Integration of eco-design into product development practice; applied in the design and manufacture of shower and tapware products

A thesis presented in partial fulfilment of the requirements for the degree of

Doctor of Philosophy in Eco-Design

at Massey University, Albany, New Zealand

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2021

Abstract

Consumers and wider society have become more aware of the environmental issues associated with products. Manufacturers of consumer products have responded to this awareness by attempting to integrate environmental strategies, tools and techniques into the processes that guide their product development efforts through idea-to-launch. This practice is commonly known as eco-design. There have been relatively very few eco-design success stories and generally eco-design has yet to have a significant influence on the development and commercialisation of mainstream products; research has shown that this is primarily because environmental practices are not effectively integrated into the product development process. Furthermore, the eco-design frameworks, models and tools available to New Product Development (NPD) practitioners are often challenging to integrate as they are too broad to provide adequate guidance to product designers.

The environmental impacts of products can significantly differ between product types and how products are used. Active product types such as showers and tapware do consume additional energy, water and/or materials in the use phase of the product's life cycle and so this phase may be the environmental hotspot for these product types. This implies that designers of active products should use a life cycle-based approach to eco-design.

This study investigated how life cycle-based environmental considerations can be integrated effectively into product development practices. Drawing on the eco-design and NPD literature, it used both qualitative and quantitative methods in an embedded action case study of a shower and tapware manufacturer, and users of its products. In the first stage of the study, data was collected on the organisational practices of the company and their product development process. In the second stage, data was collected from the product users through experimentation and user trials that informed eco-design decisions within the development process. The data from both stages was analysed using a systematic process involving categorising and explanation building

through narrative structuring. The results demonstrated that the culture of an organisation can greatly impact success of eco-design integration into the product development practices of manufactures of active products. This key finding became the foundation of the framework proposed in this thesis known as the shower and tapware eco-design product framework (STeP Framework). This framework includes an accompanying list of success factors that can be applied in an organisation that produces active products to support eco-design integration.

The analysis of results showed that NPD practitioners need to consider the unique characteristics of different types of products and associated environmental impacts in order for the eco-design frameworks, models and tools to be effective. In doing so, both technical and behavioural factors related to life cycle-based environmental impacts of products were identified that greatly influence the STeP framework and success factors.

Implementation of the key findings of the study was proposed in the form of a front-end process model suitable for producers of active products (Eco-AP Process Model). For front end stages such as idea generation, idea selection and project definition, it was found that Life Cycle Assessment is necessary to quantify the environmental impacts associated with the idea, and particularly so at a system level. In addition, with a better understanding of the relationship between human behaviour and how this can influence the life cycle-based impacts, it is necessary to include specialised eco-tools (such as Design of Experiments) that can measure, analyse and optimise the use phase by taking into consideration user interaction with the product. Other stages of the process model include opportunity analysis and opportunity identification, that focus on generating new environmental knowledge and eco-ideas rather than being driven by commercialisation deadlines. Finally, an opportunity development stage was added that creates new eco-design core capabilities within an organisation and maximises realisation of eco-opportunities in the industry.

Acknowledgements

This research was supported and funded through the New Zealand government's innovation scheme. This allowed me to join a leading product development firm and its innovation team to support its research and development efforts which was the context surrounding my research. As a recent graduate this provided an opportunity to also gain industry experience. I would like to thank Callaghan Innovation and the host company for giving me the opportunity to learn from them and contribute to their product development.

This research would not have been possible without the collaboration of the host company's Research and Development team. The expertise, advice and support of those individuals have been invaluable and helped shape this research.

I would also like to thank my supervisors Sarah McLaren and Mark Tunnicliffe for their support throughout this project. Their diverse skills and knowledge have been critical in supporting what are very divided and complex research topics. The critique and support I received has provided confidence and trust that was invaluable and allowed me to complete the project to a high standard.

I am thankful to all my friends, family and colleagues who have supported me. I would like to specifically thank Andrew Drain for the many lengthy academic discussions that helped focus my approach to research and this project. I would also like to thank Dr Aruna Shekar for supporting my work at critical stages of the research.

To Dan – thank you for constantly supporting me throughout these four years. Your patience and compassion consistently provided a sympathetic outlet when times become tough, while providing encouragement and advice that kept me motivated. Thank you for helping me balance my work and life so I could enjoy this experience.

Summary of papers

The papers provided in Appendix A through C are presented as distinct studies that were completed as part of the overall research. They are referenced throughout the results section of the thesis and represent a significant contribution of the work completed.

Paper I - Horrell, Shekar, and McLaren (2020)

Status: Published (Appendix A)

Horrell, M., Shekar, A., & McLaren, S. (2020). USE OF DESIGN OF EXPERIMENTS TO OPTIMISE THE ENVIRONMENTAL PERFORMANCE OF CONSUMER PRODUCTS: A CASE STUDY OF SHOWERS AND TAPWARE IN NEW ZEALAND. *Proceedings of the Design Society: DESIGN Conference*, 1, 1911-1920. doi:10.1017/dsd.2020.269

Paper II - Horrell, Tunnicliffe, and McLaren (2020a)

Status: Final draft for submission to Journal of Engineering Design (Appendix B)

Horrell, M., Tunnicliffe, M., & McLaren, S. (2020a). Development and performance testing of a system-based eco-shower.

Paper III - Horrell, Tunnicliffe, and McLaren (2020b)

Status: Presented at MaDE Conference December 2020

Horrell, M., Tunnicliffe, M., & McLaren, S. (2020b). The use of LCA in early design to optimise the environmental performance of active product systems.

List of frequently used abbreviations

DfE	– Design for the Environment
DfSB	– Design for Sustainable Behaviour
DoE	– Design of Experiments
EcoAP	– Eco-design Process for Active Products
EcoSTeP	– Eco-design Framework for Shower and Tapware
FFE	– Fuzzy Front End
LCA	– Life Cycle Assessment
LCT	– Life Cycle Thinking
NPD	– New Product Development
R&D	– Research and Development

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1 Introduction

1.1 Research context and topics

Consumers and wider society are becoming more aware of sustainability – in other words, of the need to account for the social and environmental impacts of activities as well as their economic aspects. Environmental sustainability is about addressing some of the more complex environmental issues that are at play in the world by making better and more informed decisions. This is equally relevant for consumer products as it is for the organisations that produce them: the decisions that people make day to day regarding purchase and use of products have significant environment impacts associated with their manufacture, distribution and use.

Product development decisions that occur within an organisation can determine to a greater or lesser extent the environmental impacts of a new product. This could be due to a material choice in the early design stage of the product or selecting a type of process at the manufacturing stage. In addition, the decisions that consumers take at different stages of the product's life (such as use or disposal) also have environmental impacts. A product development organisation can apply a combination of strategies, tools and techniques to improve the environmental performance of the manufacture, use and disposal phases of a product's life cycle (Zbicinski, 2006). This is often referred to as 'eco-design'. However, studies on the integration of eco-design into the product development practices of manufacturers have identified significant challenges to this integration (Brones, Carvalho, & Zancul, 2017; Gehin, Zwolinski, & Brissaud, 2008; Pigosso, McAloone, & Rozenfeld, 2014; Poulikidou, Björklund, & Tyskeng, 2014), and ultimately demonstrate a lack of environmental consideration in mainstream product development (Metz, Burek, Hultgren, Kogan, & Schwartz, 2016).

Some products can consume additional energy, water or materials in the use stage of the product's life cycle. These types of products are known as active products (Jolliet, Saade-Sbeih, Shaked, Jolliet, & Crettaz, 2015). Shower and tapware products are 'active products' and are considered one of the largest contributors to a household's environmental footprint. While energy and water required for a single shower may seem trivial, it can account for over 40% of a household's total carbon emissions (BRANZ, 2006) and 43% of a household's total freshwater usage (Henrich, 2009). Despite the fact that a large number of eco-design strategies, processes and tools are available to product development organisations, the shower and tapware industry has demonstrated little change towards improving the lifecycle-based impacts of its products. While some policies drive the industry to make changes in manufacturing (i.e., removal of toxic materials such as lead) the environmental impacts associated with the use-phase has been remained unaddressed. Leading manufactures of shower and tapware products may market or label their products as eco-friendly; however, this is based purely on the assumption that reducing water use improves the use-phase and there appears no evidence that eco-tools have been applied to support these claims or design decisions that result in reduced water flow.

Therefore, the purpose of this research was to determine how environmental considerations could be better integrated into product development practice with the application in the shower and tapware industry. The research integrates three central topics: (1) new product development (NPD), (2) eco-design, (3) the shower and tapware industry.

1.2 Research focus

The research topics and focus are illustrated in Figure 1. Each individual topic is covered in more detail in chapter 2. Interconnected subjects are represented as overlapping areas on the figure.

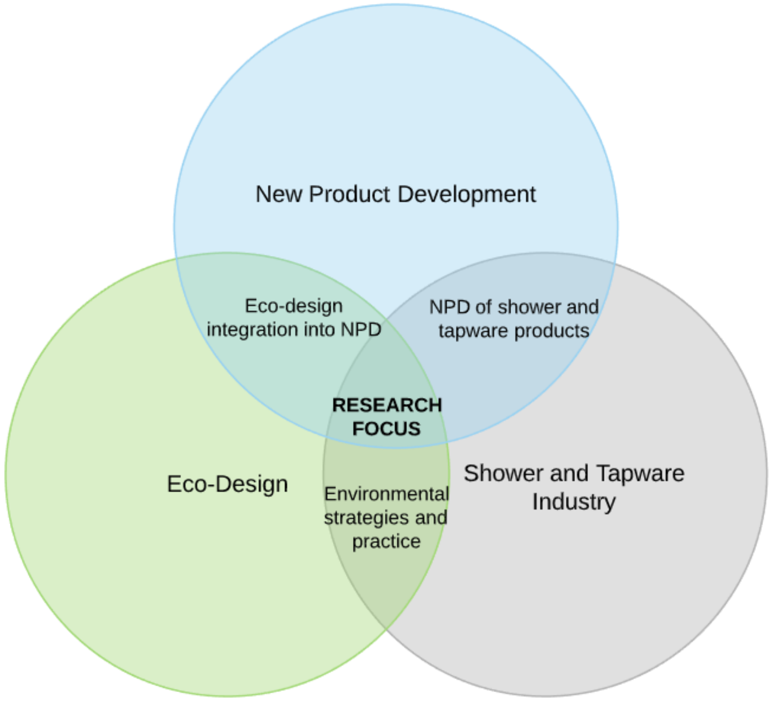

FIGURE 1 RESEARCH FOCUS

There are differing areas of eco-design (i.e., Design for Remanufacture, Industrial Ecology, Life Cycle Thinking, Design for Sustainable Behaviour) and a plethora of related tools and techniques. This means it is difficult for manufacturers to know what tools are appropriate and how best to integrate them into existing practice (Gehin et al., 2008). Also, the eco-design frameworks, models and tools which attempt to integrate environmental aspects into existing NPD processes are described as too broad resulting in a lack of guidance for NPD practitioners (Jefferson Hynds et al., 2014). In addition to this, eco-design research has developed independently of the New Product Development body of knowledge. Therefore, the fundamental principles that underpin successful product development have not been adequately considered in the current eco-design body of knowledge, creating further challenges for eco-design integration (Dewulf, 2013).

Selection of the most appropriate eco-design strategies and integrating appropriate tools and techniques is essential to successful eco-design, and this is influenced by the characteristics of different products. Shower and tapware products are associated with significant environmental impacts in households, and so are a suitable topic for analysis when considering integration of eco-design into NPD.

When the shower and tapware topic overlaps with either eco-design or NPD, the subject focus is narrowed to the strategies, processes or tools relevant to that industry. As an example of NPD overlap with the shower and tapware industry, people will be installing, using, and maintaining shower and tapware products, therefore specific rules and regulations must be built into different stages of the product development process. With respect to eco-design and shower and tapware, it is the consideration of specific strategies, models and tools that can address environmental impacts associated with those products' manufacture and use. For example, most countries have water rating schemes which are intended to incentivise consumers to purchase shower and tapware products that have been designed to reduce water and energy. However, flow restriction alone is likely to have little impact in reducing the life cycle based environmental impacts (Koeller & Gauley, 2010). This is often because manufacturers fail to consider how the product will be used. Manufacturers that make design decisions (i.e., water flow restriction) expect the user to operate the product in an optimal and efficient way. Without considering other technical and behavioural factors (water coverage, spray types, different operating conditions) and their impact on response variables beyond water use (such as energy use), it is likely that few or no improvements to the use phase are being achieved (Adeyeye, She, & Baïri, 2017). To integrate these factors and variables into product development decisions requires the inclusion of Design for Sustainable Behaviour (DfSB) intervention strategies, a subtopic of eco-design not yet applied in the shower and tapware industry.

The research focus sits in the centre of the diagram. In doing so it narrows the focus of the research to the integration of eco-design into NPD practices of shower and tapware manufacturers.

1.3 Current knowledge gap and need for research

In order to make positive change towards a sustainable society every industry needs to apply appropriate frameworks, models and tools that can effectively improve the environmental impacts of their products. The frameworks, models and tools need to be tailored to the industry or products being developed. However, when the appropriate frameworks, models and tools for an industry are unknown there is need for research to create this knowledge. Clearly, there is a wide variation in how any product is manufactured, used and disposed of and therefore it is not possible in this research to address the full range of products. This researcher chose to focus on the environmental impacts of shower and tapware products. By doing so, any framework, model or tool identified through the research avoids being too broad and provides specific guidelines or practices relevant to practitioners in this industry. However, the research must also intersect the subject of NPD. NPD is crucial for organisations, and covers the practices, methods, processes and activities that are more effective at driving success (Kahn, Kay, Slotegraaf, & Uban, 2013b). If eco-design is to be effective, it must consider this foundation and be fully integrated into the fundamental principles that underpin successful product development.

1.4 Importance of research

This research is the first to show a framework for the integration of eco-design into the NPD of shower and tapware products. It has demonstrated the impact that NPD elements (such as the culture of the organisation) can have on the implementation and success of eco-design integration. The research has contributed to the knowledge of front-end NPD process models and their significance in eco-design and based on the new framework, proposes an appropriate model for the eco-design of shower and tapware products.

The research has also contributed to a greater understanding of sustainable consumption with respect to shower and tapware products. The research has shown the importance of identifying behavioural factors that influence the use of these products and their related environmental impact. The insights and quantified results from experimentations from the research can be used by government and other research institutions to better understand household environmental impacts.

The study has linked the appropriateness of the research and the framework beyond the shower and tapware industry. Manufacturers of products who should consider user experience in the design process could use the findings of the research and framework to support the optimisation of efficiency and experience of their products.

1.5 Research questions

Three research questions were defined for the study. The initial question was based on the general purpose of the study (Figure 2) and asks:

RQ1: When applied in the shower and tapware industry, are current eco-design frameworks, models and tools used within existing NPD frameworks and processes fit for purpose?

To address this question, an extensive review was undertaken of the body of knowledge of three topics: New Product Development, Eco-Design and the Shower and Tapware Industry.

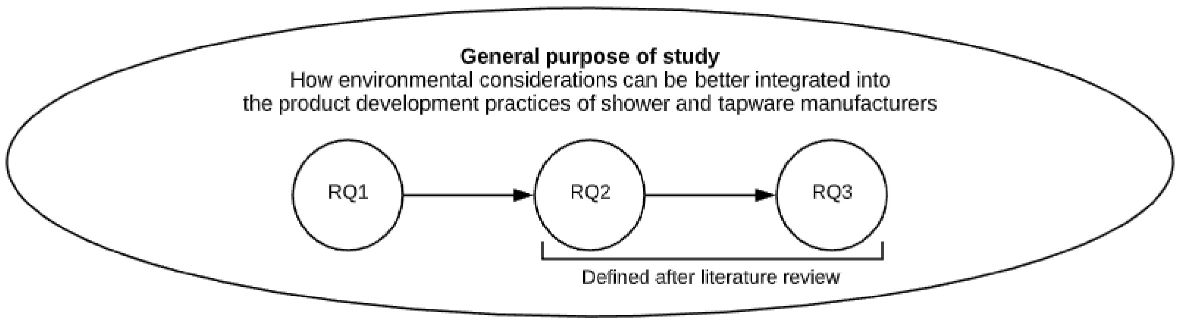

FIGURE 2 PROCESS FOR DEFINING RESEARCH QUESTIONS

This led to formulation of two additional questions. With an understanding that the current frameworks, models and tools were inadequate, the second research question asked:

RQ2: Can a more effective framework be developed and refined for a manufacturer of shower and tapware products to support integrating eco-design into their NPD operations?

Furthermore, it was identified in the literature review that the operationalisation of eco-design and NPD frameworks may require emphasis on the front-end activities. Therefore, the third question asked:

RQ3: For manufacturers of shower and tapware products, how can environmental considerations be integrated into the front-end product development process of NPD?

1.6 Overview of research

The overall structure of the research is illustrated in Figure 3 (a more detailed version is shown in Chapter 3).

RQ1 is addressed in the literature review (Chapter 1). Based on an appraisal of research methodologies, it was decided to complete a case study to address RQ2 and RQ3 (Chapter 3). The case study is an embedded design and is presented in Chapter 4 and Chapter 5. Its results are analysed and discussed in chapter 6, and lead to a proposal for a new framework and model. The overall results, and suggestions for future research, are discussed in Chapter 7.

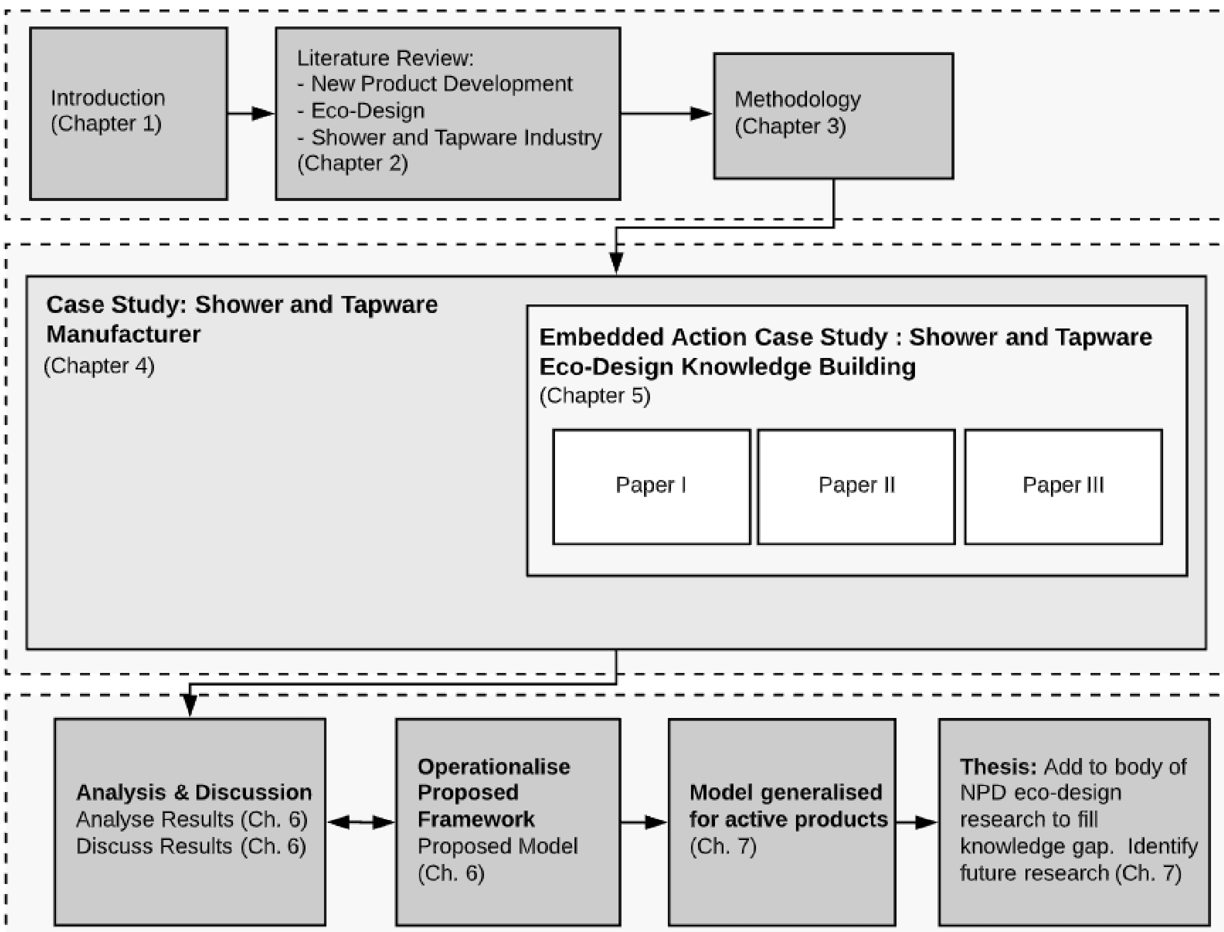

FIGURE 3 OVERVIEW OF RESEARCH (WITH ACADEMIC PAPERS)

As illustrated in Figure 3, the embedded action case study results are provided in chapter 5. The results follow a logical progression of different development cycles, each informing the next. At parts of these cycles, distinct experiments and trials were performed. These experiments and results have been presented as academic papers whose results contribute to the case study described in chapter 5. To avoid detracting from the logical progression and purpose of the overall research, they have been included in appendices and referenced where necessary.

2 Literature Review

This chapter presents a review of the academic literature relevant to the PhD research. This is presented in three main topics: product development, eco-design and the shower and tapware industry.

An information gathering strategy was used to identify the most relevant literature (Figure 4).

FIGURE 4 INFORMATION GATHERING SEARCH STRATEGY

Scopus was used to undertake the search for relevant literature. Search terms were combinations of relevant topics and often produced more than 300 results. Additional filters were applied (i.e., most publications by author or most cited authors). The results of some of the key search terms are presented in Table 1 for steps 1 and 2. Alternative spelling was included for each query search (i.e., Eco-Design or EcoDesign).

If there was one or more revisions of a publication, only the most recent one was used. For example, the most recent version of the Product Development Management Association's (PDMA) Body of Knowledge on best practice new product development (Anderson et al., 2020) replaced the PDMA Body of Knowledge book from the late 1990s (Griffin, 1997).

TABLE 1 EXAMPLES OF INFORMATION GATHERING SEARCH STRATEGY RESULTS FOR STEPS 1 AND 2

Search Terms	Filter by subject	Filter by author	Publications with top citations
“Product Development” and “Best Practice” OR “Product Design” and “Best Practice”	4294	137	Griffin (1994) Cooper (2004) Kahn (2009)
“Eco-Design” and “Best Practice” OR “Eco-Design” and “Product” OR “Eco-Design” and “Integration”	5011	203	Boks (2008) Pigosso (2010) Millet (2019)
“Eco-Design” and “Best Practice” OR “Eco-Design” and “Product” OR “Eco-Design” and “Integration” AND Reference key author (Cooper, Kahn or Griffin)	7	7	Pigosso (2019) Millet (2016)
“Product” and “Design for Sustainable Behaviour” OR “Product” and “DfSB”	57	23	Boks (2008) Bhamra (2011) Lilley (2017)
(“Life Cycle Assessment” or “Life Cycle Thinking”) and (“Product Development” or “Product Design”)	880	63	Su (2021) Pigosso (2010) Devanathan (2010)
Eco-Design and Integration and (“Product Development” or “Product Design”)	93	22	Tingstrom (2006) Dewulf (2013) Millet (2009)
Eco-Design and “Use phase”	101	18	Sakao (2017) Millet (2016) Cor (2015)

Filtered results were further analysed using the RADAR framework (Mandalios, 2013) to assist in determining the relevance to the research (step 3). A visual summary of the most relevant literature is provided in Figure 5 mapping the key authors and structure of the review.

