate the budget and resources to do so. Furthermore, to gauge the effectiveness of the design method, results from this SPD initiative would then have to be collected and assessed. As discussed in Chapter 4, identifying organisations open to conduct SPD initiatives was difficult, even for the involvement in an interview study. Other research presented in this thesis was therefore prioritised over the attempted completion of an empirical performance validity activity.

5.7 Conclusions from Chapter 5

The main contribution of this chapter is a Social Product Development Initiative Selection framework that allows practitioners to prepare for SPD implementation and identify the SPD tenant that most suits their organisation.

In the absence of existing prescriptive literature on the designing of a design framework, an existing design method was adapted from Pahl and Beitz (Pahl et al., 2013), Ullman's Stage Model (Ullman et al., 1988) and the VDI2221 Stage Model (Richtlinie, 1993). In the SPD framework, Concept Generation and Evaluation is instead Tenant Selection and Evaluation and incorporates the use of a Tenant Selection and Evaluation tool titled The Quadrants of Social Product Development. The derivation of this tool presents three variables that all SPD tenants can be defined by; the number of actors, N, the proximity of the actor to the organisations, P_o, and the proximity of the actors to each other, P_a. The emergence of these common variables allows the selection of an SPD tenant for application, according to the needs and capabilities of the user.

A case study, demonstrating the use of this selection tool, is presented and represents one of the three validation phases included in this thesis. For further development of this SPD framework, existing limitations of the framework can be addressed. The Detailed Form Design phase of the framework requires design decisions regarding the SPD tenant to be made but the literature guiding these specific decision processes is currently lacking. This SPD framework, therefore, is a high-level design process for the application of SPD tenants and offers an indicator of future research directions, that will aid the application of SPD tenants.

5.8 Implications for Chapter 6

With reference to Table 5.10, the following section 6 aims to address the lack of assessment frameworks for SPD initiatives. Having supported the initial implementation of SPD with the framework presented in Figure 5.4, there was then a need to allow practitioners to understand the impact of their structural and design decisions in implementing SPD.

The following section, aims to define assessment metrics using the three variables presented in the previous section; Number of participants, N, Actor Proximity, P_a and Organisational Proximity, P_o. By doing so, practitioners would be able to understand how their SPD initiative would perform and therefore improve prior to implementation.

5.9 Chapter 5 Summary

This chapter represents the start of the research addressing Primary Research Question 2:

How can the implementation of SPD in industry be supported?

It also represents the first areas of research addressing user-identified Secondary Research Questions in order to support SPD implementation. Specifically, this chapter addresses the following Secondary Research Questions:

1. How to prepare a problem for an SPD initiatives?
2. How to determine which type of SPD initiative to choose?

This chapter starts with a description of the methodology of creating the SPD Tenant Selection Framework. It is found that a methodology to “design a design framework” does not exist and there is therefore a need to adapt an existing design method to structure the SPD Tenant Selection Framework.

By starting with Wynn and Clarkson’s (2018) organizational framework, which is exhaustive of all design methods, the appropriate design methods are identified through elimination. Methods are first eliminated due to their level of abstraction i.e. whether they are micro-level, meso-level or macro-level. Meso-level was identified as the appropriate level due to providing strcuture for the full product development process (unlike micro-level) but providing adequate detail to guide the process (unlike macro). Procedural methods were also identified to be most appropriate in order to provide instruction and guide th eproduct development process.

Table 5.10: Thesis Organisation

Chapter	**Page**	**Primary Research Question or Purpose**	**Secondary Research Question(s)**	**Tertiary Research Question(s)**
2	19	Present existing literature and literature gaps		
3	47	Present overall approach to addressing research questions		
4	56	**1** What are the barriers to the implementation of SPD in industry?	Secondary Research Questions identified in this chapter	
5	82	**2** How can the implementation of SPD be supported?	**2.1** How to prepare a problem for SPD initiatives? **2.2** How to determine which type of SPD initiative to choose?	
6	107	**2** How can the implementation of SPD be supported?	**2.3** How do structural decisions of an engineering design SPD initiative influence its design outcomes?	
7	119	**2** How can the implementation of SPD be supported?	**2.3** How do structural decisions of an engineering design SPD initiative influence its design outcomes? **2.4** How do design decisions of an engineering design SPD (crowdsourcing) initiative influence its outcomes?	**2.3.1** How does company reputation influence SPD success? **2.3.2** How does the number of stages in an SPD initiative influence success? **2.4.1** How does framing of engineering design problems in competitive scenarios influence its solutions? **2.4.2** How can SPD initiative designers effectively decompose an engineering design problem? **2.4.3** How can optimal incentive structures be formulated for SPD initiatives? **2.4.4** How does the complexity of a problem influence SPD success?

Individual meso-level procedural methods were then further eliminated after conducting an elementary task analysis on the requirements for an SPD Tenant Selection Framework. This resulted in three remianing methods; Pahl and Beitz (Pahl et al., 2013), VDI2221 (Richtlinie, 1993) and Ullman's Stage Model (Ullman et al., 1988) which would be combined to form the SPD Tenant Selection Framework. This is shown in Figure 5.4 and repeated below for reference.

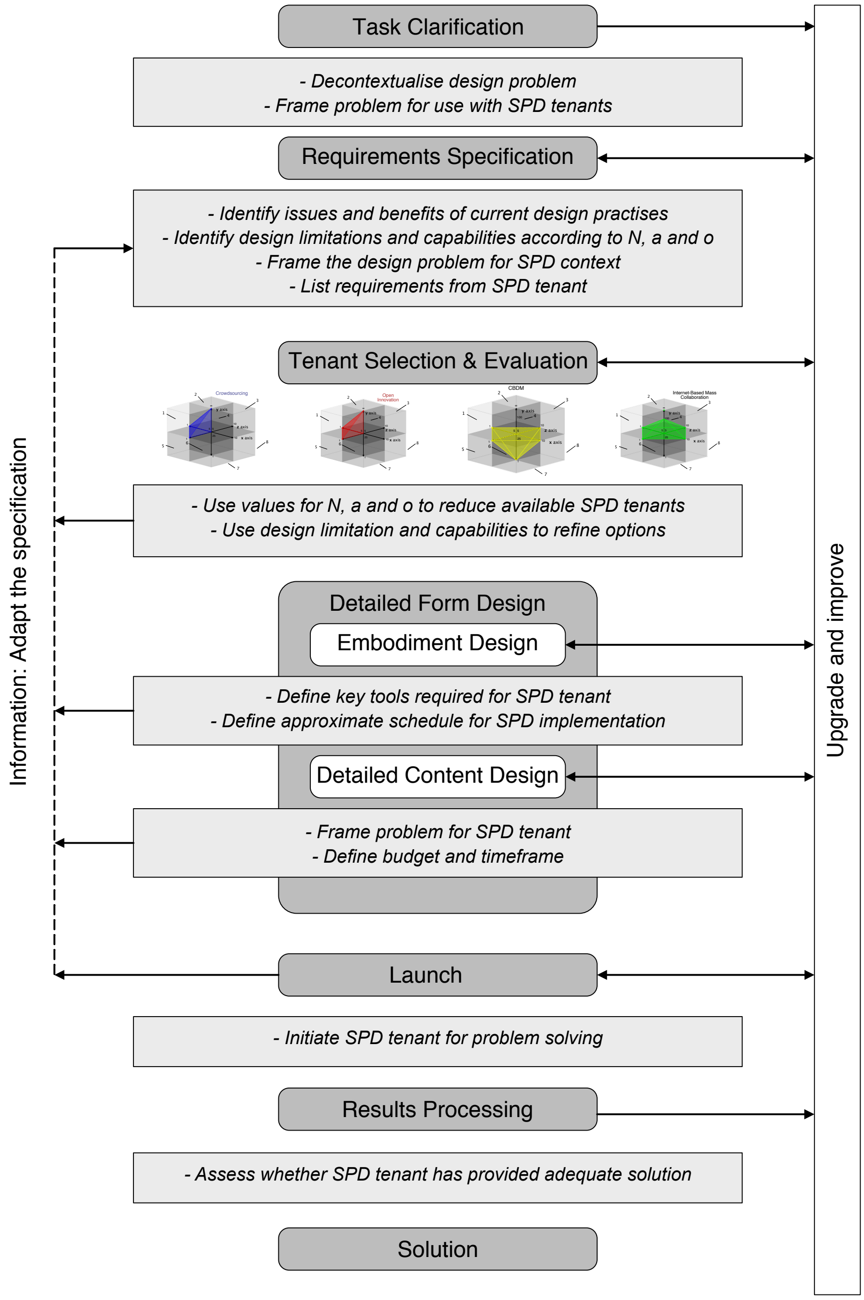

Figure 5.10: Adapted design method for SPD tenant selection

Following presentation of the overall framework, a specific stage was elaborated on; tenant selection and evaluation.

The difference between the SPD tenants can be represented by three core variables:

- Organisational Proximity (P_o): The nearness of the actors in relationship to the host organisations
- Actor Proximity (P_a): The nearness of the actors in relationship to other actors
- Number of Participants (N)

In this part of Chapter 5, each tenant is shown in relation to these core variables and the process for selecting the appropriate tenant is described. A validation process for the framework as well as a case study demonstrating how the framework may be used is included in this chapter.

The main contribution of this chapter is a Social Product Development Initiative Selection framework that allows practitioners to prepare for SPD implementation and identify the SPD tenant that most suits their organisation.

In the following chapter, the three variables presented in this chapter are tested for their suitability for an SPD success assessment framework.

Chapter 6

Assessing SPD Performance

This chapter represents a continuation of the research addressing Primary Research Question 2:

Primary Research Question 2: How can the implementation of SPD in industry be supported?

It also represents further research addressing Secondary Research Questions in order to support SPD implementation, as shown in Table 1.4. This is shown visually in Figure 6.1.

With reference to the Literature Review (Chapter 2), this chapter intends to address the literature gaps pertaining to Primary Research Question 2 as follows:

- Definitions of SPD success are very limited
- Definitions of SPD success and/or SPD tenant success are not standardized
- Metrics to assess SPD success do not exist
- Assessment frameworks for SPD success do not exist

Each of the Social Product Development tenants are related by and can be distinguished by three core variables. These variables are actor proximity (P_a), organizational proximity (P_o) and the number of participants (N). As described by Abhari et al. (2017) the involvement of external participants and how they relate to both each other and the leading organization is integral to Social Product Development success. In Chapter 5, Table 5.3 shows the scale and definitions of each variable and and Table 5.4 shows the variable values for each tenant. They are shown again in Table 6.1 and 6.2 for reference below.

Table 6.1: SPD Variables: Scale and definitions

Variable	Scale	Definition
Organisational Proximity, P_o	1 - 10	1 = the actor or involved party is an external organisation that has minimal knowledge beyond what is in the public domain 5 = the actor or involved party is within the same industry as the organisation 10 = the actor or involved party is within the same organisation but not within the same location as the project lead (Web 2.0 technologies are therefore required for involvement)
Actor Proximity, P_a	1 - 10	1 = the actors or involved parties do not have a relationship and do not collaborate with each other 10 = the actors or involved parties are within the same organisations each other and have at least professional relationships with each other
Number of Participants, N	1 - ∞	This refers to the number of people involved in the activity or the number of people with the opportunity to be involved in the activity

Table 6.2: SPD Tenants and Variable Values

SPD Tenant	P_a	P_o	N
Crowdsourcing	1 - 5	1 - 5	25 - ∞
Open Innovation	1 - 5	1 - 5	25 - ∞
Cloud-Based Design and Manufacture	1 - 10	1 - 10	1- ∞
Mass Collaboration	1- 10	1 - 10	25 - 100

Having proposed these three variables and demonstrated how each of the SPD tenants can be represented by them, a hypothesis is presented.

If these variables can define and describe the different tenants of SPD, they can be used to assess the performance of these variables.

The following section (Section 6.1) outlines the methodology for testing this hypothesis. The results are then presented in Section 6.2 followed by a discussion in Section 6.3 and conclusions in Section 6.4.

Published Work Included in the Chapter

Literature from the following published work is included in this chapter:

Forbes, H., Schaefer, D., Han, J. and De Oliveira, F.B., 2020. **Investigating Factors Influential on the Success of Social Product Development initiatives**. *Procedia CIRP*, 91, pp.107-112.

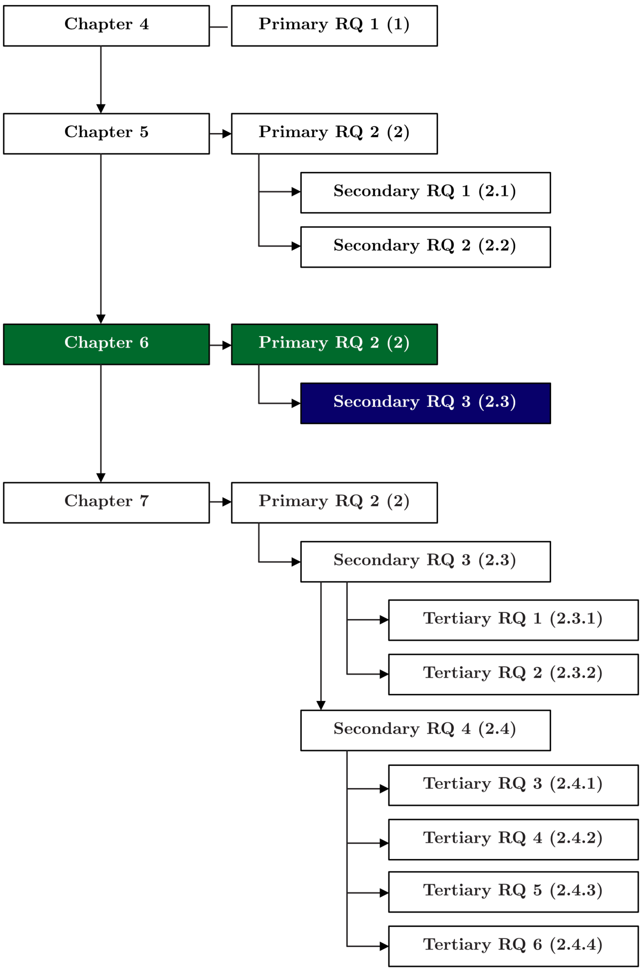

Figure 6.1: Research Question Organisation for Chapter 6

6.1 Expert Analysis Experiment Methodology

In order to test the hypothesis, an experiment was conducted to determine whether existing understanding of tenant success encompassed or was related to one or any of the variables. Metrics of success for crowdsourcing, open innovation, cloud-based design and manufacture, and mass collaboration are yet to be presented in these relatively new research fields, however, so definitions of success were instead used.

Definitions in existing literature are regularly used in design research to represent a consensus of understanding of a term (Micheli et al., 2019). For example, Han et al. (2019) use definitions of creativity in design to understand the relationship between functionality, aesthetics and creativity. Vital in this approach, however, is the use of a large number of definitions from leading journals in the field. Using Scopus, Web of Science and ScienceDirect as literature databases, keywords such as "crowdsourcing success" and "success in crowdsourcing" were used to yield 63 "statements of success". These statements were identified from existing literature as describing conditions or requirements for success for each tenant. Example success statements from each tenant are shown in Table 6.3.

Table 6.3: SPD Tenant Success Statements

SPD Tenant	Example Success Statement
Crowdsourcing	We suggest workers working collaboratively develop better crowdsourcing solutions
Open Innovation	Open innovation success is dependent on knowledge sharing with external participants
Cloud-Based Design and Manufacture	For cloud-based design and manufacture success customer expectations must be considered
Mass Collaboration	Individual personality traits influence mass collaboration success

To determine whether these success statements described a relationship between the success of the tenant and any of the variables, expert researchers were asked to tick any or none of the variables associated with the success statement. This survey is shown in Table 6.4. The use of expert researchers in similar analysis exercises is common in design research with authors such as Sarkar and Chakrabarti (2011), Chulvi et al. (2012) and Cropley and Kaufman (2019) using multiple expert researchers to establish an expert consensus in similar experiments.

Table 6.4: Analysis Experiment Participant Sheet

Success Statement	P_a	P_o	N
We suggest workers working collaboratively develop better crowdsourcing solutions			
Open innovation success is dependent on knowledge sharing with external participants			
For cloud-based design and manufacture success customer expectations must be considered			
Individual personality traits influence mass collaboration success			

Expert researchers were asked to tick the corresponding box if they thought the success statement related to the variable. Multiple variables or "None" could be selected for each success statement.

6.2 Experiment Process and Results

Five expert researchers, with a mean age of 29.6 (Standard Deviation, $\sigma = 4.0$) and a mean research experience of 4 years ($\sigma = 0.6$), were involved in this analysis experiment. The experts were all research professionals with PhDs at a Univeristy based in the UK. The experts participated in the evaluation voluntarily with intrinsic motivations (Han et al., 2019). Although the number of experts seems low, there are no common agreements on the number of experts required for an evaluation (Lai et al., 2006). Comparing with general evaluators, the required number of expert evaluators is far less (Achiche et al., 2013).

To determine whether a variable was related to the success of a tenant, each success statement was given a "relatability metric" for each variable. This metric represented the number of researchers that marked the variable as relating to the success statement. For example, if three researchers deemed the variable to be related to the success statement, a value of 0.6 was listed. These values were then averaged across all success statements for each tenant. According to List (2001), a value of 0.75 or above is required to indicate expert consensus. Table 6.5 below shows that the expert researchers determined only one relationship, of the nine tested, to represent a consensus ($*$). The expert researchers determined open innovation success to be related to organizational proximity (P_o) but determined no other relationships between tenant success and three variables as outlined in the hypothesis.

To determine internal consistency in the expert researchers results, Fleiss' Kappa coefficient was used. Fleiss' Kappa is a generalization of Scott's pi statistic (Fleiss, Cohen, 1973), a statistical measure of inter-rater reliability and works for any number of raters

Table 6.5: SPD Success Experiment Results

SPD Tenant	**Relatability Metric**		
	Pa	**Po**	**N**
Crowdsourcing	0.186	0.243	0.286
Open Innovation	0.156	0.756*	0.011
CBDM	0.108	0.215	0.123
Mass Collaboration	0.4	0.313	0.075

Table 6.6: SPD Success Kappa Results

SPD Tenant	**Kappa Metric**		
	$\overline{\mathrm{P}}$	$\overline{\mathrm{P_e}}$	κ
Crowdsourcing	0.736	0.253	0.646[a]
Open Innovation	0.816	0.463	0.657[a]
CBDM	0.646	0.380	0.429[b]
Mass Collaboration	0.671	0.291	0.535[b]

giving categorical ratings, to a fixed number of items. To calculate Fleiss' Kappa all possible outcomes must be mutually exclusive. If one researcher marked the statement as relating to P_a and another marked the statement as relating to P_a and P_o this was marked as a disagreement with "P_a" and "$P_a + P_o$" being listed as two mutually exclusive events. Fleiss' Kappa coefficient is calculated using the equation below and Table 6.6 shows the results for each tenant.

$$Kappa, \kappa = (\overline{\mathrm{P}} - \overline{\mathrm{P_e}}) \div (1 - \overline{\mathrm{P_e}})$$

Equation 6.3.1

Fleiss' Kappa is interpreted according to Table 6.7 below by Landis and Koch (1977). This defines the internal agreement between assessors as above moderate agreement for all tenants and substantial agreement for crowdsourcing and open innovation.

Table 6.7: Fleiss' Kappa Interpretation (Landis, Koch, 1977)

κ	**Interpretation**
<0	No agreement
$0.01< \kappa < 0.20$	Slight agreement
$0.21< \kappa < 0.40$	Fair agreement[a]
$0.41< \kappa < 0.60$	Moderate agreement[b]
$0.61< \kappa < 0.80$	Substantial agreement
$0.81< \kappa < 1.00$	Almost perfect agreement

6.3 SPD Success Discussion

The results show that only one relationship, between open innovation and organizational proximity (P_o), was defined by consensus by the researchers. All other relationships were deemed non-existent by at least three out of five assessors. These results, supported by moderate ($0.4 < \kappa < 0.6$) and substantial agreement ($0.6 < \kappa < 0.8$), disprove the hypothesis and suggest that organizational proximity (P_o), actor proximity (P_a) and the number of participants (N) are not influential in the success of Social Product Development (SPD) tenants and cannot be used to assess the performance of SPD initiatives.

A reason for these results could be due to the fact that most success statements focused on the outcomes as defining success as opposed to the dynamics of an SPD initiative and how that initiative was regarded as a success as a consequence. This is perhaps reflective of an existing approach to SPD tenants, by considering them as a "means to an end" without considering the design of the SPD initiative to influence the outcome. The use of "success statements" for this experiment could have also led to these results by introducing several uncertainties. In the absence of success metrics, definitions of success are often consolidated and used as a replacement (Micheli et al., 2019). In the case of this emerging field, however, definitions are often inconsistent and ambiguous. For example, Striukova and Rayna (2015), define "increasing involvement" as a factor for success in open innovation. While expert researchers, offered substantial agreement on this statement, "involvement" could refer to effort by existing participants or "increasing" number of participants. The results indicated a relationship between open innovation and organizational proximity (P_o). The authors suggest that this result emerged from a consistent theme among open innovation success statements that included references to organizational relationships. Based on the limitations discussed in this chapter, to truly establish whether this relationship exists, further research into this relationship should be conducted.

As well as ambiguity in the resulting "success statements", existing literature presented different interpretations and perspectives on success that were inconsistent. For example, Warner (2011) states that "most critical crowdsourcing success is that participants felt their input was considered and acted upon" while Westergren (2010) states "defined roles within an organization" is vital to open innovation success. It was therefore not only differing opinions on the factors for success but differing opinions on from what perspective success should be determined. Furthermore, with open innovation literature, some authors described creating a "successful open innovation environment" as opposed to "successful outcomes of open innovation". In addition, while most statements considered dynamics of the tenants that influenced success, in some cases, particularly within CBDM, "practical" aspects such as "reduce latency" were presented which were not within the realm of success factors originally considered or accounted for by the authors. Furthermore, while the authors aimed to ensure the success statements could be interpreted outside of the context of their origin, it may have been the case that a lack of context could result in different interpretations of the statement. The key issue is that, with work on SPD tenants in its infancy, the definitions of "SPD success" are still emerging and it could be said that this experiment should be conducted when success definitions are more widely known and used.

These definitions of success also encourage further consideration of the term SPD and whether tenants of differing dynamics can be usefully grouped and studied under one term. As defined in this thesis, Social Product Development tenants either individually or in concert contribute to the democratization of design, manufacture and innovation. The authors questions whether the broad subject of Social Product Development can be investigated when individual tenants, as demonstrated by definitions of success, vary significantly. It is considerations such as this which encourage deeper research to develop the field of individual tenants as opposed to consider Social Product Development as a whole.

6.3.1 SPD Success Limitations

Despite adequate agreement to validate the results, more expert researchers would improve the value of these results. Furthermore, the standard deviation of the experience of the participants ($\sigma = 0.6$) showed a limited variety of experience levels which is another limitation to these results. Furthermore, while years of experience is not a strict measurement of expertise, an average experience level of 4 years is considered low in comparison within other design research (Chulvi et al., 2012). Increasing the number of design experts, varying levels of expertise with a higher average level of expertise, limit the results of this study.

Another limitation refers to the interpretation of Fleiss' Kappa (Fleiss, Cohen, 1973) by Landis and Koch 1977. While this is most widely used to interpret Fleiss' Kappa results, it has been criticized for inaccuracies in the case of more than three variables (Sim, Wright, 2005). While the study included three variables, the ability to answer with multiple variables led to more than three mutually exclusive events for testing agreement. In general, academics suggest that agreement interpretation for larger variables is too harsh with the Landis and Koch interpretation (Sim, Wright, 2005). It is therefore the case that, if adjusted for the inconsistencies, these results would demonstrate higher agreement and the reliability of the results would not be compromised.

Finally, the success statements were collected exclusively from literature relating to the SPD tenants and therefore exclusively used this terminology. This was done to ensure consistency within the scope of the analysis study. It is the case, however, that other research areas within design will contain other success statements relating to the SPD tenants. For example, extensive research within "collaborative design" may inform the success metrics for "mass collaboration" and success statements for "open source" may inform success metrics for "crowdsourcing". These success statements were not included to limit length and complexity of the study for participants but may provide additional findings in future work.

6.3.2 SPD Success Future Work

Definitions of success for each tenant are complex but understanding the dynamics of success could allow the design industry to capture the benefits of Social Product Development. To demonstrate the complexity of the dynamics of SPD success, crowdsourcing is considered successful when it has lots of high-quality solutions. However, if there are too many solutions, the cost of evaluation may cause the initiative to be more expensive than an in-house team. This then defines the crowdsourcing initiative as a failure (Panchal, others, 2015). Valuable further work, relating to each of the tenants, could include investigating the dynamics for success then supporting practitioners in making effective design decisions.

Furthermore, designing SPD tenants has been proven important in extracting value from external participants (Panchal, others, 2015) but limited research exists in this area. Striving to create success metrics for Social Product Development should be supported by frameworks to aid the methodical design of SPD tenant initiatives. Designing SPD tenant initiatives involves a series of decisions such as which communication platform to host a crowdsourcing contest on or the incentivisation of involvement in an open innovation initiative. Recognition of this decision-making process as well as an understanding of how these decisions impact the success of an SPD tenant initiative will support practitioners in capturing the benefits of applying Social Product Development.

6.4 Conclusions for Chapter 6

Existing literature is yet to present metrics for success for Social Product Development Initiatives. In this thesis, three variables were presented and proposed as metrics of success; actor proximity (P_a), organizational proximity (P_o) and number of participants (N). To determine whether these variables were related to success, a study was conducted with expert researchers analyzing SPD tenant "success statements".

The results showed that only one relationship; organizational proximity and open innovation reached the 0.75 relatability metric required to indicate researcher consensus. The researchers showed moderate to substantial agreement, therefore indicating the results were reliable. As a consequence, the three variables were deemed to not be adequate metrics for SPD success. As well as offering insights into the best approach for allocating success metrics for SPD, this study also raises the challenge of studying a term representative of four very different tenants. This study also demonstrates the limitations of using definitions of success for analysis in an emerging field and the need to simultaneously develop design frameworks to support methodical design of SPD tenants as well as establish success metrics.

6.5 Implications for Chapter 7

The conclusions of this chapter, support the use of individual assessment framework for SPD tenants, as opposed to SPD as a whole.

It is therefore the case that this chapter did not address the literature gaps as outlined in the introduction to this chapter but instead provide evidence to support the creation of individual tenant frameworks.

As shown in Table 6.8, the following chapter aims to address the same literature gaps but for the SPD tenant of crowdsourcing, as opposed to SPD as a whole.

6.6 Chapter 6 Summary

This chapter represents a continuation of the research addressing Primary Research Question 2. It also represents further research addressing Secondary Research Questions in order to support SPD implementation:

- How do structural decision of an engineering design SPD initiative influence its design outcomes?
- How can SPD initiatives be assessed as successful or not?

This chapter builds on the knowledge created in the previous chapter with regards to the three SPD variables. Having proposed these three variables and demonstrated how each of the SPD tenants can be represented by them, a hypothesis is presented:

If these variables can define and describe the different tenants of SPD, they can be used to assess the performance of these variables

Table 6.8: Thesis Organisation

Chapter	**Page**	**Primary Research Question or Purpose**	**Secondary Research Question(s)**	**Tertiary Research Question(s)**
2	19	Present existing literature and literature gaps		
3	47	Present overall approach to addressing research questions		
4	56	**1** What are the barriers to the implementation of SPD in industry?	Secondary Research Questions identified in this chapter	
5	82	**2** How can the implementation of SPD be supported?	**2.1** How to prepare a problem for SPD initiatives? **2.2** How to determine which type of SPD initiative to choose?	
6	107	**2** How can the implementation of SPD be supported?	**2.3** How do structural decisions of an engineering design SPD initiative influence its design outcomes?	
7	119	**2** How can the implementation of SPD be supported?	**2.3** How do structural decisions of an engineering design SPD initiative influence its design outcomes? **2.4** How do design decisions of an engineering design SPD (crowdsourcing) initiative influence its outcomes?	**2.3.1** How does company reputation influence SPD success? **2.3.2** How does the number of stages in an SPD initiative influence success? **2.4.1** How does framing of engineering design problems in competitive scenarios influence its solutions? **2.4.2** How can SPD initiative designers effectively decompose an engineering design problem? **2.4.3** How can optimal incentive structures be formulated for SPD initiatives? **2.4.4** How does the complexity of a problem influence SPD success?

This hypothesis is tested by an expert analysis experiment which is conducted to determine whether existing understanding of tenant success encompassed or was related to one or any of the variables. Expert researchers were asked to tick any or none of the variables associated with the success statements.

Expert researchers were asked to tick one, several or none of the boxes represented each variable to state whether or not they believe the variables were related to the success statement.

IRR found the experts to show moderate to good agreement and therefore it was determined that these results provided evidence that the three SPD variables could not be used to assess or predict SPD initiative performance. This is because only one relationship (Open Innovation and Organisation Proximity, P_o) was shown to be significant.

Further insight into these results and limitations to the experiment are described in later sections of this chapter, along with further research avenues and conclusions. This chapter therefore does not address the primary or Secondary Research Questions but it does provide evidence for the use of individual tenant assessment frameworks, instead of assessment frameworks for SPD as a whole which, in itself, is a contribution to the field. The following chapter (Chapter 7) aims to address the same literature gaps as intended in this chapter but from an individual tenant standpoint.

In the following chapter, having determined that SPD success assessments should be isolated to individual tenants, a SPD success assessment framework is derived and presented for crowdsourcing.

Chapter 7

Crowdsourcing Success Factor Experiment

There is a need to provide practitioners with a way to understand the impact of their design decisions when implementing SPD initiatives. As shown in the previous chapter, this is most effectively provided by research on individual tenants. The individual tenant of crowdsourcing was therefore chosen to explore.

The reasons for choosing crowdsourcing is as follows:

1. The interviewees that provided Secondary Research Questions for this thesis, mostly had experience with crowdsourcing and therefore their insights are most relevant to this tenant

2. Crowdsourcing is usually time-bounded and therefore it is difficult to improve during a crowdsourcing initiative and implementing initially correctly is imporant

3. Crowdsourcing can be an unpredictable process and crowdsourcing failure is common

In this chapter a new literature review (Section 7.2.1) identifying specific gaps in the context of crowdsourcing (as opposed to SPD as a whole) is presented. As part of this section, potential crowdsourcing influential factors are identified. Data analysis and results follows in Section 7.4 then a validation is presented in Section 7.5 and a discussion in Section 7.6. This chapter finished with a discussion of the limitations and further work associated with this research. The research questions addressed in this chapter is shown visually in Figure 7.1.

Work Pending Publication Included in the Chapter

Literature from the following published work is included in this chapter:

Forbes, H. and Schaefer, D., 2021. **Investigating Factors Influential on the Success of Crowdsourcing Contests**.

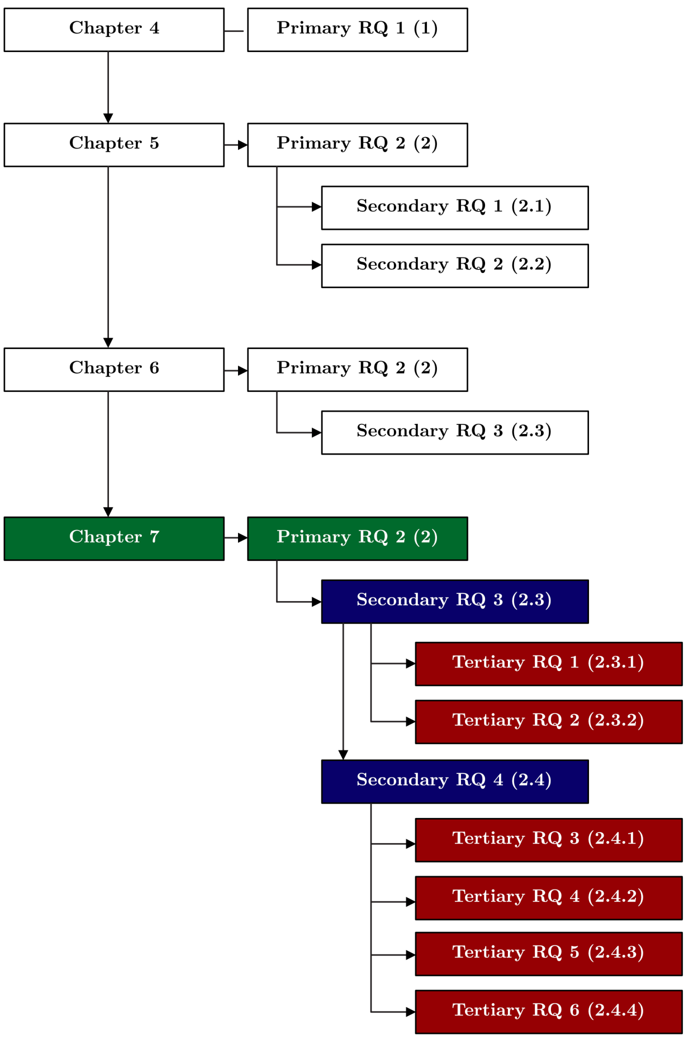

Figure 7.1: Research Question Organisation for Chapter 7

7.1 Introduction to Crowdsourcing Success Factor Experiment

Crowdsourcing is an application of open innovation methods that involves the outsourcing of a task to the crowd (Shergadwala et al., 2020; Howe, 2006). In an engineering design context, successful high profile case studies include Procter and Gamble's "Connect and Develop" (Huston, Sakkab, 2006), and DARPA's Adaptive Vehicle Make (AVM) (Shergadwala et al., 2020). The results of these studies demonstrate the power of engaging a diverse crowd in design phases such as requirements elicitation, ideation, and concept evaluation (Shergadwala et al., 2020).

While there is clear evidence of the benefits of crowdsourcing, it is also known that not all crowdsourcing initiatives are equally effective or successful (Panchal et al. 2015). Modes of crowdsourcing failure include a lack of participation, a lack of quality submissions and overspending on the initiative as to make the crowdsourcing process more expensive than in-house task completion. Crowdsourcing failure is common (Khanfor et al., 2017) and while existing literature provides some insight into influential factors for crowdsourcing success, further investigation into factors such as problem complexity, problem framing, company reputation, platform and non-monetary incentives is required to support practitioners in achieving crowdsourcing success.

In Chapter 7.2, existing crowdsourcing success factor literature is reviewed and gap analysis is presented along with the research aim and objectives for this thesis. The chapter continues with identification of all influential factors as raised by existing literature, which will be used as a starting point for the experimental work presented in this thesis.

7.2 Literature Review for Crowdsourcing Success

In this section, existing literature on crowdsourcing, within and outside the context of engineering design is reviewed. This review has two outputs; firstly the recognition of literature gaps in this sector and secondly, a consolidated list of the influential factors presented by existing literature. Existing literature can be consolidated into the following sectors:

- Experimental work on crowdsourcing success factors and identification of literature gaps
- Investigations into problem framing in context of crowdsourcing
- Investigations into motivation and incentives in context of crowdsourcing
- Investigations into platform design of crowdsourcing platforms

- Investigations into company reputation and crowdsourcing
- Investigations into problem complexity and crowdsourcing
- Investigations into IP ownership and initiative design

7.2.1 Experimental work on success factors & Identification of Literature Gaps

While academic work on crowdsourcing success factors is limited there are a few publications that present similar experimental investigations into crowdsourcing success factors. In the context of engineering design, Chaudhari et al. (2018) analyze participant behaviour in design crowdsourcing contests. In determining influential factors on crowdsourcing success they collect and analyse data from GrabCAD (GrabCAD, 2020) as well as proposing game-theoretic models for participant behaviour. They state that in order to yield insights into crowdsourcing success it is “necessary to understand how the outcomes of crowdsourcing contests are affected by sponsor-related, contest-related, problem-related, and individual-related factors”. Problem-related factors include those such as “task size”, “technical difficulty” and “feasibility”. Contest-related includes aspects of contest design such as the “number of stages” and sponsor-related includes factors related to the platform hosting the initiative such as InnoCentive, Chaordix or GrabCAD (GrabCAD, 2020; Chaordix, 2020; InnoCentive, 2020). Individual-related factors relate to participant behaviour and are not included as part of this experiment. They include factors such as “effort made by participant” and “likelihood of participant success”. The relevant factors regarded as influential on crowdsourcing success by Chaudhari et al. are presented in Table 7.1.

Zheng et al. (2011) conducted an investigation into design contests hosted in the crowdsourcing site Taskcn (2020). Specifically, they were interesting in understanding the relationship between the characteristics of the presented task, motivation and participation in the contest. They highlighted five contest-related factors; autonomy, variety, tacitness, analyzability and variability of the contest problem (as shown in Table 7.1). Li et al. (2013) investigate factors of software design contests that result in high quality. Factors investigated include the average quality score of the platform, the number of contemporary projects, the length of component document, the number of registered developers, the maximum rating of submitted developers, and the design score (shown in Table 7.1.)

Panchal (2015) presents a framework for crowdsourcing initiative design. The design decisions presented in this framework, as shown in Figure 7.2, represent factors influential on the success of a design crowdsourcing campaign. Panchal (2015) includes structural decision, problem-related decisions, and evaluation and incentive-related decisions. The specific factors included in these sectors are outlined in Table 7.1.

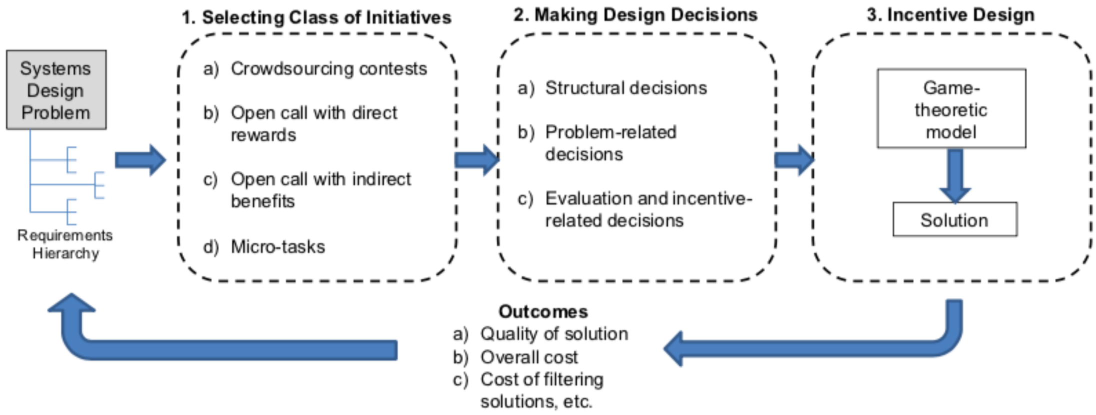

Figure 7.2: Framework for the Design of Crowdsourcing Initiatives Panchal, others (2015)

Franke et al. (2014) suggest that random and not deterministic factors result in crowdsourcing success. They hypothesise that a lack of repeated results in existing experimental investigations on crowdsourcing success factors suggest that viewing crowdsourcing success as deterministic is the core of this problem. As discussed earlier, however, several key factors such as brand reputation are yet to be considered in existing literature. We therefore suggest that it is too early in the development of the field to arrive at the conclusion that crowdsourcing success is based on randomness. As part of their investigation, Franke et al. (2014) did test several potentially influential success factors which are included in Table 7.1.

7.2.2 Problem Complexity and Crowdsourcing

Mahr et al. (2015) discuss "the role of creative and deliberate problem-solving styles" in crowdsourcing success. Mahr et al. (2015) suggest that the type of problem-solving style as well as the extent of contextualisation impacts crowdsourcing success. Furthermore, Bragg and Weld (2018) consider problem framing to be vital for crowdsourcing success. They state that "effective task design underlies nearly every reported crowdsourcing success, yet remains difficult to accomplish". They present a framework to support problem solving for crowdsourcing and highlight some aspects of problem framing that support crowdsourcing success. These suggested influential factors are shown in Table 7.1.

Romanczuk et al. (2017) considers crowdsourcing alongside other methods used to enhance defense acquisition. The thesis includes comparison of a "confluence of technologies holding the key to faster development time linked to real warfighter evaluations." Semi-structured interviews with a panel of defence acquisition experts were conducted to determine the critical success factors for all methods, including crowdsourcing. Some outcomes are specific to the context of defence acquisition such as "mission space characterization" but others are applicable to other contexts and included in Table 7.1. Gefen et al. (2016) investigate problem description length and its impact on crowdsourcing success. Specifically, they aim to determine how problem description length impacts participation in software crowdsourcing initiatives. The proposed influential factors, stated by Gefen et al. (2016) are included in Table 7.1.

7.2.3 Motivating Participation and Incentives in Crowdsourcing

As defined by Panchal (2015), lack of participation is defined as a mode of failure and for organisations with small communities or minimal awareness, attracting participation can be difficult. Several authors provide insight into attracting participation and by doing so present influential factors for crowdsourcing success.

Zheng et al. (2011) use theories of extrinsic and intrinsic motivations to develop a research model to explain participation in crowdsourcing contests. Zheng et al. (2011) found that with respect to extrinsic motivation, participators were more interested in recognition than financial reward, and initiative designers should therefore engage financial reward strategies as opposed to offering a single monetary reward. The type and number of incentives therefore influences crowdsourcing success. Zheng et al. (2011) also discussed the importance of sponsor (or initiative designer) interaction with participants and potential participants, to encourage participation. This is dependent on platform design and how GrabCAD and Innocentive each "facilitate communication with participants" Zheng et al. (2011).

With regards to intrinsic motivation, Zheng et al. (2011) found that task attributes had a significant impact on participation due to inclusion or exclusion of intrinsic motivators. For example, Zheng et al. (2011) found that task autonomy was important to participants and initiative designers should ensure contestants have sufficient flexibility in their problems to allow creativity. "Sponsors should not publish contests that include simple and repetitious activities, which may be boring to solvers" Zheng et al. (2011). Kaufmann et al. (2011) also state that intrinsic motivation significantly impact participation in crowdsourcing contests stating "task autonomy" and "skill variety" as highly valued by potential participants. Problem framing is therefore included in Table 7.1 as an influential factor that dictates motivation and therefore crowdsourcing success.

Chandler and Kapelner (2013) "explore the relationship between the "meaningfulness" of a task and worker effort". They define "meaningfulness" as the impact a participant solution may have. For example, a solution that is directly used in the fight to cure cancer is considered more "meaningful" than a solution that is not pursued further by the organisation. Chandler and Kapelner (2013) found that when a task was "framed more meaningfully" participation was increased and the quantity of output was also increased. Problem framing, specifically according to how "meaningful" the problem is considered to be is an influential factor in crowdsourcing contests.

Rogstadius et al. (2011) hypothesise that while extrinsic motivations such as "increased monetary reward generally increase workers' willingness to accept a task or the speed at which a task is completed, but do not improve the quality of the work". They instead investigate the role of intrinsic motivations in improving quality. Rogstadius et al. (2011) find that contrary to their hypothesis, both intrinsic and extrinsic motivations increase output quality but intrinsic motivations, as predicted in their hypothesis have the greatest positive impact. As listed in their hypothesis, extrinsic motivators considered influential factors are increase in monetary reward and intrinsic motivators are listed as work for a not-for-profit organisation. These are therefore included as influential factors in Table 7.1.

7.2.4 Platform Design and Behaviour

Presswire (2020) investigate the behaviour of the platform and the behaviour of the "campaign host" or company. They state that success in crowdsourcing depends on the platform and campaign host provide "pro-active" and "reactive attention". Organizations should "give to get" and "show [they] care" be communicating with potential participants before and during the campaign. Furthermore, Vignieri (2020) explore the drivers of success associated with crowdsourcing platform design. They emphasise the presence of the "network effects" triggered by the crowdsourcing platform that could impact the success of a crowdsourcing initiative. Figure 7.3 by Vignieri (2020) shows these network effects at play and the outlined influential factors are shown in Table 7.1.

Romanczuk et al. (2017) considers crowdsourcing alongside other methods used to enhance defense acquisition. The thesis includes comparison of a "confluence of technologies holding the key to faster development time linked to real warfighter evaluations." Semi-structured interviews with a panel of defence acquisition experts were conducted to determine the critical success factors for all methods, including crowdsourcing. Some outcomes are specific to the context of defence acquisition such as "mission space characterization" but others describe aspects that Romanczuk et al. (2017) consider to make a successful crowdsourcing platform.

Dissanayake et al. (2015) "inspect the social network structure within self-organized virtual teams that compete in online crowdsourcing contests involving rewards". They aim to understand how team work and collaboration impacts the quality of solutions in crowdsourcing contests. Specifically, they seek to determine how a team's social capital and intellectual capital influences their performance in crowdsourcing contest. While

Dissanayake et al. (2015) do not provide suggestions for influential factors for initiative design, instead studying team performance, they allude to the need for collaboration for crowdsourcing. This suggestion is therefore included in Table 7.1.

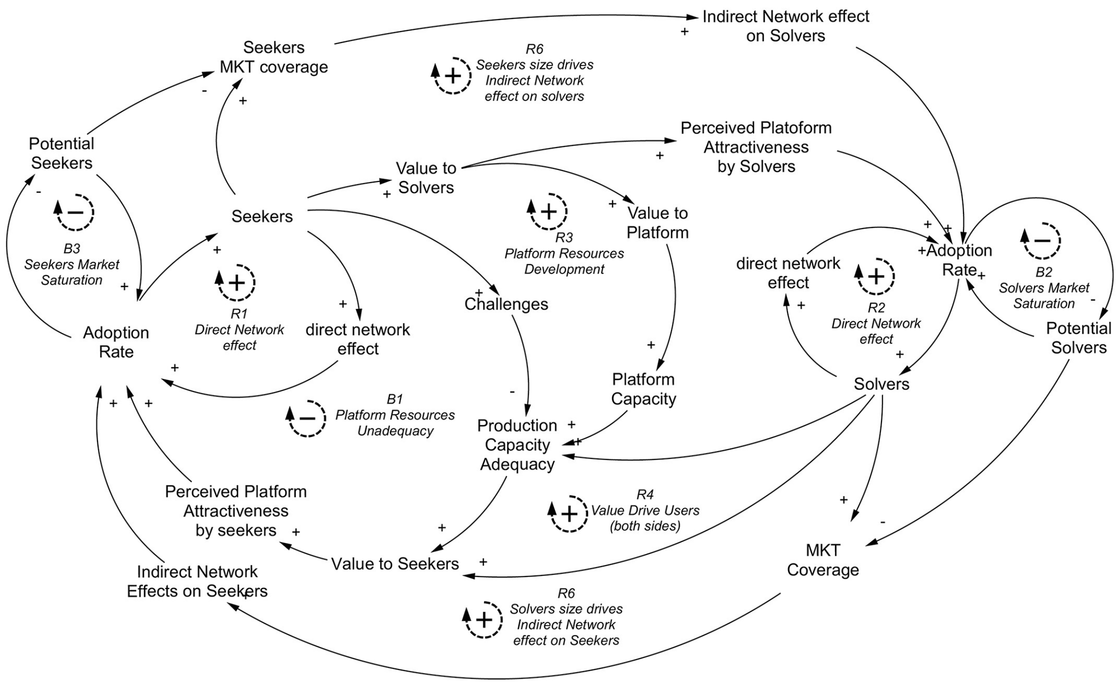

Figure 7.3: Causal Loop Diagram of Crowdsourcing Platforms Vignieri (2020)

7.2.5 Company Reputation and Crowdsourcing

Company reputation and its relationship with crowdsourcing success has not been discussed extensively in crowdsourcing literature. It is the case, however, that in areas of existing literature, company reputation or brand awareness (considered synonymous for this exercise) have been connected to crowdsourcing success.

Gatautis and Vitkauskaite (2014) discusses the use of crowdsourcing as a marketing activity, suggesting that smaller organisations can use crowdsourcing to "increase brand awareness" and large companies can "leverage their existing customer base". By making the distinction between these types of companies, Gatautis and Vitkauskaite (2014, 2016) suggests that large companies with an existing following may entice more participation and therefore a higher number of submissions. Furthermore, Hossain (2012) states that the "influential extrinsic motivational factors are reputation, status, peer pressure, fame, community identification and fun". Hossain (2012) refers to both the reputation of the individual and reputation of the company as influential factors. The reputation of an individual winner of a crowdsourcing contest is to be increased with a greater sponsor reputation.

Zolkepli et al. (2015) considers a quantitative measure of brand awareness through considering the number of Instagram followers (Instagram, 2020) in the context of crowdsourcing. Their study outlines important constructs that should be considered "as antecedents of participative behaviour of crowdsourcing". They state that social media followers can "be used as a blueprint to maximize efforts in strengthening brand value through crowdsourcing". Zolkepli et al. (2015) therefore cite company reputation, specifically the number of social media followers, as an influential factor for crowdsourcing success.

7.2.6 Intellectual Property and Crowdsourcing

Intellectual property in crowdsourcing contests is a thoroughly debated topic. There are some that believe crowdsourcing is exploitative by organisations of individual talent while others believe organisations give crowdsourcing participants a platform. As discussed in previous sections, motivation to participate is often a consequence of potential recognition or reputation gained from participation. It is therefore the case that how credit for ideas is advertised and awarded is likely to influence participation in crowdsourcing contests.

Beer de et al. (2017) discuss the legal implications of crowdsourcing and management of intellectual property. They discuss the important of managing crowd expectations and clearly defining intellectual property procedures before encouraging participation. They define intellectual property management as a significant factor in crowd engagement and emphasise the importance of intellectual property to potential crowd participants. Mazzola et al. (2018) provide a "study on the determinants and consequences of alternative intellectual property rights" stating that there is a lack of understanding between sponsors and solvers on how intellectual property should be managed. Beyond just communication of intellectual property rights "we are no closer to understanding what guides seeker firms in deciding the level at which to acquire rights from solvers". Furthermore, the effect that this decision has on the performance of crowdsourcing contests is also not understood. Mazzola et al. (2018) conclude in their study that the type of intellectual property does impact crowd participation. As a consequence, they also suggest further research in problem framing to ensure expectations regarding intellectual property are clearly communicated to potential participants. Furthermore, Kannangara and Uguccioni (2013) state that if the crowd have the ability to "generate intellectual property" through a crowdsourcing contest engagement will be increased.