Section 2.1 discusses the product development body of knowledge and best practices; this includes both strategic and operational aspects of product development. Section 2.2 covers the environmental product development body of knowledge which is often referred to as Eco-design. This follows the same structure as the previous section, including both strategic and operational aspects of this topic. Section 2.3 explores the existing literature on consumer products and their environmental impacts with a focus on products which consume energy or materials during use, known as “active products.” This is followed by a more detailed exploration of the approaches to product development and eco-design adopted in the shower and tapware industry (Section 2.4). Section 2.5 concludes by discussing the integration (or not) of product development and eco-design theory and practices, and its relevance to the shower and tapware industry.

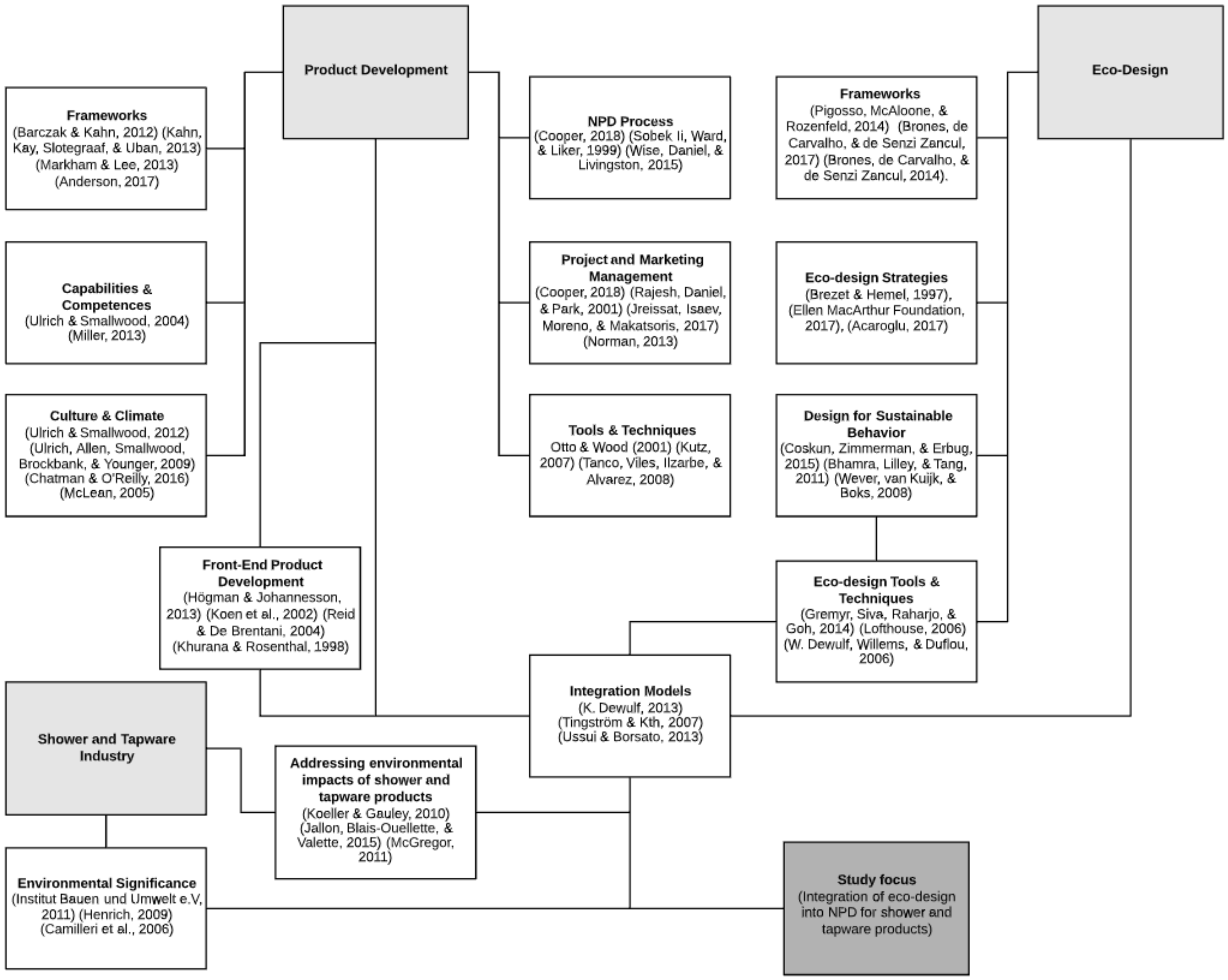

FIGURE 5 LITERATURE REVIEW MAP

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2.1 New Product Development

Approximately 40% of new products developed in companies fail to launch and only 30% of those that do are considered to be a commercial success (Cooper, 2018). Not surprisingly, then, there is a significant body of literature dedicated to new product development (NPD), analysing and exploring how companies can successfully innovate in their product design processes. This research has sought to better understand what separates the winners from the losers, and to identify the fundamental principles that underpin successful product development and product management (Bigelow, 2005). These principles have provided the groundwork for many frameworks, models and tools that assist organisations in identifying and improving on the various activities that are required to be a successful innovating company (Kahn et al., 2013b).

2.1.1 NPD Frameworks

One of the highly referenced NPD best practice frameworks is the KBM framework (Kahn, Barczak, & Moss, 2006). This six-dimensional best practice NPD framework includes the elements Strategy, Portfolio Management, Market Research, People, Metrics and Performance Evaluation, and Process. For each element, there is a description of process and practices at four levels of sophistication, allowing businesses to compare and benchmark their current practice with best practice (Kahn et al., 2006). Addressing some of the limitations of the framework highlighted in criticisms (Adams-Bigelow, 2006; Kuczmarski, 2006; Notargiacomo, 2006; Peters, 2006), Barczak & Kahn (2012) provided an updated framework which redefined some of the dimensions and included the relative importance (Figure 6). In addition, the four levels of sophistication were replaced with just two, “poor” and “best” practice, as there was lack of agreement on what constituted good practice between these two extremes (Barczak & Kahn, 2012). The updated framework also included a list of questions designed to enable identification of best practices, to be answered by NPD practitioners (such as product managers) who could effectively use these questions as an auditing tool for their own company NPD efforts.

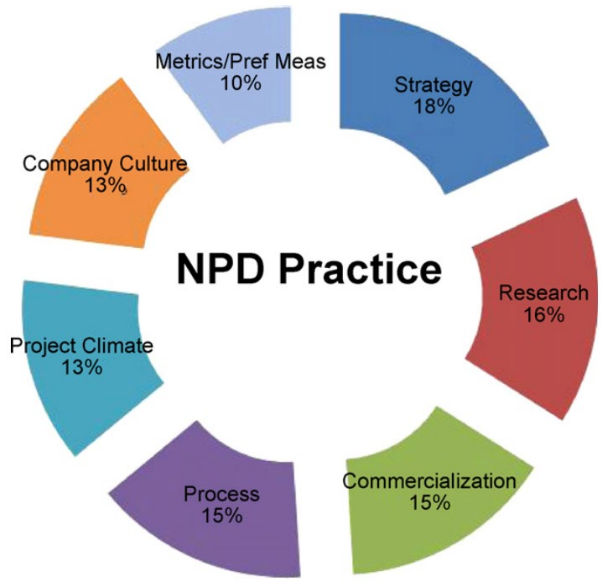

FIGURE 6 RELATIVE IMPORTANCE OF DIMENSIONS (FROM BARCZAK & KAHN FRAMEWORK 2012)

The Innovation Management (IM) Framework was popularised in the book Traversing the Valley of Death (Markham, Mugge, & Tucker, 2014) intended to help managers identify what activities are required to be a successful innovator. The IM Framework is similar to the KBM framework, particular with respect to defining what the elements of NPD are (Strategy, Organisation and Culture, Process, Tools & Techniques and Metrics) and the associated best practices. One of the unique features of the IM framework is the inclusion of Competences and Organisation Levels as additional dimensions that, together with the NPD elements, can be envisaged as a three-dimensional cube (Figure 7).

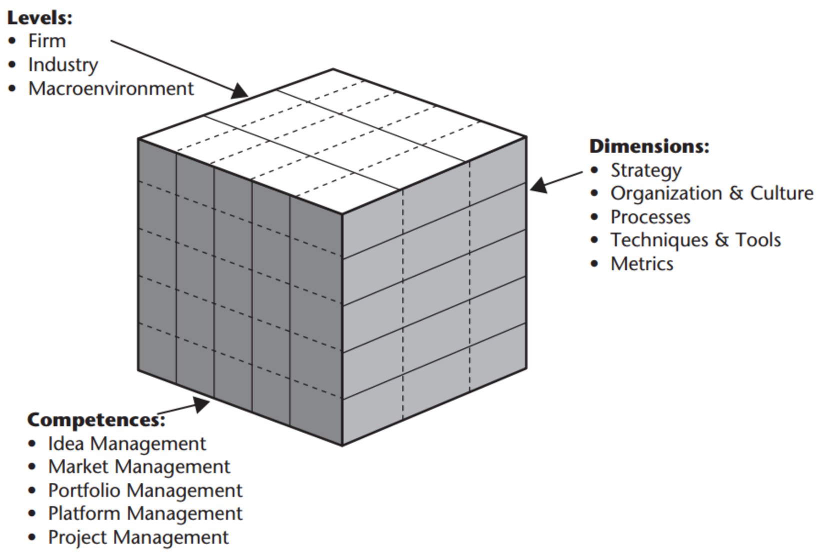

FIGURE 7 IM NPD FRAMEWORK (MUGGE & MARKHAM, 2013)

The operationalization of this framework is in the form of an audit tool (Innovation Management Maturity Assessment (IMMA). The use of the audit tool provides a measure of current practice so the company can determine where to improve on its NPD practices, the level at which improvements need to occur, and the management competences that need to be strengthened.

The NPDP certification framework is one of the most recent NPD frameworks (Anderson, 2017).

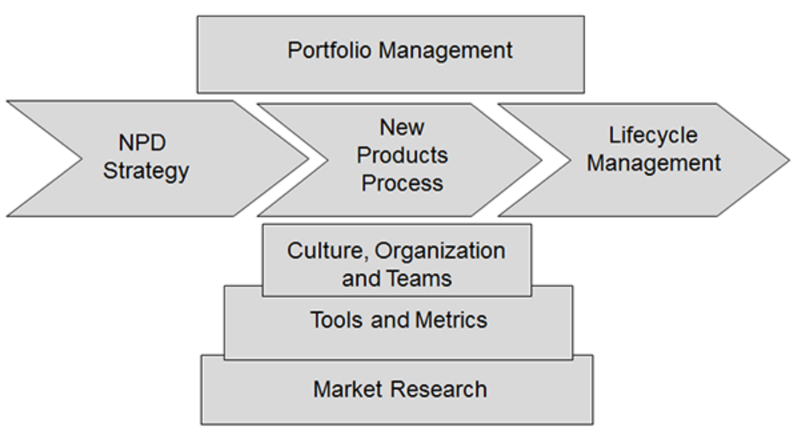

FIGURE 8 NPDP CERTIFICATION FRAMEWORK (ANDERSON, 2017)

This framework is represented in Figure 8. The framework is in the form of a manual intended to provide the body of knowledge required to pass the NPDP certification – a qualification that identifies an individual as an expert in the field of NPD according to the Product Development Management Association (PDMA). Compared to other frameworks previously discussed, there is an inclusion of an additional element "Life Cycle Management" that defines best practices with respect to the sequence of stages that a product goes through after it has been developed. This includes its commercial launch (market introduction), increasing market share (growth) and defending the market share from competition (maturity) and then how to react when sales of the product start to drop (decline). While important aspects to cover, this adds some confusion since there is no mention or distinction of the term Life Cycle Management (LCM) in the sense that it is used by the United Nations Environmental Program i.e. the management framework to be used by an organization to improve its environmental practices (Remmen, Jensen, & Frydendal, 2007). However, the Life Cycle Management element includes well established strategies, models, and tools for Sustainable Product Innovation including Circular Economy and Life Cycle Assessment. A "Sustainable Innovation Maturity Model" (Jefferson Hynds et al., 2014) is also mentioned that resembles models in eco-design literature (Pigosso, Rozenfeld, & Seliger, 2011) with respect to moving from introducing sustainability practices to becoming a leader of sustainable product innovation. However, it does not build on existing maturity models within the eco-design body of knowledge.

Many of the frameworks draw conclusions based on the same studies (Markham & Lee, 2013), individuals considered to be NPD experts (Cooper, Ulrich, Kahn) or organisations that support the body of knowledge (i.e. PDMA). This positions the NPD frameworks as mainstream and unchallenged. As a result, it is not surprising that there is good alignment across the NPD frameworks on what is considered best practice NPD. Strategy is commonly referred to as the foundation or engine of best practice NPD, where practitioners establish and communicate goals and objectives that direct and align other functions or elements of NPD. As an example, it is commonly recommended that prioritization of projects within portfolio management should be based on pre-established strategic goals and objectives. As another example, within the NPD process it is recommended to establish go/no-go criteria to help decide if an NPD project should continue or be terminated. These criteria should reflect how well the product, and its current definition reflects the strategic direction of the organization and the current product portfolio. Thus, strategy is seen as influential across a number of different elements, shaping the way an organization performs NPD.

However, a common weakness across the frameworks is the lack of inclusion of sustainability aspects. While the NPDP certification framework does include some environmental strategies and models, there is still a lack of well-defined best practices for this element that would provide practitioners with a benchmark to evaluate their organization. For example, short descriptions of high-level principles or concepts (such as the Triple Bottom Line) are provided, but with a lack of information on how these relate to other elements of NPD (such as the NPD Process), that would guide practitioners on integration of relevant sustainability principles, concepts and tools.

2.1.2 Capabilities & Competences

NPD frameworks typically define what technical and social capabilities should be in evident at an individual and organisational level as these will impact the organisational ability to innovate. Often the terms capabilities and competences are used interchangeably or definitions can vary slightly creating inconsistencies in the literature. Ulrich and Smallwood (2004) categorise each by social and technical aspects at both an individual and operational level of an organisation.

TABLE 2 CAPABILITY AND COMPETENCY COMPARISON MATRIX (ULRICH & SMALLWOOD, 2004)

	Individual	**Organisational**
Technical	An individual's functional experience	An organisation's core competencies
Social	An individual's leadership ability	An organisation's capabilities

The individual-technical cell (1) of Table 2 represents a person's functional competency. Examples include expertise in different areas of NPD (i.e., marketing, portfolio management, life cycle management), or in an activity (i.e., design modelling, prototyping and testing). The individual-social cell (2) in an individual's ability to provide good leadership. This is an individual's ability to establish goals or objectives and communicate them to relevant individuals or teams while also motivating people to perform required activities or tasks. The organizational-technical cell (3) is a company's core technical competencies. For example, a manufacturing department must be able to manage quality of the production line. The organisational-social cell (4) represents the overall culture and climate of the organization that often embodies some strategic advantage over a competitor for example 'speed to market'. Ulrich & Smallwood (2004) list 11 capabilities that best performing NPD organizations tend to be good at:

- attracting, motivating, and retaining competent and committed people
- making important changes rapidly
- ensuring that employees and customers have positive and consistent images of and experiences with our organization
- obtaining high performance from employees
- working across boundaries to ensure both efficiency and leverage
- generating and generalizing ideas with impact
- embedding leaders throughout the organization
- enduring relationships of trust with targeted customers
- articulating and sharing a strategic point of view

- doing something new in both content and process
- managing cost.

The alternative to the definitions of competences and capabilities provided by Ulrich & Smallwood (2004) is to view product development elements (i.e. Strategy, Portfolio Management, Culture) as core competences (Holahan, Sullivan, & Markham, 2014). For example, an NPD organisation may be very good at formally selecting what new ideas or concepts to develop based on strategic alignment of the business or market demands. The organisation is therefore competent at managing its product portfolio. Capability is then defined as the organisations ability and capacity to use that portfolio management expertise perhaps as a competitive advantage or to improve its overall NPD efforts.

Figure 9 uses product portfolio as an example to compare the differences in definitions. Ulrich & Smallwood (2004) consider capability to sit at a lower level of the organisation, while Holahan et. al (2014) view capability as higher level (perhaps at a strategic level).

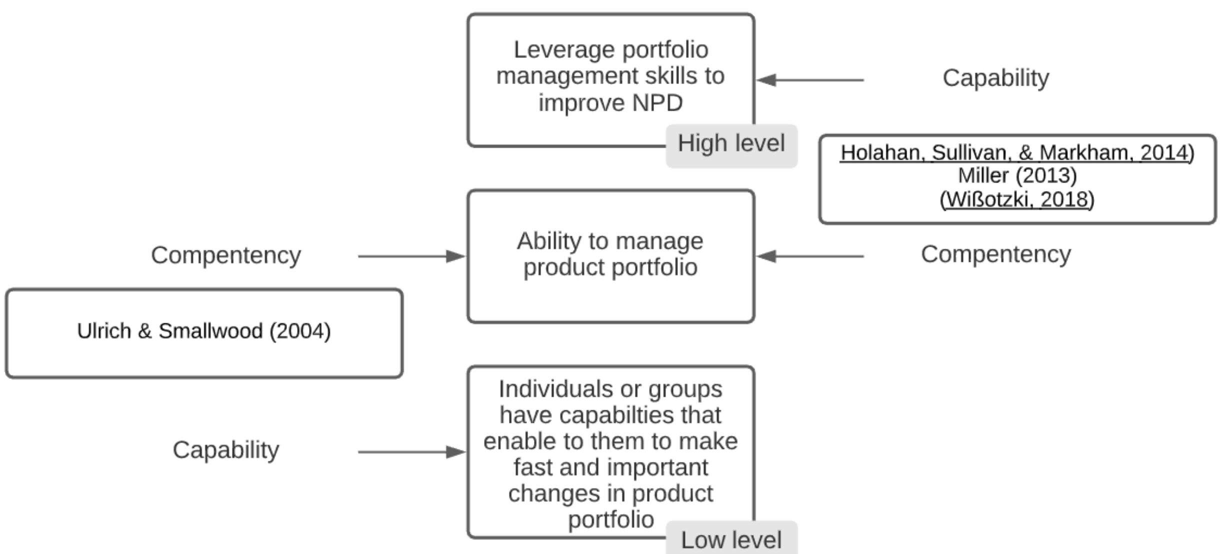

FIGURE 9 ILLUSTRATIVE DIFFERENCES IN DEFINITIONS OF COMPETENCIES AND CAPABILITIES

Therefore, capabilities emerge when an organization leverages the combined core competences of individuals and teams. If an organization is driven by new challenges or opportunities, they will take appropriate actions that are strategically planned, designed and implemented as capabilities (Wißotzki, 2018). This is supported by Miller (2013) who suggests that capabilities often emerge when an organization ventures into a new market or technology platform. Driven by strategic direction or product road-mapping, they may be required to step into a technical area or market where they have little knowledge or skills. The organization must then plan and develop core competences in that area.

The competencies that an organisation develops can have a significant impact on NPD performance. It will influence company strategy, support frontline leaders to make things happen and identify the intangible value of an organisation and the impact those capabilities have on NPD activities.

2.1.3 Culture & Climate

Climate is defined as "the meanings people attach to interrelated bundles of experiences they have at work" (Schneider, Ehrhart, & Macey, 2013). The term "climate strength" is used to measure the perceived consensus of the work environment amongst groups and teams. A strong climate has been shown to improve team performance, customer service, employee satisfaction and company turnover (Chatman & O'Reilly, 2016). The PDMA recommend that team development and formation can improve the climate strength within NPD teams (Anderson, 2017). An example is improving the quality of leadership. This is often achieved by creating cooperative and collaborative team environments with involvement from senior management that drive innovation to support the company goals – creating more cohesion within NPD teams and a stronger understanding of the direction of projects within an NPD process (Cooper, 2012). Another example is providing recognition of employee contributions and involvement to impart a sense of belonging to individuals of the team. Climate can also be improved by giving individuals the power to make or influence NPD decisions. They should feel confident that their views or recommendations are being considered in the decision making process (Anderson, 2017).

Culture differs from climate in a number of ways. It is defined as how the values of an organisation are reflected and infers how work is performed. These include patterns of expected behaviour that individuals perceive as required (Chatman & O'Reilly, 2016). These are not necessarily rules or regulations that individuals must adhere to, but rather a broad range of related norms such as collaboration, openness, togetherness or innovation. This makes shaping culture much more difficult requiring considerably more time to influence compared to climate since the focus is not on a particular aspect of the work environment (i.e., safety or service). In addition, many aspects of what shape an organization's culture are often assumptions that are hidden or unconscious and are described as 'just how we do things around here' which makes it difficult to identify the operations that reflect that perception (Schein, 2004).

Despite the differing descriptions of culture and climate, there is strong agreement across the literature that both have a significant impact on organizational performance (Cooper, Edgett, & Kleinschmidt, 2004; McLean, 2005; Ulrich, Allen, Smallwood, Brockbank, & Younger, 2009). There are a number of frameworks models or guidelines available to organizations to improve in this area. For example, Ulrich et al. (2009) suggest that culture should be generated from the outside-in by asking questions of "*what we want to be known for by our best customers*" rather than looking at "*what we currently do and how we can do better*" and propose a four-step model for achieving this. The steps are:

1. Clarify a compelling strategy to identify target customers - provides an understanding of who the best customers are when considering the realities of the industry environment, stakeholders and voice of the customer

2. Create a unity of identity – identifies what the organization wants to be known for and provides a process for shifting the development emphasis to align with the required identity
3. Make that identity real for customers – links the new identity with required capabilities that need to be developed or improved
4. Make that identity real for employees – aligns the internal communication, behaviours, practices and processes with the new capabilities.

Research by Cooper et al. (2004) found that climate and culture were two of the most important drivers of successful product development. The study identified best practices and principles that promote positive climate and culture within NPD and categorized organisations into best performing and worst performing with respect to each practice (Cooper et al., 2004). Encouraging open communication was described as one of the most important success factors that separated the best and worst performers. Amongst many others, support for entrepreneurial activities and innovation at a team and individual level as well as strong project leadership are considered other important success factors. Cooper et al. (2004) provide a list of actionable items to drive positive culture and climate best practice. Examples include "take on the odd venturesome project" and "provide leadership training for those involved or managing the NPD process".

Creativity, defined as the ability to produce work that is novel and fit for purpose, is concerned with the development of a new idea, invention or breakthrough. McLean (2005) investigated the relationship between culture and creativity and found that both are closely related. The study showed that culture can both support and impede creativity within an organization. Culture and climate aspects which support creativity include organizational encouragement, supervisory encouragement, work group encouragement, freedom/autonomy, and resource availability. Control is the major factor which impedes creativity. Control culture examples include "decision making, information flow, or a perceived control from extrinsic motivators". McLean (2005) concludes that climate and culture success factors that support creativity differ from those that support innovation. However, when comparing the success factors with those related to innovation (such as Cooper et al. (2004), Ulrich et al. (2009), Anderson (2017)) there is good alignment.

Culture and Climate pervade across both strategic and operational elements of NPD. Without a well-defined strategy, the first step of Ulrich et al. (2009) four step model would not be possible. It is reliant on knowing the organization's reason for existing (mission statement) and having objectives that can define its product innovation attack-strategy. Inversely, the first step of the model helps to clarify what that attack-strategy is by better defining who the best customers are.