Intellectual property management has therefore been raised as an influential factor on crowdsourcing success and is included in Table 7.1. All influential factors as presented by this literature review are shown in Table 7.1.

Table 7.1: Factors influential to the success of crowdsourcing initiatives according to existing literature

References	**Success Factors**
Chaudhari et al. (2018)	Problem-related: Task size, technical difficulty, variability of required skills, uncertainty in solution, feasibility Sponsor-related: Sponsor interaction, feedback to participant's questions, trust worthiness, reputation popularity Contest-related: Number of prizes, Monetary amount of prizes, number of stages
Zheng et al. (2011)	Contest-related: Autonomy, variety, tacitness, analyzability, variability, number of incentives, type of incentive, platform (facilitation of communication with participants), problem framing (task autonomy and variety)
Panchal (2015)	Structural decisions: Number of stages, restrictions to entry, duration and team formation Problem-related decisions: System decomposition and information shared Evaluation and Incentive-related decisions: quality assessment, choice of winners, distribution of rewards
Mahr et al. (2015)	Problem-related: Required problem solving style (creative or deliberate) and extent of contextualization of problem statement
Franke et al. (2014)	Organization of tournament: incentives, interaction, task framing Situation: external support, motivation, time spent, timing of tournament
Presswire (2020)	Platform-related: Ease and facilitation of communication with participants and potential participants
Bragg and Weld (2018)	Problem-related: number of required affordances, ambiguity of the problem, contextulaization of the problem Platform-related: Opportunity for workers to receive feedback, opportunity to ask questions over ambiguous problem statement
Vignieri (2020)	Platform-related: Facilitation of communication between participants, facilitation of feedback from platform, facilitation of feedback from organization, facilitation of clarification questions (regarding problem)
Romanczuk et al. (2017)	Platform-related: Accessibility of crowdsourcing problem, support from organisation, responsibility of evaluation, feedback available to solvers, collaboration available between solvers
Gefen et al. (2016)	Problem-related: Length of project description Design-related: Duration of initiative
Zheng et al. (2011)	Number of incentives, type of incentive, platform (facilitation of communication with participants), problem framing (task autonomy and variety)
Kaufmann et al. (2011)	Problem framing (skill variety and task autonomy), type of incentive
Chandler and Kapelner (2013)	Problem framing (meaningfulness of task)
Rogstadius et al. (2011)	Sponsor (profit or not-for-profit), monetary reward
Gatautis, Vitkauskaite (2014), Gatautis, Vitkauskaite (2014), Hossain (2012)	Company reputation
Zolkepli et al. (2015)	Company reputation (Number of social media followers)
Beer de et al. (2017), Mazzola et al. (2018), Kannangara, Uguccioni (2013)	Intellectual property management

7.2.7 Gap Analysis for Crowdsourcing Success Literature

The consolidation of crowdsourcing success factor literature, presents several literature gaps. Firstly, problem complexity is measured by only Chaudhari et al. (2018) despite acknowledgment of the importance of problem-related factors by other authors. Furthermore, problem complexity in Chaudhari et al. (2018) is a single assigned value. There is therefore an opportunity to include a more detailed consideration of problem complexity and its influence on crowdsourcing success.

Secondly, problem framing is not included in other crowdsourcing success factor literature, therefore, consideration of sentiments, problem description length and other problem framing metrics will be, for the first time, considered in the context of crowdsourcing success.

With regards to incentives, the influence of non-monetary rewards is not considered in existing literature. As stated by Forbes et al. (2020), non-monetary rewards are more attainable for smaller organisation and by considering non-monetary rewards in further detail, crowdsourcing initiatives may be more accessible to SMEs.

In addition, existing crowdsourcing success literature does not compare two or more platforms. Considering projects from two platforms offers insight into whether findings from an experiment are truly representative of all crowdsourcing initiatives or are unique to a single platform. Furthermore, several other factors such as “communication with sponsors” and “feedback” are facilitated on GrabCAD but not Innocentive. By including projects on both platforms, additional success factors are indirectly included in this experiment through comparison of the two platforms.

Finally company reputation is currently not considered in crowdsourcing success factor literature. As discussed by Forbes et al. (2020), the size of the organisation, the company’s reputation and therefore awareness of the brand can make a significant difference in terms of crowdsourcing participation. An individual participant may be a lot more motivated to participate in a NASA (Forbes et al., 2020; Zammit et al., 2016) crowdsourcing contest as opposed to an organisation they are not familiar with, despite the incentive.

7.2.8 Research Aim and Objectives for Crowdsourcing Success Experiment

The aim of this chapter is to yield new insights on what influences crowdsourcing participation and success. In addressing the literature gaps outlined above, the objectives of this thesis are as follows:

- Compare two crowdsourcing platforms to determine whether insights are unique to one platform or potentially representative of all crowdsourcing initiatives

- Include an investigation into company reputation vs. Number of submissions
- Include an investigation in non-monetary incentives vs. Number of submissions
- Derive a metric for problem complexity and its influence on crowdsourcing success
- Include an investigation into problem framing vs. Number of submissions

7.3 Data Collection for Crowdsourcing Success Experiment

To fulfill the research aim of this chapter, an experimental approach was adopted. Data was collected from 219 successfully completed projects on two platforms; Innocentive and GrabCAD. "Successfully completed" is defined as projects that stated a successful winner was chosen. The assumption is made that they therefore received the quality of solutions that was required and projects can be differentiated in terms of "how successful they" by the number of submissions. The dependent variable is therefore the number of submissions (also listed on the platforms as the number of solvers and the number of entries). In this section, existing literature is reviewed to determine the appropriate metrics to fulfill the research aim of this chapter.

Table 7.1 shows the first iteration of dependent and independent variables. Having listed all influential success factors, for each factor it was determined whether it could be measured and, if so, what were the metrics. In doing this further literature sectors are explored to uncover appropriate metrics. For example, in considering how the nature of the proposed problem impacts participation, literature on task attributes and participation can be explored. In Table 7.6 the influential factors and their metrics are listed. In the following sections, some factors that required literature exploration are discussed in more detail.

7.3.1 Measuring Problem Complexity

Existing literature provides many definitions and characteristics of problem complexity. According to Salado and Nilchiani (2014) there are three types of system complexity:

- Structural complexity: Complexity resulting from physical interconnection of components
- Functional complexity: Complexity resulting from interconnectivity of system functions

- Organizational complexity: Contractual interconnectivity of different organisations developing the system

According to existing literature, problem complexity influences crowdsourcing success. In this context, problem complexity refers to the complexity conveyed by the problem brief. This is essentially measuring the complexity of the expected solution suggested by the brief. Organizational complexity can therefore not be considered in this context but the structural complexity and the functional complexity of the expected solution can be measured from the brief alone. While these terms allow for more focused literature searching, they remain at too high a level of abstraction to be measured as part of this crowdsourcing experiment.

In the context of engineering design, Ameri et al. (2008) state that "complexity can be defined as a quality of an object with many interwoven elements and attributes which make the whole object difficult to understand in a collective sense". The measures of complexity stated by Ameri et al. (2008) are as follows:

- Entropy (Mina et al. (2006))
- Randomness (Grassberger (1991))
- Predictability (Boffetta et al. (2002))

These three factors have been used to measure design problem, design product and design process. In the context of crowdsourcing, the complexity of the design problem is the influential factor. Ameri et al. (2008) provide two empirically derived equations that can determine the complexity of the design problem.

$$PC = \sum_{j=1}^{k} * F_j * j$$

where

PC = Problem Complexity

F_j = Number of functions at level j

k = Number of levels in the function tree

Equation 7.3.1.1

$$E = a * PC^b * SR^c$$

where

E = Effort for the Design problem

SR = Severity of the requirements

PC = Problem complexity

Equation 7.3.1.2

From these equations, several potential metrics emerge. Firstly "severity of requirements", which is represented by an arbitrary value of 1, 2 or 3. Secondly, the "number of functions" and the "number of levels in the function tree" is used as a measure of functional complexity. The overall function tree of a solution is difficult to be determined prospectively from a design brief. However, "Severity of requirements" and "number of functions", can both be used to measure the problem complexity presented by a design brief, and are included in Table 7.2.

Bashir and Thomson (2001) also propose models for estimating design effort and time. The proposed models are based on product functional decomposition and list the following as core metrics:

1. Product complexity
2. Technical difficulty: Severity of requirements and use of new technology
3. Experience, Skill and Attitude of Team Members
4. Team structure: Team size and methods of communication
5. Use of design assisted tools
6. Existence of formal design process

"Severity of requirements", and the assigned arbitrary values, is again raised as a metric for judging problem complexity. "Use of new technology" and "use of design assisted tools" demonstrates the tools required to complete the task dictate the complexity of a deign brief. These three metrics, are included in Table 7.2. Points 3, 4 and 6 demonstrate the influence of team experience and process on design effort. In the context of a crowdsourcing design problem, the behaviour of the solver or solver's organisation is not included in judging complexity of the brief and therefore is not appropriate for metrics in this experiment.

Bashir and Thomson (2001) discusses problem complexity "predominantly in the context of a systematic design process". Therefore, problem complexity in the context of axiomatic design is also considered. Maier and Fadel (2006) defines complexity as "a measure of uncertainty in achieving the specific functional requirements". Suh (1999) presents a similar definition of "real complexity"; "uncertainty associated with the known possibility of a solution not completely satisfying the desired objective". Braha and Maimon (1998) also defines functional complexity using the probability of success as the core metric.

$$F = log_2(\frac{1}{P})$$

where

F = Functional design complexity

P = Probability of success

Equation 7.3.1.3

$$P = Prob[a \leq r \leq b]$$

Equation 7.3.1.4

$$\begin{aligned} P &= Prob[a \leq r \leq b] \\ &= \int_a^b f(r)dr \\ \Rightarrow F &= log_2 \left[\frac{1}{\int_a^b f(r)dr} \right] \end{aligned}$$

Equation 7.3.1.5

In considering the use of uncertainty and probability in the context of crowdsourcing, one can understand how "design a running shoe for use on Mars" would be deemed more complex than "design a running shoe for use in London" due to the greater uncertainty of Mars' environment and surface. In the context of crowdsourcing design problems, however, where the relative uncertainty associated with a proposed solution is a lot less obvious and difficult to determine prospectively, the uncertainty associated with a single design brief. This is also true for the concept of affordances and complexity, as discussed by Braha and Maimon (1998). Braha and Maimon (1998) state that "the concept of affordance is more appropriate for measuring complexity in design than function". Similarly to uncertainty in achieving the solution, how a design property dictates the usage of the object is difficult to measure from the design brief. Therefore, neither uncertainty, probability or affordance are included as metrics in this experiment.

Dixon (1987) states that problem complexity is based upon the coupling between design targets and design variables. The more coupled the design problem, the more complex it is. For example, if each design variable impacts only one design target this is of lower complexity than is each design variable impacted several design targets.

A linear equation can be used to quantify coupling. The number of design targets and design variables, and therefore the coupling ratio, can be identified from a design problem brief and these metrics are therefore appropriate for use in this crowdsourcing experiment (as shown in Table 7.2).

Braha and Maimon (1998) also presents complexity measurement equations based on variables and targets defined as "operators" and "operands". An operand is a variable or a construct and an operator is an entity that can alter either the value of an operand or the order in which it is altered (Braha, Maimon (1998)). Braha and Maimon (1998) first describe the level of abstraction as a clear indicator of complexity and yield equations using the number of operators and operands.

where

ρ = Number of unique or distinct operators appearing in the design form

N = Number of unique or distinct basic operands appearing in he design form

N_1 = Total number of occurrences of the operators in the design form

N_2 = Total number of occurrences of the operands in the design form

$$\eta = \rho + N$$

where

η = Number of operators and operands

Equation 7.3.1.6

$$L = N_1 + N_2$$

where

L = Length of the design form

Equation 7.3.1.7

An important characteristic of a particular level of abstraction is its size. Whenever a given design is translated from one abstraction level to another the size changes.

$$\begin{aligned} H &= Llog_2\eta \\ &= (N_1 + N_2)log_2(\rho + N) \end{aligned}$$

Equation 7.3.1.8

where H^* denotes the parameters of the design in the design's most compact form

$$\begin{aligned} H^* &= L^* log_2 \eta^* \\ &= (2 + N^*) log_2 (2 + N^*) \end{aligned}$$

Equation 7.3.1.9

therefore

$$A = \frac{H^*}{H}$$

where

A = Level of abstraction

Equation 7.3.1.10

Several potential metrics emerge through presenting the above derivation. Firstly, the number of operators and operands. While operators and operands are normally identified from a design form, depending on problem formulation these could be yielded from the design brief and are therefore considered as metrics for this experiment (as shown in Table 7.2). Level of abstraction, as derived from the number of operators and operands, is also shown to be a measure of complexity and therefore is also included in Table 7.2.

Braha and Maimon (1998) further demonstrates the use of level of abstraction (A) to yield design effort and design time.

where

E = Design effort

T = Design time

S = The rate at which the brain makes elementary mental discriminations

$$\begin{aligned} E &= \frac{1}{A} * H \\ T &= \left(\frac{1}{S * A}\right) * H \\ &= \frac{H^*}{H * S} \end{aligned}$$

Equation 7.3.1.11

According to Stroud (1956) the rate at which the brain makes elementary mental discrimination (S) "is about one-tenth of a second, but can be varied somewhat by experimental operations". Design effort (E) and design time (T) can therefore be derived providing the number of operators and operands can be defined from the design brief.

Table 7.2 consolidates the potential metrics that can be used to determine problem complexity of a crowdsourcing design brief. In the following section, the data collection process of the metrics in Table 7.2 are considered.

Table 7.2: Problem Complexity Dimensions from Existing Literature

Problem Complexity Components	**References**
Severity of requirements*	Ameri et al. (2008)
Number of functions*	Ameri et al. (2008)
Severity of requirements	Bashir, Thomson (2001)
Use of new technology	Bashir, Thomson (2001)
Use of assisted design tools	Bashir, Thomson (2001)
Number of target variables	Dixon (1987)
Number of design targets	Dixon (1987)
Coupling ratio	Dixon (1987)
Number of operators	Braha, Maimon (1998)
Number of operands	Braha, Maimon (1998)
Level of abstraction	Braha, Maimon (1998)

Having consolidated the potential metrics presented by existing literature. Further consideration of these metrics in the context of crowdsourcing and the process of measurement.

Number of operators and operands are the metrics that dictate several other potential metrics such as design effort and level of abstraction. The detail of the design brief for the crowdsourcing projects dictates whether the number of operators and operands can be consistently and accurately yielded from the design brief of the Innocentive and GrabCAD projects. The projects included in this can be consolidated into several types as shown in Table 7.3.

Table 7.3: Project types in the Innocentive and GrabCAD data set

Project Type	**Attributes**	**Example Project Title**	**Condensed Project Brief**
Visionary	Limited constraints, large number of target variables	Take a bite out of malaria	Your challenge is to design a solution to help eradicate Mosquitoes. According to the World Health Organization, close to one in seven people in India are at risk of contracting Malaria. India aims to be Malaria free by 2027. The goal of the challenge is to create an original and unique way to combat the malaria problem in places like India. Your design should be able to positively impact the general population by eradicating mosquitoes, the primary carrier of malaria.
Technical	Large number of target variables, several technical constraints	Strain measurement of Kevlar Webbing	The research team suffered from a 3-year-old problem for how to test Kevlar webbing for its durability in the trying conditions in space. No existing method of testing works for all scenarios, since the best available method would fail at high temperatures. Due to competing priorities, the team no longer had enough time to give the problem the time and attention it needed.
3D Model	Design a 3D model, constraints are bed size and dimensions	Extreme Redesign	Open to students worldwide, Extreme Redesign is an annual 3D printing challenge created by Stratasys, Inc. that invites students to design an original piece of art, jewelry or architecture, or to make an existing design better.
Retrofit or Redesign	Replace or upgrade components in existing systems, large number of constraints	Design a new gas pedal for a potentiometric sensor.	The goal of this challenge is to design an innovative yet robust passenger automobile accelerator pedal assembly and interface for a new Microtechnologies potentiometric sensor. The system is intended for use in emerging market automotive applications. Automotive companies in China, India and South America could be using this gas pedal in the next generation of economy cars.
Technical Skills Challenge	Model or drawing of complex part	Make The Unmakeable Challenge	Fathom's Make the Unmakeable Challenges of 2015 will demonstrate an original way 3D printing can enhance the product development process.

For a "Retrofit or Redesign" project some operators and operands can be yielded from the brief. For example, this project brief, by Rabaconda allows this (operators and operands bolded).

"Rabaconda challenges you to create portable folding work desk for dirt bike riders and racing teams to be used at the track and garage for servicing the vehicles. This challenge is about designing compact, portable and ***collapsible*** *working desk, mainly focused for motorcycle riders needs, but could also be used in other areas. The desk should be* ***easy to set up, has holders for tools, spray cans and paper roll, drawer(s) for tools, small spare parts and goggles****. The desk can be used instead of tool case and has also clean working surface. It* ***should have feet*** *for setting up outdoors and also a possibility to* ***easily fix on a wall.****"*

On the other hand, "Visionary" projects, such as the example below, do not provide a large number of constraints or functional requirements.

"Your challenge is to design a solution to help eradicate Mosquitoes. According to the World Health Organization, close to one in seven people in India are at risk of contracting Malaria. India aims to be Malaria free by 2027. The goal of the challenge is to create an original and unique way to combat the malaria problem in places like India. Your design should be able to positively impact the general population by eradicating mosquitoes, the primary carrier of malaria."

Due to the varying types of projects presented in the dataset, it is not possible to include the number of operators, operands or level of abstraction in this experiment as identification of operators and operands are sometimes not possible and if so, could be collected inconsistently and innaccurately.

The term "severity" is considered to represent "intensiveness" or "difficulty". In the context of requirements this could mean the severity of individual requirements and how difficult they are to fulfill or the number of requirements and overall how difficult all the requirements are to fulfill. In considering the definition of "severity" to be how difficult an individual retirement is to fulfil, Ameri et al. (2008) and Bashir and Thomson (2001) propose an arbitrary scale (of 1 to 3) which requires the data analyst to distinguish between project descriptions on this basis. As shown in Table 7.3 the "severity" of requirements, with regards to ease of fulfilment is relatively difficult to determine from the project brief alone. For example, what could be considered more "severe" between "making a desk collapsible" and " making a desk portable". An alternative way to consider "severity" is by considering the number of submission requirements that have to be fulfilled to allow submission. In the context of this crowdsourcing experiment, this is possible to determine from the project briefs and allows "severity" to be more easily compared between projects. "Severity" of requirements is therefore included in this experiment but not by using the arbitrary but instead by counting the number of tasks required for submission. In both GrabdCAD and Innocentive, submission requirements are listed in bullet points allowing easy manual counting.

Use of new technology and design tools - all GrabCAD projects require submission using CAD so individual GrabCAD projects are not comparable. Furthermore, Innocentive project briefs in some cases do not define the specific tools required for submission. Use of new technology and use of design tools are therefore not included in this experiment.

To determine whether number of design targets, variables and therefore coupling ratio could be determined, a similar examination of the project brief, as used for operators and operands, was completed. The key difference between operators and operands, and target and constraints is that the former is making an assumption of the form of the design, while the latter is yielded directly from the design brief. As a consequence, the number of targets and constraints, could be counted in the design brief and included in this experiment.

The final metrics to include a measurement of problem complexity are therefore as follows:

- Number of target variables: Counted from the design brief
- Number of constraints: Counted from the design brief
- Coupling ratio: Calculated (Number of design targets/constraints)
- Number of tasks: Counted from the design brief

7.3.2 Problem Framing

Despite framing of the project brief having been presented as an influential factor in existing literature, other success factor literature does not include problem framing metrics. Instead, problem framing and problem complexity are consolidated into problem related metrics. For example, Panchal (2015) includes "information shared" and "system decomposition" as problem-related factors and Koh (2020) includes "design effort" required by the brief as a metric but assigns an arbitrary value to selected briefs. Furthermore, Sha et al. (2015) provides a high level discussion on problem framing and how it may impact solution quality but includes "problem complexity" as a metric in the experiment. In this experiment, problem framing and problem complexity are two distinct factors. Problem framing describes to the way the problem brief is communicated and problem complexity, as shown in Section 7.3.1, describes the complexity of the problem. Problem framing metrics directly measure the contents of the brief while problem complexity metrics are measuring the problem.

Since, existing crowdsourcing success factor literature did not provide specific problem framing metrics, literature external to this sector was reviewed. Birch (2005) provides in-depth guidance on language analysis and defines the following as the three "pillars" for analysing text:

- Dimensions of text (length)
- Meaning of words
- Feeling of words

The metrics to represent the "dimensions of text" on this experiment are simply the number of words and the number of characters. The number of words shows length while the number of characters allows the average length of words used to be found.

In the context of design, Blyth and Worthington (2010) define several requirements for an effective design brief including "planning for future change", "understanding of underlying agendas" and "defining the process". One of their requirements, "clear and concise communication", refer specifically to the language of the design brief and emphasises the need to limit "business jargon" and use words "understood by the layman". In considering jargon, there is reference to the "meaning of words", how they are interpreted and if they are understood. Should a crowdsourcing brief use lots of technical jargon they are likely to limit the number of potential participants that understand the brief to the extent that allows submission. Studies have shown that a reader needs to understand 98% of vocabulary in a text to adequately comprehend the content (Hu, Nation, 2000; Zammit et al., 2016). The use of jargon therefore may reduce the number of submissions. To represent the "meaning of words", as proposed by Birch (2005), a tool called "De-jargonizer" by Rakedzon et al. (2017) is used to count the number of words considered jargon, mid-frequency words and common words. A "De-jargonizer score" is also assigned to the text. "The De-Jargonizer is an automated jargon identification program aimed at helping scientists and science communication trainers improve and adapt vocabulary use for a variety of audiences" (Rakedzon et al., 2017; Zammit et al., 2016). It works by evaluating inputted text to a database generated by "crawling 9 million words from all BBC News articles from 2012 to 2019" (Rakedzon et al., 2017). "Frequently used words may receive thousands of appearances and jargon may have only few appearances: e.g. season, pressure, and current received over 10,000 appearances, pollution 1,608 appearances, gene 389 appearances and specifications, 90 appearances" (Rakedzon et al., 2017). De-Jargonizer was used to determine the percentage of common words, percentage of mid-frequency words, the percentage of jargon and the de-jargonizer score for every project brief for the Innocentive and GrabCAD projects.

Finally, the "feeling of words" needed to be represented in this experiment. "In recent years, the computational linguistics community has turned its attention toward the modeling of the subjectivity and sentiment of language" (Birch, 2005). One tool to measure the "sentiment" of language is Text Analytics, a tool provided by Microsoft. Text Analytics is a natural language processing tool that provides insight through "sentiment analysis, key phase extraction, language detection and named entity recognition". For sentiment analysis it works by "by analyzing raw text for clues about positive or negative sentiment" and then returning a score between 0 and 1. Text Analytics was used to provide the sentiment, the sentiment magnitude and corresponding sentiment score and whether the text was positive, negative or neutral. This sentiment analysis was performed for all project briefs in the GrabCAD and Innocentive database.

The final metrics to include a measurement of problem framing are therefore as follows:

- Sentiment score
- Number of words
- Number of characters
- Percentage of common words
- Percentage of mid-frequency words
- Percentage of jargon words
- De-jargonizer score

7.3.3 Company Reputation

Existing crowdsourcing experiments have not considered how company reputation impacts the number of crowdsourcing submissions. However, literature on crowdsourcing suggests company reputation does impact participation in crowdsourcing initiatives. In this section, existing literature on company reputation is presented to identify potential metrics for use in this crowdsourcing experiment.

Schwaiger (2004) presents several "tools to measure cooperate reputation" used consistently to rank global companies. The most well-established is *Fortune*'s AMAC (America's Most Amazing Companies) that presents an ORS (Overall Reputation Score) which is the arithmetic mean of the attributes interviewees provided on eight 11-point scales. Attributes include economic performance, risk, advertising expenditure, size, institutional ownership, market-book ratio, yield, visibility, beta, favourability and charity work.

Fombrun et al. (2015) define seven dimensions of reputation:

- Product or services
- Innovation
- Workplace
- Governance
- Citizenship
- Leadership
- Performance

Also listed is further attributes associated with these dimensions such as "Meets consumer needs" for "Product of Services".

Aaker (1996) use the term "brand equity" to discuss company reputation and define ten measures:

- Price of product or services
- Satisfaction of product or service
- Perceived quality
- Leadership
- Perceived value
- Brand personality
- Organizational associations
- Brand awareness
- Market share
- Price and distribution indices

Several other similar studies to Schwaiger (2004), Aaker (1996) and Fombrun et al. (2015) list various dimensions that dictate company reputation. These are consolidated in Table 7.4.