There is also a close relationship between culture and capabilities (Ulrich et al., 2009). Research that defines best practice organizational climate highlights the importance of high-performing teams and individuals/NPD champions. These require capabilities to be embedded such as collaboration, leadership and customer connectivity (Yeung & Ulrich, 2020).

2.1.4 Organisational Change

Organisational change is defined as the approach or process used to achieve a desired change in a business. This change can relate to new business goals or direction, the structures of the business units or capabilities to serve some competitive advantage (Todnem By, 2005). As change reflects the attitudes and behaviours of people in the business, the best practice process to accomplish change is positioned within the field of human psychology.

As discussed in sections 2.1.2 and 2.1.3, developing capabilities and shaping the culture and climate have an impact on new product development success. However, the NPD body of knowledge lacks insights from the field of human psychology on how to implement change.

There are two general approaches to organisational change (Figure 10): (1) change program which is commonly considered the traditional approach, and (2) grassroots approach (Beer, Eisenstat, & Spector, 1990).

The traditional approach is often reactive and temporary and driven from the top down. Senior management will identify a change they want in the business, match this with a change program or project and lead this program from the top until its completion. The goal of such programs is to promote middle managers and workers to change their behaviours and attitudes to change culture, increase participation or generate empowerment at the middle manager and worker level. Examples of such change programs can be in the form of team restructures, training programs to improve capabilities or competencies, and establishing performance appraisal programs for individuals and teams (Graetz, Smith, Rimmer, & Lawrence, 2010).

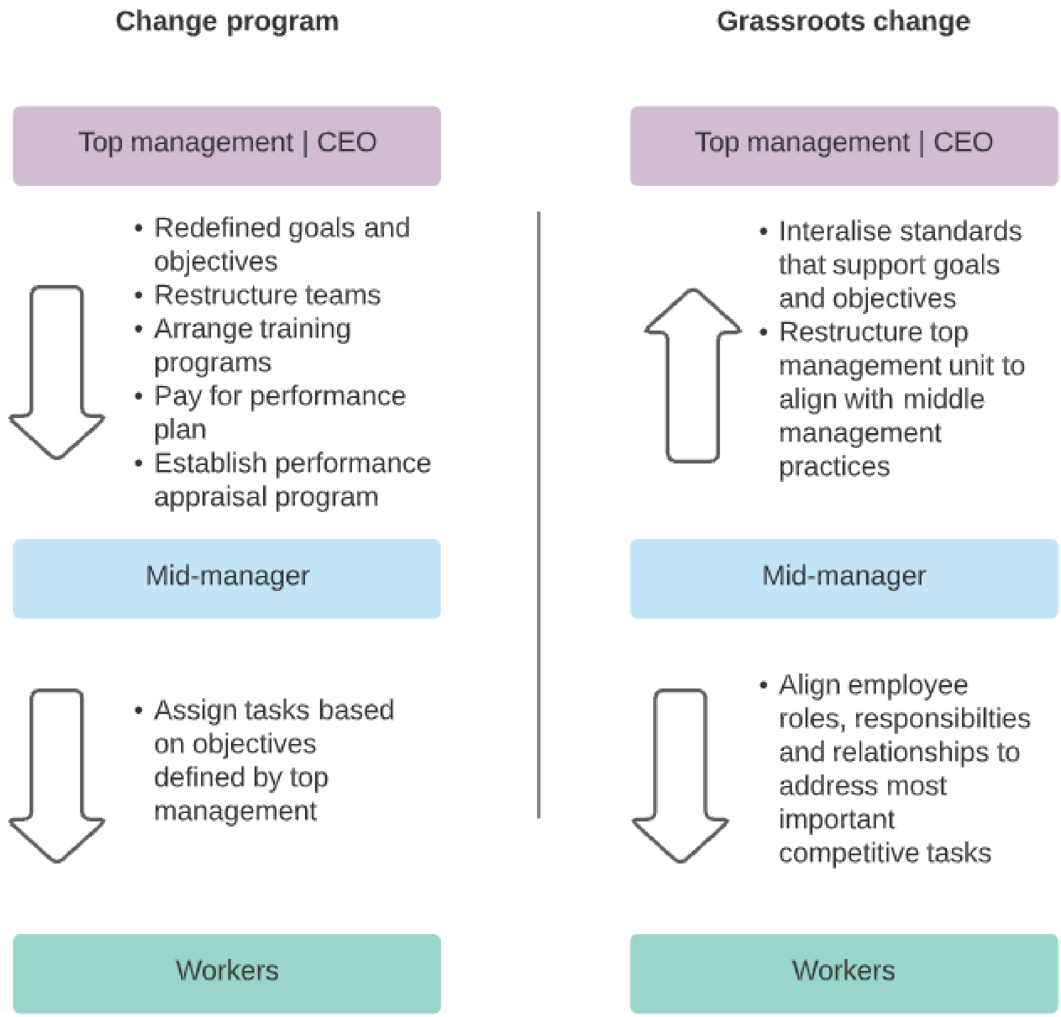

FIGURE 10 CONCEPTUAL ILLUSTRATION OF THE APPROACHES TO ORGANISATIONAL CHANGE

The alternative approach is considered emergent and starts at middle management (Beer et al., 1990). Managers will ad-hoc implement some type of change at the worker level to solve a problem. The manager will align various tasks to individual capabilities and make the 'work' or 'task' the central focus, rather than abstractions such as empowerment or culture. As managers and workers have led the change (behaviour) from a psychological perspective, they are more likely to have a positive attitude towards the change (Graetz et al., 2010). The senior or top manager’s role in this change approach is to then align business structures or policies to support the practices that the managers and workers are implementing.

While change programs are still widely applied, there is strong agreement in literature that they do not work (Beer et al., 1990; Graetz et al., 2010; Kotter, 2007; Todnem By, 2005). Various reasons are given. Beer et al. (1990) suggests that change programs try to change attitudes of the individual managers and workers, while they should adopting approaches that change behaviours (that ultimately change attitudes). Kotter (2007) suggest that change programs fail because top managers see them only as discrete events rather than a process and thus are prone to skip important steps and make critical mistakes.

A comprehensive review of organisational change found that, regardless of the approach, organisational change management models lacked valid frameworks, offered confusing theories and conflicting advice, and most lacked empirical evidence, often based on unchallenged hypotheses (Todnem By, 2005). Recent studies have attempted to address some of these limitations by adding empirical evidence to support theories (Henricks, Young, & Kehoe, 2020) or revise existing models and frameworks with greater inclusion of the behavioural psychology body of knowledge (Oreg & Berson, 2019). However, the limitations and concerns raised by Todnem By (2005) remain largely unaddressed and indicate that the best practice process for managing organisational change is still unknown. Without further research on the subject, change management studies can only reliability propose what to change, rather than how to change it.

2.1.5 NPD Process

The quality of the product development processes and practices implemented by companies has a significant impact on new product success (Anderson, 2017). An NPD process typically provides a number of functions (adapted from Ulrich & Eppinger, 2012):

a. Provides a structured approach to moving a product from concept to launch with distinct stages that represent how far through development a product is – this assists in scheduling and plans the overall process and communicates roles and activities to the project team
b. Provides a decision support tool that helps product managers decide if a product should continue in development often by separating the stages of development with an evaluation point between each stage (a gate) – these check points provide quality assurance, preventing poor quality from passing through.
c. Identifies key tasks that must be performed at each stage - allows for assessment of the overall development of a project so problem areas can be identified
d. Facilitates knowledge management - allows for continuous improvement throughout the product development journey and future projects

The NPD process can therefore be often used for both a structured decision support tool and a project management tool.

It is recommended that most companies should have a generalized process that they can customize for specific products or programs (Ullman, 2016). There is good agreement on what characteristics define a best and poor NPD process. As an example, Barczak and Kahn (2012) has identified best and poor performance characteristics that are applicable across a generalised process (*Table 3*).

TABLE 3 NPD PROCESS BEST AND POOR PRACTICE ADAPTED FROM TABLE 1 OF BARCZAK AND KAHN (2012)

Poor Practice	Best Practice
Criteria for evaluating NPD projects are not defined	A common NPD process cuts across company groups
Limited documentation exists regarding the NPD process	The NPD process is flexible and adaptable to meet the needs, size, and risk of individual projects
Minimal testing (concept, product, market) performed	Go/No-Go criteria are clear and pre-defined for each review gate
No NPD process exists	The NPD process is visible and well-documented
There is no discipline in using the company's NPD process	A clear NPD process exists
There is no NPD process owner or NPD process champion	An IT infrastructure with appropriate hardware, software, and technical support is available to all NPD personnel
Not all NPD personnel have access to the same IT tools (software, hardware)	
Projects are not reviewed at completion	
The NPD process can be circumvented without management approval	

Based on the significant impact of the NPD process on new product success, a plethora of research has been dedicated to the subject. As a result, a number of NPD process models have emerged in industry and academia. Some of these include:

- Stage-Gate® (Cooper, 2011b)
- PACE (McGrath, Anthony, & Shapiro, 1992)
- Set-Based (Sobek Ii, Ward, & Liker, 1999)
- Spiral (Boehm et al., 1998)
- Agile (Wise, Daniel, & Livingston, 2015)
- Lean PD (Rossi, Taisch, & Terzi, 2012)
- Design Thinking (IDEO, 2019)
- Hybrid Stage-Gate® (Sommer, Hedegaard, Dukovska-Popovska, & Steger-Jensen, 2015)

Three of the most established NPD processes (Stage-Gate®, Agile, Design Thinking) are described and compared below to identify similarities and differences.

Stage-Gate® was created in the 1980s by Cooper and Edgett based on a comprehensive study of successful product development practitioners within large corporations (Cooper, 2014). The Stage-Gate® model strongly resembles the Waterfall model which developed in the 1970s to assist with software development in space-craft mission planning (Royce, 1987). Both Stage-Gate® and Waterfall break up the stages of a development project into macro planning steps that are both customer focused and iterative. Stage-Gate® has been continually updated to reflect changes in industry needs such as the ability to adapt quickly to market changes and consumer needs.

An example of a Stage-Gate® process is illustrated in Figure 11. The gates are the project reviews where formal meetings take place, and a decision to progress to the next stage, revise/rework in the current stage, or terminate the project may occur.

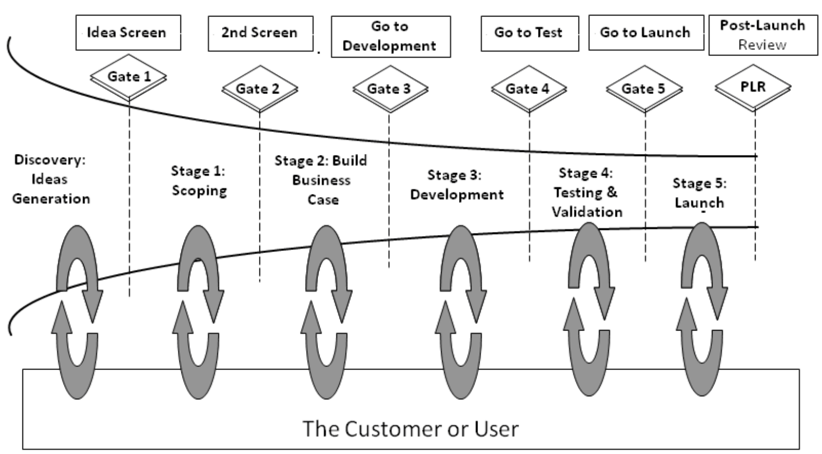

FIGURE 11 GENERIC STAGE-GATE® PROCESS ((COOPER, 2011A))

A considerable body of literature is dedicated to defending Stage-Gate criticisms. Notable criticisms are that it is too linear, and it is too rigid with a planning structure that does not accommodate a dynamic environment. It is also proposed that it creates waste within the process by inherently generating non-value added work (Becker, 2006; Lenfle & Loch, 2011). One study found that strict adherence to Stage-Gate® philosophy could kill off viable products which was often due to prioritising and evaluating financial costs too early (van Oorschot, Sengupta, Akkermans, & van Wassenhove, 2010). The responses to these types of criticism are convincing in their explanations. Cooper (2011) breaks down each criticism and comprehensively addresses why Stage-Gate® is not supposed to be a bureaucratic rigid system that strangles innovation. At the root of the argument is a lack of understanding and poor implementation by businesses and researchers (Becker, 2006; Cooper, 2011b, 2014). Traditional Stage-Gate® models typically implement financial measures as decisions for go-no/go at gates. This is often most evident in early stages of the process when developing and analysing the business case for a new product before significant resources are committed. From this perspective the model is being utilized as a portfolio management tool – providing decision support on what products to develop based on the best financial result (Cooper, 2014). However, research has shown that some of these financial tools (i.e. Internal Rate of Return, Net Present Value) do not yield the best results (Cooper, 2014) with some experts arguing that it is due to the financial tools being short-term focused - creating an unsustainable product innovation system (Christensen, 2013). As a result, more progressive organizations have started to implement strategic criteria into their decision gates – criteria that reflect the strategic-fit or market potential rather than profit measures.

Agile Product Development, better recognised in recent literature by terms such as “Scrum” and “Sprint”, emerged in the late 1990s as a solution to many problems that the Software Development industry was facing (Cooper, 2016). The software industry changed rapidly, and projects that used a traditional gated or waterfall product development approach would often take too long and cause highly perishable work to quickly become outdated as customer demands changed. Often with gated or waterfall development models, early commitments are made to the design, specifications, features and the schedule of the overall development, which locks in upfront planning. When the customer requirements change further down the development cycle, the resulting change management control slows the process and creates inefficiencies (Cooper, 2016).

It is recommended that in order to successfully implement an agile product development model, a supporting culture and climate should be in place. Wise et al. (2015) provide four spheres that can assist in Agile transformation as shown in Figure 12.

The terms ‘scrum’ and ‘sprint’ is unique to Agile. The term ’scrum‘ originates from a rugby term where the game is restarted after an infraction (Cooper, 2016). In product development, it is a meeting of a project team to determine how to “move the ball forward” – again associating the term with rugby.

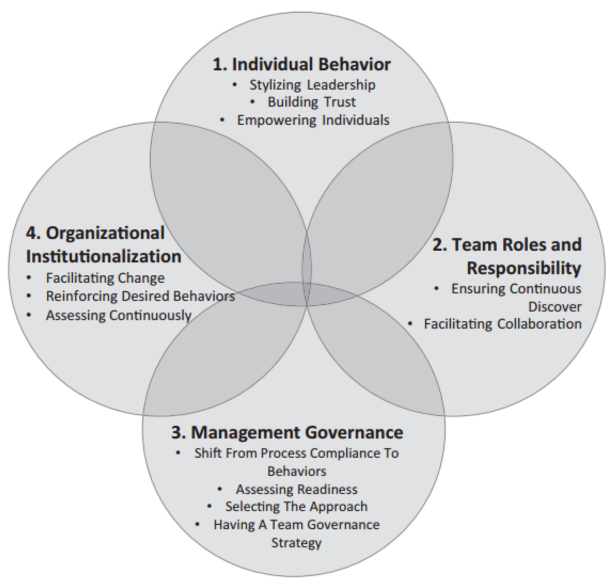

FIGURE 12 FOUR SPHERES OF AGILE TRANSFORMATION ADAPTED FROM WISE ET AL. (2015)

Figure 13 illustrates the process flow of a generic scrum cycle. Typically a sprint could last for 30 days with scrum meetings occurring daily to determine (1) what has happened since last meeting, (2) what were the obstacles, (3) plan what will be done before the next scrum meeting (Boehm & Turner, 2005).

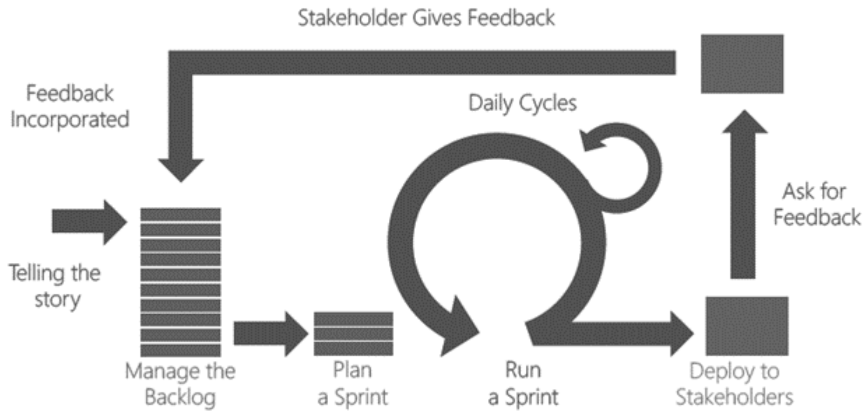

FIGURE 13 GENERIC STRUCTURE OF A SCRUM CYCLE ADAPTED FROM HARRY (2011)

One key difference between software and hardware is the type of expected outputs in a sprint. In the software industry it is possible to release a function or useable software program at the end of the sprint. In contrast to this, with hardware development it is not usually feasible to expect a releasable product (Cooper, 2016). Cooper (2016) proposes that the definition of a successful sprint will need to relate to the type of activities in the cycle or context that it is being applied. The most recent adaptation of Agile has demonstrated it can be adapted to use in Stage-Gate® and applied successfully within NPD, providing faster response to change and higher R&D productivity while maintaining a robust macro-level project management tool for go/no go decisions (Cooper & Sommer, 2020).

The Design Thinking process model was popularized by David Kelley who is the founder of one of the most influential product development firms, IDEO. It has been successfully applied in renowned companies such as Apple, SAP and Protor & Gamble (Davis & Rose, 2013; Efeoglu, Møller, Sérié, & Boer, 2014). The process is defined as five phases (Figure 14) which can be categorized into problem and solution spaces.

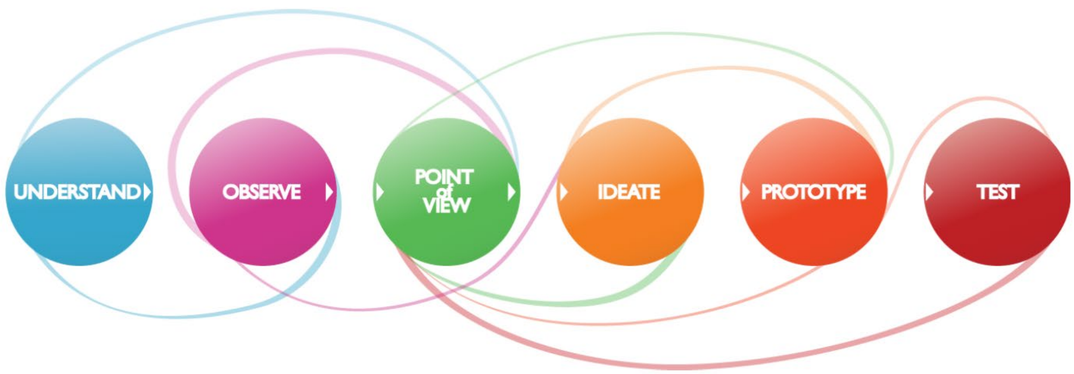

FIGURE 14 DESIGN THINKING PROCESS TAKEN FROM EFEOGLU ET AL. (2014)

The problem space compromises the Understand, Observe and Point of View phases, while the solution space is the Ideate, Prototype and Test phases. These phases and the illustrated iteration between them closely resemble other NPD process models. Implementation of the process model differs in other operational and strategic aspects. Firstly, there is a strong emphasis on consumer empathy in the front-end homework phase of development. When scoping and defining the problem, the customer's viewpoint is the central focus. Practitioners empathize with the consumer by observing their behaviour – their experience will communicate the focus of the solution. This approach is thought to lead to better products and services (IDEO, 2019). Another differentiating characteristic of the model is the structure of product development teams. In order to fully explore the solution space, collaboration between individuals across a multiple disciplines is required (Efeoglu et al., 2014). Furthermore, the individuals within the project team need to be competent on building on each other ideas. This is a good example where strategic elements of NPD (culture, leveraging capabilities) disseminate and impact the operational aspects of NPD.

2.1.5 Tools & Techniques

There are an excessive number of tools and techniques available to NPD practitioners that can improve the outcomes of NPD projects. These are categorised into:

a. Ideation - intended to be used throughout the NPD process (particularly in the early stages of development), often to aid in the exploration of a problem/solution space
b. Design Engineering Tools – provides technical and operational support in the development stages of projects (usually in later stages – post design specifications)
c. Project Scoping and Market Research Tools - applied at appropriate points along the NPD process to manage the scope, budget and schedule of an NPD project. Marketing is intended to better inform NPD projects through collecting consumer data in the form of market trends, patterns and user feedback often analysing and integrating this information into the development process
d. Financial - used to analysis the likely success with respect to financial feasibility of a product – most critical during go/no-go decision points of an NPD process

The choice of tools and techniques by an NPD practitioner depends upon many factors (e.g., size of the project, type of products being developed, organizational characterizes such as size, industry focus, etc.) and therefore it is not possible to review all tools and conclude which tools are better or worse. However, some tools can be used generically across many product development situations or environments. One study has identified these and shown that the best performing NPD companies are 50% more likely to use these tools compared to the rest of companies that do not (Markham & Lee, 2013). Therefore, this section describes both generalizable best practice tools and selected industry specific tools that are considered to be relevant to the study.

A) Ideation Tools

Ideation tools are used to generate ideas for new products (Bigelow, 2005). They are vital for the design process and are often applied at the front end for the purposes of generating solutions to consumer problems.

PDMA lists several tools they consider to be general ideation tools used by product developers (Anderson, 2017) (see Table 4).

TABLE 4 POPULAR IDEA GENERATION TOOLS

Tool	Overview
SCAMPER	Uses a set of simplified, direct questions (heuristics) to help improve or build on an existing product or concept. It is often limited by the practitioner's ability to use the heuristics and therefore not suitable for untrained designers.
Brainstorming	Usually applied at the beginning of idea generation this method focuses on generating creative solutions to problems, free of criticism with a preference on quantity over quality of the ideas.
Mindmapping	A graphical technique for expanding a central ideal. Lines are drawn to new nodes which are related ideas. This method is suitable for understanding the levels or connections between the nodes.
Storyboarding	A graphical representation of how a consumer might use a product or system. This is typically broken up into steps to fully understand problems that might be encountered by the user.
Brain writing	Thought to produce more creative ideas, this method works in a team of six people who write down three ideas in five minutes. The ideas are then passed clockwise to the next team member to add or modify the ideas. It is particularly useful for idea generation where the group is at risk of team members dominating the session.
Six thinking hats	Often used more during evaluation it can also be used to generate new ideas around existing ones. This method uses role-play where each team member wears a metaphorical hat that represents a different orientation to solving problems. This method allows for evaluating ideas subjectively and objectively as well as identifying the pros and cons of an idea.
SWOT	SWOT is an acronym for Strengths, Weaknesses, Opportunities and Threats. Typically, this method is used as an evaluation technique for a new idea by listing all the characteristics of the idea under each of these headings.

sources:
Delft Design Guide (Boeijen, Daalhuizen, Zijlstra, & Schoor, 2013)
The Innovators Toolkit (Silverstein, Samuel, & DeCarlo, 2009)
The PDMA Body of Knowledge Certification Training (Anderson, 2017)
Product design (Otto & Wood, 2001)

B) Design Engineering Tools

While some design engineering tools attempt to also generate new ideas and solve problems, they differ from ideation tools since the outcomes or solutions are less abstract or concept orientated and more focused on specifications, features or improvements of a product in development. Many design tools follow a method that an organisation can step through which often complements the NPD process rather than replace it (Anderson, 2017).

Design for Six Sigma is a design engineering tool that is increasing in popularity with NPD practitioners and is reported to be one of the tools more commonly used in best performing product development companies (Markham & Lee, 2013). A key component of Six Sigma processes is some form of experimentation to test how the input variables from a device, component or manufacturing process affect the response variables that need to be optimised. DoE is considered to be the most effective experimentation tool when considering multiple input variables for a product system (Roy, 2001; Tanco, Viles, Ilzarbe, & Alvarez, 2008). DoE avoids the misleading results that are often found in alternative experimentation methods such One Factor at a Time (OFAAT) and Randomised Control Trials (RCT), where the results only yield first order responses and ignore interactions between factors (Kutz, 2007). One study showed that most manufacturing companies applying DoE were those doing Research and Development projects (Tanco et al., 2008); however, the majority of manufacturing companies still apply inferior tools such as OFAAT (Granato & Ares, 2013).

C) Project and Market Research Tools

Within the context of NPD, project management is a term used to describe the overall process for developing and commercialising a single project or composite of smaller ones (Anderson, 2017). It is integrated as part of the NPD process defining the individual tasks and goals that need to be carried out to achieve success. Common tools applied in project management include Gantt

Charts, Critial Path, Decision Trees and Risk Management. Project scoping is an important activity within project management and often must consider the voice of the customer and market requirements. Scoping is part of the homework phase of product development and is considered to be a critical success factor of NPD. Scoping typically occurs prior to development work and sets the parameters for a new project (Cooper, 2012). This scoping phase will describe the products features and added value, the target price and market and the internal scope within the organisation (ie is the product part of a line extension or a new product platform). It will typically include a list of objectives that the project should achieve. This information is recorded and communicated to team members in a living document known as a Product Innovation Charter (Anderson, 2017). Based on the results of best practice NPD studies Cooper (2012) provides a list of recommendations that companies should follow when scoping a project including market-orientated idea generation activities, design decisions based on customer inputs and comprehensive concept developing and testing (Cooper, 2012).

Cooper (2012) proposes that market research activities are an integral part of project scoping. To create a unique product that is superiour to competitors, it must come from the customers standpoint, rather than the NPD development team (Cooper, 2012). The customer's influence plays a critical role in new product success (Rajesh, Daniel, & Park, 2001). It is well established that new product development teams can enhance a product's innovativeness, ensuring a new product concept will add value by integrating customer input into the design process and concept testing phase (Rajesh et al., 2001) (Cooper, 2012). Jreissat, Isaev, Moreno, and Makatsoris (2017) recommend a close collaboration between the end-users and the manufacturers to succeed in consumer-driven new products. Good consumer research will reveal insights beyond the functional requirements of a new product often highlighting consumer importance of the aesthetics, form and prestige (Beckley, Paredes, & Lopetcharat, 2012). Therefore deatiled market studies must be performed (such as Voice-of-Customer research) that can obtain this information and build it into the development and decision making process for new products. The CPAS study showed that best performing compaines used market research tools signficanly more than the rest of companies surveyed (Markham & Lee, 2013).

D) Financial Tools

Financial tools are used throughout an NPD project to assess the sales potential or financial risk. The tools are often most useful at the early stages of development to assess the viability of a project. Examples of tools include Internal Rate of Return, Payback Period, and Net Present Value. Often these tools are integrated into the Product Development Process and Portfolio Management of an organistion, providing criteria to evaluate the go/no-go decisions. As prevoiusly mentioned Cooper (2014) suggests that using only Financial Tools within the NPD process does not always yield the best results, yet, Markham and Lee (2013) highlight that Payback Period is still one of the most commonly used Financial tools that separate the best from the worst performing NPD companies.

2.1.6 Front-End

The front end of product development (often referred to as Fuzzy Front End (FFE) or Early NPD) is considered to be one of the most important stages in NPD. Miller (2002) suggests that at least half of development time should be dedicated to this early stage as it provides one of the greatest opportunities for improvement of the overall innovation process. Decisions made at this early stage will impact the later stages, and so applying effective methods, tools and techniques early on can improve the overall cycle time and efficiency of the entire NPD process (Koen, Ajamian, & Boyc, 2002).

There is a lack of alignment between experts on what is considered best practice front-end product development practices. Barczak and Kahn (2012) suggest that a common NPD process should cut across different parts of the organization (such as Design, Engineering, R&D). However, others argue that common NPD process models (such as Stage-Gate) fail to accommodate the differing characteristics of organizations (Ledwith, Perks, & Nicholas, 2011) or different types of projects (i.e. radical vs incremental) (Koen, 2004). As an example, the traditional stage-gate NPD process considers Discovery, Scoping and Business Case stages to be part of the FFE (Cooper, 2011b). However, Veryzer (1998) argues that the activities performed in these stages (such as concept testing and market assessments) are conducted too early and, for many projects that might be considered more radical, could discourage major innovation breakthroughs. This is often because a radical innovation can span up to 20 years causing market assessments and product understanding to become less relevant. However, in a related study. Verworn, Herstatt, and Nagahira (2008) suggested that there are no distinct differences in the fundamental steps between incremental and radical NPD, stating that it is the specific activities that vary within the process. As an example, market assessments are still required to reduce the uncertainty during development; however, they can be conducted in different ways to account for the different time-horizons of projects (e.g. an emphasis on fore-sighting exercises for a radical innovation). Holahan et al. (2014) found that more control was required in the radical innovation process, recommending less flexibility was required with more engagement and leadership from senior management. Irrespective of how the process should change (activities or steps), Cooper (2006) states that traditional methods do not work for non-traditional projects and practitioners should avoid ‘force-fitting’ these projects through a company’s established product development process.

Given the perceived limitations of traditional NPD process models for FFE activities, new or modified models have been proposed. The objective of these models is to replace or improve the front-end stages and activities of the NPD process (Table 5).

TABLE 5 COMMON FRONT END PROCESS MODELS

Author	Model	Differentiating characteristics
(Khurana & Rosenthal, 1998)	Fuzzy Front-End Model	Does not distinguish between technology projects and NPD projects. Activities within stages resemble traditional stage-gate models. Front-end activities grounded in strategic fit/portfolio management practice
(Reid & De Brentani, 2004)	Fuzzy Front-End Information Flow and Decision-Making Process: Discontinuous Innovations	An abstract perspective of the fuzzy front end and the way in which information flows to decision makers. Focus on managing discontinuous innovation projects which originate in an environment that is disconnected from an organisations NPD process
(Cooper, 2006)	Technology Development Stage Gate	Iterative between stages but ultimately sequential. Utilised as an operational blueprint or roadmap that generalises and prioritises technology projects in preparation for entering the NPD process. Traditional business measures used to evaluate new technology development opportunity.
(Koen, Bertels, & Kleinschmidt, 2012)	New Concept Development Model	Interrelated activities (the stages) are non-sequential. The model focuses on how activities and understanding the relationship between the engine (the organisation culture and strategy) and uncontrollable influencing factors (consumers, market)

The Technology Development Stage Gate (TD Stage-Gate) is process model that is integrated into the traditional Stage-Gate model. The New Concept Development Model (NCD) is a stand-alone model that embeds other elements of NPD (such as culture and strategy). These two models are compared and contrasted here in order to illustrate the contrasting approaches of different FFE models.

Högman and Johannesson (2013) state that TD Stage-Gate (Figure 15) differs from a traditional stage-gate NPD process in that the aim is to advance or mature a technology for the purposes of creating new knowledge, skills or artefacts. The developed technology may then contribute or become the basis for a product development project which would progress through a common NPD process (such as traditional stage-gate).

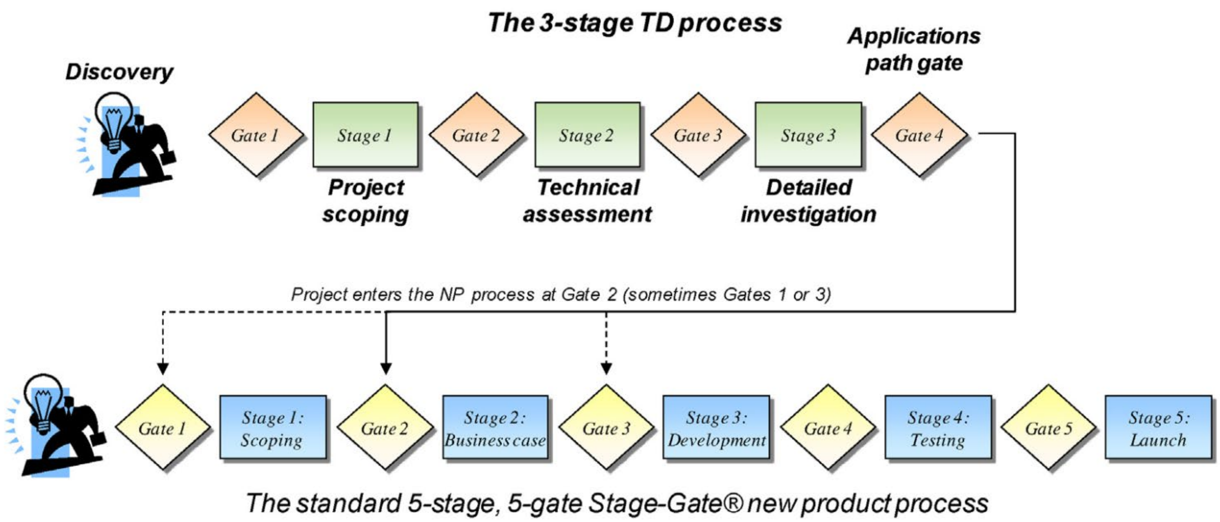

FIGURE 15 THE TECHNOLOGY DEVELOPMENT STAGE-GATE PROCESS PROPOSED BY COOPER (2006)

The discovery stage of TD shares many similarities with the discovery stage of a traditional stage-gate. Ideas can be generated from many activities such as strategic planning, brainstorming, customer insights and foresighting. The criteria and go/no-go decision for evaluating the ideas is similar (strategic fit/likelihood of commercial success/size of prize); however, it differs in its qualitative approach to scoring. The project scoping stage and activities required are described in a similar way to traditional stage-gate but there is more emphasis on reviewing technical literature, related IP searches and preliminary technical assessments to address the primary question asked at the subsequent gate review: "Does the idea merit undertaking limited experimental work?" (Cooper, 2006). The technical assessment stage represents experimental work (pilot studies, technical feasibility). The activities in this stage generate data that inform gatekeepers if the project should move to the next stage. This requires committing significantly more resources. If the project proceeds successfully through the gate, the final stage "detailed investigation" is the implementation of a full experimental plan to prove the technology that will lead to commercial products.

The NCD model (Figure 16) was developed by Koen et al. (2012). The type of projects that the NCD model is suited for has a similar description to that of the TD model i.e., projects that are experimental, chaotic and with great uncertainty on revenue expectations. The outputs are generally strengthened concepts rather than commercial outputs. There are three key parts to the model:

- The engine includes top management support, culture and business strategy that drive the stages of the NCD model
- The inner spoke contains the stages of the process that are arranged in a circular shape providing iteration between stages.
- The influencing factors are the organization's capabilities, and the outside world influences (such as government policy, customers, competitors, environment, distribution channels etc.). These factors are considered to be uncontrollable by the organization.

Ideas can enter the NCD model from different stages of development and exit when the concept or idea is defined enough to enter the common NPD process.

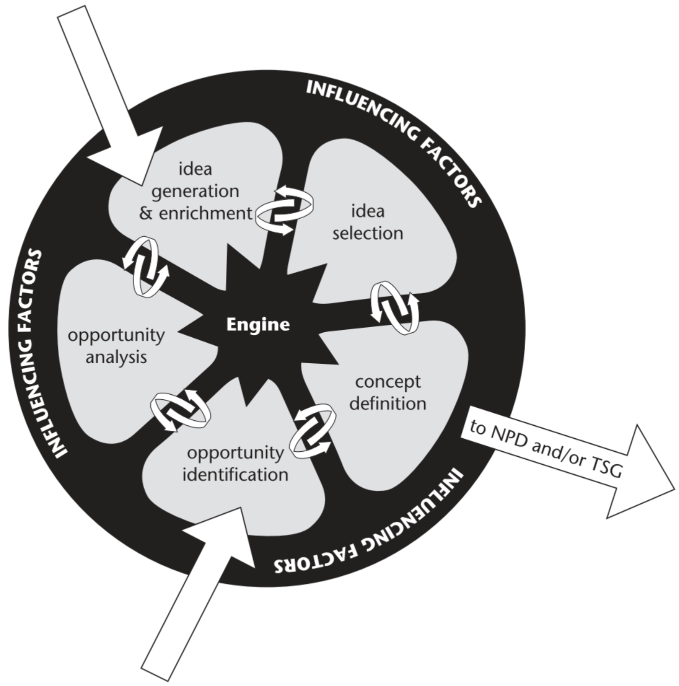

FIGURE 16 THE NEW CONCEPT DEVELOPMENT MODEL PROPOSED BY KOEN ET AL. (2012)

The recognition of the *engine* and its impact on the product development stages is one of the defining characteristics of the model. Culture within the NCD model engine is fundamentally different from previously discussed. This is because the FFE is experimental and ambiguous, it requires a culture that allows individuals to explore the unknown or to consider the unreasonable without fear of failure (Sheldon A. Buckler, 1997). This stands in contrast to the 'product delivery process', when there is a defined product and predictability of what task will come next and in what stage of the process, development costs have been allocated and a timeline and targets have been set – the stakes for failure are higher and unacceptable at this stage of development. These aspects require a disciplined culture, the ability to adhere to the process and follow a procedure. In contrast, in order to support the NCD engine, the follow success factors are suggested:

- A culture that encourages innovation and creativity

- Early involvement of top management who has direct influence over resource allocation
- A collaborative culture
- Project leaders who maintain constancy of purpose
- Setting ambitious project goals.

Another defining characteristic of the NCD model is the *influencing factors*. Koen, Ajamian, Boyce, et al. (2002) argue that the NCD process is sustained (or limited) by the influencing factors. The influencing factors include the origination's capabilities, the customer and competitor influence and other outside world influences (i.e., government policy). These are considered uncontrollable factors but critical for the organization to recognize and understand and develop capabilities to manage the impact they have on the development process. The only success factor provided for this aspect of the NCD model is the ability to react quickly when the influencing factors change.

Comparing the two models, TD stage-gate is a very linear and structured approach while the NCD model is more iterative and recursive. However, a study which followed six companies implementing the TD stage-gate demonstrated that the inherent uncertainty of the TD projects forced them to adapt the model to a point where it closely resembled the NCD model, with 'loop-backs' to other stages and considerable iteration between the stages (Högman & Johannesson, 2013). Another difference is that the NCD model also contains no distinct gates between each stage. This could be representative of the engine's impact on the stages – providing an undisciplined 'micro-culture' that supports the FFE activities. However, with no gates it could provide a situation where a project could advance from one stage to the next too early.

2.2 Eco-Design

Eco-design is considered to be a proactive approach to integrating and managing environmental issues in company product development processes (Baumann, Boons, & Bragd, 2002; Brones et al., 2017; Dekoninck et al., 2016; Pigosso & McAloone, 2015a). Indeed, Pigosso et al. (2013) suggest that eco-design has become essential to manufacturers who see environmental considerations as part of their strategies (Pigosso, Rozenfeld, & McAloone, 2013).

However, due to conflicting views and opinions on eco-design and a lack of consistent terminology within the literature, the subject of eco-design can be described as messy and fragmented (Baumann et al., 2002; Driessen, Hillebrand, Kok, & Verhallen, 2013). It is also generally regarded as poorly applied in companies and much eco-design research is dedicated to understanding why this is (Devanathan, Ramanujan, Bernstein, Zhao, & Ramani, 2010; Driessen et al., 2013; Issa, Pigosso, McAloone, & Rozenfeld, 2015; Maccioni, Borgianni, & Pigosso, 2019).

2.2.1 History of Eco-design

From the late 1990s the subject of eco-design and related frameworks, methods and tools became increasingly popular. Charter and Chick (1997), in the first issue of *The Journal of Sustainable Product Design*, proposed that, to meet global resource and energy reductions, manufacturers need to focus on re-thinking and re-designing their products (Figure 17). The Four Step Model of Charter and Chick (1997) described the current eco-design efforts of most companies as focusing on the “Re-PAIR” step; only some leading edge companies were seen as operating at the Re-FINE and Re-DESIGN levels of the model. Charter and Chick (1997) argued that companies should be striving for the Re-THINK level.

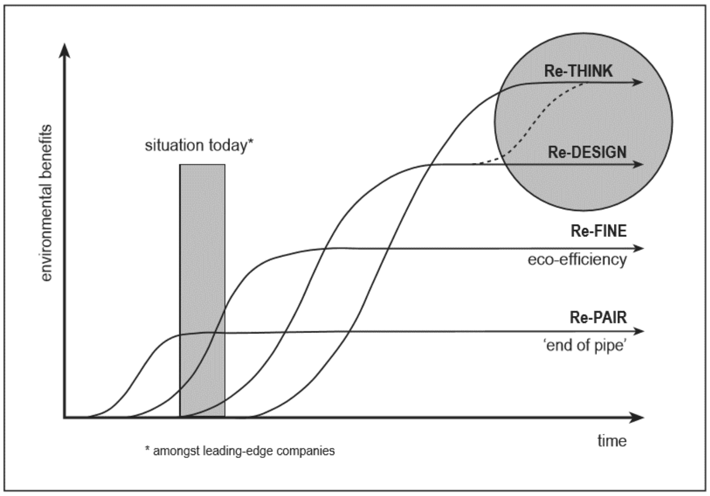

FIGURE 17 THE FOUR STEPS MODEL FOR ECO-DESIGN (CHARTER & CHICK, 1997)

At the beginning of the 2000s, the situation was much the same despite the considerable research on the subject of eco-design and the development of an extensive range of new decision-support tools such as Life Cycle Assessment (LCA) that could support the higher tier steps within product development (Baumann et al., 2002). Baumann et al. (2002) concluded that there had been a focus on the engineering perspective[1] in eco-design research, and that important business and policy perspectives[2] were missing from this research; others argued that the industrial design perspective was also missing (Lofthouse, 2006). As a result, researchers began to provide guides, frameworks and models to support strategic management of environmental considerations in NPD (Nidumolu, Prahalad, & Rangaswami, 2009). This research involved addressing environmental issues in relation to wider contextual aspects such as company culture and human factors, often referred to as the soft-side of eco-design (Boks, 2006).

[1] The Engineering perspective of eco-design literature prioritises consideration of operational activities. i.e. applying an eco-tool (such as Life Cycle Assessment) by an engineer (Baumann et al., 2002).
[2] The business and policy perspectives are focused on the aspects that impact the business image, strategy and overall direction (Baumann et al., 2002)

Pigosso et al. (2011) asserted that the lack of application of eco-design was mainly due to companies not understanding which eco-design strategies, guidelines and tools should be implemented in their organisation (Pigosso et al., 2011). They proposed five explanations for this:

- Lack of systematization of existing eco-design practices
- Development of new eco-tools, instead of refining existing ones
- Lack of integration of eco-design in the context of NPD
- Lack of measurement of eco-design in the context of NPD continuous improvement
- Existing eco-design practice is poorly applied based on the limitations or capabilities of the organisation.

Eco-design experts have since attempted to includes stragies or develop frameworks that address these issues (Brones, Carvalho, & Zancul, 2014; Hallstedt, Thompson, & Lindahl, 2013). However, there are some experts who still argue that current frameworks, strategies and tools are too broad and lack guidance for NPD practitioners (Jefferson Hynds et al., 2014; Kim, Cluzel, Leroy, Yannou, & Yannou-Le Bris, 2020). Furthermore, many compaines will often limit eco-design to assessment criterion of existing products rather than analysing the performece of the products function (i.e. radical product innovation) (Rossi, Papetti, Marconi, & Germani, 2019). This is possibly due to the lack of linking to existing NPD theory that include best practice product design, project management and product innovation(Malte & Manuel, 2021).

2.2.2 Frameworks

In the most recent research, there is an attempt to complement the technical ‘hard-side’ with the ‘soft-side’ of eco-design, and offer continuous improvement frameworks as a solution to implementation and integration (Pigosso & McAloone, 2015b). The objective of a continuous improvement framework is to define a benchmark for eco-design, thus providing a measure for companies to assess their performance, and to offer recommendations or guidelines to improve company practices. Four of the most popular eco-design frameworks for continuous improvement are the EcoM2, Green Product Development Framework, eco-Design Transitional Framework, and IRI Sustainability Maturity Model.

The **EcoM2 (Eco-Design Maturity Model)** is one of the most highly referenced eco-design integration frameworks . It systemises eco-design practices into strategic, tactical and operational activities   Pigosso et al. (2014) proposed 62 management practices which are classified under a high-level NPD process model that represents the different stages of product development (e.g. Concept Design, Project Planning). The practices are organised across a matrix of evolution levels that describe various levels of eco-design performance and sophistication, and these are used to benchmark a company's existing performance (Brones et al., 2017; Pigosso et al., 2014). In a recent study, the EcoM2 management practices were used to statistically evaluate product success by comparing Envioronmental Product Declarations (EPD's) to a customised measure for success (focused on seven levels that were qualitatively generated from a review of literature) (Maccioni et al., 2019).

The **Green Product Development Framework** is based on a comprehensive eco-design literature review and was collaboratively developed with NPD practitioners and academics (Naga Vamsi Krishna, Aditya, & Shashikantha, 2015). The framework proposes 11 elements (the pillars) of eco-design and a so-called "stakeholder commitment foundation" upon which the pillars stand. This foundation is defined as stakeholder commitment to green product development and green strategic business strategy. The pillars include management pre-requisites and principles that should be adapted to promote Green Product Development. Examples of the pillars include "environmental management systems", "life cycle assessment", "product and process planning" and "strategic management".

Brones et al. (2014) offer an alternative approach to integration of eco-design into NPD where project management is identified as the missing link between the technicalities (the tools and methods) and strategic management of the business (Brones et al., 2014). This approach uses an “**eco-design transitional framework**” which specifies a number of eco-design transitional principles across the strategic, tactical and operational aspects of the business (Brones et al., 2017). Unlike other eco-design frameworks, the principles identify sociological and psychological approaches in order to influence change in eco-design improvement cycles. This is represented as a maturing of eco-design management within the business.

The **IRI Sustainability Maturity Model** has a focus on the activities performed at the front end of NPD that support technology research (Jefferson Hynds et al., 2014). Similarly to the EcoM2 model, the implementation of the framework progresses through a matrix of maturity levels and practices where the company can benchmark their performance, and address areas of weakness by improving on eco-design practices thus allowing them to reach a higher level of eco-design performance.

Each of these frameworks has a differing approach but there are three common weaknesses. The first is that they lack the up-front consideration of NPD frameworks, or a body of knowledge that relates to NPD best practice. They do identify elements of NPD (e.g. NPD Process); however, each framework orginates from the eco-design body of knowledge and either attempts to fit elements of NPD into its framework (and establish best practice around this) (Figure 18) or ignores these NPD elements. In other words, the existing frameworks do not consider the integration of eco-design practices into existing NPD processes, and how this can be optimised.

FIGURE 18 CONCEPTUAL REPRESENTATION OF THE FOUNDATION OF ECO-DESIGN FRAMEWORKS

The second weakness is a lack of assessment and focus on which specific management practices can provide the greatest potential for environmental improvement for the product category or industry sector in which the organisation is situated. For example, an organisation could apply most of the eco-design management practices defined in the EcoM2 framework but not address practice 10023 “Implement the Life Cycle Thinking into the product development and related process” (Pigosso et al., 2014). If the greatest environmental impacts occur in the use phase of the product, the company would be failing to address the major environmental impacts associated with the product category.