Table 7.4: Company Reputation Dimensions from Existing Literature

References	**Company Reputation Dimensions**
Schwaiger (2004)	Economic performance, risk, advertising expenditure, size, institutional ownership, market-book ratio, yield, visibility (Media exposure), Beta, Favouribility (Media exposure), Charity and Foundations
Fombrun et al. (2015)	Product or services, Innovation, Workplace, Governance, Citizenship, Leadership and Performance
Aaker (1996)	Price of product or services, Satisfaction of product or service, Perceived quality, Leadership, Perceived value, Brand personality, Organizational associations, Brand awareness, Market share, Price and distribution indices
Wiedmann et al. (2007)	Emotional appeal, products and services, financial performance, vision and leadership, workplace environment, social responsibility
Schwaiger (2004)	Quality of employees, Quality of management, Financial performance, Quality of products and services, Market leadership, Customer orientation, Attractiveness, Social responsibility, Ethical Behavior, Reliability
Lewis (2001)	Quality of products or services, customer service, treatment of staff, financial performance, quality of management, environmental responsibility, social responsibility
Caruana, Chircop (2000)	Quality of products, Cleanliness of work place, Quality of advertising, Public or private ownership, transparency, employer perception, strong management, care of employees, care of employee family, customer service, tradition, brand awareness
Feldman et al. (2014)	Generating positive feelings in people, discretionary social responsibility practises, good workplace environment, practice standards in ethics, good relation in consumers,having good products and services, leadership and innovation
Puncheva-Michelotti, Michelotti (2010)	Management excellence, social responsibility, customer value, economic performance, patriotic appeal, consumer impact, emotional appeal, credibility
Schwaiger (2004)	Emotional appeal, products and services, financial performance, vision and leadership, workplace environment, social responsibility

The various dimensions presented by existing literature and as showing in Table 7.4 can be consolidated into the headline dimensions/categories as shown in Table 7.5.

Table 7.5: Company Metric Categories

Category	Company Reputation Dimensions from Existing Literature
Financial performance	• Economic performance • Advertising expenditure • Performance • Market share • Price and distribution indices • Financial performance • Market leadership
Brand awareness	• Emotional appeal • Credibility • Brand awareness • Attractiveness • Reliability
Employee satisfaction	• Workplace environment • Employer perception • Quality of employees • Treatment of staff • Care of employees • Care of employee family
Management reputation	• Vision and leadership • Management excellence • Leadership and innovation • Strong management • Quality of management • Leadership
Quality of products or services	• Products and services • Having good products and services • Quality of products • Price of product or services • Satisfaction of product or service • Perceived quality

The categories shown in Table 7.5 should be represented in this crowdsourcing experiment in order to include company reputation. The existing literature shown in Table 7.4 used interviews with the general public to assign values to the company reputation attributed listed. In this case, forming company reputation values from participants is not possible, so existing and publicly available metrics must be used.

Online ratings such as from Glassdoor, LinkedIn and Crunchbase have been used extensively to rank companies according to their reputation. Suen et al. (2020) use Glassdoor ratings as a company reputation metric in investigating Fortune 500 companies in the US, Gadgil and Sockin (2020) use Glassdoor ratings as a company reputation metric in assessing impact of company scandals and Dalle et al. (2017) used Crunchbase for determining economic performance of large organisations. Glassdoor especially was used as a metric for representing company reputation.

Glassdoor is "an open community that allows employees and employers to create free accounts in order to read, post and respond to company reviews, salary data and more". It is a value yielded from crowdsourced employee review data, salary data, data on management and data on company performance. Input data is curated by "existing employees, past employees and company leadership". As stated by Landers et al. (2019), "provide evidence that overall Glassdoor ratings of satisfaction within US federal agencies correlate moderately with aggregated FEVS overall ratings (r = .516), supporting the validity of the overall Glassdoor rating". It is therefore used in this experiment to represent two of the required attributes shown in Table 7.5; employee satisfaction and management reputation.

The remaining categories are financial performance and brand awareness. There are several possible indicators of financial performance such as profit, revenue and investment portfolio (Gamra, Plihon, 2011). Since there are not-for-profit organisations included in the crowdsourcing dataset, profit should not be used. Furthermore, the investments of individual organisations are not always publicly and completely available. Revenue (£p.a.) is therefore used to represent financial performance. Brand awareness, as shown by Aaker (1996) and Caruana and Chircop (2000), can be determined by interviews of the general public but without experimental results is difficult to determine except numerically. Brand awareness is therefore represented by the number of employees and number of Twitter followers. The final metrics to include a measurement of company reputation are therefore as follows:

- Glassdoor rating: Inputted from Glassdoor.com
- Revenue (£p.a.): Inputted from Crunchbase
- Number of Twitter followers: Inputted from Twitter
- Number of employees: Inputted from Glassdoor and LinkedIn

7.3.4 Basic Campaign Details & Incentives

The final metrics included in this experiment were the basic campaign details (as shown in Table 7.6 and incentives. Basic campaign details and offered incentives for GrabCAD were scraped using Scraper Bot and Task Hub. For Innocentive, basic campaign details and the incentives were manually collected. Having collected the incentives offered, further metrics were yielded including the number of incentives, the percentage of monetary incentives and the value of the top incentive. The value of non-monetary incentives, if not explicitly stated, were found by searching for retail value of an item. In the few cases where a monetary value could not be found e.g. "get your 3D model printed with the GrabCAD logo", a value was assigned. The assigned values were used consistently if other projects had the value and any assigned values were considered relative to other assigned values. Since Innocentive provides only one monetary incentive split between one or more winners, non-monetary incentives could not be investigated. As shown in Table 7.6, GrabCAD allows consideration of non-monetary value and distribution of reward while Innocentive does not. The final metrics i.e. independent and dependent variables are shown in Table 7.6.

7.3.5 Influential Factors removed from Experiment

Influential factors from the literature table that were not included (e.g. IP ownership)

Of the influential factors presented by existing literature and shown in Table 7.1, some were directly included in the experiment, some were indirectly included in the experiment (for example, quality of platform was included by using data from two platforms) and some were excluded. Those excluded and their reasoning for exclusion is outlined below:

1. Attributes of the task such as "autonomy", "variety" and "tacitness" (Zheng et al. (2011)) were excluded due to the subjectivity of these statements. The researcher could assign arbitrary or relative values to aim to quantify these statements but the usefulness of this measurement was considered minimal.

2. Panchal (2015) stated "team formation", "quality assessment" and "choosing of winners" as influential factors. These were excluded because data on these factors were not available or not available consistently in the public domain. If a team submitted a solution as opposed to an individual, it was not clear from the single submission. In addition, the judgement criteria was sometimes included on individual projects but this was inconsistent and often incomplete.

3. External support and time spent was provided by Franke et al. (2014) and similarly to the factor in the above point, these were not measurable since information was not available in the public domain

Finally, Intellectual Property was not included in this experiment. Despite being considered important by the researcher and in existing literature, the data was not available in the public domain to allow consistent and accurate measurement of intellectual property management for individual projects. Many, for example, stated that the management of IP "would be discussed on awarding of the winners". This meant that any incentive associated with IP ownership was ineffective at the point of submission and projects could not be compared according to IP management.

7.3.6 Final List of Dependent and Independent Variables

Table 7.6: Influential Factors and their Metrics

Influential Factor	**Metrics**
Problem Complexity	• Number of Target Variables • Number of Constraints • Coupling Ratio • Number of Tasks
Problem Framing	• Sentiment Score • Number of words • Number of characters • Percentage of common words • Percentage of mid-frequency words • Percentage of jargon words • De-jargonizer score
Company Reputation	• Glassdoor rating • Revenue • Number of Twitter followers • Number of Employees
Incentives	• Incentive(s) • Number of Incentives • Percentage of non-monetary incentives • Top Reward Value • Total Monetary Value
Basic Campaign Details	• Days Active • Number of Stages

7.4 Data Analysis and Results for Crowdsourcing Success Experiment

The purpose of this experiment was to yield new insights on crowdsourcing success by determining whether a range of factors influenced the number of crowdsourcing submissions and therefore crowdsourcing success. As shown in Table 7.6, a total of 22 data variables were collected. The number of solvers is the dependent variable and several others were not directly included in the analysis. Firstly, data was analysed for the two platforms separately for comparison so "Platform" was not included in analysis with all other variables. Furthermore, the following variables were included for indexing reasons and are not included in the analysis:

- Campaign Title
- Company
- Data collected
- Start date
- End date

"Company" is included via company reputation metrics such as "Glassdoor rating" but individual companies are not considered. This leaves a total of 22 independent variables to be analysed with reference to the dependent variable, the number of submissions.

Multiple regression analysis is used to predict the value of a variable based on the value of two or more other variables (Edwards, 1985). It has been proven to be a robust method for experiments of this kind with other authors using multiple regression analysis in crowdsourcing factor experiments (Chaudhari et al., 2018). Multiple regression analysis works by aiming to optimize a response (dependent variable) by finding the best levels for different variables (Celik, Ozdemir, 2020). In general, the multiple regression equation of Y (dependent variable) on $X_1, X_2, \ldots, X_k$ is given by:

$$Y = b_0 + b_1X_1 + b_2X_2 + ... + b_kX_k$$

Equation 7.4.1

According to Edwards (1985) "many difficulties tend to arise when there are more than twelve independent variables in a multiple regression equation". As a consequence, there is a need to reduce the number of variables to be tested before use in multiple regressions analysis. Principle Component Analysis is therefore used prior to Multiple Regression Analysis.

Principle Component Analysis is used to "identify a smaller number of uncorrelated variables, called "principal components", from a large set of data" (Wold et al., 1987). It works by reducing each dimension of data into a best-fit line with a gradient known as a "principle component". The gradient shows which dimension (or by which variable) the data is being most influenced. This allows variables that are most representative of the spread of the data to be highlighted and used in further analysis. In Section 7.4.1, principle component analysis is used to identify the independent variables that are most representative of the spread of the data.

7.4.1 Principle Component Analysis Results

A principle component analysis was first conducted on the full set of data from GrabCAD and Innocentive, to determine whether any variables could be immediately identified, or whether categorical PCA was required.

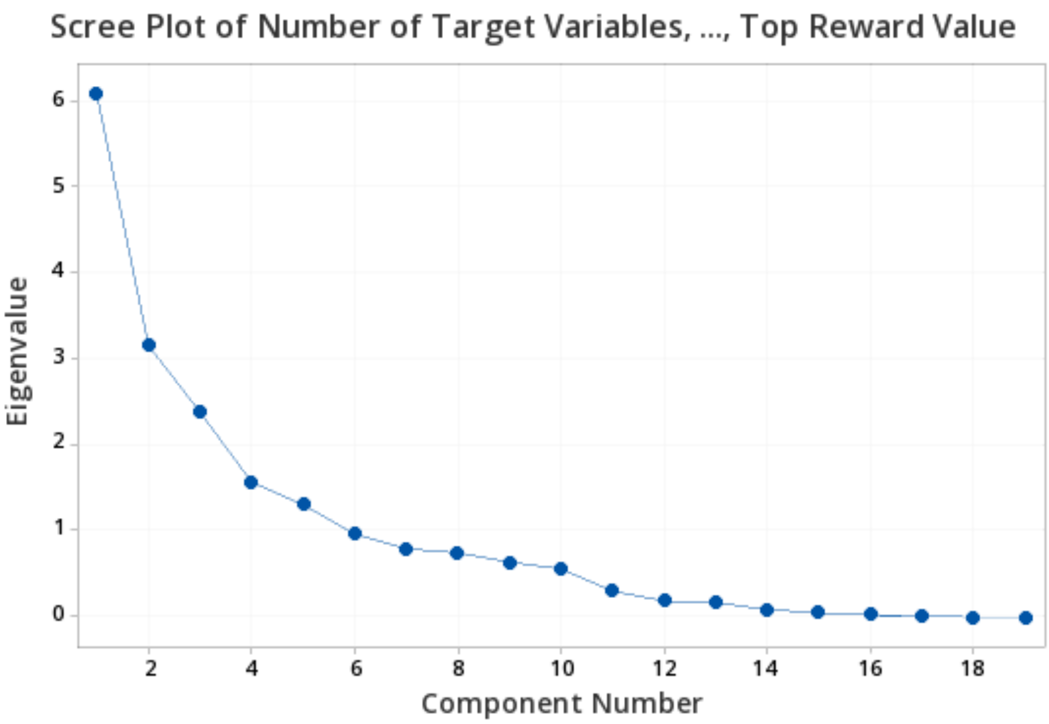

Figure 7.4: Scree Plot for Full GrabCAD PCA

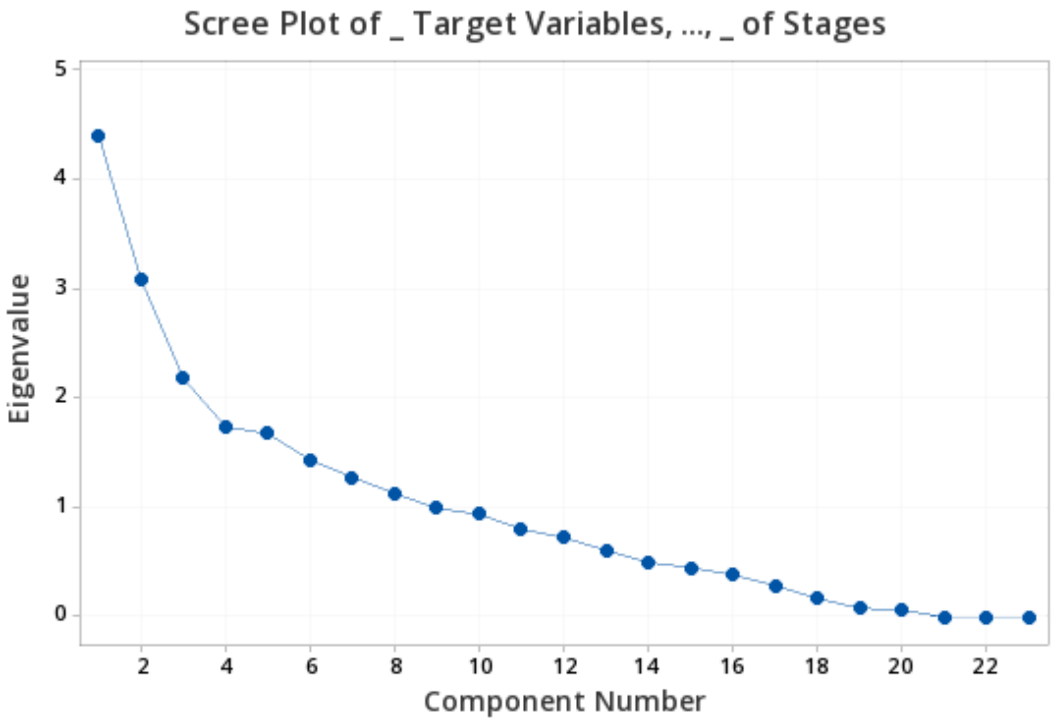

Figure 7.5: Scree Plot for Full Innocentive PCA

The lines shown in Figure 7.4 and Figure 7.5 provide a visual representation of the percentage of variance that each principle component is responsible for. Ideally, Figure 7.4 and Figure 7.5 should show the early principle components as being responsible for upwards of 75% of the variance of data. This would then allow further principle components to be removed, while leaving a dataset that is mostly representative of data variance. However, Figures 7.4 and 7.5 show that the combination of later principle components represent a large amount of data variance. This means that judging this data, and therefore removing certain variables, on PC1 and PC2, for example, would limit the accuracy of further analysis.

As presented in Section 7.2.7, there are several literature gaps that this research looks to address as follows:

1. Compare two crowdsourcing platforms to determine whether insights are unique to one platform or potentially representative of all crowdsourcing initiatives
2. Include an investigation into company reputation vs. Number of submissions
3. Include an investigation in non-monetary incentives vs. Number of submissions
4. Derive a metric for problem complexity and its influence on crowdsourcing success
5. Include an investigation into problem framing vs. Number of submissions

With reference to points 2 to 5, an investigation of company reputation, incentives, problem complexity and problem framing are vital to fulfill the aim of this research. There is therefore a natural need to perform Principle Component Analysis on each of these categories of metrics, with the hope that at least one metric from these categories can be included in the final regression analysis. Each category of variables and the PCA is included in the following sections.

GrabCAD

The following sections show the following for each category:

1. A Scree plot and Principle Component (PC) Eigenvalues to show which PCs are most responsible for variance in the data
2. A Loading plot and PC Eigenvectors to show the magnitude of each variable in each dimension
3. The weighted magnitude values and plot showing overall influence of each variable weighted according to the influence of the principle components

The purpose of examining each category of variables is to allow variables to be selected to represent a category. For example, in incentive metrics, the total monetary reward may be shown to represent the majority of data variance of the other metrics and therefore is selected to represent "Incentive" in the multiple regression analysis. After each results section, interpretation of the results will be presented along with any decisions regarding the exclusion of variables.

Problem Complexity

Table 7.7: GrabCAD Problem Complexity PCA: Eigenvalues

Eigenvalue	1.5712	1.3495	0.8780	0.2012
Proportion	0.393	0.337	0.220	0.050
Cumulative	0.393	0.730	0.950	1.000

Table 7.8: GrabCAD Problem Complexity PCA: Eigenvectors

Variable	**PC1**	**PC2**	**PC3**	**PC4**
Number of Target Variables	-0.587	0.531	0.055	-0.608
Number of Constraints	0.143	0.785	-0.304	0.520
Coupling Ratio	-0.717	-0.140	0.326	0.600
Number of Tasks	0.347	0.286	0.893	-0.004

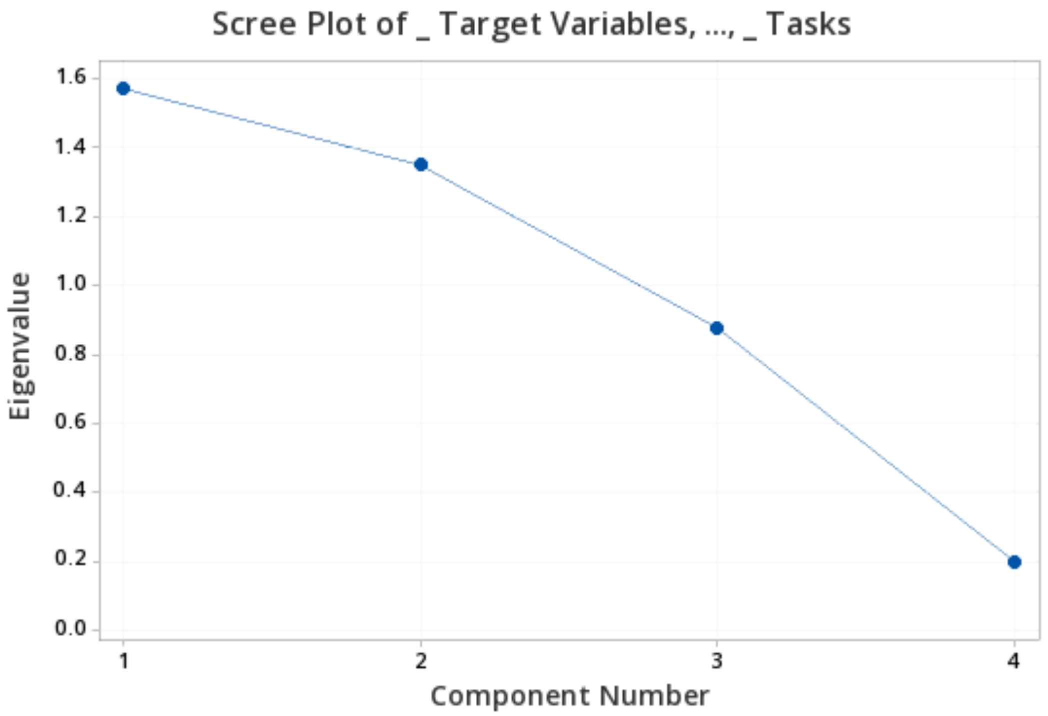

Figure 7.6: GrabCAD Problem Complexity PCA: Scree Plot

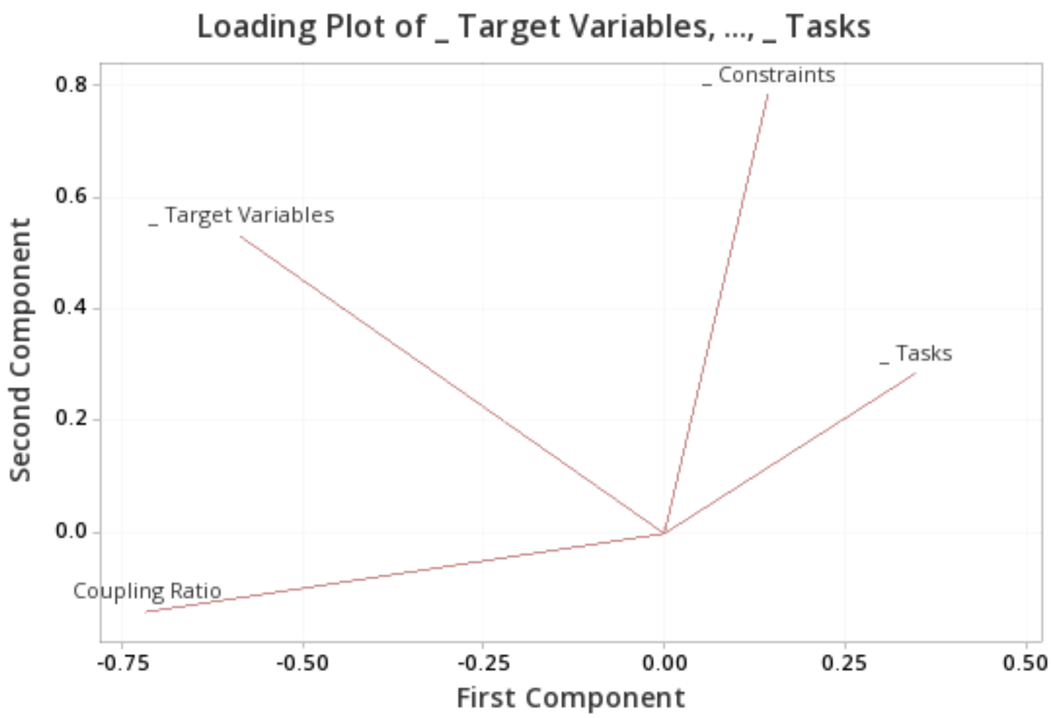

Figure 7.7: GrabCAD Problem Complexity PCA: Loading Plot

Table 7.9: GrabCAD Problem Complexity PCA: Weighted Eigenvectors

Variable	**Total Weighted Eigenvector**
Number of Target Variables	0.452
Number of Constraints	0.414
Coupling Ratio	0.401
Number of Tasks	0.429

Interpretation of Results: Problem Complexity PCA

In Table 7.13 it can be seen that PC1 and PC2 are responsible for 73% of data variance, with PC1 responsible for 39.3% and PC2 responsible for 33.7%. The visual representation in Figure 7.6 shows an almost linear movement from PC1 to PC4.

This means that limiting the data based on PC1 or PC1 and PC2 alone would exclude a large amount of data variance, and therefore any decisions made to nominate variables for multiple regression, would like significantly impact the overall findings from this data.

Furthermore, Figure 7.7 shows each variable to impact the variance of the data by a similar magnitude and across a wide range of directions. This means clustering the data would be innaccurate. It is therefore not appropriate to nominate any variables based on individual values from PC1 or PC2.

Principle component analysis therefore provides inadequate evidence to nominate or exclude problem complexity variables for GrabCAD data. Further discussion over the nomination of variables for this category will be discussed in Section 7.4.2.