Lastly, the eco-design body of knowledge distinguishes levels of eco-design which require different types of processes and practices within product development. The theory assumes these levels to be a linear progression from one level to the next. In contrast, it appears that in practice companies do not always require sequential implementation and instead implement eco-design based on new product development opportunity and internal capabilities. There are many case examples (Coelho & McLaren, 2013; Frame, Gordon, & Mortimer, 2010; Hume & Mortimer, 2011; Reim, Lenka, Frishammar, & Parida, 2017; Roy, 2000) of companies who have implemented eco-design at higher levels without the need to progress through each level sequentially.

2.2.3 Eco-design product strategies

An NPD organization can implement different eco-design product strategies that define what type of environmental products they will develop, how they can make those appeal to customers and what production and operational changes might be needed to enable this (Mulder, 2017). There are tools and techniques available to engineers and designers (e.g. the eco-design strategy wheel in Appendix D) that assist in selecting an appropriate eco-design strategy (Boeijen et al., 2013). Three of the most commonly used eco-design product strategies are discussed here: Classes of Eco-design, Circular Economy, Disruptive Design.

Classes of Eco- Design

Eco-design can be performed in a company using different scopes that vary from incremental improvement of an existing product through to complete re-envisioning of a service. Research in this area has framed these different scopes as levels representing strategic and operational practices at various degrees of sophistication (as discussed in section 2.2.2). The "Levels of Eco-Design Model" was first established by Ab Stevels (1999) and was influenced by the "Substitution of Resources Model" (Mansson, 1993) and by ongoing environmental research for the consumer electronics industry (Stevels, 1999). Stevels (1999) concluded that a business could make environmental improvements to a product by either modifying an existing product's attributes, re-developing the product with environmental considerations at the forefront, or widening the boundaries of the product system to include systems that it interacts with. There are some variations of this model that follow a similar classification including the "Eco-Design Strategy

Model" (Brezet & V. Hemel, 1997; Roy, 2016), and the four types of environmentally friendly product service development of (Zbicinski, 2006).

The development and refinement of new concepts, such as the Circular Economy, has led to refining of these levels (Nidumolu et al., 2009). However, they all still follow a linear progression where each subsequent eco-design level has the potential to achieve a better environmental performance of a product. As discussed previously, this assumption about a linear progression can be challenged. Therefore, for the purposes of this research, the adapted model in Figure 19 is used, where the levels are redefined as 'classes' of eco-design without an assumption of a linear progression from one class to another class.

FIGURE 19 FOUR CLASSES OF ECO-DESIGN (DERIVED FROM BREZET AND V. HEMEL (1997)

The **product improvement** class is where small incremental improvements are made to existing products to improve their environmental performance. Producers investigate their current products, quantify the environmental impacts and take steps to mitigate those impacts. This class and its application are well established in product development, and producers regularly use advanced tools such as Life Cycle Assessment to quantify the environmental impacts of their products from raw material extraction through to end-of-life. This enables the producer to identify alternatives that will improve the product's environmental performance.

In the **redesign and functional innovation** class, a product is redesigned with environmental considerations at the forefront of the design process. Decisions made in the early design phase of a new product's development can be a significant contributor to its life cycle-based environmental impacts (Dewulf, Willems, & Duflou, 2006). Therefore, a producer applying this type of eco-design has a greater opportunity to understand the wider implications of those decisions and change the proposed product design accordingly. Often the process is guided by consideration of how the user interacts with the product and the aim is to find new ways to deliver the same function but with reduced environmental impact.

The **system innovation** class widens the boundaries of the product to the system(s) that it interacts with, allowing producers to address optimisation of other integrated products and systems normally not considered in the product design process. This is particularly important for products that are considered “active”. An “active” product typically has a dominant use stage, typically involving energy consumption, and Jolliet et al. (2015) recommend that eco-design efforts should generally be focused on reducing the energy during the use phase of these types of products. For example, one study showed that a shower product’s use-phase dominates the environmental performance based on use of energy to heat the water and use of the water itself (Institut Bauen und Umwelt e.V, 2011). This encouraged the producer (Hansgrohe) to consider the supply and waste systems that interacted with their product. Ultimately this led to innovations in new large scale systems that focused on recovering the heat and water from commercial buildings (such as hotels and apartments) (Hansgrohe, n.d.).

The **business model** class is concerned with producers rethinking the linear economic model where products are produced, distributed and sold to customers, who use them for a limited time and then dispose of them. This end-of-life is often built into products and allows this linear process to be repeated – thus the same (or a similar) product can be manufactured and sold to a returning customer. An organisation that can deliver the same product value but as a service or new platform rather than the described linear model, can often realise the greatest environmental improvement. This is the type of thinking encapsulated in the circular economy concept, which suggests that industrial economic models can reduce waste and pollutants from a product’s life cycle by changing from the current linear model “extract, make, dispose” to a closed loop system that recovers and reuses the materials (Bocken, de Pauw, Bakker, & van der Grinten, 2016). Implementing this approach would require an organisational shift and radical redesign of material use, production processes and the supply chain.

Circular Economy

The Circular Economy is an eco-design concept that focuses on increasing the environmental and economic value of a product by prolonging its life and then returning the materials used back into the production system where they can be reused (Ellen MacArthur Foundation, 2017). One popular example is the case of Philips ‘Pay-per-lux’ solution in which Philips retains responsibility for maintaining the hardware over a contracted period while the customer pays for the energy used. This allows Philips to recover and reuse the materials and parts and, as a result, reduces production costs and environmental impacts of the lamps (Roy, 2016). Desso carpets is another example of an industry applying the Circular Economy approach. They retain responsibility for maintaining the carpets while the customer pays for the use of them. In order to easily maintain them, Desso supplies the carpet in tiled form, allowing the customer to remove a damaged carpet tile and replace it with a new one. The tiles which are recovered during use and at the end of the contract are recycled in the production of new carpet tiles (Desso, 2016). The economic benefits of a Circular Economy business model within product development are well established (Shahbazi & Jönbrink, 2020), however, Evrard, Rejeb, Zwolinski, and Brissaud (2021) suggest this may not be the case for products that change with fashion. For example, consumers may be less accepting of older, refurbished products that are no longer on trend. There is also a need for more research on the integration of Circular Economy into existing NPD practice (Shahbazi & Jönbrink, 2020). For example, there are few Circular Economy tools that can assist designers and engineers in the early design stages of product development.

Disruptive Design

Disruptive Design originates from the industrial product design field and is the idea that many environmental problems related to products and systems can be addressed by taking a life cycle approach and creating elegant "design solutions" to address those problems (Acaroglu, 2017). It is completely unrelated to the popularised term 'Disruptive Innovation' and in many cases has contrasting objectives. For example, a Disruptive Innovation might set out to convert non-consumers into consumers by offering a parallel product or platform (sometimes a new or less established technology), often at the lower end of a market, allowing consumers access to a product or service that was once out of their price range. Disruptive Design instead attempts to reduce or remove consumption by redesigning existing products to be more efficient in their use, and last longer, while identifying ways of moving the function of the product to a service (such as in Circular Economy). The disruptive design methodology is founded in systems thinking, design thinking and critical pedagogy and is orientated to drive sustainable solutions to existing environmental problems (Eggink, 2016). It is applied in well-known product development organizations (Google, IDEO) and through workshops has facilitated co-creation of toolkits for businesses, educators and government organizations (Unschool, 2020).

2.2.4 Design for Sustainable Behaviour

As previously discussed, consumers play a critical role in the NPD process. Consumers and their behaviours will influence design decisions surrounding the function, form, aesthetics and many other product characteristics. Prior studies have indicated that significantly more environmental improvements can be made if consumers' behaviour and the way they interact with the product are also considered in the design phase, with changes then made to the product that facilitate consumers to adopt pro-environmental behaviours (Kuo, Tseng, Lin, Wang, & Lee, 2018). This area of research is known as Design for Sustainable Behaviour (DfSB) and is based on the principle that product developers can actively influence product-user interactions through psychological triggers built into the product design (Tromp, Hekkert, & Verbeek, 2011).

Household water and energy use is often a focus of DfSB studies. Brick et al. (2017) conducted a study which focused on consumer products and a reduction in water and energy use. The study showed that pro-environmental behaviour could be predicted based on how the consumer identifies in a social context (e.g. liberal, Green Party, vegetarian) (Brick, Sherman, & Kim, 2017). When a consumer does not wish to be seen as an environmentalist, they may avoid pro-environmental behaviours such as not switching to energy efficient lightbulb when it is paired with an environmental sticker on the packaging. Consumers will often value passive-eco products rather than active products that reduce their consumption in it's the products use (Aibar-Guzmán & Somohano-Rodríguez, 2021) however it the psychological factors of this phenomenon are not well understood (Maccioni et al., 2019). In a study of bathing under radically different methods to showering, users were required to bath under various radical prototypes and then surveyed on their psychological perspectives (Kuijer, De Jong, & Van Eijk, 2013). The approach has similar characteristics of human centred design (where the user becomes a part of the design process), however the NPD process or product innovation was not considered in the study and therefore limits the application in a commercial context.

De Mederios et al. (2018) analysed existing DfSB frameworks qualitatively through expert opinions (including psychologists and engineers) to create a decision support diagram for the development of goods and services (De Medeiros, Da Rocha, & Ribeiro, 2018). The decision support is broken down into a number of high-level stages from User Analysis to Control and Strategies. While the experts who analysed the model did include some engineering and design practitioners, psychological frameworks dominated the final decision support diagram. This may limit its practical application in a traditional product development context since NPD teams may not have expertise in understanding these behavioural psychology aspects and how they relate to design decisions.

A similar study was conducted by Lilley (2009) to understand the process and application of eco-design strategies in manufacturing companies. Expert opinion was obtained through questionnaires with participants ranging from industrial designers to engineers working in the product design field. A useful output of the study was identification of a number of attributes (Table 6) for 'behaviour change devices' that can help developers to form appropriate design specifications when developing eco-products based on DfSB intervention strategies. However, Lilley (2009) argued that many manufacturing companies would likely exclude this decision process at the pre-development phase. The argument was that most manufacturers would only be willing to include DfSB intervention strategies when there was public pressure to do so. This could be in the form of social norms or legislation that defines negative perceptions of a product and its type of use. In addition, if the DfSB strategy requires reducing the use of the product then factors such as economic growth and profit can be another barrier to adoption. As an example, mobile phone profits depend on the increased usage of communication services - advocating less usage could therefore be detrimental to the company business model.

TABLE 6 DESIGN SPECIFICATIONS WHEN DEVELOPING DFSB PRODUCTS, PAGE 706 (LILLEY, 2009)

1	Make resource use and resulting waste visible,
2	Be coupled with eco-efficiency improvements
3	Provide tangible incentives and measurable outcomes
4	Use predominately positive, rather than negative, reinforcements
5	Avoid competing with other values
6	Provide feedback in real-time
7	Ensure reinforcements are varied in frequency and modality
8	Adjust to respond to changes in user behaviour
9	Not compete with, but be supported by, and support, the context of use
10	Be, as far as possible, ethical in their intent and predicated outcomes

Kuo et al (2018) propose the relationship between how a consumer interacts with a product and its environmental impact is a significant gap in current eco-design literature. The study presented an experiment where consumers were digitally monitored interacting with varying active products under different controls in a factorial experiment (Kuo et al., 2018). This was followed by a quantitative questionnaire. The results indicated that pro-environmental behaviour could be driven based on design changes by providing 'eco-feedback' to the user. While useful insights were obtained that could hypothetically drive design changes, the study does not make any recommendations on how these could be integrated into the product development process and instead chooses to focus on demographic differences in eco-performance of the experiment – information which is potentially less relevant to designers.

Bhamra, Lilley, and Tang (2011) is one of the most highly referenced studies on DfSB. This study highlights strategies (Table 7) that can be adopted by designers and draws on case studies as reference points. These strategies are then critiqued by designers on their appropriateness and effectiveness. However, the strategies only provide a starting point with no investigation into the operational activities that may follow or how these strategies can be practically integrated into the product development process and other innovation elements. Bhamra et al. (2011) propose that further research is needed to identify the effectiveness of the strategies from a theoretical and practical dimension. In addition, they propose that many of the strategies which require a coercive approach (i.e., Eco-Steer, Eco-Technical) may present ethical dilemmas, and developers may be unwilling to adopt such strategies. They conclude that behaviour-changing devices need to be prototyped and user-tested to better understand their effectiveness and explore ethical considerations.

TABLE 7 DESIGN INTERVENTION STRATEGIES (BHAMRA ET AL., 2011)

	Aim	Method
Eco-Information – design-oriented education	Make consumables visible, understandable and accessible to inspire consumers to reflect upon their use of resources.	1. Product expresses the presence and consumption of resources e.g., water, energy etc. 2. Product encourages the user to interact with resource use.
Eco-Choice – design-oriented empowerment	Encourage consumers to think about their use behaviour and to take responsibility of theirs actions through providing consumers with options.	Users have a choice, and the product enables sustainable use to take place.
Eco-feedback – design-oriented links to environmentally or socially responsible action	Inform users clearly about what they are doing and to facilitate consumers to make environmentally and socially responsible decisions through offering real-time feedback.	The product provides tangible aural, visual, or tactile signs as reminders to inform users of resource use.
Eco-spur – design-oriented rewarding incentive and penalty	Inspire users to explore more sustainable usage through providing rewordings to 'prompt' good behaviour or penalties to 'punish' unsustainable usage.	The product shows the user the consequences of their actions through 'rewarding incentives' and 'penalties'.
Eco-steer – design-oriented affordances and constraints	Facilitate users to adopt more environmentally or socially desirable use habits through the prescriptions and/or constraints of use embedded in the product design.	The product contains affordances and constraints which encourage users to adopt more sustainable use habits or reform existing unsustainable habits.
Eco-technical intervention – design-oriented technical intervention	Restrain existing use habits and to persuade or control user behaviour automatically by design combined with advanced technology.	The product utilises advanced technology to persuade or control user behaviour automatically.
Clever design	Automatically act environmentally or socially without raising awareness or changing user behaviour purely through innovative product design.	The design solution decreases environmental impacts without changing the user's behaviour.

Boks (2015) recommended that DfSB research should be used to improve reliability in Life Cycle Assessment of products with a dominant use phase. Analysing previous case studies, Daae & Boks (2015) highlight that due to resource limitations during the LCA process, companies only complete small-scale user study experiments. These experiments largely yield statistically unreliable data due to the variations in populations using the studied product (Daae & Boks, 2015).

However, the results still may contribute information that led to more valid assumptions about the use phase in the LCA.

Table 8 provides a summary of the gaps and key findings of the literature on DfSB. There is a lack of real, valid and reliable data that would allow greater understanding of behaviours that can be changed to improve environmental outcomes (Kuo et al., 2018). The majority of DfSB studies and reviews have been done outside of an industry-based context, and this could be why many fail to integrate findings or eco-strategies into existing product development practices, often concluding with behavioural psychology results that do not necessarily correspond to a recommended design or process change. While some of the insights can be used to improve the value proposition of products, there are few examples of integrating DfSB into the entire NPD process from 'clever design strategy' and ideas, through to operation activities that lead to the design changes and a commercially viable product.

TABLE 8 DFSB LITERATURE SUMMARY

Insights	Product strategy and marketing insights dominate the DfSB Literature
Unit of Study	There has been a focus on how eco-strategies impact a consumer, rather than how the strategy can be integrated into the process
Study Type	Studies have been predominatly qualatative
Tools	There is limited output of tools or techniques that guide NPD practitioners on implemented DfSB product strategies
NPD	Very few studies consider best practice NPD

2.2.3 Popular Eco-Tools

Eco-design tools provide systematic ways of assessing and improving a product's environmental performance at an operational level of product development. Three types are discussed here: checklists, ranking and analytical tools.

Checklists tools are similar to ranking tools in that they can generally be used at any stage of the product development process. **Checklist tools** provide support in the form of many generalised questions that step the product developer through various stages of the life cycle of the product from production and supply (e.g., “How much energy is required to transport the components and materials?”) to recovery and disposal (e.g., “Can the materials/parts be detached quickly?”). These questions are intended to prompt a review of the opportunities to improve the life cycle-based impacts of the product.

Typically **ranking tools** are a quantitative system to assess alternative materials, parts or product concepts in the design process (Baumann et al., 2002). The ranking of an attribute could score the impact of each material (0-10), which is then multiplied by the amount of material used, and these attributes are added together for the concept or intended product (Baumann et al., 2002). Two ranking tools that appear regularly in literature are the MET matrix and the Eco-design strategy wheel. The MET matrix (Figure 20) shows the material flows (M), energy use (E) and emissions of toxic substances (T) for each stage of a product’s life. The completed matrix is intended to provide an overview of the environmental impacts of a product, component or concept and highlight the hotspots with respect to their life cycle (Zbicinski, 2006).

	M - Materials	E - Energy use	T - Waste/ Toxic emissions
Production and supply of all materials and components			
Manufacturing: in-house production			
Distribution			
Use: operation and servicing			
End-of-life system: recovery and disposal			

FIGURE 20 EXAMPLE OF MET MATRIX (ZBICINSKI, 2006)

The eco-design strategy wheel (often also referred to as the "eco spider diagram" or "eco-compass") provides a visual representation of the fields of interest in eco design and is typically used to assess the environmental performance of existing products to show where improvements could be made (an example is provided in Appendix A).

It can be argued that many of these tools are very subjective and rarely offer concrete solutions (Devanathan et al., 2010), since they rely too heavily on existing environmental knowledge of the practitioner for them to be effective (Devanathan et al., 2010). The existing guides (Boeijen et al., 2013; J. C. Brezet & C. v. Hemel, 1997; Zbicinski, 2006) on checklists and ranking tools provide a more conceptual overview of their application but lack good examples of their successful use and industry outcomes.

Analytical tools are considered to be more comprehensive and quantitative in their evaluation and measurement of the environmental performance of products (Baumann et al., 2002). These tools include carbon or water foot-printing, Life Cycle Assessment (LCA), risk assessment (Design

Cost Assessment) and total cost tools (Life Cycle Costing). The most popular and widely applied analytical eco-tool is LCA.

LCA requires upfront detailed information, which could be the design specifications of various parts, the materials that will be used, the processing and manufacturing methods of those parts, and what happens to the product at the end of its life (Devanathan et al., 2010). Since much of this information is only known in the later stages of the product development process, it makes LCA limited in its usefulness in early product development decision support. Despite this limitation, there are numerous reports of successful eco-design cases where LCA has been applied and as a result a new or better environmental product has emerged. Some examples are provided in Table 9.

TABLE 9 LCA EXAMPLES OF SUCCESSFUL ECO-DESIGN CASES

Example	Outcome
Steam Whistle Brewing (Steam Whistle, 2013)	Increasing recyclability (factor of 3) of glass used in bottle by increasing glass content by 30%.
Yealands Winery (Garnevska, McLaren, & Hiroki, 2014)	Reduced the greenhouse gas emissions of the glass wine bottle by 54% by substituting it for PET plastic.
Toyota Prius (Toyota, 2009)	Substitution of parts for lightweight plastics (6kg) to reduce weight and increase fuel economy. Battery banks made 85% recyclable and 95% recoverable.
Nokia Cell Phones (Roy, 2016)	LCA showed that significant amount of energy (relative to the phones life cycle based environmental impacts) was used by phone chargers if left on standby resulting in development of more efficient chargers.
Apple iPhone 5S (Roy, 2016)	Learning from previous LCA work by Nokia and improving their chargers, Apple's LCA work showed that 83% of emissions was due to materials and manufacturing and as a result of the study they focused their efforts on greening the supply chain and switching to renewable energy in production.
Bosch Washing Machine (Roy, 2016)	LCA studies led to development of machine that used 20% less energy and 35% less water.
Unilever Tablet Detergents (Unilever, 2000)	Using LCA in the design process has reduced detergent consumption through controlling the dosage required while increasing the biodegradable potential of the organics used and reducing the packaging requirement for the product.

2.3 Integration of NPD and eco-design

Companies that have attempted to develop eco-products have had mixed experiences (Berchicci & Bodewes, 2005). In search of reasons for the failure of eco-design projects, a state-of-the-art review by Baumann et al. (2002) identified that many eco-design studies that focus on integration of environmental issues into product development omitted an explicit link to the mainstream NPD body of knowledge. Some of the most highly referenced eco-design frameworks from section 2.2.2 (Brones et al., 2017; Rodrigues, Pigosso, & McAloone, 2017) maintain this disconnect.

There are a few studies which attempt to address the disconnect. Boks and Wever (2007) argued that it was critical to work at the front-end of the NPD process; however, the findings showed that eco-design had largely ignored relevant front-end NPD elements or activities (i.e., portfolio management, strategic planning, idea selection). A recent study concluded that there were many front-end tools available for NPD, but none that systematically yield sustainable- product ideas. Such tools would assist in generating new eco-ideas that would ultimately define the function that will be fulfilled. Boks, Diehl, and Wever (2020) suggest that future eco-design research should be focused on the appropriateness and effectiveness of tools and methods that assist in generation of ideas in the fuzzy front end that fulfil a green function (denoted by the question mark in Figure 21).

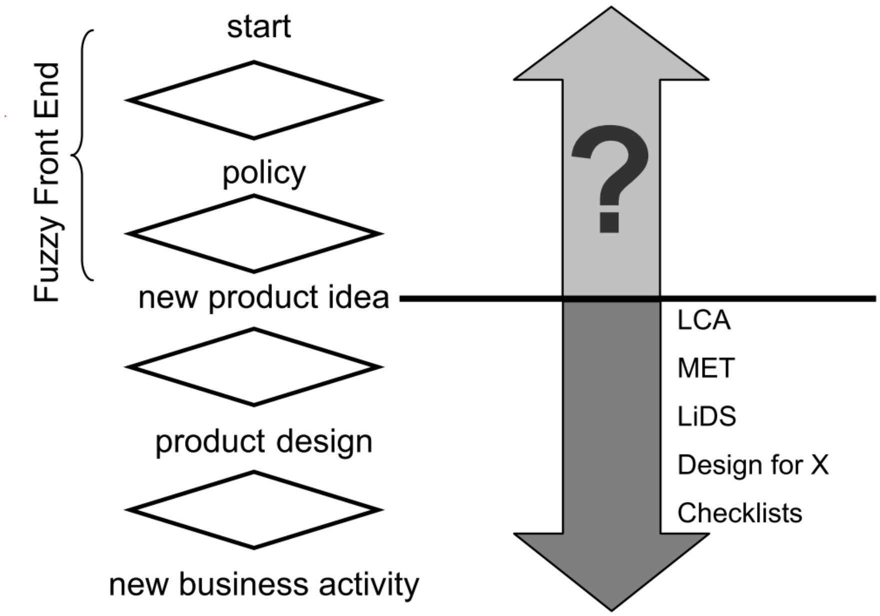

FIGURE 21 ECO-DESIGN TOOLS GAP WITHIN FRONT END OF NPD PROCESS (BOKS ET AL., 2020)

A related study by Hassi and Wever (2010) categorized products into active and passive (see Section 2.4) and argued that the FFE is more important for active products. As decisions made about function and use of a product are often made at the front-end of an NPD process, for eco-design to lower the environmental impact of these products it too must be considered at the same point in the NPD process (i.e. during idea generation and selection) (Hassi & Wever, 2010).

Dewulf (2013) conducted a review of the NDP and eco-design literature to better understand how sustainable design considerations can be systematically integrated into NPD. A focus was to understand what determines best practice for integrating eco-design. One of the key success factors identified was to tackle sustainability problems at higher system levels. Dewulf (2013) suggest that organizations typically use existing products as a starting point rather than take a wider systems-based approach to developing eco-solutions. A wider systems-based approach would involve linking the four levels (classes) of eco-design (as previously discussed) with both the strategic ("What eco-products should we develop?") and operational ("How should we develop these eco-products?") activities of the organization. However, there is a significant lack of tools and techniques to help companies with this approach (Dewulf, 2013). In addition, Jugend, Pinheiro, Luiz, Junior, and Cauchick-Miguel (2019) argue that there are a number of barriers commonly found in organisations that prevent the available eco-tools and techniques from being adopted and integrated. These include:

(i) No clear environmental benefit

(ii) Not yet required by legislation

(iii) Not yet required by customers

(iv) Commercial disadvantages

(v) Conflict with product requirements

(vi) No innovation opportunities

(vii) No alternative solutions available

(viii) Fruitless investment

(ix) Insufficient time

(x) Insufficient knowledge.

These barriers are acknowledged in recent eco-design reviews (Malte & Manuel, 2021; Singh & Sarkar, 2019), highlighting insufficient time and knowledge as a key barrier to integration.

Jugend et al. (2019) suggest that these barriers are closely linked with the organisational culture as often eco-design principles are not seen as the responsibility of sector or employees.

A study conducted by Berchicci and Bodewes (2005) found that the implications of eco-design with regards to product development and market performance were not well understood. Their proposed model (Figure 22) defines three operational components to support integration of NPD and eco-design: Design Specifications, Project Team Coordination and Management Support.

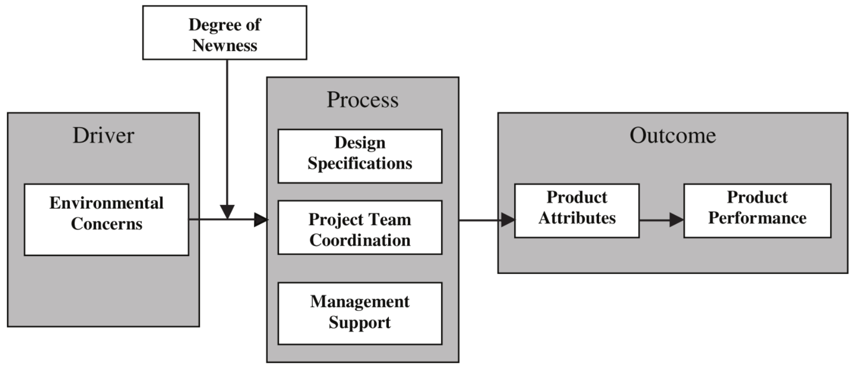

FIGURE 22 SUPPORTING NPD PROCESS COMPONENTS FOR INTEGRATION OF ECO-DESIGN (BERCHICCI & BODEWES, 2005)

In this model, when defining design specifications, environmental attributes are seen as distinct from traditional specifications (i.e., price, quality). Traditionally, consumer perception of ‘what is green’ is based on materials or different waste management options. It is traditionally those perceptions that make their way into design specifications (Chialin, 2001). However, environmental attributes are often perceived differently by various stakeholders – aspects thought to be important by a product development team are perhaps not at all important to consumers (Veryzer Jr, 1998). Berchicci and Bodewes (2005) state that clearly defined environmental requirements need to be incorporated without the risk of market rejection. If consumer perception does not match what the development team believe are required environmental design specifications, it’s likely the product will not be as successful.

Team Coordination is considered another success factor for integration. NPD best practice states that collaboration and communication within teams is important; however, with eco-design integration, this is not enough. Knowledge resources and interpretative structures or techniques (i.e. Life Cycle Thinking) must be embedded in the project team to align development efforts Berchicci and Bodewes (2005). This can lead to eco-design competencies within the team allowing the organisation to develop the capability to enact those competencies (as discussed in section 2.1.2).

Finally, management support is crucial within the NPD process. This is consistent with NPD literature where Cooper (2018) defines 'top management support and leading the innovation effector at every opportunity' as one of the drivers of NPD success. Berchicci and Bodewes (2005) suggest that integration of environmental aspects into the NPD process creates uncertainty or risk that requires strong management support to promote project continuation. This finding is consistent with other eco-design integration studies where management support for eco-projects was a key success factor (Tingström & Kth, 2007). This study showed that management support was also responsible for motivating staff and creating a positive eco-design culture.

2.4 Shower and tapware products

This section discusses the relevant literature relating to shower and tapware products. To explore the links between these products, and their environmental impacts, it is necessary to identify the relevant eco-design sub-topics. Since shower and tapware products consume water and energy in their use it falls within the eco-design sub-topic of 'Active products'.

In addition, environmental issues in a wider context (such as contribution of these category of products have on global carbon emissions) are reviewed to identify the significance of the environmental impact and what eco-design strategies have been developed for the industry to mitigate these.

2.4.1 Active products

An active product consumes 'something' (often energy) in its use (Jolliet et al., 2015). Examples of active products include mobile phones, coffee machines, TVs, fridges and most kitchen appliances. In contrast, a passive product typically does not consume anything while being used although it could be argued that there is some consumption in order to maintain some of these types of products (e.g., cleaning products). Examples of passive products include desks, chairs, and cooking utensils.

With respect to a passive product's environmental impacts, the eco-design efforts could focus on several of the life cycle stages such as extraction, production, transport and end-of-life, as this is typically where most environmental improvements can be made for such a product. However, an active product will typically have a dominant use stage with respect to environmental impacts. The magnitude of these impacts may be directly related to the user's behaviour in relation to the product or it may be determined by the wider system in which the product is used. An example of the former is leaving lights on which don't have a movement sensor. An example of the latter is the domestic fan heater: while a producer may be able to design the heater to be more efficient, without considering the wider system (i.e., the home and its insulation where the heater is being used), the main source of the environmental hotspot remains unaddressed. In order to address the environmental impacts of an active product's use phase, it may be important to consider this wider system and behaviours of users in varying situations, aiming to raise the awareness of users through design intervention strategies (such as DfSB) (Bhamra et al., 2011; Renström, 2013).

2.4.2 Environmental significance of shower and tapware products

Many active products today have a significant impact on the environment, and one such group of consumer products is showers and taps. There are two main environmental issues associated with showers and taps: water use and carbon emissions (Shahmohammadi, Steinmann, King, Hendrickx, & Huijbregts, 2019).

Water

Water scarcity is a global problem. With a rising population, more resource intensive consumption patterns, coupled with pollution, consumer waste and climate change factors, sustainable freshwater supply has become a global concern (Gleick, 2014; McGlade, 2012). However, as illustrated in Table 10, water availability, use and distribution (agriculture, industrial, municipal) can vary greatly between countries.

TABLE 10 WATER AVAILABILITY COMPARISON

	New Zealand	Canada	Australia	United States	China	UK
Availability (million litres per person per year)	145	82	22	9	2	2
Water Used Range* (million litres per person per year)	1.1 and 1.8	1.3 and 2.3	2.3 and 2.8	1.5 and 2.8	0.2 and 1.1	0.2 and 1.2
Domestic Use	21%	20%	16%	13%	12%	57%
Agriculture & Industrial Use	79%	80%	84%	87%	88%	43%

Availability & Range and Proportion (Gleick, 2014)
Country Comparison & Range (Water Footprint Network, 2016)
New Zealand Water Consumption and Use (Ministry for the Environment, 2016)

Note: Water use range is aggregate of above sources

Countries that appear to have good water availability can still experience water scarcity. This is often due to infrastructure limitations (Rijsberman, 2006) or regional variations in availability. For example, New Zealand is ranked fourth in the world for freshwater availability per capita, yet some regions still experience water scarcity due to regional variations in rainfall and population density (NIWA, 2017). For example, the Kapiti Coast region regularly experiences water scarcity, often placing water restrictions on certain areas, and banning irrigation systems to ensure freshwater is available for other domestic activities (Kapiti Coast District Council, 2014). As well as freshwater quantity, freshwater quality may be degraded and also contribute to water scarcity (Pereira, Cordery, & Iacovides, 2009). By drawing on a water supply that is already stressed it can cause the rate of filtration of contaminants to slow, ultimately lowering the quantity of the water that is supplied. This relationship is due to the rate of catchment filtration and supply compared with what the pre-treatment facility is capable of performing.

Due to concerns over water use, many governments have undertaken studies to better understand water use for different purposes in households (Table 11).

TABLE 11 COMPONENT WATER USE BREAKDOWN FOR DOMESTIC HOUSEHOLDS

(Litres per person per day)

	[1]	[2]	[3]	[4]
Region	Kapiti, New Zealand	Perth, Australia	Queensland, Australia	Melbourne, Australia
Sample Size (Households)	12	120	100	151
Shower	45.3 (28%)	51 (34%)	42.7 (31%)	49.1 (29%)
Tap	24.3 (15%)	24 (16%)	27.5 (20%)	27.0 (16%)
Clothes Washer	41.8 (26%)	42 (28%)	31 (22%)	40.4 (24%)
Toilet	35.5 (22%)	33 (22%)	23.7 (17%)	30.4 (18%)
Bathtub	3.1 (2%)	Included in Shower	1.8 (1%)	3.2 (2%)
Dishwasher	2.7 (2%)		2.5 (2%)	2.7 (2%)
Leak	6.7 (4%)		9 (7%)	5.9 (9%)
Outdoor Use	44.2 (% Removed)		7 (% Removed)	168.7 (% Removed)
Miscellaneous		18 (% Removed)		
Total (Excluding Outdoor and Misc)	159.4	150	138.2	158.7

[1] (Henrich, 2009), [2] (Loh & Coghlan, 2003) *Single Resident Results, [3] (Beal, Stewart, Huang, & Rey, 2011), [4] (Roberts, 2005)

All the studies identify showers to be the most significant contributor to water use in the home. This breakdown is consistent with other reports across a number of different regions and countries (Canada, Finland, Portugal and China) (Lallana et al., 2001; Lu, 2007).

Energy

Household energy use is considered one of the most significant environmental issues (Tukker et al., 2008). "Household Carbon Emissions" (HCE) include all the carbon emissions associated with a domestic household use including lighting, appliance use and heating. Governments have promoted reduced energy use in the home by funding campaigns to encourage consumers to use more efficient products. HCE can vary greatly between countries. New Zealand is at the lower end of the scale, producing approximately 1.7 tons CO_2eq per capita each year (NERI, 2006); in Australia this value is as high as 7 tons CO_2eq per capita each year (McGee, 2013). One of the most significant contributors to HCE is hot water heating which accounts for 44% of total HCE in

New Zealand (BRANZ, 2006). In a domestic dwelling, showers and taps are the primary method for delivering hot water to the users.

A comparison of different New Zealand household appliances and their electricity use is shown in Table 12. This demonstrates the significant energy requirements and resulting environmental impacts to that of other consumer products.

TABLE 12 ENERGY USE COMPARISON BY PRODUCT(CAMILLERI ET AL., 2006; HENRICH, 2009)

Product	Average kWh/year
Shower	4640
Dishwasher	107
Dryer	119
Electric Jug	152
Microwave	62
Washing Machine	63
Stovetop	497
Refrigerator	367

2.4.3 Eco-Design in the shower and tapware industry

Although water and energy use for showers and tapware might appear trivial per use, over the entire life of the product this use can accumulate to a significant portion of a household's environmental footprint, and dominate the product's life cycle based impacts (Institut Bauen und Umwelt e.V, 2011).

Governments and environmental groups have identified shower and tapware water use as an environmental issue (MFE, 2020), and as a result many leading shower and tapware manufacturers have developed products that reduce water (Grohe, 2020; Vokins, 2019). This is often accomplished through modifications to existing products such as flow restriction or varying the spray type. However, only a small number of niche products address both water and energy as environmental issues for shower and tapware products. These can be grouped using Bhamra et al. (2011) DfSB intervention strategies into: Eco-feedback, Eco-steer and Clever Design product categories.

Eco-feedback products and systems inform users about what they are doing and provide formative feedback that guides them to take actions with better environmental outcomes. Examples include:

- Aguardio: a stand-alone product that is installed in a shower cubical and uses sensors to detect when the shower is operating. Feedback is provided to the user via a display screen that advises the user of how long they have spent in the shower (Aguardio, 2019).
- Amphiro is installed in-between the shower hose and shower handset; the device provides real-time and trend analysis data which is sent via Bluetooth and accessible via smartphones (Amphiro, 2019).

Eco-steer are products which constrain users to a prescribed behaviour by modifying the design of the product or system. The most common example of shower and tapware technology that adopts this strategy is the auto-off timer. These are commonly found in public or commercial buildings where there is high usage. Typically products which have this control mechanism built into the design are rewarded through a star-rating – a scheme indented to inform consumers of the efficiency of a product (Standards New Zealand, 2003). These water rating schemes can be a significant driver for producers of shower and tapware products as new building sites often use this standard as a way to obtain green credentials (Modern Plant, 2015). There is a lack of data on the effectiveness of this strategy or consideration of rebound effects. As an example, it is possible that while the tap may auto switch off, it may not get the job done and the user must reactive the timer to finish washing which then leads to an oversupply of water. There is also a term known as “ghost activation” where the motion sensors which start the timer and flow of water are inadvertently activated (e.g. due to close proximity of a passer-by) (Koeller & Gauley, 2010).

An example of an eco-steer product is the AXOR Starck (Axor Design, 2020). This tap has an electronic valve that turns the device on and off, which can be programmed to open the valve for a specified duration. A motion sensor is used to active the tap.

Clever design involves designing a product that automatically improves the environmental impacts associated with the use phase without raising awareness or changing behaviour of the user. There are two distinct approaches for doing this in the shower and tapware industry. The first is heat recovery – recovering heat energy that might normally be wasted as used water goes down the drain, and transferring a portion of it back to the shower system. Despite the patenting of different designs and a number of start-ups for heat recovery systems, they have yet to become mainstream within the shower and tapware industry. These systems are reported to deliver 15% to 40% savings on energy (AIMC4, 2014); however, there is currently no standardised method for benchmarking heat recovery systems and, therefore, there is a lack of information on the sampling and methodology for these types of studies that would help validate the findings.

The second approach to clever design for shower and tapware systems is a closed-loop system where used shower water is recovered, filtered and recycled back into the shower system (Jallon, Blais-Ouellette, & Valette, 2015). Since no comprensive environmental assessment has been completed for such shower systems, it is difficult to conclude what, if any, environmental improvements these systems offer across the life cycle of the system. This is an important consideration since the system has many additional components and sub-systems that could contribute to the life cycle-based impacts of the system.

Examples of closed-loop systems include:

- HeatBack: uses copper cavities to transfer heat that would normally be lost down the drain to fresh incoming cold water (HeatBack, 2016).
- Oas Digital Recirculating Shower: recovers all water that would normally exit via the drain, and pumps it through a filtration process then sends its back to the shower mixer (Orbsys, 2020).

2.4.4 Existing eco-products and environmental claims

Recent studies have shown that eco-products are valued by consumers. (Aibar-Guzmán & Somohano-Rodríguez, 2021; Oh, Shin, Park, & Kim, 2020) presen empirical evidence that enviormental labels, claims and promotional material will positively impact sales of the related product. This could explain why almost every shower and tapware producer will make some environmental claims regarding their products. For example, most European companys have a page dedicated to how they are applying the circular economy concept by recovering their products at the end-of-life. In addition, some European and Australiasian companies will have a product range or specific spray technology built into their showers which are marketed primarly as a unique experience for the consumer – with a secondary benefit that less water is used per minute during use. This is based on the assumption that washing behaviours remain the same for every unique spray technology and therefore less water is consumed per showering event. Since this has not been validated, the products that use these unique sprays cannot be considered eco-designed products.

Table 13 provides the total number of products and eco-products for leading shower and tapware manufactueres worldwide. Those listed as having “high” sustainability claims are defined as those companys which have a dedicated page or website with considerable detail on how they apply eco-practices in the design and development of their products. Low claims are those companys who only provide a small paragraph in their company decription on how they value taking care of the environment, but lack detail on how they are applying this in their practice. Eco-products are defined as those that fit the product description provided in section 2.4.3.

TABLE 13 CURRENT SHOWER AND TAPWARE ECO-DESIGN PRODUCERS AND THEIR PRODUCT'S

Location of Company	Approximate number of products in portfolio	Eco- products (address use phase)	Eco-design products (Other stages of life cycle)	Sustainability claims
European	300	1	0	High
European	200	1	1	High
New Zealand	250	1	0	High
Australia	300	0	0	High
American	300	1	0	Low
American	300	1	0	Low
European	300	0	0	High
American	50	0	0	Low

Despite the significant environmental impact of shower and tapware products (section 2.4.2), there is a distinct lack of eco-products in the shower and tapware industry that are available for consumers.

2.5 Conclusions

Mainstream products in the shower and tapware industry do not actively address environmental considerations and there are only a few niche products which have been developed specifically to address the major environmental impacts of the use phase. The most common approach to address the use phase is flow restriction. Products which are designed to do so are marketed to consumers as both an economic and environmental savings. There is also some evidence that flow restriction may overstate the environmental savings since average quantity per use may increase (Koeller & Gauley, 2010). While there are some niche products which have attempted to directly address the use phase by management of incoming and wastewater systems (such as recirculation systems), they target only one environmental aspect, water use, and so do not address wider environmental impacts associated with heating of the water.

As shower and tapware products are active products, a manufacturer interested in improving the environmental footprint of these products must develop a better understanding of the life cycle-based impacts of these systems in order to inform New Product Development decisions. The eco-design body of knowledge provides strategic frameworks, continuous improvement methods and operational guidance for this purpose. However, there is a lack of alignment between NPD and eco-design which makes effective implementation of eco-design initiatives challenging. As an example, the information gathering search strategy (Section 2, Table 1) identified that eco-design researchers commonly fail to include consideration of best practice NPD practices have been established for decades. Instead, the studies often establish their own frameworks, models and tools with differing terminology (such as an equivalent formalised process for NPD) or highlight findings that had been previously established in existing NPD literature (such as the importance of a positive culture and climate on NPD). Additionally, the eco-design frameworks, models and tools which attempt to integrate product development environmental aspects into existing NPD processes are described as too broad and thus insufficient to provide guidance for NPD practitioners (Jefferson Hynds et al., 2014).

It is recognised that there is considerable variation in product and services across industries (Anderson, 2017) and therefore it is understandable that most literature on eco-design and NPD has focused on broad practices and principles across different innovation elements (strategy, process, tools) and how they can be applied across a range of product and service situations.

This means that, when investigating the effectiveness of a specific product development process (e.g., stage-gate) in different industries (e.g., showers and tapware, furniture), the literature focuses on generalizable practices and principles applicable to these two very different industries. Yet the products and users have very different characteristics and many of the activities that need to occur to take an eco-product from idea to launch can vary greatly, perhaps beyond what is generalizable across both industries. An alternative perspective is to assume that the success of eco-design is dependent upon its adaptation to different product categories or industries. This is particularly true for active products where specific eco-design methods, tools and techniques related to behavioural change (DfSB) are likely to be a major consideration compared with passive products (Kuo et al., 2018). As recommended by Boks et al. (2020), the integration of these tools into the NPD process should consider the Fuzzy Front End (FFE) of development. There is currently a lack of appropriate and effective methods and tools that can assist in eco-idea generation and evaluation for the FFE.

Shower and tapware products are active products with a dominant use phase and contribute significantly to household environmental impacts. Yet there is little evidence that the mainstream industry has taken a life cycle-based approach to design of its products as evidenced by the fact that the dominant stage of the life cycle (the use phase) has not been adequately addressed. Addressing this product category would mean that companies that produce shower and tapware products would offer circular systems and products that address the use phase (such as recirculation systems), yet these remain niche. This makes the industry a good case study to investigate how environmental life cycle-based approaches and DfSB techniques can be used to support eco-design and be integrated more effectively into NPD.

3 Methodology

3.1 Research Aim

The aim of this study was to contribute original knowledge to the body of knowledge that exists in relation to eco-design and its integration within New Product Development (NPD) of active consumer products, specifically in the shower and tapware industry. The literature review (Chapter 2) highlights the lack of research on the integration of eco-design and NPD with respect to active products. In the category of active products, shower and tapware products are one of the most significant contributors to household environmental impacts and yet these products have received little attention with respect to eco-design. Therefore, the aim of the study was defined as developing a better understanding on how to effectively integrate eco-design practices, principles and concepts into the NPD operational practices of manufacturers of these products.

The research utilised an embedded case study methodology where the primary unit of analysis was a shower and tapware manufacturer.

The researcher was inducted into the organisation's R&D team for the duration of the study and acted in the capacity of both a distance researcher (case study) and participant (embedded action case). The boundaries of the research are illustrated in Figure 23 for each one of three focus areas for the research: the company, the activities within NPD, and company project categories. The case company is involved in many types of projects; however, the primary focus on this research is eco-design projects. The research is concerned with the operational elements of eco-design (Project Management, Processes, Tools and Techniques) and how these elements drive success in eco-design. While strategic elements were not the primary focus of the research, some elements were considered later in the research when their importance became apparent (in particular, culture).

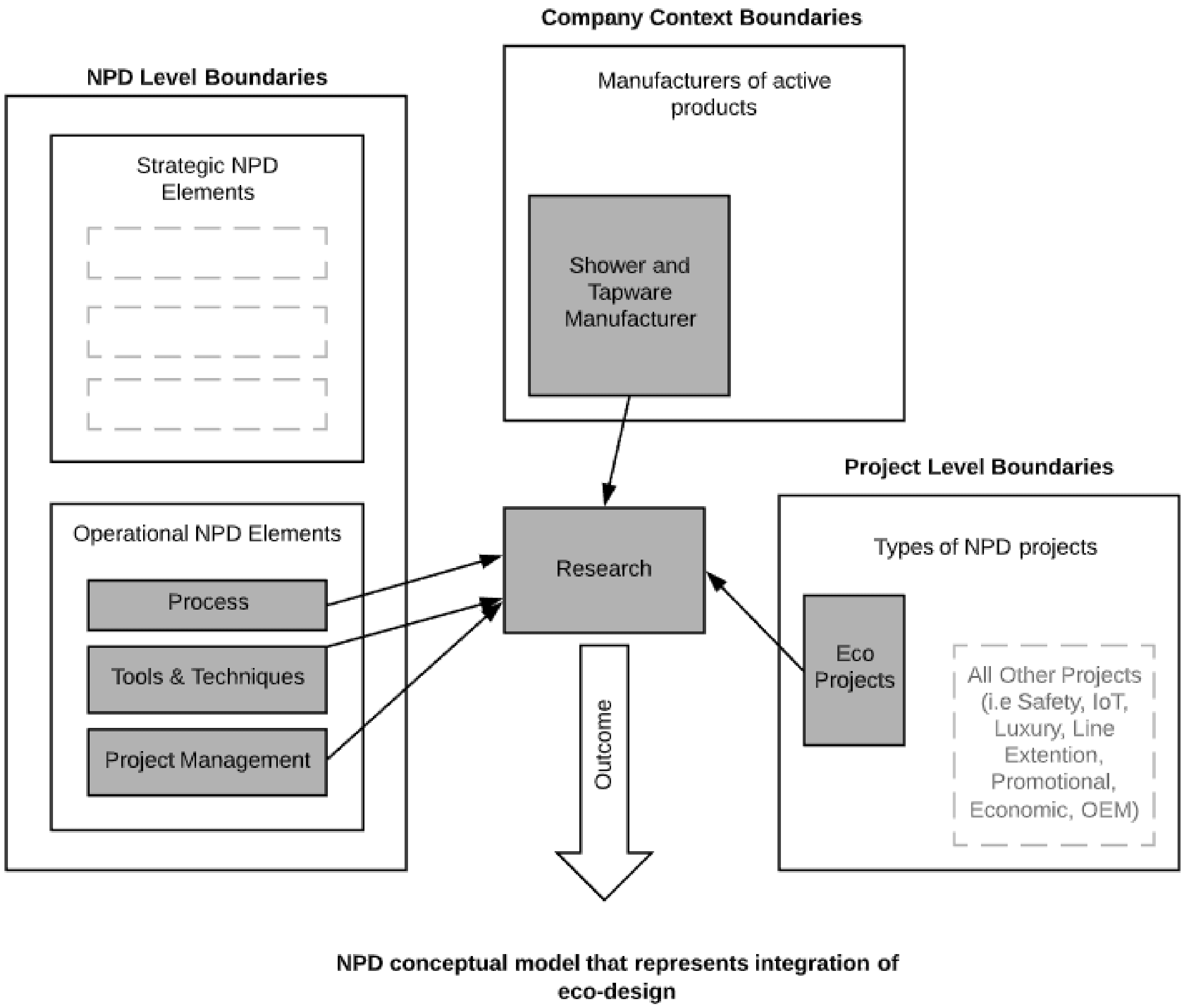

FIGURE 23 BOUNDARIES OF RESEARCH IN THE CONTEXT OF EACH OF THE COMPANY, NPD AND PROJECT

As introduced in Chapter 1, the primary research question was defined:

RQ1 When applied in the shower and tapware industry, are current eco-design frameworks, models and tools used within existing NPD frameworks and processes fit for purpose?