Problem Framing

Table 7.10: GrabCAD Problem Framing PCA: Eigenvalues

Eigenvalue	4.1363	1.9174	1.4606	0.8441	0.527	0.1048	0.0046	0.0027	0.0025
Proportion	0.46	0.213	0.162	0.094	0.059	0.012	0.001	0	0
Cumulative	0.46	0.673	0.835	0.929	0.987	0.999	0.999	1	1

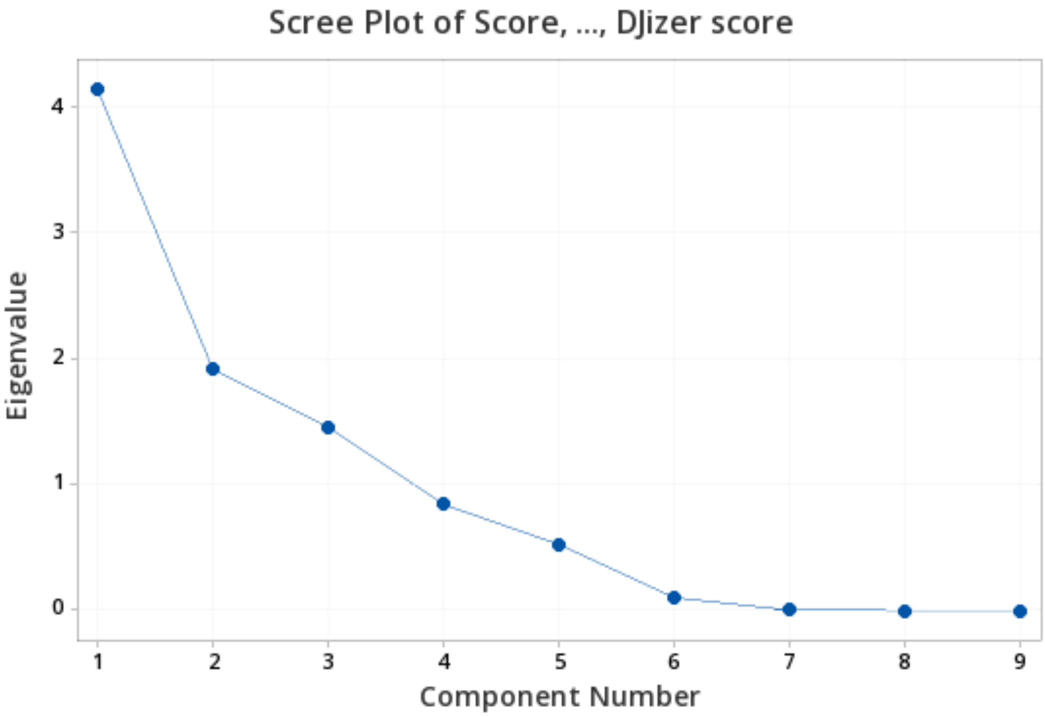

Figure 7.8: GrabCAD Problem Framing PCA: Scree Plot

Table 7.11: GrabCAD Problem Framing PCA: Eigenvectors

Variable	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**	**PC8**	**PC9**
Score	0.005	-0.654	-0.281	0.124	-0.045	-0.689	0.008	-0.013	0.003
Magnitude	0.136	-0.154	0.392	-0.875	0.089	-0.176	-0.002	0	0.004
Sentiment	0	-0.683	-0.178	-0.099	0.014	0.701	-0.002	0.013	-0.001
Words	0.438	-0.052	0.188	0.107	-0.514	0.016	-0.655	0.234	-0.103
Characters	0.437	-0.054	0.21	0.114	-0.493	0.033	0.665	-0.226	0.104
Common	0.411	0.133	-0.404	-0.129	0.157	0.004	0.153	0.081	-0.761
Mid-Frequency	0.066	-0.233	0.667	0.393	0.429	-0.007	-0.021	-0.165	-0.36
Jargon	-0.464	0.003	0.008	-0.117	-0.431	0.007	-0.145	-0.624	-0.418
DJizer score	0.459	0.069	-0.219	-0.01	0.296	0.017	-0.288	-0.686	0.309

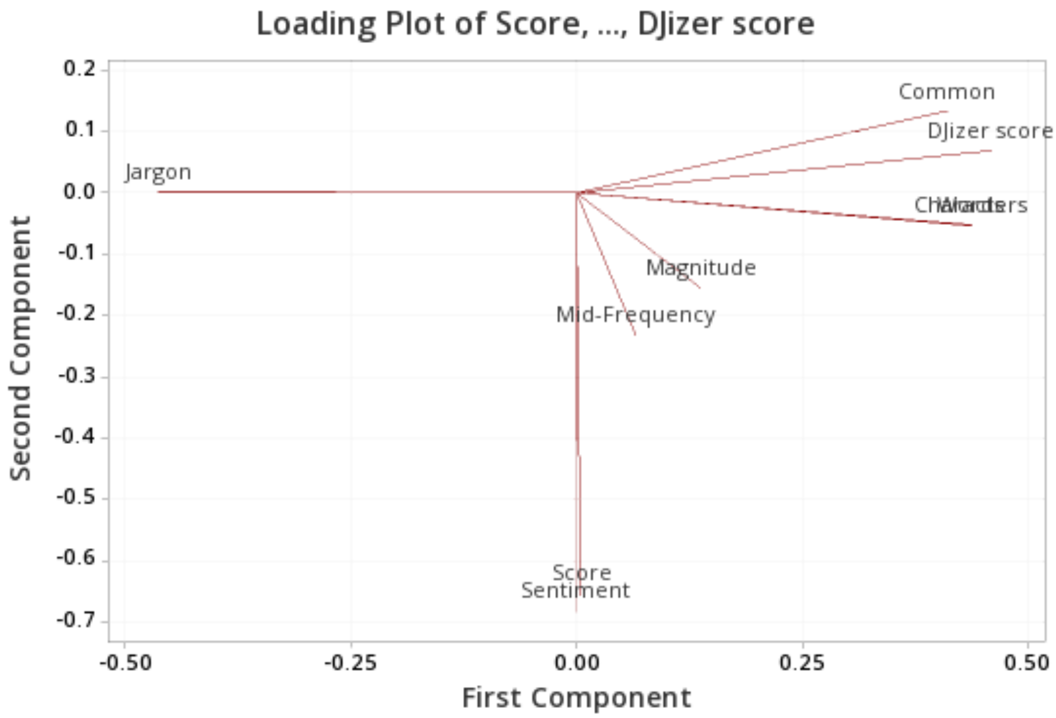

Figure 7.9: GrabCAD Problem Framing PCA: Loading Plot

Table 7.12: GrabCAD Problem Framing PCA: Weighted Eigenvectors

Variable	**Weighted Eigenvector for PC1, PC2 and PC3**
Score	0.187124
Magnitude	0.158866
Sentiment	0.174315
Words	*0.243012*
Characters	*0.246542*
Common	*0.282837*
Mid-Frequency	0.188043
Jargon	*0.215375*
DJizer score	*0.261315*

Interpretation of Results: Problem Framing PCA

Figure 7.8 represents a greater proportion of variance attributed to early principle components. As can be seen in Table 7.10, PC1, PC2 and PC3 represent 85% of the variance of the data and can therefore be used to nominate or exclude variables for the multiple regression analysis.

Table 7.12 shows the weighted eigenvectors for variables and the italicized values show the variables that represent the most variance in the data. Jargon, de-jargonizer score, the number of common words, the number of characters and the number of words are most representative of the variance of this data. However, as can be seen by Figure 7.9, Score Sentiment is responsible for large variable in the second principle component (or the second dimension) while common words, de-jargonzier score, the number of characters and the number of words are clustered and therefore represent similar variance.

As a consequence, sentiment score is nominated for multiple regression, jargon is nominated for multiple regression, and number of characters is nominated for multiple regression. Three aspects of problem framing are therefore nominated: interpretation of words, length of description and sentiment (Birch, 2005).

Company Reputation

Table 7.13: GrabCAD Company Reputation PCA: Eigenvalues

Eigenvalue	2.1191	0.88	0.6761	0.3249
Proportion	0.53	0.22	0.169	0.081
Cumulative	0.53	0.75	0.919	1

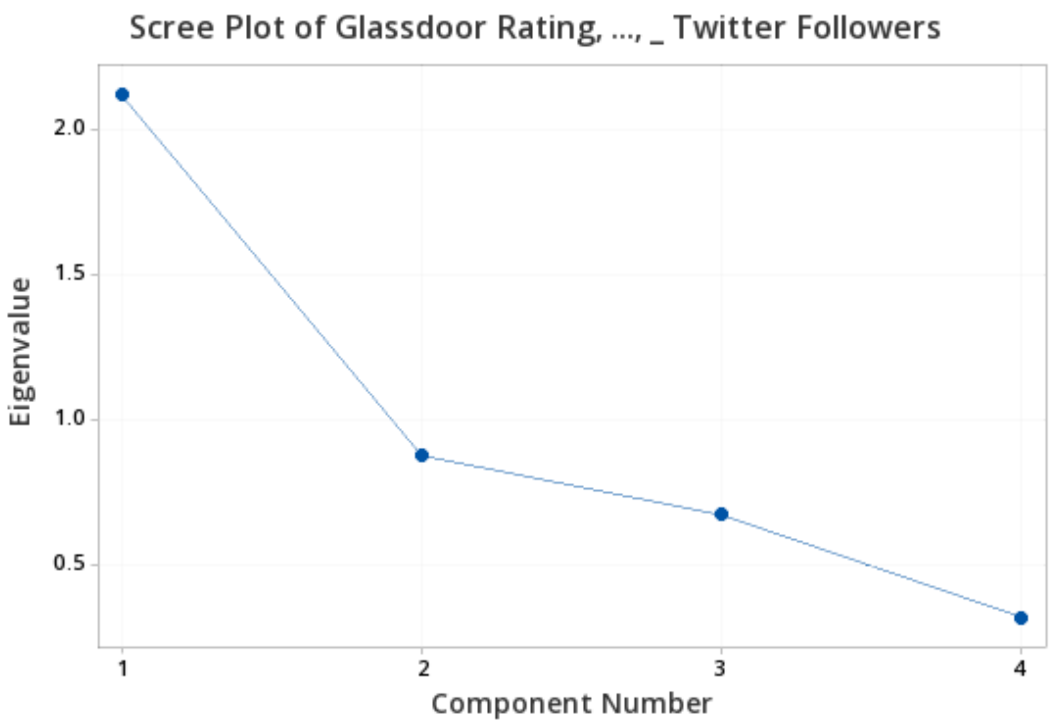

Figure 7.10: GrabCAD Company Reputation PCA: Scree Plot

Table 7.14: GrabCAD Company Reputation PCA: Eigenvectors

Variable	PC1	PC2	PC3	PC4
Glassdoor Rating	0.383	-0.766	0.496	-0.143
Number of Employees	0.576	-0.128	-0.448	0.671
Revenue	0.583	0.190	-0.359	-0.704
Number of Twitter Followers	0.426	0.600	0.651	0.183

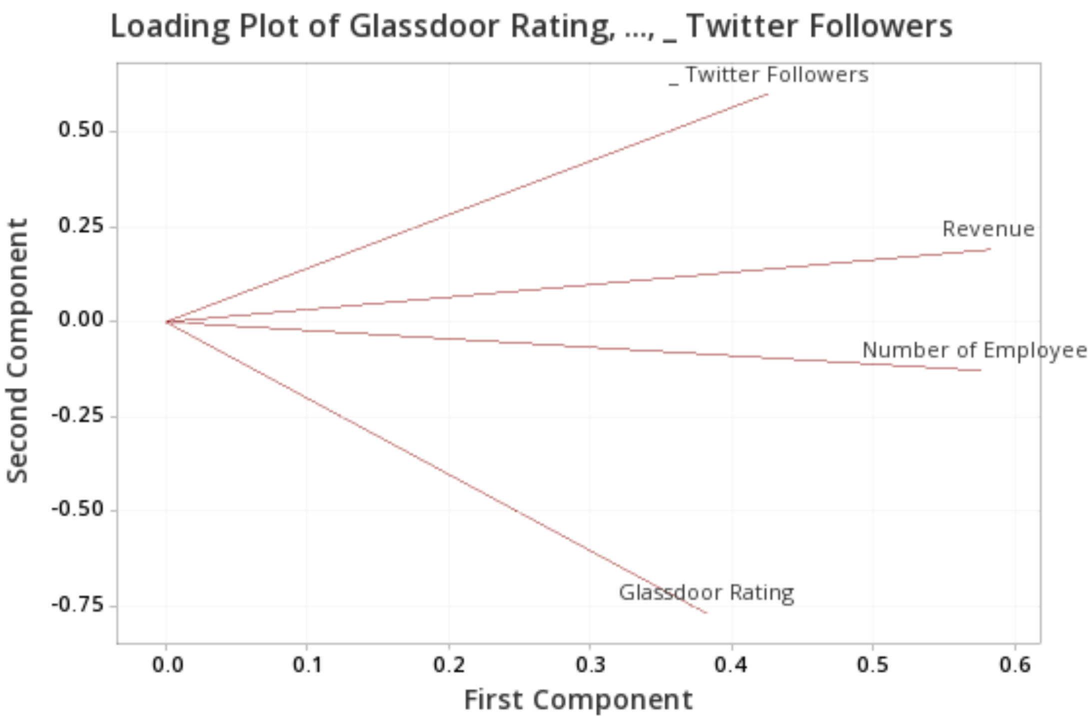

Figure 7.11: GrabCAD Company Reputation PCA: Loading Plot

Table 7.15: GrabCAD Company Reputation PCA: Weighted Eigenvectors

Variable	Total Weighted Eigenvector for PC1 and PC2
Glassdoor Rating	0.37151
Number of Employees	0.33344
Revenue	0.35079
Number of Twitter Followers	0.35778

Interpretation of Results: Company Reputation PCA

As visually represented by Figure 7.10 and presented in Table 7.13, PC1 and PC2 are largely responsible for the variance in data, representing 75% of data variance.

However, in considering the eigenvectors for each variable, as shown in Table 7.17, the variables responsible for data variance is less clear. Figure 7.11 shows no clustering of the data and Table 7.15 shown similar weighted eigenvector values for each variable. Further discussion in Section 7.4.2 is therefore required to nominate or exclude variables.

Incentives

Table 7.16: GrabCAD Incentives PCA: Eigenvalues

Eigenvalue	2.0373	1.1201	0.7491	0.0936
Proportion	0.509	0.28	0.187	0.023
Cumulative	0.509	0.789	0.977	1

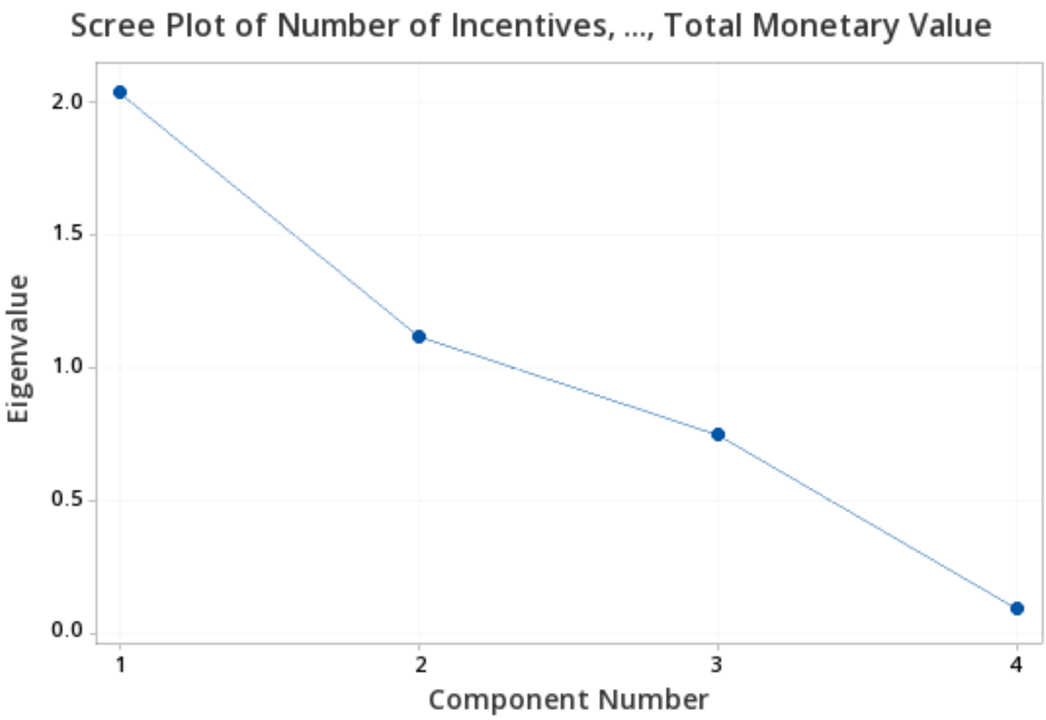

Figure 7.12: GrabCAD Incentives PCA: Scree Plot

Table 7.17: GrabCAD Incentives PCA: Eigenvectors

Variable	PC1	PC2	PC3	PC4
Number of Incentives	-0.081	0.818	-0.562	-0.093
Percentage of non-monetary ince	-0.348	0.51	0.785	0.047
Top Reward Value	0.66	0.149	0.237	-0.697
Total Monetary Value	0.661	0.22	0.107	0.709

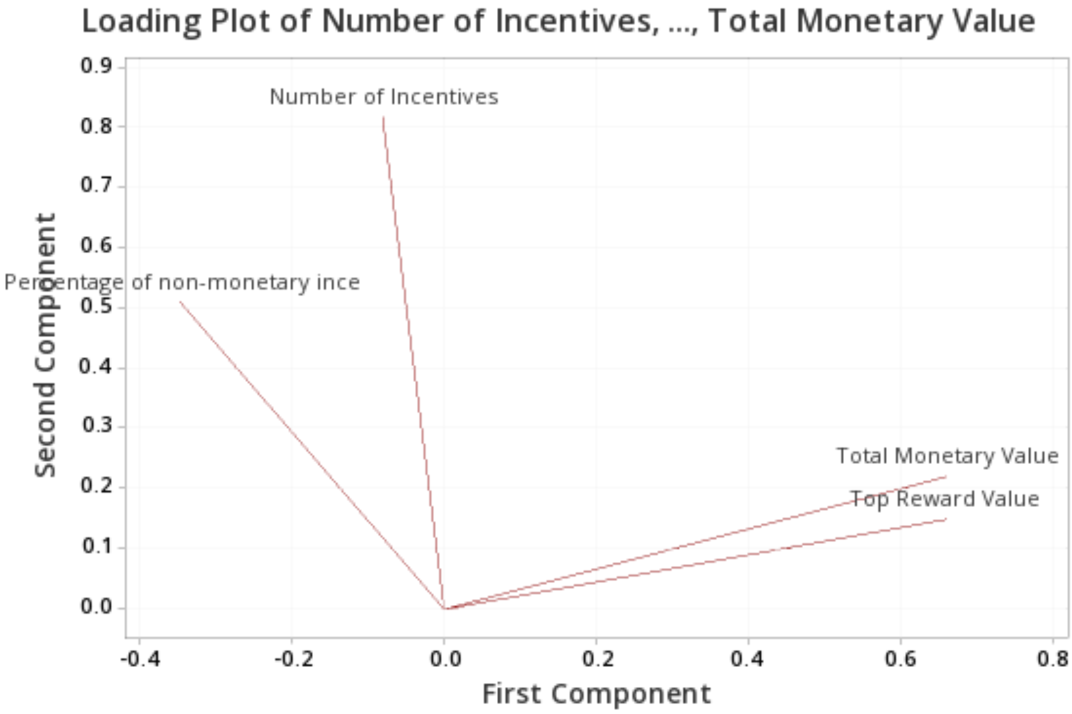

Figure 7.13: GrabCAD Incentives PCA: Loading Plot

Table 7.18: GrabCAD Incentives PCA: Weighted Eigenvectors

Variable	**Total Weighted Eigenvectors for PC1 and PC2**
Number of Incentives	0.270269
Percentage of non-monetary ince	0.319932
Top Reward Value	0.37766
Total Monetary Value	0.398049

Interpretation of Results: Incentives PCA

As visually represented by Figure 7.12 and presented in Table 7.16, PC1 and PC2 are largely responsible for the variance in data, representing 78.9% of data variance.

Figure 7.13 shows top reward and total monetary value are clustered and therefore show similar variance while number of incentives and percentage of non-monetary incentives are separated with regards to the variance in PC1 and PC2.

Table 7.18 shows that Total Reward Value represents a slighter greater proportion of variance and therefore Total Monetary Value is excluded while Total Reward Value, Percentage of Non-Monetary Incentives and Number of incentives are nominated for Multiple Regression.

Innocentive

The following sections show the categorial principle component analyses for the data collected for Innocentive.

Problem Complexity Metrics

Table 7.19: Innocentive Problem Complexity PCA: Eigenvalues

Eigenvalue	1.902	1.141	0.7605	0.1965
Proportion	0.475	0.285	0.19	0.049
Cumulative	0.475	0.761	0.951	1

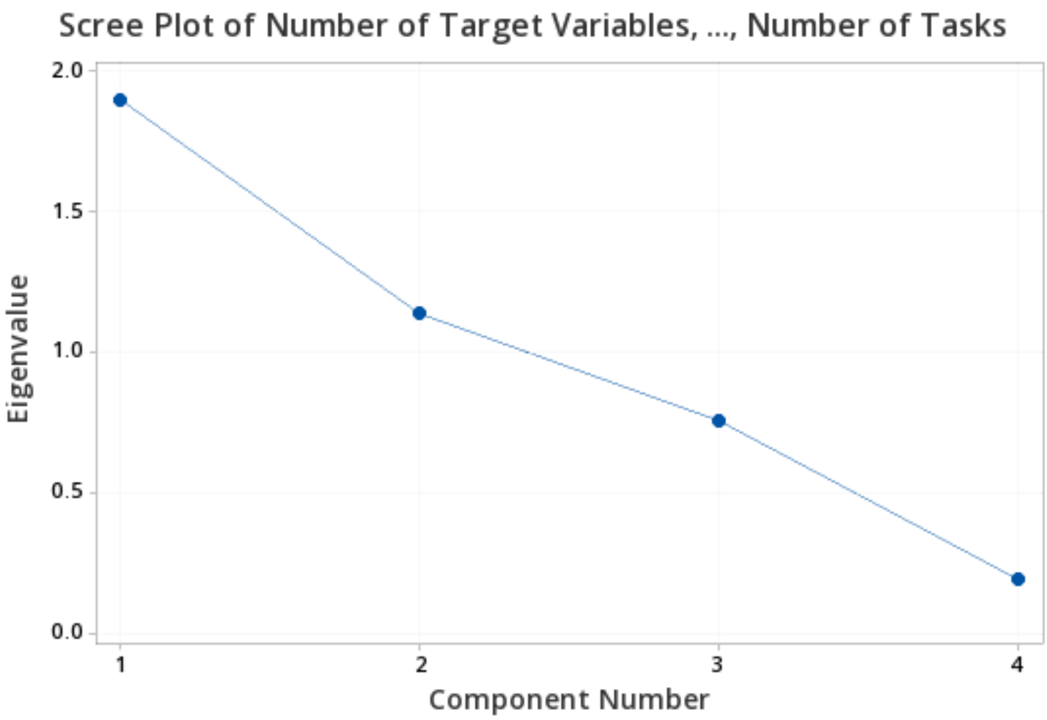

Figure 7.14: Innocentive Problem Complexity PCA: Scree Plot

Table 7.20: Innocentive Problem Complexity PCA: Eigenvectors

Variable	**PC1**	**PC2**	**PC3**	**PC4**
Number of Target Variables	0.489	-0.582	-0.366	0.537
Number of Constraints	-0.359	-0.786	0.032	-0.503
Coupling Ratio	0.657	0.121	-0.307	-0.678
Number of Tasks	0.447	-0.171	0.878	0.005

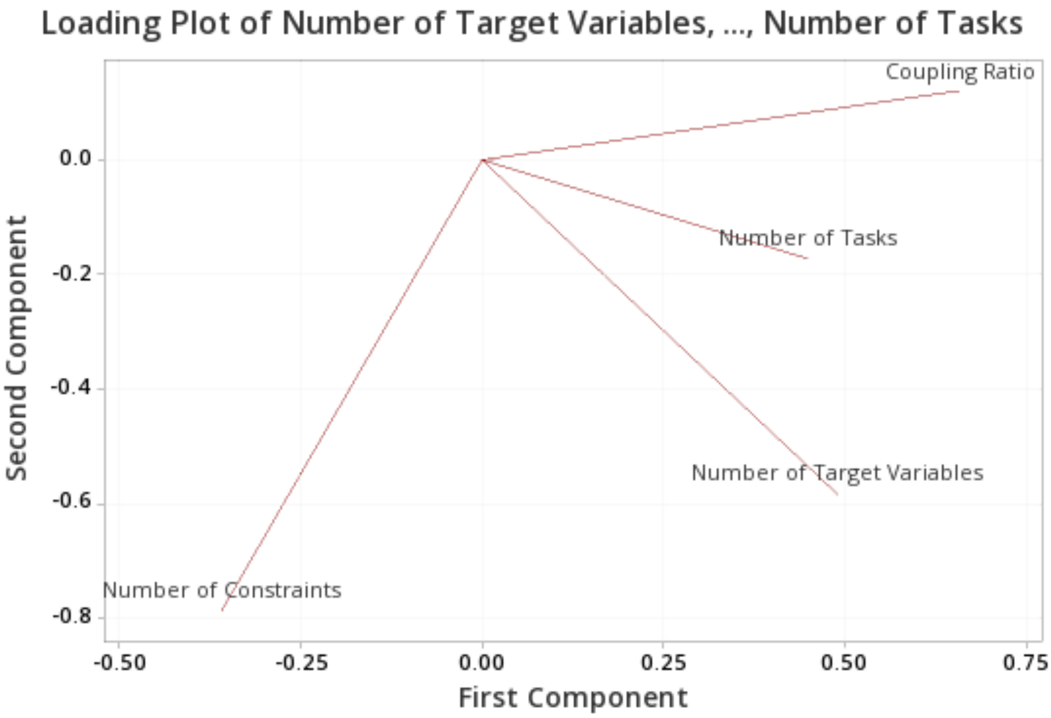

Figure 7.15: Innocentive Problem Complexity PCA: Loading Plot

Table 7.21: Innocentive Problem Complexity PCA: Weighted Eigenvectors

Variable	**Total Weighted Eigenvectors**
Number of Target Variables	0.493998
Number of Constraints	0.425262
Coupling Ratio	0.438112
Number of Tasks	0.428125

Interpretation of Results: Problem Complexity PCA

Showing similar results to the GrabCAD data for problem complexity (Section 7.4.1), the loading plot for this data (Figure 7.7) shows no clustering of data and the total weighted eigenvectors, in Figure 7.7, are similar. The PCA for this data is therefore inconclsuive and further discussion in Section 7.4.2.