From the literature review, two additional research questions were defined.

RQ2: Can a more effective framework be developed and refined for a manufacturer of shower and tapware products to support integrating eco-design into their NPD operations?

It is recognised that the front end of NPD is one of the most important phases of NPD and that the environmental impacts associated with active products are often due to early development decisions (Section 2.3). Therefore, a more focused third research question was defined as:

RQ3: For manufacturers of shower and tapware products, how can environmental considerations be integrated into the front-end product development process of NPD?

To address these research questions, the study objectives were to:

1. Identify and compare existing eco-design frameworks, models and tools that could be integrated into the product development operational practices of a shower and tapware manufacturer.
2. Evaluate the applicability of eco-design frameworks, models and tools in the product development practices of a shower and tapware company to determine opportunities for improving these practices.
3. Identify the success factors that facilitate effective integration of the most appropriate eco-design frameworks, models and tools into the existing product development practice of a shower and tapware company.
4. Develop a conceptual eco-design model for the shower and tapware industry that is also applicable to other producers of active products.
5. Identify the transferability of the framework to manufacturers of other active consumer products.

3.2 Research Ontology and Epistemology

In an academic context, ontology is the description of what is reality in a predetermined field and includes questions related to hierarchy or processes that describe the structures in that field. When that field involves individuals interacting in an environment, a central question often asked is how these social entities (the processes, organisational structure, rules and regulations) exist (Bryman, 2016). There are two contrasting positions. At one end of the spectrum social entities exist independently of the social actors - this is referred to as objectivism. At the other end of the spectrum, social entities are constructs of the social actors – this is constructivism.

The ontological question in this inquiry is if eco-design in the shower and tapware industry is independent of social actors - or if the eco-design entities (processes, people, products and techniques) are constructs of social interactions. For this research, a constructivist ontological position seems reasonable based on understanding that the elements within both the NPD and eco-design fields of study are produced by social interaction and are in a constant state of revision (Saunders, Lewis, & Thornhill, 2009). This position is consistent with the aim of the study which involves investigating how to integrate eco-design models, tools or frameworks with NPD in order to assist with the environmental improvement of products. Integration is a revision to the process. The literature review showed that NPD and eco-design are people-orientated, and this provides further justification for this position. However, in identification of the most appropriate eco-design models, tools or frameworks, the researcher takes the objectivism ontological position. This is based on an understanding that user interaction with a product and its resulting environmental impacts is independent of social actors – the product and the subsequent consequence of its use follows a rule or standard. The justification for this is the close relationship between the ontological position and the epistemological paradigm and the way in which knowledge is obtained and understood.

The approach to understanding social entities from an objectivist position is known as positivist. A focus is given to studying empirical data with an understanding that it truly measures reality (Bryman & Bell, 2011). The researcher has taken a positivist approach in generating knowledge by assuming that any environmental data generated in the application of eco tools and techniques is reliable and generalizable to a wider population. In addition, if products are to be designed to influence the user to consume less (water, energy) in their use, then the effect of these designs need to be generalizable to a wider population; empirical data collected with methods founded in natural science should provide reliable conclusions.

In contrast to a positivist approach of constructing knowledge is the interpretivist approach. Data and its interpretation are established from an individual's lived experiences, which are often subjective. In this process many observations can be made, a pattern can be identified and generalisation about those patterns conclude in a theory. Social actors within an organisation attach meanings to interactions and physical factors leading to subjective interpretation. This provides depth and richness to data allowing the complexities of social entities to be better understood.

Many social entities within NPD involve people and their development environment. This is particularly the case for those that are operational in nature (processes, product teams, development and manufacturing techniques). In order to gain knowledge and draw conclusions on how eco-design can be integrated into these operational elements of NPD, an interpretivist approach seems most appropriate.

In conclusion, both positivist and interpretivist approaches are required in the study. The middle ground of these contrasting approaches is referred to as pragmatism. This combines both observable phenomena and subjective meanings (Creswell, 2014). A pragmatist philosophy is used at various points of the study. The adopted approach is illustrated in Figure 24 which shows that, in order to gain knowledge on the integration of eco-tools and techniques (by adopting an interpretivist approach), the researcher must also understand the results produced by these tools and techniques (by adopting a positivist approach). Interpretation requires a pragmatic approach in order to combine both the results regarding the integration process and the assessed environmental impacts of the products.

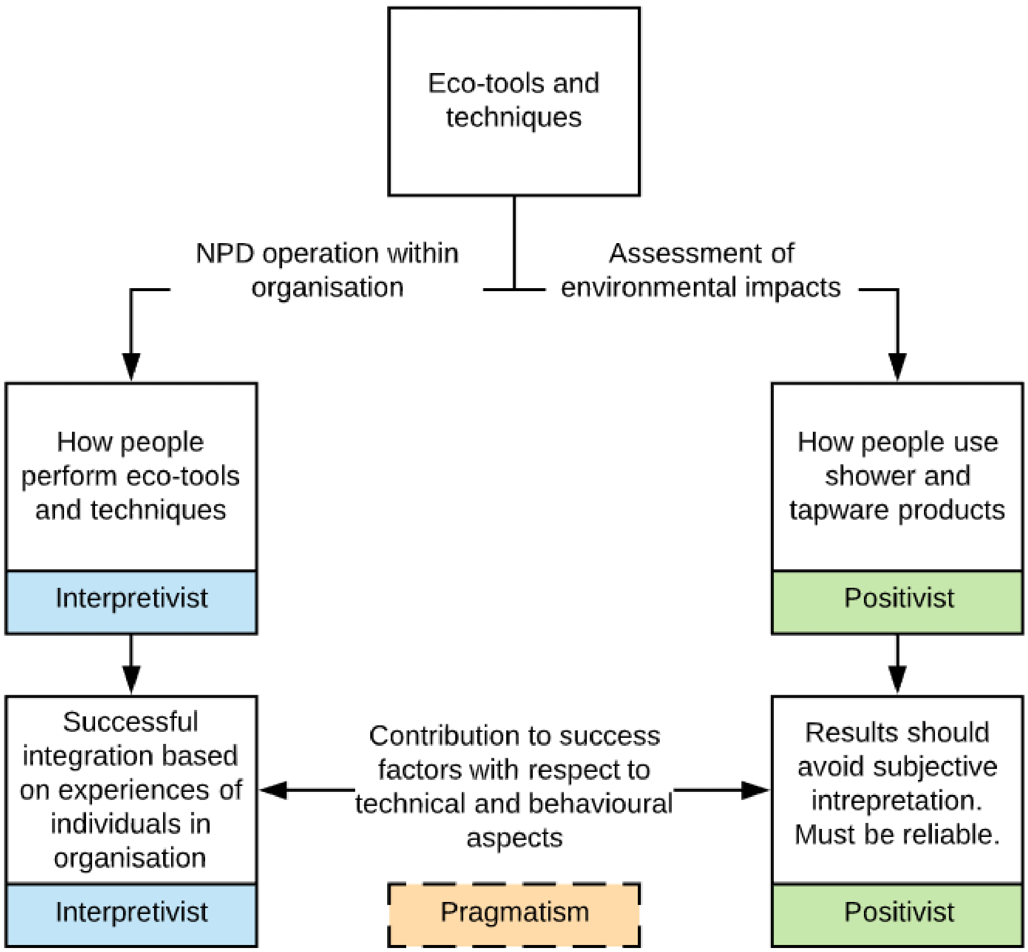

FIGURE 24 JUSTIFICATION FOR PRAGMATIC PHILOSOPHY

3.3 Research Methodology

The following section describes the chosen research methodology. This is accomplished by firstly categorising and defining existing methodologies (3.3.1), and then comparing these to the research aims, objectives and the epistemological position of the researcher in order to choose the most appropriate research methodology (3.3.2).

3.3.1 Appraisal of alternative research methodologies

Research methodologies can typically be categorised into: a) quantitative, b) qualitative and c) mixed (Saunders et al., 2009). These categories typical align with three epistemological perspectives: positivist, interpretivist and pragmatist respectively (Creswell, 2014).

A) Quantitative Methodology

Quantitative methodology takes a positivist worldview and often utilises surveys or experiments to study causal links. It is typically deductive, testing or verifying existing theories or explanations (Creswell, 2014). Surveys that take a quantitative approach often apply statistics to the data to assist in determining trends, opinions or attitudes of a population. In a classic experiment a control and experimental group is established by assigning members at random. Some form of intervention (an independent variable) is made to the experimental group to test the outcome (response variable). Based on the randomized assignment of the control group it removes the possible effects of alternative explanations and eliminates threats to internal validity (Saunders et al., 2009).

Quantitative methods can therefore be very useful in drawing conclusions for large populations in a very efficient way. Due to their design, it makes them highly replicable and testable in other contexts, which provides generalisability and strong internal validity. However, this approach typically does not record the subjective experiences of the participants and this limits the understanding of the context and the individual's views of reality (Creswell, 2015).

B) Qualitative Methodology

Qualitative methods typically involve observing and interviewing in an attempt to advance knowledge and understanding about experiences, thoughts, and human behaviour. The data that is collected in the process tends to be from the field and at the site of interest with respect to the issue or problem under study. This data will often be collected by the researcher themselves as they observe behaviours, examine documents or interview participants. Case study and action research are two of the common qualitative methods. More recently these methods have been combined into an action case study method.

One of the most powerful research methods options within qualitative research is **case study research**. It can be used for different types of research including exploration, theory building and theory testing. Yin (2014) defines case study research as:

> "an empirical inquiry that investigates a contemporary phenomenon ("the case") in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident."

A benefit of case study is that it comprises an all-encompassing method providing researchers with a logical research design, specific data collection methods and approaches to data analysis (Yin, 2014). Case study research is particularly useful for obtaining a rich understanding of the context by generating answers to why, what and how style questions (Saunders et al., 2009). The case study design typically follows a strict protocol to ensure robust and reliable results are achieved and the researcher remains focused on the research questions. Yin (2014) distinguishes two types of case studies: single- and multiple-case design. Single case design is appropriate when the case can represent the critical test of the significant theory or when the researcher has access to a situation previously inaccessible to empirical study. Another rational for single case design is when the case is longitudinal, gathering information over two or more points in time. Alternatively, there might not be specific points, but rather following the development of individuals or groups within the case to identify trends or patterns. Multiple-case designs are often considered more robust than single-case designs. However, they require extensive resources and can be difficult to develop a reliable procedure for selecting and analysing the multiple cases. Case studies can also have embedded case or sub-unit of analysis that provide a supporting, secondary role in a study based primarily on the other unit of analysis (Creswell & Plano Clark, 2007; Yin, 2014). An embedded case is often used to seek information at different levels or to ask different types of questions than might not be able to be answered by the primary case.

Action research is defined as a "democratic and participative orientation to knowledge creation" (Bradbury, 2015). It is argued that unlike conventional inquiry methods, action research is able to keep pace with the changing world. It has a similar process to other methods in that it allows the researcher to identify a question, test a strategy, gather data, and determine if that strategy works. Action research (AR) has become more popular in product development research. Bjork & Ottonsson (2007) argue that to really understand what happens on a daily basis within a product development project in is necessary to conduct AR since it provides greater opportunities to reflect on the complex nature of the NPD process (Björk & Ottosson, 2007). It is proposed as one of the best methodologies for researchers involved in NPD and studying the design process (Farel, 2013).

There have been an increasing number of NPD studies that use AR as the primary methodology. It has been applied in NPD portfolio management research (Abrantes & Figueiredo, 2014) and Product Life Cycle Management research (Estruch, Vila, Siller, Romero, & Abellan, 2016). Sakellariou et al. (2014) argue that existing case studies which address improvements at the front end of product development fail to provide adequate guidance to stakeholders who face complexity at that stage of development, and suggest that the inherit characteristics of AR can address those deficiencies (Sakellariou, Karantinou, & Poulis, 2014).

Often researchers will conduct action research in a cycle that plans an intervention, carries out some action, checks the results and then enacts some change (Plan, Do, Check, Act). The objective is to evaluate the effectiveness of the change and make adjustments (Johnson & Lipp, 2007). Often there will be multiple cycles with each informing the next. This methodology is therefore particularly useful when describing a series of unfolding changes over a period of time.

An **action case study** is the term used to describe the combination of both action research and case study methods. It combines fundamental research approaches (induction and deduction) into a hybrid abductive approach that is appropriate for creative and pragmatic research. Halecker (2015) lists several advantages when combining case study and action research:

- Testing theory in both a natural environment and in real-time
- Provides both concrete results (problem solving) and conceptual results in terms of proposed changes to the theoretical frameworks
- Allows gathering more profound crucial information because it enables a participatory and distance mode
- It leads to a research project with temporary interaction, thus having a shorter time span compared to action research
- It enables small-scale changes within the organization while using intervention
- Researchers can actively participate in practical projects without becoming the ultimate decision maker
- Participating managers and organizations obtain new insights and probably solve their practical problem

As illustrated in Figure 25, the action case study sits between action research and (soft) case study.

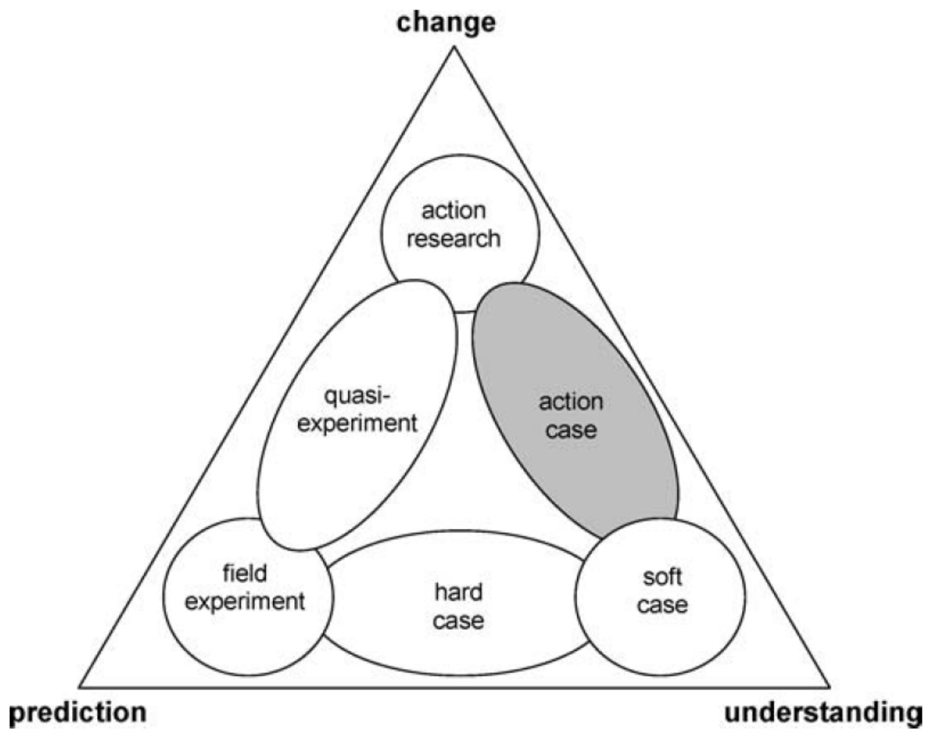

FIGURE 25 POSITION OF ACTION CASE ACROSS DIFFERENT CASE METHODOLOGY (BRAA & VIDGEN, 1999)

C) Mixed Methods Methodology

Mixed methods combine both qualitative and quantitative methods to draw on the strengths of both. As an example, the researcher can combine statistical trends (quantitative) with stories and personal experiences (qualitative) into a single rigorous study. Often the rational for applying a mixed method approach can be driven from contrasting world views of the researcher (i.e. pragmatism) (Creswell, 2015).

Research designs under this methodology can be sequential (i.e., quantitative data collection and analysis and followed up with qualitative) or parallel (i.e., quantitative and quantitative data collection and analysis is compared and related).

3.3.2 Chosen research methodology

Case study methodology is appropriate for this research project as it offers a structured mode of inquiry for investigating the organisational practices and eco-design of a shower and tapware manufacturer in order to understand how integration should occur. However, in addressing the research questions that relate to the applicability of eco-design tools methods and frameworks within a shower and tapware manufacturer, it is necessary to ask questions not only directly related to the primary unit of analysis (the case company) but also related to the secondary unit of analysis i.e., the users of shower and tapware products. Questions asked about this secondary unit of analysis concern the influence of user behaviour, and the analysis of empirical data can generate informed answers to these questions. Case study methodology is therefore inadequate as the only research method. Also, a mixed methods approach is required that can apply alternative quantitative approaches such as quasi-experiment, field experiments and action research that make predictions and/or act on them to enable change. Including these methods requires the collection and analysing of both qualitative and quantitative data.

Based on this reasoning it was decided to use an embedded case study approach to answer the research questions (Figure 26). An action case study is the most appropriate method to be embedded within the primary case.

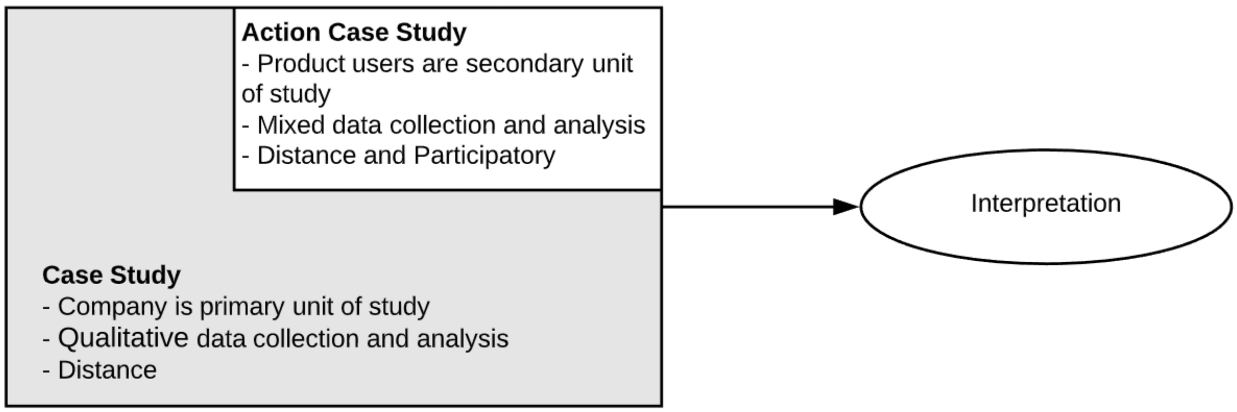

FIGURE 26 EMBEDDED CASE STUDY DESIGN – ADAPTED FROM (CRESWELL & CRESWELL, 2005)

3.3.3 Overview of research design

The overview of the research design in Figure 28 illustrates where each objective of the research is addressed.

The case study addresses RQ 2, about how eco-design tools, methods and frameworks can be integrated into NPD. This combines data collected from the case study (NPD operational factors) and embedded action case study (eco-design user factors, eco-design operational factors). The primary unit of analysis was the Innovation group and all teams within it (R&D, Product Development, Design, Marketing). The structure of the company is detailed in chapter 4.

The embedded action case study asks questions of a different type about two secondary units of analysis. The secondary units of analysis are:

- Specific team responsible for the development of eco-products (R&D team)
- Users of shower and tapware products.

The questions included “What tools, methods are applicable and why?” which better informed the case study question (RQ 3) on “How can these be integrated? Development of an understanding about how eco-design integration should occur required an iterative interpretation of the links between the operational aspects of the organisation and how users interacted with the products. In other words, to know what tools or techniques are appropriate to integrate, the organisation needs an understanding of how their users impact the environmental performance of the product. In turn, the users influence the company and their process but are not directly part of the internal operations of the organisation.

The embedded action case study therefore sits at a different level to the primary case study as illustrated in Figure 27. It focused on the tools and techniques applicable to shower and tapware product and how they can be integrated into specific development processes of the R&D department.

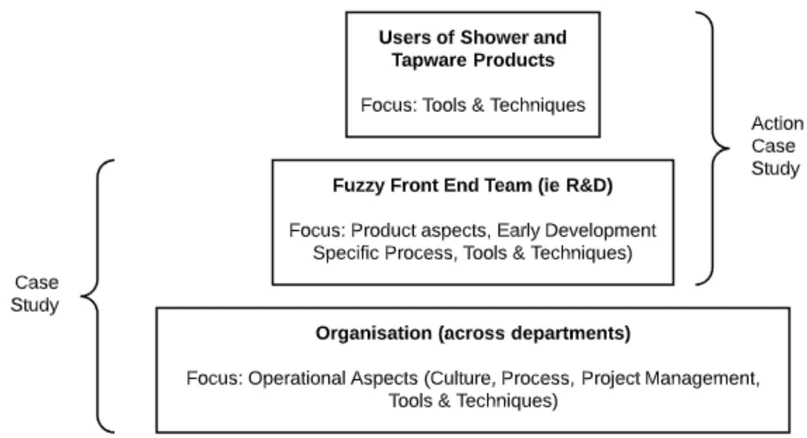

FIGURE 27 LEVELS OF RESEARCH DESIGN

A core principle of an action case study is how the researcher becomes embedded in the company department and acts as an initiator within a team or group (Halecker, 2015). In this research, the researcher worked collaboratively with the R&D team to help initiate, perform, analyse and reflect on a number of eco-projects using different eco-strategies.