Problem Framing

Table 7.22: Innocentive Problem Framing PCA: Eigenvalues

Eigenvalue	5.6714	1.8106	0.8625	0.4876	0.1194	0.0419	0.0037	0.002	0.001
Proportion	0.63	0.201	0.096	0.054	0.013	0.005	0	0	0
Cumulative	0.63	0.831	0.927	0.981	0.995	0.999	1	1	1

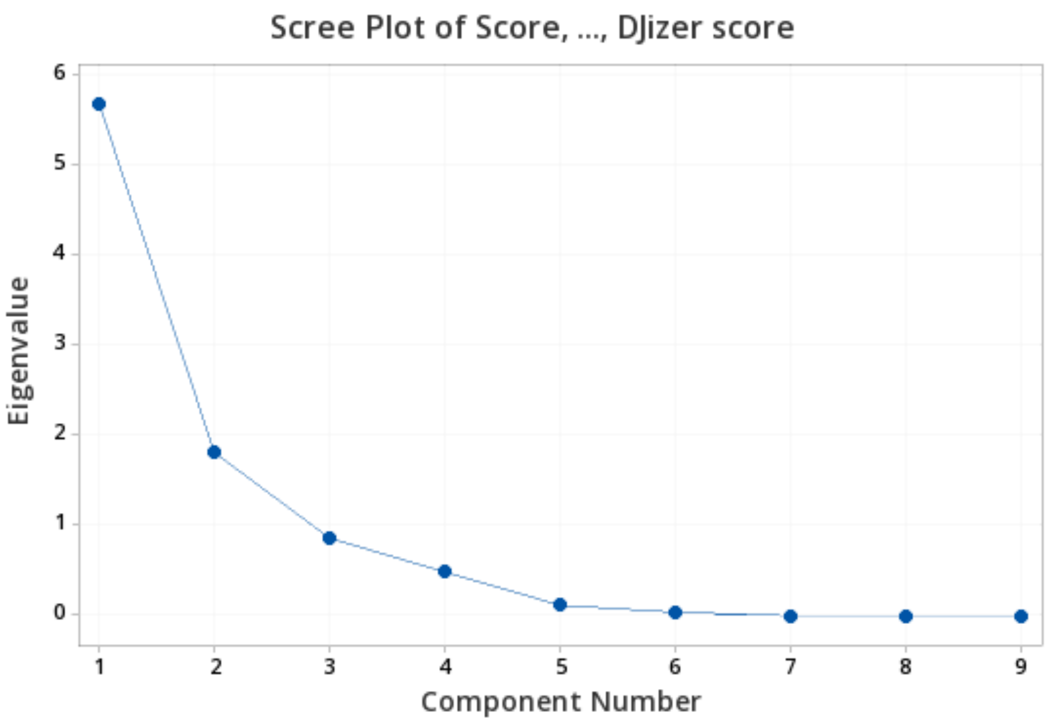

Figure 7.16: Innocentive Problem Framing PCA: Scree Plot

Table 7.23: Innocentive Problem Framing PCA: Eigenvectors

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
Score	-0.151	0.657	0.134	0.163	0.706	0.05	-0.013	0.013	-0.005
Magnitude	0.388	0.136	0.118	-0.39	0.08	-0.811	-0.017	0.02	0.015
Sentiment	-0.148	0.663	0.065	0.19	-0.697	-0.111	0.013	-0.01	0.004
Words	0.387	0.191	0.1	-0.37	-0.069	0.417	-0.686	-0.072	0.113
Characters	0.387	0.183	0.136	-0.364	-0.046	0.391	0.701	0.062	-0.126
Common	0.361	0.086	-0.497	0.26	0.015	0.005	-0.1	0.681	-0.271
Mid-Frequency	0.238	-0.177	0.789	0.416	-0.037	-0.003	-0.087	0.196	-0.263
Jargon	-0.403	0.009	0.037	-0.401	-0.019	-0.005	-0.143	0.05	-0.808
DJizer score	0.395	0.038	-0.255	0.338	0.032	-0.026	-0.001	-0.697	-0.42

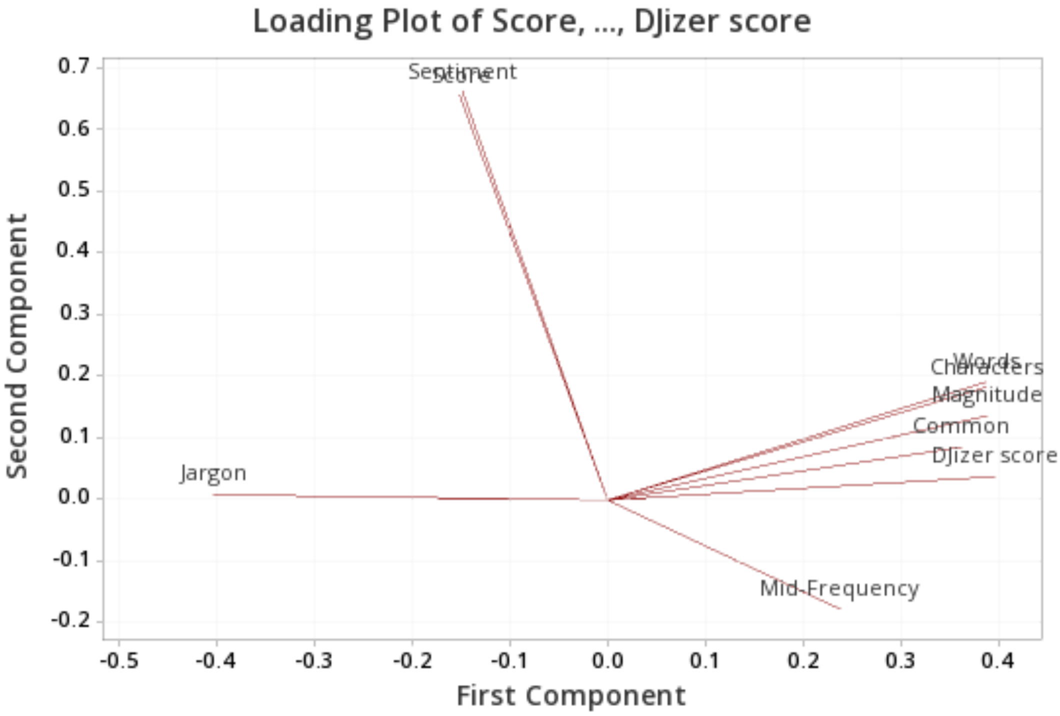

Figure 7.17: Innocentive Problem Framing PCA: Loading Plot

Table 7.24: Innocentive Problem Framing PCA: Weighted Eigenvectors

Variable	**Total Weighted Eigen Vectors for PC1 and PC2**
Score	0.227187
Magnitude	*0.271776*
Sentiment	0.226503
Words	*0.282201*
Characters	*0.280593*
Common	0.244716
Mid-Frequency	0.185517
Jargon	*0.255699*
DJizer score	*0.256488*

Interpretation of Results: Problem Framing PCA

Figure 7.14 shows an almost exponential curve, representing a large proportion of data variance attributed to earlier principle components. PC1 and PC2, as shown in Table 7.22, represent 83% of data variance.

Examination of Figure 7.17 shows number of words, number of characters, magnitude of sentiment, number of common words, number of mid-frequency words and de-jargonzier score to be clustered while sentiment, sentiment score are clustered and jargon represents a separate direction of variance. Furthermore, magnitude of sentiment, number of words, number of characters, jargon and de-jargonzer, in Table 7.24, are shown to be most representative of data variance.

As a consequence, and with a similar approach to teh decision on GrabCAD problem framing data. The nominated variables correspond to the three aspects of language analysis; feeling, length and content (Birch, 2005). The nominated variables are sentiment score, jargon and number of words.

Company Reputation

Table 7.25: Innocentive Company Reputation: Eigenvalues

Eigenvalue	2.7059	0.9749	0.2738	0.0453
Proportion	0.676	0.244	0.068	0.011
Cumulative	0.676	0.92	0.989	1

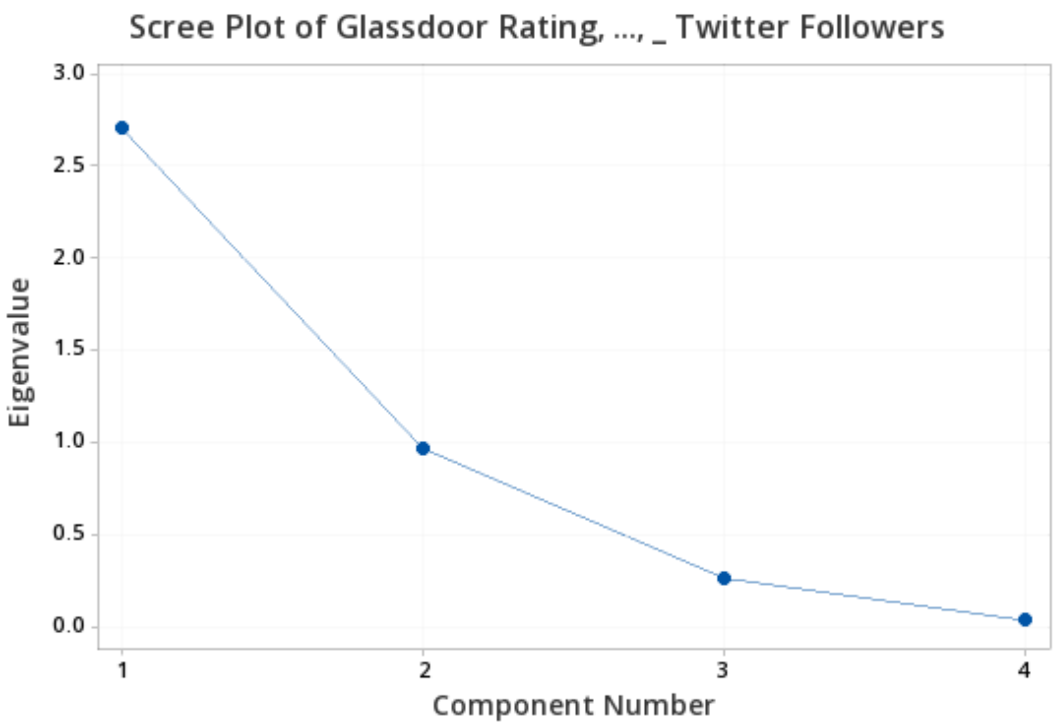

Figure 7.18: Innocentive Company Reputation: Scree Plot

Table 7.26: Innocentive Company Reputation: Eigenvectors

Variable	PC1	PC2	PC3	PC4
Glassdoor Rating	0.547	0.024	0.832	0.09
Number of Employees	0.547	-0.388	-0.274	-0.689
Revenue	0.583	-0.048	-0.454	0.672
_ Twitter Followers	0.247	0.92	-0.161	-0.258

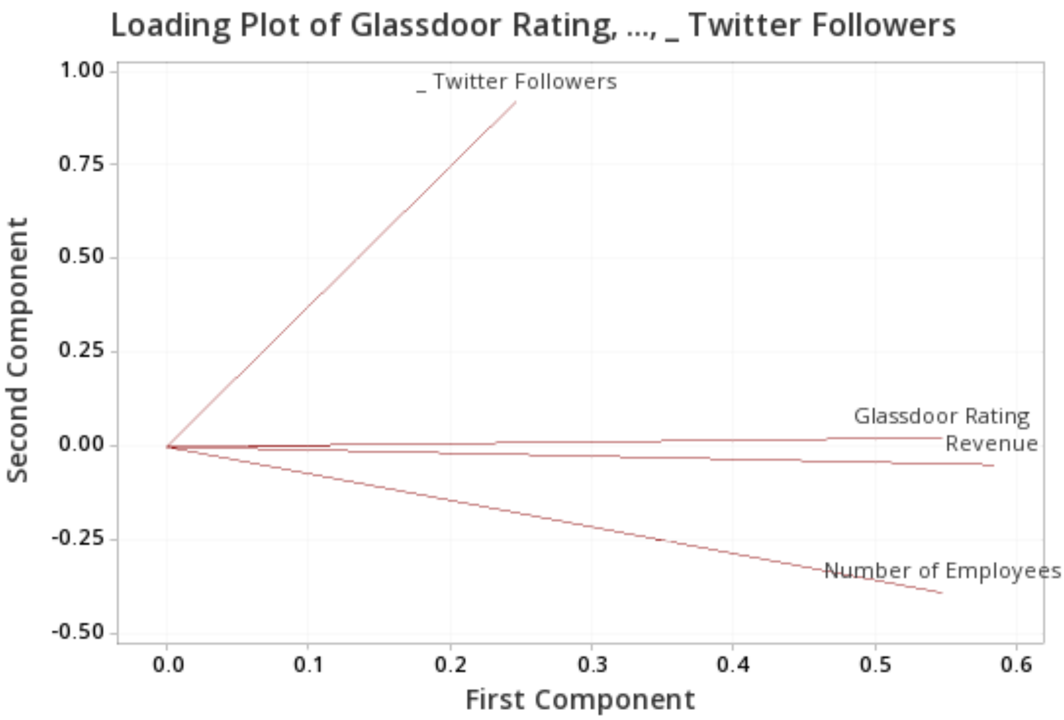

Figure 7.19: Innocentive Company Reputation: Loading Plot

Table 7.27: Innocentive Company Reputation: Weighted Eigenvectors

Variable	**Total Weighted Eigen Vectors for PC1 and PC2**
Glassdoor Rating	0.375628
Number of Employees	0.464444
Revenue	0.40582
_ Twitter Followers	0.391452

Interpretation of Results: Company Reputation PCA

Figure 7.18 and Table 7.25 show that 92% of data variance can be attributed to PC1 and PC2, with PC1 representing 67.6% of variance and PC2 representing 24.4% of variance.

With such a large proportion of variance attributed to PC1, it would be possible to nominate or exclude variables based on PC1 alone. However, with reference to Table 7.26, both Glassdoor rating and number of Employees share the eigenvector of 0.547 and Revenue is very close with an eigenvector of 0.583.

Table 7.27 was therefore generated to show the weighted eigenvector for PC1 and PC2. Table 7.27, shows Number of Employees to be most representative of the variance of data and it is therefore nominated for use in the Multiple Regression analysis. The other three variables have eigenvectors that are very close in magnitude and therefore, with reference to Figure 7.19, clustering is considered. Glassdoor rating, Revenue and Number of Employees are clustered and therefore represent the similar variance in data while Twitter followers is separate. Therefore, the number of Twitter followers is nominated. Two variables, one being an attribute of the company's size and the other being an attribute of the company's awareness by the public, is nominated for use in the multiple regression analysis.

Incentives

Innocentive offers a different structure of incentives compared to GrabCAD. While GrabCAD allows sponsors to offer some non-monetary rewards at different tiers, Innocentive only allows sponsors to present one monetary reward to a disclosed number of winners. There is therefore only two variables for incentives in the Innocentive data; total reward value and number of incentives. These are both included in the multiple regression analysis.

Consolidated Results from PCA from Innocentive and GrabCAD

Table 7.28: PCA Results

Platform	Category	Results
GrabCAD	Problem Complexity	PCA inconclusive
	Problem Framing	Jargon, Number of Characters and Sentiment Score nominated
	Company Reputation	PCA inconclusive
	Incentives	Number of Incentives, Percentage of Non-Monetary Incentives and Total Reward Value nominated
Innocentive	Problem Complexity	PCA inconclusive
	Problem Framing	Jargon, Number of Words and Sentiment Score nominated
	Company Reputation	Number of employees and Twitter followers nominated
	Incentives	Number of incentives and Total Reward Value nominated

7.4.2 Multiple Regression Analysis

Final selection of metrics

For the GrabCAD data, eight metrics (including campaign details of days active and number of stages) have been nominated for multiple regression analysis with metrics representing problem complexity and company reputation requiring further discussion. For the Innocentive data, nine metrics (including campaign details) have been nominated for multiple regression analysis with metrics representing problem complexity requiring further discussion.

For both Innocentive and GrabCAD, four metrics were collected from problem complexity; number of target variables, number of constraints, coupling ratio and number of tasks. Including the number of target variables without including the number of constraints (and vice versa) removes significant context that defines the complexity of a problem. A problem may present many constraints but the complexity of a problem varies significantly depending on whether there are many or few target variables. Coupling ratio is derived from both the number of target variables and the number of constraints and therefore should be nominated as inclusion in the multiple regression analysis. For Innocentive, three more variables can be included therefore both number of tasks and coupling ratio is nominated for multiple regression analysis.

Principle Component Analysis was inconclusive for GrabCAD data but conclusive for Innocentive data on company reputation with Number of employees and number of Twitter followers nominated for the Innocentive multiple regression analysis. These two metrics represent an attribute of the firm's size (number of employees) and an attribute of the firm's public popularity (number of Twitter followers). A similar approach should be taken for GrabCAD data therefore number of Twitter followers should be nominated. With reference to Table 7.15, Glassdoor rating represents the greatest variance in the data and encompasses several other measurements such as leadership quality, quality of product and public perception (considered significant in defining company reputation as discussed in Section 7.3.3 (Fombrun et al., 2015). The final metrics for each multiple regression analysis are shown in Table 7.29.

Table 7.29: Metrics for Use in Multiple Regression Analysis

Platform	**Nominated Metrics**
GrabCAD	1. Coupling Ratio 2. Number of Tasks 3. Jargon 4. Number of Characters 5. Sentiment Score 6. Glassdoor Rating 7. Number of Twitter Followers 8. Number of Incentives 9. Percentage of Non-Monetary Incentives 10. Total Reward Value 11. Days Active 12. Number of Stages
Innocentive	1. Coupling Ratio 2. Number of Tasks 3. Jargon 4. Number of Words 5. Sentiment Score 6. Number of employees 7. Number of Twitter Followers 8. Number of Incentives 9. Total Reward Value 10. Days Active 11. Number of Stages

Multiple Regression Analysis Results

For both Innocentive and GrabCAD, a multiple regression analysis with the twelve listed variables was conducted. Unfortunately, despite taking guidance from existing literature there were several issues with using the full number of variables. Firstly, only one or two variables are shown to be statistically significant which, considering the adequate sample size (Chakraborty et al., 2020), suggested the linear regression model does not fit this data. Furthermore, the R^2 values shown in Tables 7.32 and 7.30 also suggest this with the R^2 predictor value, which determines whether the assumptions can apply to new observations, at 0.00%.

Table 7.30: GrabCAD Multiple Regression Results with 12 Variables

S	R-sq	R-sq(adj)	R-sq(pred)
103.498	7.18%	0.00%	0.00%

Table 7.31: Innocentive Multiple Regression Results with 12 Variables

S	R-sq	R-sq(adj)	R-sq(pred)
250.406	56.89%	46.35%	0.00%

As a consequence, the number of variables needed to be reduced further. Existing literature also suggests five variables as the optimum number of variables to do for multiple regression (Chakraborty et al., 2020). Since there were five categories to be included; problem complexity, problem framing, company reputation, incentives and basic campaign details, one variable from each category is nominated. To determine which variable from each category should be nominated each variable combination was tested to determine which variables fitted the model most closely and therefore offered the most useful associations between the independent and dependent variables. An excerpt of the results of this process are shown in Table 7.32.

Table 7.32: Innocentive Multiple Regression Fit Test with 5 variables (Excerpt)

Problem Complexity	Problem Framing	Company Reputation	Incentives	Basic Campaign Details	R^2
Coupling Ratio	Number of Employees	Sentiment Score	Number of incentives	Days Active	61.72%
Coupling Ratio	Number of Employees	Sentiment Score	Number of incentives	Number of stages	8.62%
Coupling Ratio	Number of Twitter Followers	Jargon	Total Reward Value	Number of Stages	71.08%
Coupling Ratio	Number of Employees	Sentiment Score	Number of Incentives	Number of Stages	8.62%
Coupling Ratio	Number of Twitter Followers	Sentiment Score	Number of Incentives	Days Active	61.72%
Number of Tasks	Number of Twitter Followers	Sentiment Score	Number of Incentives	Days Active	61.72%

The following variables were shown to best fit the multiple regression model for Innocentive with an R^2 value of 84.93%. The relationship between Y and the X variables is statistically significant ($p < 0.05$).

- Problem complexity: Coupling Ratio
- Company Reputation: Number of Employees
- Problem Framing: Number of Words
- Incentive: Total Reward Value
- Basic Campaign Details: Number of Stages

The resulting equation is as follows:

$$\begin{aligned} S = -13344 + 9699X_1 + 1.298X_2 - 8.13X_3 + 0.00595X_4 + 13709X_5 \\ -0.000032{X_2}^2 + 0.00447{X_3}^2 - 2.55X_1X_3 - 9078X_1X_5 \\ +0.000083X_2X_3 - 0.987X_2X_5 + 6.20X_3X_5 - 0.00449X_4X_5 \end{aligned}$$

Equation 7.4.2.1

where

S = Number of Submissions

X_1 = Coupling Ratio

X_2 = Number of Employees

X_3 = Number of Words

X_4 = Total Reward Value

X_5 = Number of Stages

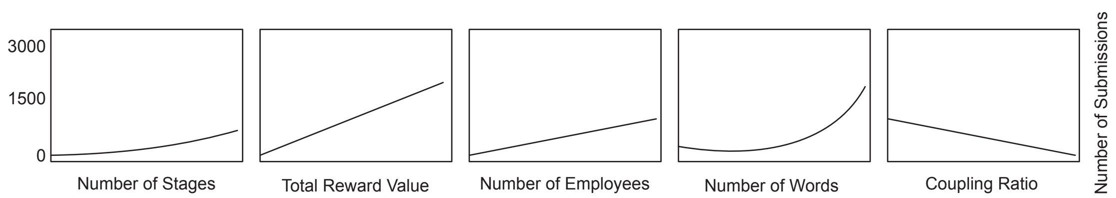

Figure 7.20: Innocentive: Relationships between Independent Variables and Number of Submissions

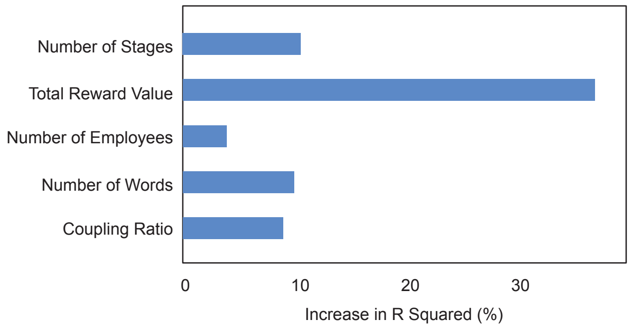

Figure 7.21: Innocentive: Influence of Variables

The following variables were shown to best fit the multiple regression model for GrabCAD with an R^2 value of 70.08%. The relationship between Y and the X variables is statistically significant (p $<$ 0.01).

- Problem complexity: Coupling Ratio
- Company Reputation: Twitter followers
- Problem Framing: Jargon
- Incentive: Number of incentives
- Basic Campaign Details: Number of stages

$$\begin{aligned} S = -111.1 + 97.3X_1 + 36.90X_2 + 5.48X_3 + 1375X_4 - 0.000582X_5 \\ -2.669{X_2}^2 + 0.1455{X_3}^2 - 907X_1X_4 + 0.000293X_1X_5 \\ -0.646X_2X_3 - 58.8X_3X_4 + 0.000009X_3X_5 + 0.001061X_4X_5 \end{aligned}$$

Equation 7.4.2.2

where

S = Number of Submissions

X_1 = Number of Stages

X_2 = Number of Incentives

X_3 = Coupling Ratio

X_4 = Jargon

X_5 = Twitter Followers

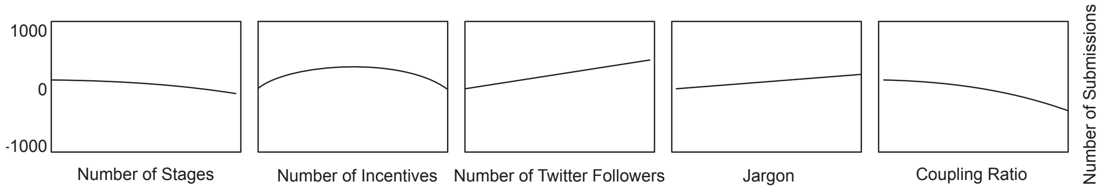

Figure 7.22: GrabCAD: Relationships between Independent Variables and Number of Submissions

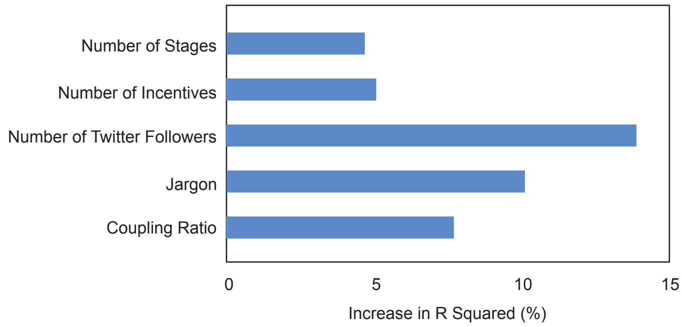

Figure 7.23: GrabCAD: Influence of Variables

7.5 Validation for Crowdsourcing Success Experiment

To validate the prediction equations, ten of the most recent completed projects from GrabCAD and Innocentive, not included in the original database, were used. The most recent projects were used to provide the most accurate indication of how the tool would perform on future projects. These projects represent open contests on both Innocentive and GrabCAD and each consist of a problem statement, sometimes with accompanying material, that participants are encouraged to submit solutions for. For Innocentive, the number of submissions, the coupling ratio, number of employees, number of words, total reward value and number of stages were collected. For GrabCAD, the number of submissions, the number of stages, the number of incentives, the coupling ratio, the percentage of jargon and the number of Twitter followers were collected. Data was collected in the same way as data was collected for the success factor experiment. The number of submissions, the number of stages and the number of incentives were scraped with a data scraping tool while the coupling ratio, the percentage of jargon, the number of Twitter followers and the number of words were calculated manually or with other websites such as Glassdoor and Jargonizer. Table 7.33 and Table 7.34 show the results from the validation.

Table 7.34: GrabCAD Validation

Project	X1	X2	X3	X4	X5	Y Real	Y Calculated	Diff (%)	ABS
GrabCAD	1	4	0.22	0.04	9289	108	26.67	26.67	26.67
IDSA	2	2	0.67	0.04	32600	132	8.25	8.25	8.25
Stratysys	1	2	0.57	0.04	3500	68	-39.02	39.02	39.02
Stratysys	1	3	0.57	0.04	3500	91	-1.63	1.63	1.63
Stratysys	1	4	0.57	0.04	3500	109	-20.78	20.78	20.78
Massachusetts General Hospital	2	4	0.50	0.06	416	162	-24.03	24.03	24.03
NASA	1	3	0.25	0.11	500000000000	-85019876	-26160061.96	26160061.96	26160061.96
Grundfos	2	2	0.80	0.06	7295	121	19.07	19.07	19.07
GrabCAD	1	3	0.57	0.02	9289	81	-17.14	17.14	17.14
ASME	2	4	1.50	0.04	27700	174	18.12	18.12	18.12
Stena Teknik	1	4	0.67	0.01	3461	96	-12.33	12.33	12.33
								Accurate Within (%)	**20.78**

Table 7.33: Innocentive Validation

Project	X1	X2	X3	X4	X5	Y Real	Y Calculated	Diff (%)	ABS
ICL	0.13	10000	124.00	10000	1	219.00	262.57	19.90	19.90
MISO	1.33	1000	382.00	15000	1	139.00	141.83	2.03	2.03
Anonymous	0.25	0	227.00	1000	2	214.00	13011.63	5980.20	5980.20
Seoul Institute of Technology	0.11	10000	338.00	1000	1	348.00	388.56	11.66	11.66
NOVO Nordisk	0.13	10000	288.00	25000	1	411.00	350.34	-14.76	14.76
Corteva Agriscience	1.40	10000	674.00	50000	1	110.00	100.43	-8.70	8.70
Enel Green Power	0.33	10000	209.00	30000	1	340.00	313.50	-7.79	7.79
Anonymous	1.50	0	210.00	30000	2	178.00	1588.18	792.23	792.23
Decathlon	0.43	10000	168.00	25000	1	397.00	335.40	-15.52	15.52
Enel	1.20	5000	258.00	50000	2	310.00	310.89	0.29	0.29
Anonymous	1.40	0	222.00	25000	2	58.00	2534.15	4269.22	4269.22
								Accurate Within (%)	**10.08**

As highlighted in Table 7.33, the model is shown to be incorrect for challenges where the sponsor is anonymous and therefore the “Number of employees” is zero. Table 7.34 is shown to be incorrect for companies with a significant number of Twitter followers (in this case 5 million from NASA). As additional cases are completed on the GrabCAD platform, further validation will be required to determine the number at which the model ceases to function.

With removal of these outliers, the Innocentive model is shown to be accurate within an average of 10.08% of the true number of submissions and the GrabCAD model is shown to be accurate within an average of 20.78%. This means that organisations can input values in the above variables and get a predication within an average of 10.08% for Innocentive and 20.78% for GrabCAD.

7.6 Discussion for Crowdsourcing Success Experiment

In this section, there are three areas of discussion. Firstly, the relationships between each variables and the number of submissions, for both platforms, are discussed. Secondly, the results from both platforms are compared and a discussion on whether crowdsourcing platform is an influential factor is presented.

7.6.1 Relationships shown for Innocentive

With reference to Figure 7.20, the results from the regression analysis show how each variable is related to the number of submissions. The Number of Stages (X_5) is shown to have an almost linear and positive relationship with the Number of Submissions (Y). This means that when sponsors introduce an increased number of stages of submissions before selecting a winner, the number of submissions is higher. This is counter to the findings of Chaudhari et al. (2018) who find that design effort does not have a linear relationship with the number of submissions. It could be the case that when introducing multiple stages, sponsors should be mindful of the design effort required at each stage. A first stage with a low level of effort may allow greater access, which may result in higher submissions, with further stages increasing the effort required and therefore the quality of submissions. Further work, is therefore required to consider how submissions from the first to the final stage vary and whether this provides further insight into why increasing the number of stages increases the number of submissions.

The Total Reward Value (X_4) is shown to have a linear positive relationship with the Number of Submissions (Y). This means that when sponsors provide incentives with a larger overall value, they receive an increased number of submissions. In the specific context of Innocentive, total reward value refers to the total monetary reward offered and shows that an increased monetary incentive increases submissions. Furthermore, with reference to Figure 7.21, Total Reward Value is shown to be the most influencing variable and responsible for over 30% of the information in the model. This means that the other relationships presented in Figure 7.20, are highly influenced by the reward value presented by the sponsor. This ultimately shows the importance of increasing the Total Reward Value as a priority in comparison to increasing the Number of Stages or the Number of words.

The Number of Employees (X_2) also shows a positive linear relationship with the Number of Submissions. This suggests that the larger a company, with regards to the number of variables, the higher the number of submissions and suggests company reputation influences crowdsourcing success. With reference to the Company Reputation PCA for Innocentive (Figure 7.19 and Table 7.27), the Number of Employees is clustered with Revenue and Glassdoor rating, and is representative of the majority of data variance. This suggests that the relationship with Number of Employees is representative of the relationships between Number of Submissions and both Revenue and Glassdoor Rating. Therefore, the better a company's reputation, as quantitatively defined by Glassdoor, their Revenue and the Number of Employees, the higher the number of submissions. It should be noted that this excludes the influence of Twitter followers as this metric was not included in the same cluster as the other company reputation metrics. Furthermore, it should also be noted that the influence of Number of Employees on the other variables (see Figure 7.21) and the overall results are small suggesting the influence of the Number of Employees when isolated, and therefore company reputation, are not significant.

The Number of Words (X_3) has a non-linear relationship with the Number of Submissions (Y) as shown by the hockeystick graph shown in Figure 7.20. This suggests that there is a slight dip in submissions from short project descriptions but then a significant increase in submissions with longer project descriptions. This provides several potential insights, depending on the assumptions made regarding the change in content with an increase in length. It could be said that longer project description provide more detail on the potential solution and therefore an increased length results in an increase in understanding for potential solvers and therefore an increase in submissions. Alternatively, it could be assumed that longer project descriptions represent projects which require more effort. Alternatively, it could be assumed that longer project descriptions represent more complex problems, therefore suggesting that projects that appeal to higher qualified potential solvers get more submissions. The need for these assumptions shows the need for further insight to draw additional conclusions from this finding, but sponsors should consider increasing the length of their project description to increase the number of submissions.

Number of Words, with reference to the Innocentive PCA for Problem Framing (see Figure 7.17 and Table 7.21) is representative of several of problem framing variables including De-jargonizer Score and the Number of Common words. Furthermore, Table 7.24 shows the Number of Words to be most representative of all problem framing data for Innocentive. This suggests that the relationships yielded for the Number of Words vs. the Number of Submissions could be representative of the relationship between other Problem Framing variables. However, with reference to Figure 7.15 Sentiment and Jargon are not included in the main cluster of data. This suggests that Number of Words (representative of length of text Birch (2005)) should not be used to represent the feeling of text (Sentiment) or the comprehension of the text (Jargon). Further insight into how the feeling and comprehension of text influences the number of submissions should be considered in future work on this topic.

Coupling Ratio (X_1) is shown to have a negative and linear relationship with the Number of Submissions (Y). Coupling Ratio is the Number of Target Variables divided by the Number of Constraints. This means that for a single constraint, an increasing number of target variables reduces the number of submissions and for a single target variable, an increasing number of constraints increases the number of submissions. This suggests that problems with an open design solution space, with regards to constraints, but with a large number of required objectives are less popular than problems with a small design solution space, due to a higher of number of constraints, that have relatively few targets to fulfill. With reference to Table 7.3 (Page 137), this suggests that Visionary Project invite less submissions than Retrofit or Redesign projects. Potential solvers prefer to work on a problem within a well-bounded set of constraints as opposed to find a new solution, from a large solution space, that has to fulfill a number of target variables. The principle component analysis for problem complexity for Innocentive data was inconclusive therefore this relationship is not representative of the relationship between the Number of Submissions and the Number of Target Variables, the Number of Constraints or the Number of Tasks. It is the case, however, that the coupling ratio as described by Chaudhari et al. (2018), can be used to represent problem complexity as a whole. Problem complexity therefore increases the number of submissions decreases, therefore suggesting that complex projects are not as suitable for crowdsourcing.

7.6.2 Relationships shown for GrabCAD

Figure 7.22 shows the Number of Stages (X_1) to have a non-linear negative relationship with the Number of Submissions (Y). It shows there to be no changes in the Number of Submissions between Stage 1 and Stage 2 but a linear decrease in the number of submissions for initiatives with three stages. This suggests that potential solvers have a limit to the number of stages they are open to participating in before increasing stages begins to reduce the pool of potential solvers. The data set only includes contests with a maximum of three stages, therefore further work on how solvers respond to initiatives with more than three stages, is required to determine whether this relationship remains linear after two stages.

Number of Incentives (X_2) is shown to have a non-linear relationship with Number of Submissions (Y) with the Number of Submissions increasing then decreasing with the Number of Incentives. This suggests that there is an optimal Number of Incentives at approximately six, that encourages submissions. Number of Incentives is not representative of the influence of Incentives on the Number of Submissions, as a whole. As can be seen in Table 7.18 (Page 159), Number of Incentives is responsible for the least amount of data variance and is not closely clustered with any other variables (see Figure 7.13). It is the case however that the vast majority of projects that offer more than three incentives, include non-monetary rewards. This therefore suggests that including an optimal number of additional non-monetary rewards, can increase the number of submissions. Further work should consider how the top reward value and the distribution of reward value across incentives influences number of submissions.

Figure 7.22 illustrates a positive linear relationship between the Number of Twitter Followers (X_5) and the Number Submissions (Y). It is also the case, with reference to Figure 7.23, that it has the most influence. This suggests that an increased Number of Twitter followers can significantly influence the number of submissions a sponsor can expect, demonstrating the importance of online presence in crowdsourcing. With reference to Figure 7.11 and Table 7.15 (Page 157), the Number of Twitter Followers is not representative of a significant proportion of data variance and therefore cannot be used to determine a relationship between Company Reputation as a whole and the Number of Submissions.

Jargon (X_4) is shown to have a non-linear positive relationship with the Number of Submissions (Y). As the amount of jargon in a project description increases the number of submissions increases. This suggests that appealing to a more “qualified crowd” through domain-specific language increases the number of submissions. By tailoring a project description to appeal to those with domain expertise, you increase the engagement with a project. This not only shows the importance of language but also shows that in the context of crowdsourcing creating exclusivity through domain-specific language increases success as opposed to refining a project description for accessibility. This raises a further discussion regarding the use of crowdsourcing as a vehicle for the democratisation of design. If increasing the barrier to entry through the use of jargon increases the number of submissions, crowdsourcing is not necessarily increasing access to design but instead matching experts across the world to organisations. Jargon, as shown by Figure 7.9 (Page 155), is not clustered with any other problem framing variables and therefore cannot be used to show the influence of any other problem framing variables on the number of submissions. It is the case, however, that Jargon is responsible for a relatively large amount of data variance (see Table 7.12) and it could be said that the influence of Jargon (as shown in Figure 7.23) is representative of the influence of problem framing on the number of submissions.

Coupling Ratio (X_3) is shown to have a negative non-linear relationship with the Number of Submissions (Y). It is shown to have an increasingly negative gradient with an increase in coupling ratio. This suggests that as the Number of Target Variables increases relative to the Number of Constraints, the number of submissions decreases increasingly quickly. With reference to Table 7.3 (Page 137), this again shows that solvers prefer projects with a larger number of constraints relative to target variables (such as Retrofit projects) over projects with a larger number of target variables relative to the number of constraints (such as visionary projects). The Innocentive Problem Complexity PCA (Page 152) is shown to be inconclusive and, therefore, this result is not representative of other problem complexity variables and their relationship with the number of submissions nor the relationship between problem complexity and the number of submissions as a whole.

7.6.3 Comparison of Platforms

There are several results that can be used to compare the platform data and determine whether crowdsourcing platform is influential on success. By doing so, a conclusion on whether all or either of the platform results are representative of all crowdsourcing platforms or only the corresponding platform.

Firstly, the Principle Component Analysis for each set of data can be considered. By considering Innocentive Problem Complexity data with GrabCAD Problem Complexity data, and so on, similarities in the data can be seen. For example, for both problem complexity results, a wide spread in PC1 and PC2 is shown for both and both PCA were considered inconclusive as a consequence. In the company reputation data, both sets of data show minimal clustering with significant movement by all variables in the direction of PC1. Finally, in the problem framing data, a cluster of the number of words, characters, common words, mid-frequency words and the de-jargonizer score is seen in both with jargon and sentiment being separated from the rest of the data. The PCA therefore demonstrates similarity in the variance of both data sets and therefore suggests that the platforms propose similar results that are representative of crowdsourcing in general.

When considering the multiple regression results, however, further differences in the data emerges. Table 7.35 consolidates the results for each relationship for each platform.

Table 7.35: Comparison of category and variable relationships for each platform

Category	Variable	Relationship	
		Innocentive	**GrabCAD**
Basic Campaign Details	No. of Stages	Non-linear positive	Non-linear negative
Incentives	Total Reward Value	Linear positive	
	Number of Incentives		Normal curve
Company Reputation	Number of Employees	Linear positive	
	Number of Twitter Followers		Linear positive
Problem framing	Number of Words	Non-linear (hockeystick)	
	Jargon		Linear positive
Problem Complexity	Coupling Ratio	Linear negative	Non-linear negative

There are two categories that allow direct comparison of the results; basic campaign details with the number of stages, and problem complexity with the coupling ratio. Coupling ratio show similar outcomes with Innocentive presenting a linear negative relationship and GrabCAD presenting increasing negative relationship. These results support each other in suggesting how users respond to different project types. On the other hand, the relationship between the number of stages and the number of submissions are directly conflicting with Innocentive presenting a non-linear positive relationship and GrabCAD presenting a non-linear negative relationship. Several conclusions could be drawn from these conflicting results:

1. The solvers on GrabCAD and the users on Innocentive respond differently to the Number of Stages of a project
2. GrabCAD and Innocentive or the sponsors on each platform divide projects into rounds in different ways
3. There are other differences between the platforms (such as the submission process) that cause this difference
4. The results for one or either are inaccurate due to limitations of the model

In addition, Figures 7.21 and 7.23 show different categories as the most and least influential. For example, the Number of Employees is shown to be the most influential variable for Innocentive results but the Number of Twitter followers is shown to be the least influential factor for GrabCAD results. This difference between platforms as well as the other differences between category variables shown in Table 7.35, ultimately show that further work is needed to ascertain which of the above explanations is correct. As a result of the differences between the results, it cannot be said that either or both of these results are representative of crowdsourcing in general and it highlights the importance of considering the influence of the platform on crowdsourcing experiments and crowdsourcing success.

7.7 Limitations for Crowdsourcing Success Experiment

The limitations of this model relate to three areas of work; the data collection, the fit of the multiple regression model and the validation of the model. Firstly, with regards to data collection, the limited range and type of data that is publicly available representations some limitations. For the collection of the number of employees, LinkedIn was used. As a consequence, the exact number of employees was not available and instead LinkedIn provides only a range. For this data, the top end of the range was taken meaning, firstly, the exact value was not included for each company and secondly, the variance of the data was limited. This means for companies with the number of employees within the same bracket, the results may not vary as significantly as they should do. Secondly, data for problem complexity; specifically the number of target variables and the number of constraints, could be considered arbitrary and subject to interpretation. For example, some data collectors may consider a statement such as “it would be useful if the weight was reduced” to represent a target variable while others may not. The same data collector was used for interpretation of target variables and constraints to reduce the impact of this limitation but this may impact the repeatability of these results. Thirdly, assigned values for the monetary value of non-monetary rewards is likely to have introduced innaccuracies due to the subjective nature of this process. The monetary value of “we’ll give your idea credit in our newsletter”, for example, is likely to be different depending on the solver. One researcher was used for these assignments but this again may impact the repeatability of these results. A significant limitation of the model is represented by the model fit. The Innocentive model fit with 84.93% of the data and the GrabCAD model fit with 70.08% of the data. While these are high enough R^2 values for the relationships to be considered significant, a fit lower than 100% shows potential inaccuracies in the model may arise with real-world use. Furthermore, the validation of the model shows that results provided by the Innocentive model are, on average, within 10.08% and results provided by the GrabCAD model are, on average, within 20.88% of the true number of submissions. More importantly, these figures are based on exclusion of outliers as follows:

- The Innocentive model does not allow prediction of submissions if the Number of Employees is not provided (i.e. the sponsor is anonymous)
- The GrabCAD model provides an innaccurate value for the number of submission (of 1000% of the true value or more) for very high Twitter followers

These both represent limitations of the model and further work is required to understand the extent of these limitations. For example, GrabCAD was shown to be innaccurate for NASA with a Twitter following of 5 million but all other companies had a following of fewer than 100,000. It is therefore not clear at what number of Twitter followers the model becomes innaccurate.

7.8 Further work for Crowdsourcing Success Experiment

There are several research opportunities that have emerged as a consequence of both the findings and limitations of this model. Firstly, the difference in the results from both data sets (as consolidated in Table 7.35) show that the crowdsourcing platform influences the relationships between the factors and crowdsourcing success. It is therefore the case that crowdsourcing success factor experiments that use data from only one crowdsourcing platform cannot be deemed representative of crowdsourcing projects as a whole. However, how the crowdsourcing platform specifically influences these results and how platform features influence user decisions is yet to be discovered. Further insight into the impact of crowdsourcing platform design on crowdsourcing success would provide useful insights for this sector. In addition, the validation of these models, shown in Section 7.5, revealed several limitations with regards to the number of Twitter followers the model is accurate for. Further work is required to determine when the model becomes inaccurate and to exclude this limitation from the model.

The relationships identified for the Number of Stages vs. the Number of Submissions were conflicting for the Innocentive and GrabCAD data. Furthermore, projects were collected with a maximum of three stages, whereas there is the option to add an infinite number of stages on both GrabCAd and Innocentive. Two avenues for further work therefore emerge; firstly, work is required to determine whether this discrepancy is a result of the platform or not, and secondly, work is required to understand how these relationships change when the number of stages is greater than 3. Additional stages, allows the sponsor to reduce time associated with final solution evaluation and also increases accessibility; allowing solvers to participate with a smaller task before committing significant design effort. Further research into the relationship between the Number of Stages and the Number of Submissions could therefore be valuable to this sector. In addition, excluded Basic Campaign variables such as Days Active and the Year could be included in this further work.

Project length was shown to have a positive linear relationship with the number of submissions which poses further research questions such as:

- Why does increased project length increase submissions?
- How does the sentiment of a project description influence the number of submissions for the same project length?

- How does the inclusion of jargon influence the number of submissions for the same project length?

Furthermore, the total reward value was shown to have a linear positive relationships with the number of submissions but there was shown to be an optimal number of incentives. This suggests that the distribution of rewards is an important factor. Furthermore, the investigation into the influence of the number of incentives, yielded some insight into the impact of non-monetary rewards. However, as discussed by existing literature, the influence of non-monetary rewards is considered to be significant, therefore further research on the impact of non-monetary rewards would be valuable to this sector. Furthermore, prior to reducing the number of variables by Principle Component Analysis, 22 potentially influential factors were raised by existing literature. The excluded variables such as Intellectual Property and Status of the Sponsor (profit or non-profit), each represent further avenues of research.

Finally, there is potential to combine this experimental work with theoretical models to predict user behaviour, a discussed by Chaudhari et al. (2018). Theoretical models could be used in addition to PCA to reduce the number of variables with consideration of solver behaviour. There is also potential to expand the data set to include the use of Machine Learning algorithms to provide increasingly accurate predictions for the number of submissions.

7.9 Conclusions for Chapter 7

The aim of this chapter was to yield new insights on factors influential in crowdsourcing success by investigating new variables including company reputation, platform and problem framing. Following identification of variables from existing literature and subsequent reduction in the number of variables, a multiple regression analysis was performed to output two equations to predict the number of submissions for crowdsourcing contests on Innocentive and GrabCAD. The resulting equations were validated to show accuracy within 10.08% and 20.78% respectively. Several relationships between factors and the number of crowdsourcing submission were identified including the positive linear relationship that exists between company reputation and the number of submissions. Furthermore, problem complexity, as represented by coupling ratio, was shown to have a linear negative relationship with the number of submissions and project description length and the presence of jargon was shown to have a positive relationship with the number of submissions. These relationships show, firstly, that the more well-known a company is the more submissions they are likely to receive. The relationship yielded for coupling ratio suggests that visionary projects invite fewer submissions than Retrofit or Redesign projects and that potential solvers prefer to work on a problem within a well-bounded set of constraints as opposed to find a new solution, from a large solution space, that has to fulfill a number of target variables. Furthermore, the relationships shown for problem framing suggest that project descriptions that contain more domain-specific knowledge invite more submissions, presenting evidence that tailoring project descriptions to a "qualified crowd" is encouraged for crowdsourcing success. Finally, discrepancies between some comparable relationships from Innocentive and GrabCAD data shows that data from a single crowdsourcing platform is unlikely to be representative of all crowdsourcing platforms, and platform itself is an influential factor on crowdsourcing success. Overall this thesis provides new insights into crowdsourcing success and offers a method for application of this knowledge through the two equations that allow prediction for the number of submissions.

7.10 Chapter 7 Summary

In this chapter, Primary Research Question 2 as well as the following Secondary Research Questions were addressed:

- How do structural decisions of an engineering design SPD (crowdsourcing) initiative influence its outcomes?
- How does framing of engineering design problems in competitive scenarios influence its solutions?
- How can SPD initiative designers effectively decompose an engineering design problem?
- How can optimal incentive structures be formulated for SPD initiatives?
- How do design decisions of an engineering design SPD (crowdsourcing) initiative influence its outcomes?

It includes a crowdsourcing success prediction tool that allows users to enter aspects of their crowdsourcing content (such as budget and time constraints) to then receive an estimate on the number of participants it will receive.

Since this chapter is on crowdsourcing along, as opposed to SPD as a whole, a new literature review on crowdsourcing is provided to prove existence of the literature gaps in this particular focus. Furthermore, reasoning for choosing crowdsourcing as the individual tenant to focus on is provided. The aim of this chapter was to yield new insights on factors influential in crowdsourcing success by investigating new variables including company reputation, platform and problem framing.

Following identification of variables from existing literature and subsequent reduction in the number of variables, a multiple regression analysis was performed to output two equations to predict the number of submissions for crowdsourcing contests on Innocentive and GrabCAD. The resulting equations were validated to show accuracy within 10.08% and 20.78% respectively. Several relationships between factors and the number of crowdsourcing submission were identified including the positive linear relationship that exists between company reputation and the number of submissions. Furthermore, problem complexity, as represented by coupling ratio, was shown to have a linear negative relationship with the number of submissions and project description length and the presence of jargon was shown to have a positive relationship with the 169 number of submissions.

These relationships show, firstly, that the more well-known a company is the more submissions they are likely to received. The relationship yielded for coupling ratio suggests that visionary projects invite less submissions than Retro fit or Redesign projects and that potential solvers prefer to work on a problem within a well-bounded set of constraints as opposed to find a new solution, from a large solution space, that has to fulfill a number of target variables. Furthermore, the relationships shown for problem framing suggest that project descriptions that contain more domain-specific knowledge invite more submissions, presenting evidence that tailoring project descriptions to a “qualified crowd” is encouraged for crowdsourcing success. Finally, discrepancies between some comparable relationships from Innocentive and GrabCAD data shows that data from a single crowdsourcing platform is unlikely to be representative of all crowdsourcing platforms, and platform itself is an influential factor on crowdsourcing success. Overall this chapter allows practitioners to understand the impact of their circumstances and their crowdsourcing initiative design decisions on its success, thus supporting the implementation of crowdsourcing and SPD in industry.

In the following and final chapter, the contributions of the thesis are reviewed and a discussion on whether this theiss fulfills the research questions, is discussed.

Chapter 8

Consolidation and Further Work

In this section, the implications of this research, from both an academic and industry standpoint is then presented along with suggestions for future research directions. This chapter ends with concluding remarks. The research questions addressed and their relevant chapters are presented visually in Figure 8.1

8.1 Overall Contributions and Success at Addressing Research Questions

The aim of this thesis was to provide applicable research to support the implementation of social product development. In order to do so there was first a need to identify the reasons for a lack of implementation thus far. This was representative by the presentation of the first Primary Research Question:

Primary Research Question 1: What are the barriers for the implementation of SPD in industry?

This then provided a foundation and focus for research designed to provide tools and knowledge to support implementation, as represented by Primary Research Question 2:

Primary Research Question 2: How can the implementation of SPD be supported?

In this section, the addressing of each research question by the research presented in this thesis is presented as well as the value and wider implications of this research.

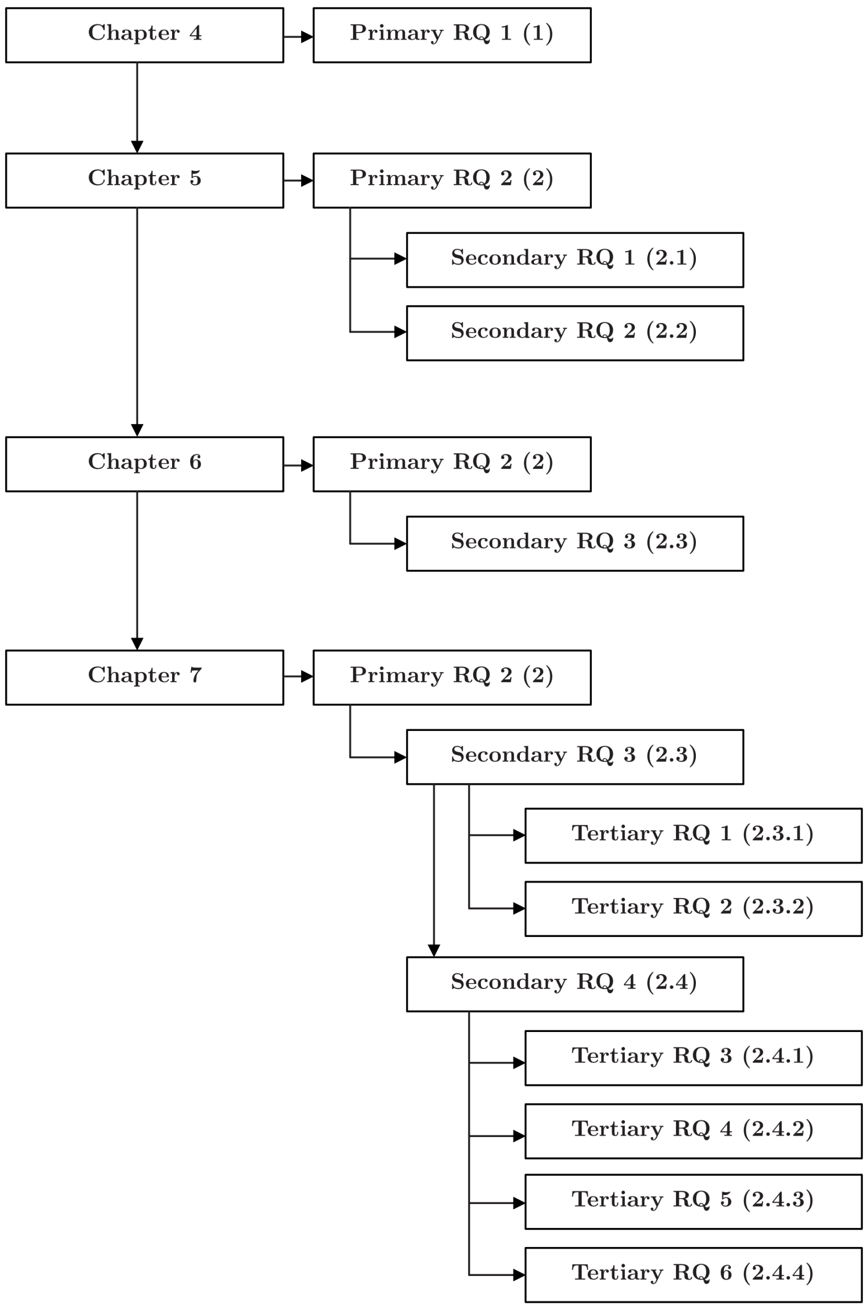

Figure 8.1: Research Question Thesis Organisation

8.1.1 Addressing Primary Research Question 1

Primary Research Question 1 was addressed in Chapter 4 via semi-structured one-on-one interviews with industry professionals. Questions asked to participants related to the challenges they faced in either participating or intending to participate in SPD initiatives. The output from these interviews include the barriers to the implementation of SPD and a list of research directions to overcome them. Whether these results address Primary Research Question 1 is dependent on the appropriateness of the research method as well as the effectiveness of the execution of the research method.

With regards to the appropriateness of the use of semi-structured interviews to understand industry's perspective on SPD, it can be deemed that this method is highly appropriate. Industry practitioners are addressed directly with adequate structure in the questioning to ensure a useful outcome but with openness in the question to allow involvement of additional insight from the participant. Semi-structured interviews are used extensively to address the Primary Research Questions, of a similar kind, and this method is therefore considered appropriate in this case (Krippendorff, 2018).

With regards to the effectiveness of the execution of this research method, there are several aspects to discuss, namely;

- The number of participants
- The type of participants
- The questions posed to the participants
- The data anlysis process

With regards to the number of participants, this is acknowledged in Chapter 4 to be relatively low. While open research questions, similar to Primary Research Question 1, have been addressed with number of similar sizes (Han et al., 2019) the author recognises that the number of participants can be considered low. However, in the case where the number of organisations who have implemented or considered SPD initiatives is incredibly low (Forbes et al., 2019) and often not in the public domain, seeking participants for this study was difficult. To counter this issue, the author did ensure there was a range of participants with regards to both experience and type of organisation. As a consequence, while it is difficult to consider results exhaustive in any experiment where opinions are sought, the results from this interview are considered to provide valuable insights with respect to this research question. Furthermore, each barrier identified by the participants is supported with existing literature to determine whether or not, it has been addressed, increasing the robustness of these results. With regards to other aspects of the research method's execution, questions were phrased to be open where possible and followed existing interview methodologies to reduce bias. Furthermore, in the coding process, two researchers were used to ensure content analysis reliability and the transcribed interviews were coded several times by the researchers. The result is a high Inter-Rate Reliability (IRR) of above 85% for all professionals, with two analyses of participant responses receiving an IRR of 100%. The analysis of the transcribed interviews were therefore considered to be robust by either use of validated methodologies or quantitative assessment of reliability.

Overall, the research presented in Chapter 4 is considered to adequately address Primary Research Question 1 by providing an extensive detail of the barriers and challenges to the implementation of SPD as well as a list of Secondary Research Questions to inform the further research presented in this thesis.

8.1.2 Addressing Primary Research Question 2

Primary Research Question 2, unlike Primary Research Question 1, is relatively open. The intention of this research was to provide applicable research for industry practitioners for the implementation of SPD, however, what that meant specifically was unclear. In addressing Primary Research Question 1, focus on what kind of support would be most beneficial to practitioners was provided. It is therefore the case that addressing Primary Research Question 2 actually meant addressing the more granular research directions provided at the end of Chapter 4. This section therefore discusses how this research addressed the Secondary Research Questions presented in Chapter 4 as well as the overall Primary Research Question 2.

The results from the interview study presented in Chapter 4 show Secondary Research Questions pertaining to five categories of research:

1. Determining whether to use SPD
2. Selecting an SPD initiative
3. Designing an SPD initiative
4. Post-SPD initiative
5. General implications of SPD

Categories 4 and 5 were considered to be outside the scope of this research (reasoning provided in section 4.7 on page 78) while categories 1, 2 and 3 were addressed in the following chapters of the thesis. As shown in Table 1.4, specifically this meant:

- Determining whether to use SPD and selecting an SPD initiative was addressed in Chapter 5

- Research directions on designing an SPD initiative were addressed in Chapters 6 and 7

The following sections discuss how each of these areas of research address the research directions identified in Chapter 4.

Effectiveness of Chapter 5 in addressing Secondary Research Questions

The purpose of this research was to support the decision making and tenant selection process for industry practitioners. Having identified literature gaps in existing literature it was determined that a guidance framework to support the launching of an SPD initiative was most appropriate. To assess whether this research adequately addressed the Secondary Research Questions this section discusses; whether the creation of a framework was most appropriate, whether the process of framework creation was appropriate and whether the final framework adequately addresses the Secondary Research Questions.

With regards to the development of a framework, the reasoning for this is two-fold. Firstly, guidance frameworks are one of the most common research outcomes or present applicable research (Forbes et al., 2019). Frameworks, specifically prescriptive frameworks as presented in Chapter 5, provide users with a consolidated step-by-step process that is easier to digest and apply compared to guidance in text-form. Secondly, as discussed in Chapter 2 (Literature Review), a key literature gap within existing literature was a lack of applicable frameworks. By developing a framework, it was deemed that a significant contribution would be made to this academic sector, as well as provide practitioners with the most valuable research outcome format.

As for the methodology for the development of this framework, as outlined in the Methodology section of Chapter 5, the author was limited by a lack of existing or validated methodologies for the "design of a design framework". It was found that the conception process of design frameworks was rarely documented. As a consequence, in the absence of an existing methodical approach, the author chose to conceive an SPD framework by adapting existing and established design methods. Chapter 5 then shows a methodical process starting with all design methods as presented by Wynn and Clarkson (2018); considered to be an exhaustive reference of all design methods. Design methods are excluded based on their level of abstraction, the extent that they are instructional and guide the user and an elementary task analysis is conducted to choose the final design methods to be adapted. This process is considered to be robust and appropriate for the development of the design framework.

Finally, the research framework outcome is considered to address the Secondary Research Questions for the following reasons. Firstly, the early phases of the framework, direct the preparation of the design problem for suitability for SPD whereby addressing the first question in Table 1.4:

How to prepare a problem for SPD initiatives?

Secondly, the tenant selection phase of the framework provides detailed guidance on choosing between the tenants with criteria that can be drawn from the practitioners own experiences and company environment. This phase therefore addresses the second question in Table 1.4:

How to choose an SPD tenant?

Overall, the chosen research method, the execution of the research method and the research outcome are consider to address the Secondary Research Questions and provide applicable research for the implementation of SPD.

Effectiveness of Chapters 6 and 7 in addressing Secondary Research Questions

Chapter 5 is considered to support practitioners in choosing between SPD tenants and implementing an SPD initiative. At this stage in the thesis, however, what is yet to be presented is an understanding of how the decisions made in preparing for implementation, impact the success of the SPD initiative. The framework presented in Chapter 5 provides *what* to do, but not *how* to do it successfully. There was therefore a need to support successful implementation and address the following Secondary Research Questions:

1. How do structural decisions of an engineering design SPD (crowdsourcing) initiative influence its outcomes?
2. How do design decisions of an engineering design SPD (crowdsourcing) initiative influence its outcomes?
3. How does framing of engineering design problems in competitive scenarios influence its solutions?
4. How can SPD initiative designers effectively decompose an engineering design problem?
5. How can optimal incentive structures be formulated for SPD initiatives?

To first address these Secondary Research Questions, a hypothesis was formed that the

SPD variables (N, P_a, P_o) defined in Chapter 4 could be used to assess the success of an SPD initiative prior to launch. The aim was to start by addressing questions 1 and 2 above. The results of this process is outlined in Chapter 6.

However, it was found that while the SPD variables could be used to select an SPD tenant, they were not aligned with definitions of SPD success and SPD tenant success presented in existing literature. Chapter 4 therefore does not address the Secondary Research Questions above but instead provides vital contributions to further inform Chapter 7, specifically:

- Chapter 6 demonstrates the need for success assessment processes to be unique to SPD tenants
- Chapter 6 demonstrates the lack of consistency or specificity in current definitions of SPD success
- Chapter 6 demonstrates the lack of SPD success metrics

These findings therefore inform the approach to Chapter 7 in addressing the Secondary Research Question for crowdsourcing initiatives.

Chapter 7 therefore addresses the Secondary Research Questions, not addressed by Chapter 6, in the specific context of crowdsourcing. While this focuses the context on a single tenant, as shown in Chapter 6 it was determined that addressing the Secondary Research Questions for a single tenant context would provide more value than attempting to address them for SPD as a whole.

To address these Secondary Research Questions, data was collected from 219 successfully completed projects from GrabCAD[*] and Innocentive[†] covering aspects relating to the Secondary Research Questions. For example, to understand how design decisions influence crowdsourcing success the platform was one of the metrics identified and to understand how structural design decisions influence crowdsourcing success, the number of days active was identified as one of the metrics. Table 8.1 below provides all metrics collected and the Secondary Research Question they corresponded to.

[*] www.grabcad.com
[†] www.innocentive.com

Table 8.1: Influential Factors and their Metrics

Influential Factor	**User RQ**	**Metrics**
Problem Complexity	How can SPD initiative designers effectively decompose an engineering design problem?	• Number of Target Variables • Number of Constraints • Coupling Ratio • Number of Tasks
Problem Framing	How does framing of engineering design problems in competitive scenarios influence its solutions?	• Sentiment Score • Number of words • Number of characters • Percentage of common words • Percentage of mid-frequency words • Percentage of jargon words • Dejargonizer score
Company Reputation	How can optimal incentive structures be formulated for SPD initiatives?	• Glassdoor rating • Revenue • Number of Twitter followers • Number of Employees
Incentives	How can optimal incentive structures be formulated for SPD initiatives?	• Incentive(s) • Number of Incentives • Percentage of non-monetary incentives • Top Reward Value • Total Monetary Value
Basic Campaign Details	How do structural decisions of an engineering design SPD (crowdsourcing) initiative influence its outcomes?	• Days Active • Number of Stages

Chapter 7, through collection and analysis of this data, results in a series of relationships between the categories shown in Table 8.1 and crowdsourcing success. For example, project description length and the presence of jargon was shown to have a positive relationship with the number of submissions. This provides insight on how to frame a problem for a crowdsourcing initiative.

With regards to whether Chapter 7 adequately addressed the Secondary Research Questions, firstly, the method used to yield new insights has been used by several authors (Shergadwala et al., 2016). The data collection process is shown to be rigorous, identifying all crowdsourcing success factors raised in existing literature and then allocating metrics for each success factor, again using validated existing literature on contest design. As for the execution of the method, several iterations of the multiple regression analysis are performed to ensure the model fits as accurately as possible, and, in addition, a validation exercise is completed with the results.

Overall, Chapter 7 adequately addresses the Secondary Research Questions and provides detailed and applicable support for industry practitioners interesting in applying crowdsourcing SPD initiatives.

Overall effectiveness of thesis in Addressing Primary Research Question 2

Primary Research Question 2 is relatively open by encouraging the presentation of research to support the implementation of SPD. It is the case that Primary Research Question 2 could be considered addressed by Chapter 5 alone, since Chapter 5 provides a framework to support the implementation of SPD. It is the case, however, to provide more extensive support Primary Research Question 2 was fragmented into secondary and tertiary research questions, as identified in Chapter 4. Therefore, by demonstrating that Chapters 5 to 7 address these Secondary Research Questions, it is demonstrated that Primary Research Question 2 has been addressed.

The sections above show that determining to whether to use SPD and selecting an SPD initiative were Secondary Research Questions addressed in Chapter 5 and research questions relating to the design of an SPD initiative were addressed in Chapters 6 and 7.

8.1.3 Value of this Thesis for Academia

The aim of this thesis is to provide applicable research to industry practitioners and, as a consequence, the main contributions of the thesis are framed according to the value for industry. However, it is the case that this thesis, as well as addressing the literature gaps outlined in Chapter 7.2 also provide several specific academic contributions.

Firstly, while the field of social product development research is still emerging, there is a lack of standardisation on what the term means (Forbes et al., 2019). In Chapter 5, the tenant selection framework provides a clear understanding of what SPD is, what the tenants are and how they interact with each other. Furthermore, terms that are sometimes mistakenly used interchangeably, such as participatory design and user-centred design are clarified with reference to SPD. Following from this, the presentation of the three SPD variables (N, P_o and P_a) is another academic contribution, providing a tangible way to distinguish the SPD tenants, identify SPD initiatives and define SPD as a whole. This thesis can therefore act as a reference for those defining SPD or those who seek to understand the term and what it represents.

Secondly, as presented in Chapter 5, there is a lack of existing literature on "how to design a design framework". For example, Panchal's (2015) framework for the design of crowdsourcing contests presents a framework as a "step towards addressing this research gap" and the conception process is not described. Larsson et al. (2003) present a framework for developing products with distributed teams that was conceived using an ethnographical study of practitioners. While the results of the ethnographical study are presented and analysed in this literature, the specific process of using the experimental findings to conceive the presented framework is not described (Larsson et al., 2003). As a consequence, a new process for "designing a design framework" is presented in this thesis, thus providing a worked example for future researchers who wish to design a design framework.

Chapter 6 in this thesis, as described in further detail in the previous section of this chapter, does not address Primary Research Question 2 nor the Secondary Research Questions. This is a consequence of disproving a hypothesis suggesting the three SPD variables could be used as performance assessment metrics. In the process of disproving this hypothesis, however, evidence was provided for the need to examine performance on an individual tenant basis. Therefore, a key contribution to academia is evidence for the limit for which research in SPD can be done on SPD as a whole before there is a need to examine SPD tenants individually. Specifically, in the context of assessing the success of SPD initiatives, this thesis provides evidence that performance should be assessed on an individual tenant basis.

In Chapter 4, professionals from a range of types of organisations, a range of sizes of organisation and with varying experience in SPD initiatives, were interviewed about the barriers to the implementation of SPD. While there are some cases in existing literature of industry practitioners having been approached for their thoughts on SPD, interviews on the barriers to implementation is a contribution to academia. Overall, there is shown to be a lack of involvement or understanding of how industry practitioners approach the implementation of SPD and the barriers that industry practitioners face. Any research addressing this gap is focused on a specific context that means insights are not validated for general use across industries or types of organisations. There was therefore a need for increasing empirical research in this area involving industry practitioners from a range of industries and types of organisations, something that is provided by Chapter 4 of this thesis.

Finally, Chapter 7 provides several contributions to academia by identifying gaps in previous empirical crowdsourcing studies and addressing them. For example, existing literature had to yet to determine how problem framing and company reputation influences crowdsourcing success, or provide detailed insight into how incentives influences crowdsourcing success. In Chapter 7 relationships between these and other influential factors are provided and a prediction equations are derived to allow practitioners to understand how various inputs influence crowdsourcing success.

8.1.4 Value of this Thesis for Industry

The value of this thesis for industry is defined in the conclusions of each chapter and consolidated here for reference. Chapter 4 presents key issues for the implementation of SPD, this providing insight on implementing SPD for industry. Barriers to SPD in Chapter 4 have been verbalised which allows for further discussion and insight. Chapter 5 provides a methodical approach to identify and launch an SPD initiative, whereby providing industry practitioners with a process to follow and support the implementation of SPD. Chapter 7 allows industry practitioners to understand how key inputs to an SPD initiative (such as budget and time constraints) will impact their initiative's success. This allows industry practitioners to tailor their initiative design to increase success as well as determine whether launching an SPD initiative will be worthwhile under their current constraints. Overall, this thesis provides applicable research and tools to support the implementation of SPD for industry practitioners.

8.1.5 The Wider implications of this Thesis

The research in this thesis fundamentally sits within the wider context of the democratisation of product design and development, and provides support to those seeking to involve external individuals in design and knowledge generating activities. The wider implications of this movement are extensive, creating new opportunities in the future of work while disrupting traditional approaches to product design and development.

First and foremost, the effective implementation of Social Product Development can support businesses in adopting more modern working practises. The Covid-19 pandemic has forced businesses to embrace remote working, effectively decentralising organisations and resulting in the reliance on socio-technological tools. Social Product Development and the research in this thesis supports the collaboration of remote teams (Forbes et al., 2019). Specifically, the framework presented in Chapter 5 can support the involvement of both participants external to the organisation and remote employees in collaborative product development activities.

Secondly, social product development will allow organisations, large and small, to have flexible work forces, allowing them to be more adaptable to the changing business climate. Adoption of online learning tools has significantly increased in recent years (Dhawan, 2020) allowing those interested in product development to gain skills and design and manufacture products without gaining a formal qualification or working in a product development organisation. As a consequence, a new generation of talent has emerged outside of the traditional realms of the product development industry. Social product development will allow organisations to more easily collaborate with these external participants, increasing their organisational capacity when needed. The framework presented in Chapter 5 will support organisations in launching these initiatives and the tool presented in Chapter 7 will provide them with insight into how to run an effective initiative.

Social product development also support workers in this new future of work by allowing them to access new revenue streams as "portfolio careers", i.e. those that allow an individual to leverage their knowledge or skills in a range of short-term opportunities, are on the rise (Mainiero, 2018). Involvement in social product development initiatives usually allows workers access to the resources of established organisations, it offers them the opportunity to showcase their knowledge to leading organisations and it offers the opportunity to gain credibility through their involvement. Participants in Procter and Gamble's Connect and Develop initiative has resulted in external participants owning IP to multi-million pound products sold all over the world (Huston, Sakkab, 2006). By providing tools to support organisations in launching and running effective SPD initiatives, this thesis can increase the implementation of SPD and therefore open more opportunities for flexible and remote workers pursuing a "portfolio career".

To summarise, the tools provided in this thesis, specifically the framework in Chapter 5 and the tool provided in Chapter 7, support the implementation of social product development which have several wider implications. Adopting social product development processes offers increased resource capacity and increased diversity of solvers, both proven to reduce development time and costs, and drive innovation. Furthermore, integrated social product development processes can improve communication and collaboration regardless of external involvement and offer an opportunity to gain competitive advantage in an increasingly competitive business environment. Finally, the coronavirus outbreak has and will drastically change the way organisations function. Social product development offers opportunities for potential solvers to gain income as part of "portfolio careers" and offers a route to recovery for organisations.

8.2 Limitations & Future Research Directions

The results from the interviews presented in Chapter 4 are limited most significantly by the number of professionals. There was a need to get a range of perspectives from both different types of organisations, different sizes of organisations and, most crucially, from those with different levels of experience with SPD. This final point meant finding appropriate organisations very difficult as those that have conducted SPD initiatives are limited and often those that had, did so in private. The rigorous coding technique and the use of existing literature to validate Secondary Research Questions meant that this chapter provided an extensive list of barriers to the implementation of SPD. It is not claimed that these barriers are exhaustive, however, and provide an extensive list of research questions which provide focus for further research presented in this thesis. The fact remains, however, that further empirical research and interviews with industry to gain more understanding of the barriers to implementation should be conducted.

The framework presented in Chapter 5 has limitations relating to its long-term use and validation. The framework is intentionally designed to be high-level to be fit-for-purpose for a range of types and sizes of organisations. However, as a consequence, it is not detailed in instruction which may limit its value for those very unfamiliar with SPD and how to implement an initiative. Secondly, three validation stages of the Validation Square (Seepersad et al., 2006) are described in Chapter 5 but the final fourth validation stage is not presented. This stage is Empirical Performance Validity which requires actual use in its intended scenario. This would require an organisation to use this framework and commit to launching an SPD initiative within a relatively short timeframe. This was deemed not possible within the scope of this research but represents a further research avenue. The framework could be used in an industrial setting to implement SPD and the findings used to iterate and improve on the framework.

Another limitation of the framework is its derivation from an exhaustive list of design methods. In the absence of an existing methodology for the “design of a design framework”, the framework was created by removing design methods from an exhaustive list provided by Wynn and Clarkson (2018). It is the case, however, that new design methods may occur which means a new exhaustive list would need to emerge. While it may not be the case that new design methods would result in a change to the final framework, it is worth noting that as the field develops, a new design method may arise which could represent a superior framework format.

Finally, with regards to Chapter 5, a limitation is its format. The framework was intentionally developed using a meso-procedural design method to ensure design practitioners would be familiar with the approach and therefore find following the process easier. However, it is the case that the implementation of an SPD initiative is likely to require cross-disciplinary collaboration and business or marketing professionals may not find the approach as familiar or understandable. A further research direction is therefore to redesign the framework to be less specific to a design context and more understandable for other types of professional.

The limitations and future research directions relating to Chapter 7 are provided in detail in sections 7.7 and 7.8. However, to summarise, limitations to the prediction tool relate to three areas of work; the data collection, the fit of the multiple regression model and the validation of the model. With regards to data collection, there were some limitations due to the use of publicly available data, such as the number of employees in an organisation was often represented as a range or estimate. The multiple regression model fit with at least 70% of the data in the case of both GrabCAD and Innocentive but this does represent the potential for some inaccuracies. Finally, the prediction tool accurately estimated the number of submissions within a 20% margin but this does represent a limitation. Further work should be done to increase the amount of data used to derive the prediction equation with possibly the use of a machine learning algorithm to allow the tool to become more accurate with use.

8.3 Concluding Remarks

The aim of this thesis was to provide applicable research to industry practitioners and specifically sought to identify barriers to the implementation of SPD and provide support for the implementation of SPD. It is deemed to have addressed these Primary Research Questions by providing the barriers to implementation of SPD, as identified by interviewees, in Chapter 4, an SPD implementation framework in Chapter 5 and a SPD participation prediction tool in Chapter 7. Key findings show that the barriers to implementation of SPD relate to several categories including; the lack of case studies and education, a lack of understanding of how initiative design impacts success and a lack of understanding of when a problem is suitable for SPD. This, in turn, led to a series of Secondary Research Questions that informed the further research presented in the thesis. With regards to tools and support for implementation, a high-level framework was provided but more detailed guidance such as assessing the success of an SPD initiative was required to be presented at an individual tenant level. Overall this thesis provides valuable contributions both to academia and those in the field of the democratization of design, as well as industrial professionals seeking a new way to involve external participants and compete in a changing business climate.

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