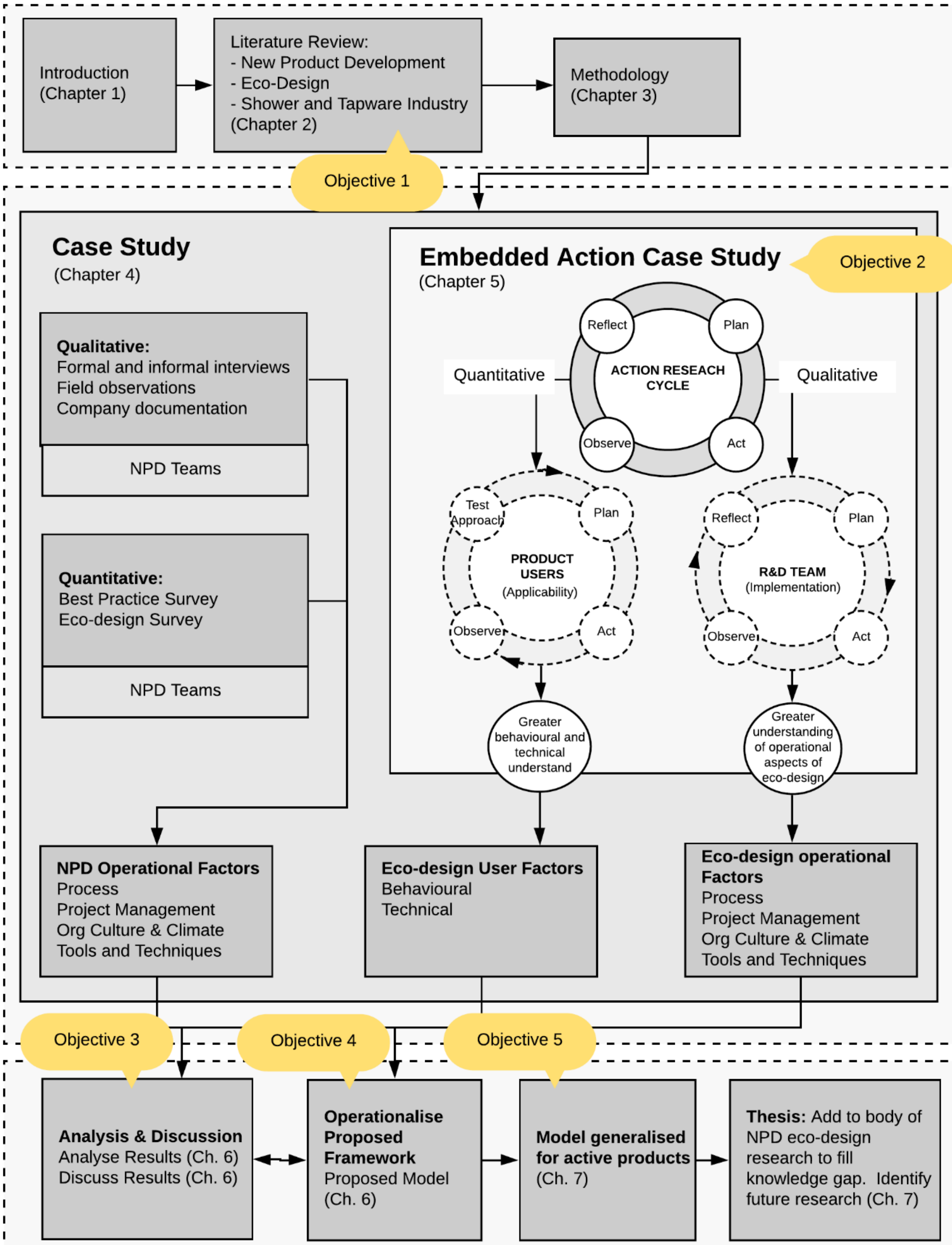

FIGURE 28 OVERVIEW OF RESEARCH DESIGN

3.4 Research Plan

The research involved three distinct research stages: capability assessment, integration and interpretation (Figure 29).

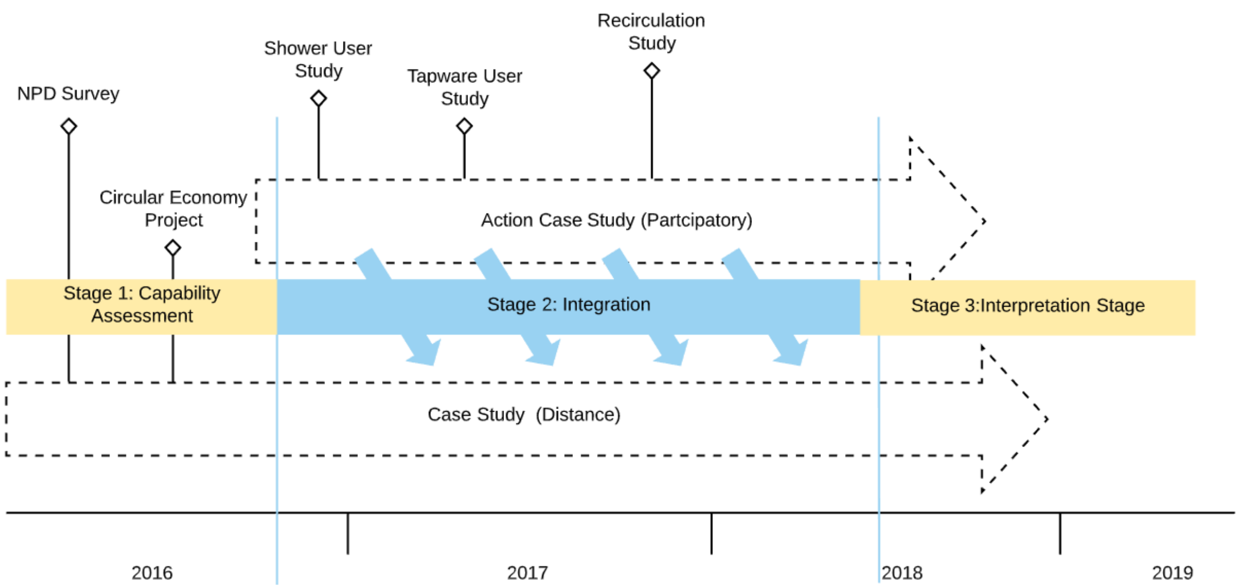

FIGURE 29 RESEARCH STAGES AND TIMELINE

The purpose of the capability assessment (Stage 1) was to understand the company's practice of NPD compared to best practice for elements such as portfolio or project management (refer to chapter 2). Observations, interviews and surveys were the primary data collected in this stage. During this time the progress of 16 NPD projects were observed (some of which included eco-design aspects) that provided the researcher with an understanding of the drivers of their NPD and eco-design practices.

The integration stage (Stage 2) was centred on the action case study. During this stage three distinct projects unfolded over a period of time. These projects occurred in series i.e., each informed the next through analysis and reflection. As questions of applicability of eco-design tools, methods and frameworks for the case company were answered in each project in the action case study, more structured and relevant questions were developed for the next project within the action case study. These all informed the overarching case study which continued to run in parallel to the action case study. As an example, in relation to eco-design principles, methods or tools, the case study protocol (Appendix E) contained questions that asked what works (or doesn't work) at an operational level. The results of this data collection allowed broader questions to be asked about why these methods or tools worked or didn't work, and these could be linked to factors related to NPD operations; this provided data enabling a greater understanding of the position and drivers of NPD and eco-design within the innovation group at case study level.

The primary case study evolved in a more ethnographic and naturalistic way with few distinct milestones. The action case study, while inherently emergent, had a clear structure due to the stages of the cycles. These cycles are represented in Figure 30.

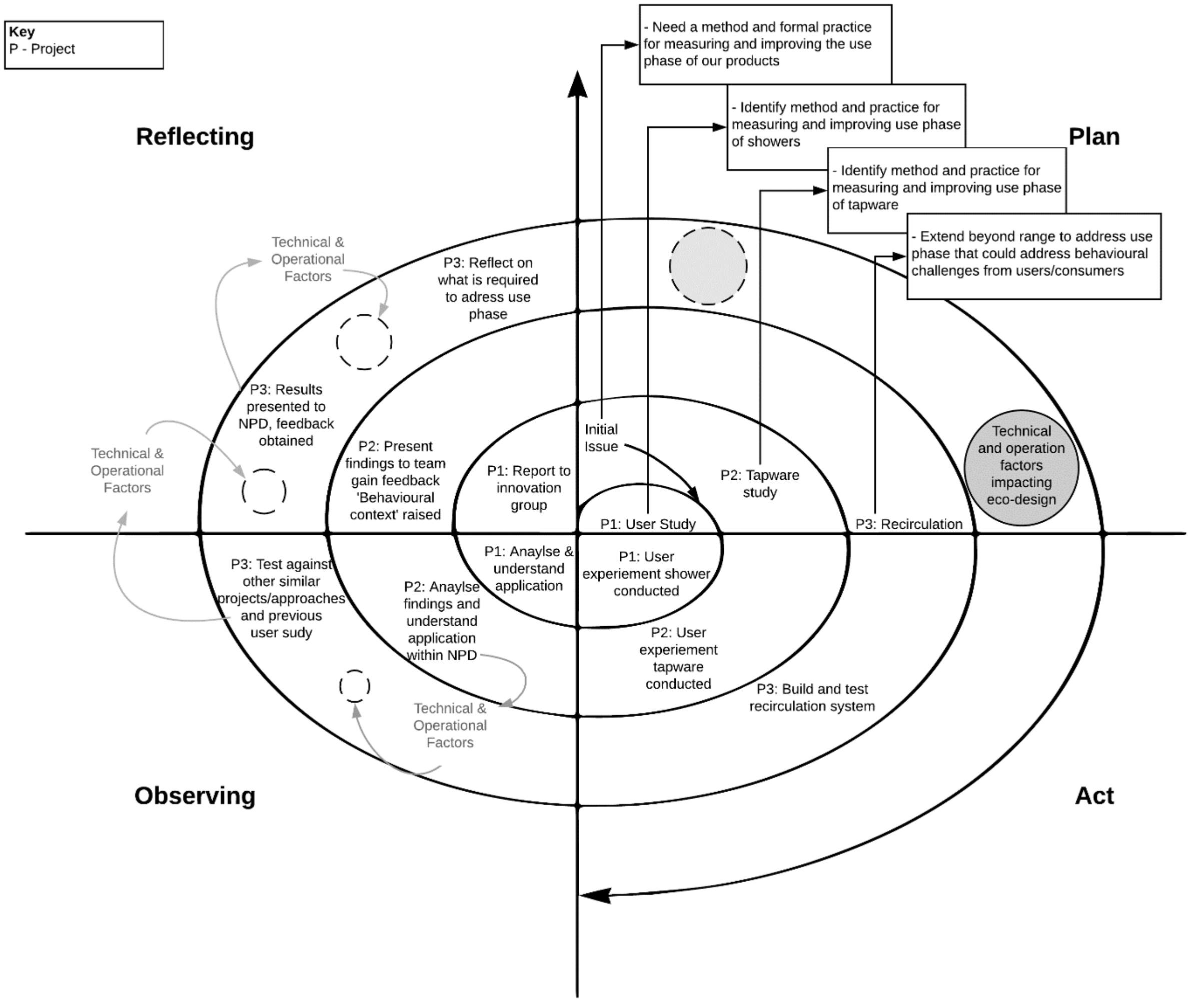

FIGURE 30 CYCLES OF ACTION CASE STUDY

In Figure 30 each cycle represents the planning of either an experiment or R&D project, the implementation of that plan, the collection and analysis of the data and finally reflecting on the findings. In this process, new insights emerged along with further questions needing to be answered with respect to operational, technical and behavioural factors of eco-design integration into NPD.

The following provides a high-level overview of the cycles from Figure 30.

3.4.1 Cycle One

A series of Life Cycle Thinking workshops were facilitated by the researcher. At these workshops, the researcher introduced the principles of Life Cycle Thinking and how behaviours of users can impact the environmental based impacts of using shower and tapware products. This was followed by brainstorming sessions that identified components and product designs that could signify environmental improvements and opportunities.

The R&D team selected ideas from the brainstorming session for further investigation. Applying Design of Experiments, a multi-factorial experiment was planned to collect environmental data on these ideas (factors). This included finding appropriate participants, designing and building testing equipment, scheduling and running the trials. Box 1 provides more details.

The equipment was installed in participant showers to collect data. Each trial ran for a week, at which time the researcher returned to the households to collect the data and make the appropriate changes for the next trial. There were 9 nine trials per household.

Box 1 – Activities of Cycle One

- R&D Collaborative Eco-design Workshops / Brainstorming
- Shower design of experiment planned
- Design and build test equipment
- Identify participants for trials
- Install and test equipment
- Run trials
- Collect and analyse data
- Debrief meetings/ R&D team reflection of results

3.4.2 Cycle Two

The outcomes of the first cycle produced valuable insights while generating more questions to be answered with respect to eco-design. In particular, the questions concerned how the operational aspects of eco-design might change depending on the product category. As an example, tapware products are more functional compared to shower products (which are more experiential) and therefore different DoE factors may be important in the testing of tapware products. Therefore, the DoE design and how this is incorporated into the design process may also vary.

Therefore, an additional experiment was designed and trialled to determine what factors (components, designs) impact the environmental performance of tapware. Trials ran over two weeks using modified equipment from the first cycle / trial. The activities of this cycle are provided in Box 2.

Box 2: Activities of Cycle Two

- Collaborative meetings with R&D team
- Tapware design of experiment planned
- Modify test equipment to work with new product
- Identify appropriate test location
- Install and test equipment
- Run trials
- Collect and analyse data
- Debrief meetings/ R&D team reflection of results

3.4.3 Cycle Three

Based on the operational challenges encountered in the first two cycles, the R&D team adopted a systems-based approach to eco-design. This cycle involved designing and testing a water recirculation system that the R&D team thought could overcome many of the user behaviour challenges encountered in the first two cycles. LCA was used to quantify the environmental impacts. This provided an opportunity to better understand the applicability of LCA in this context and what operational factors relate to its integration into the product development process for a system-based eco-design.

The experiment was split into two parts (with two separate test systems) to minimise risk and health hazards association with recirculating water in an R&D environment. The first test system was installed in users' households and simply recorded data on how they showered (such as when soap was used and when it was not) to identify when water could have been recirculated. The second test system was the recirculation system that simulated a shower based on the data collected from the first test system. The activities and steps taken for this cycle are provided in box 3.

Box 3 Activities of cycle three

- Plan experiment
- Design and construct user test equipment for recording washing vs not washing
- Install in households
- Collect data
- Build and test recirculation system
- Collect data
- Combine results
- Perform Life Cycle Assessment (based on combined results)
- Debrief meetings/ R&D team reflection of results

The interpretation stage (Stage 3) combined all the data collected from both the action case study and the overarching case study and is discussed further in section 3.5.

3.5 Overarching Case Study Data Collection Procedures

The case company data collection occurred in two parts. The initial situational analysis occurred from February 2016 to August 2016. There were four main collection activities: reviewing internal documentation on the NPD process, field notes from inductions, interviews with innovation staff who are at different levels and departments of the organisation and observational recordings during reoccurring NPD meetings. This data collection occurred concurrently to the action case study (August 2016 to July 2017),

Documents

Internal company documentation was collected throughout the case study. This provided insight into past NPD practices such as post-NPD project reviews or reports. Other documents were updated with revisions as part of a continuous improvement effort within NPD (i.e., NPD Process Documentation) that provided data on trends or patterns of change over time.

Market research reports included data and analysis of previous studies conducted by the organisation including consumer surveys and focus groups.

Interviews

Interviews were conducted throughout the case study and used a combination of structured and semi-structured interviews. Participants were from various departments within the innovation group who were involved in the NPD operational activities.

Open and closed style questions were asked during interviews. Open questions provide an opportunity for the respondent to answer in their own terms, perhaps providing unusual answers that the researcher may not have contemplated (Bryman & Bell, 2011). However, this makes coding data difficult and therefore time consuming when comparing answers of the same or similar questions asked of other respondents. It is for this reason that in Stage 1 (refer Figure 29) the questions asked of participants were closed and addressed aspects related to understanding the practice of the organisation with respect to NPD and the operational activities.

TABLE 14 DATA COLLECTION - DOCUMENT TYPES AND OBJECTIVES

Documentation Type	Objective
NPD Process Documentation	• Understanding stages of development • Compare how NPD process is documented vs how it is occurs in projects • Examples of criteria used in evaluation of new projects (included environmental criteria) • Record how process changes or improves • Compare with best practice body of knowledge
NPD Proposals, NPD Post Project Reports, Meeting minutes	• Outcomes of past projects • Measure of successful NPD within organisation • Examples of killed projects and reasons why they were not successful • Examples where environmental consideration has been included in product
NPD Roadmaps, Opportunity Identification and Portfolio Management	• Understanding how new NPD opportunities are generated and assessed (including eco-opportunities) • Compare with best practice body of knowledge
Market Research Reports	• Linking NPD practice with identified consumer drivers or trends (such as the voice of customer • Consumer insights (such as importance of environmental aspects related to products)

At the integration stage (Stage 3) there was more use of probing and open-ended questions to allow the research to gain deeper insights from responses by asking follow-up questions to unexpected responses. The questions were framed to ensure the topics discussed related to environmental consideration and how this aspect should be incorporated into the NPD practice of the innovation group. To assist with coding, all structured interviews were voice-recorded and later transcribed.

Semi-structured interviews were conducted more frequently and often resembled informal meetings or progress updates on a project. As the researcher was embedded in the R&D team, a natural employee relationship formed amongst the employees across the innovation group and the researcher; this is a recognised characteristic of action research (Bradbury, 2015). This created a situation where employees were available to commit time to an unplanned discussion with the researcher on the NPD related activities they were involved with. The nature of these discussions was often steered by the researcher asking specific questions on how eco-design activities were being incorporated into their practice.

An example of an interview has been provided in Appendix G.

TABLE 15 DATA COLLECTION - INTERVIEW TYPES AND OBJECTIVES

Interview Type	Objective
Structured	• Data on how NPD occurs • To understand how NPD is perceived across different departments (Marketing, R&D, NPD, Design) • To gain insights on where environmental consideration is being included within the innovation group
Semi-structured	• Track progress and performance of projects • Gather data on individual's perspective on the operational activities of the organisation • To gain insights on where environmental consideration is being included within the innovation group

Observation (Distance)

Observational data was recorded in both a physical and electronic logbook throughout the study. This involved observing the innovation group (and teams within it) when performing NPD activities and taking notes in an open and exploratory way. Effectively it was an ethnographic study, where the researcher immerses themselves in the day-to-day lives of the individuals being studied (Saunders et al., 2009). The researcher was hosted at the case company from February 2016 to January 2019 during the hours of 9am to 5pm from Monday to Friday. This provided an opportunity to collect data throughout different times and on different days of the week. This is an important consideration for collection of qualitative data since it avoids drawing inferences about certain people's behaviours or generalisations made about organisational practices that may only be valid for specific times or days (Bryman & Bell, 2011).

Structured observation was performed during meetings that were reoccurring and regular such as project progress meetings (gate meetings). The researcher collected data by making notes in a logbook on behaviour and conversations that might reflect trends or patterns of these events.

TABLE 16 DATA COLLECTION - OBSERVATION TYPES AND OBJECTIVES

Observation Type	Objective
Structured Observations	• Provided comparison of NPD process documentation • Allowed for trends or patterns of improvement or deterioration of NPD process or project planning
Field Notes	• Mental notes – such as conversations between individuals which represent behaviours, attitudes or activities within the context of NPD or eco-design • Record of events within NPD projects that reflect practice • Ability to compare and contrast with other data sources

Surveys

Survey data was used in Stage 1 to provide an initial situational analysis of the organisation. This was used as a starting point for further follow-up questions (such as in structured interviews).

The method for creating the survey was guided by Saunders et al. (2009) recommended process for survey design. The main outcome of the study is to understand how well the innovation team believes it performs NPD.

The survey questions were based primarily on the (Barczak & Kahn, 2012) NPD benchmark framework. This framework groups NPD practice into categories (e.g., Process) with practices that are sub-categories as best and poor.

PROCESS	
Poor Practice	**Best Practice**
Criteria for evaluating NPD projects are not defined	A common NPD process cuts across company groups
Limited documentation exists regarding the NPD process	Go/No-Go criteria are clear and pre-defined for each review gate
Minimal testing (concept, product, market) performed	The NPD process is flexible and adaptable to meet the needs, size, and risk of individual projects
No NPD process exists	The NPD process is visible and well-documented
There is no discipline in using the company's NPD process	An IT infrastructure with appropriate hardware, software, and technical support is available to all NPD personnel
There is no NPD process owner or NPD process champion	A clear NPD process exists
Not all NPD personnel have access to the same IT tools (software, hardware)	
Projects are not reviewed at completion	
The NPD process can be circumvented without management approval	

FIGURE 31 PROCESS BEST AND POOR PRACTICES FROM NPD BENCHMARK FRAMEWORK (BARCZAK & KAHN, 2012)

The categories included in the survey were: Strategy, Portfolio Management, People, NPD Process, Market Research and Metrics. The questions asked in each of the sections were based on the descriptions within each level. These descriptions provided structured multiple-choice answers for each of the questions (an example is provided in Figure 32). The questions were structured so as not to reveal what constitutes best or poor practice to encourage honest responses.

3. When it comes to New Product Development strategy this organisation has

- ◯ no NPD goals
- ◯ unclear NPD goals
- ◯ NPD goals which are clearly aligned with organisation mission and strategic plan
- ◯ Other (please specify)
- ◯ NPD goals defined by a mission statement, and opportunities that were identified through analysis of strategic arenas
- ◯ The NPD goals are clear in my silo, I am not sure about other silos

FIGURE 32 SURVEY QUESTION EXAMPLE

A total of 39 questions were created across the different categories.

An additional six eco-design specific questions were added for the purposes of understanding what the team believes are the barriers that limit their ability to develop environmental products or where the opportunities are for improvement. Many of the responses were provided on a Likert scale (1 – 5) for ranking or provided flexibility in the scaling of the answers (i.e., strongly disagree or somewhat disagree). Where possible these have been combined to simplify the representation of the results (i.e., strongly agree, agree and somewhat agree combined to agree).

Survey monkey was used as the application to send out the survey and collect responses (Appendix F).

3.6 Action case study data collection procedures

The action case study data collection occurred concurrently to the action case study. The data collection was from August 2016 to July 2017.

Observation (Participatory)

A distinct difference of the action case study compared with that of a traditional soft case was the participatory nature of the research. With the researcher embedded within the team, the observational notes included both observing individual team members (i.e., behaviours, practices, opinions), self-reflecting (i.e., performing an eco-activity and recording what the researcher believed worked well, what didn't and the reasons for that,) and team events (i.e., process and outcomes of meetings or projects).

Interviews

Interviews in the Action Case Study were very structured. The interviews were often conducted at the end of an R&D product experiment or project for the purposes of gathering qualitative data that could better inform the analysis and reflection stages to direct the planning of the next cycle.

Each interview had a clear aim and objectives based on the project or experiment and all questions asked during the interview were orientated around this objective (an example is provided in Table 17).

TABLE 17 EXAMPLE OF STRUCTURED INTERVIEW AIM, OBJECTIVES AND QUESTIONS

Aim	To understand how to improve the NPD process, tools and organisational structure so that products can be redesigned to improve the environmental performance when the use phase (and user centred behaviour) is a driving factor
Objective	- How are current environmental issues addressed with respect to the Process, Tools & Techniques and current projects? - How can the benchmarking method used influence the Process, Tools & Techniques and future projects? - What changes are necessary to the Process, Tools & Techniques and project management techniques to increase successful implementation?
Example Questions	Do you think that the use phase, and its environmental impact is an important consideration in current R&D work of new products? Did the way in which the method was implemented impact future experiments and how could it be improved? Is it possible to build on the statistical method (DOE) implemented for future projects?

Experiments

Two types of experiments were used within the action case study to assist in answering the research questions. The question around applicability of eco-design tools and techniques for a shower and tapware manufacturer required answering questions such as "What are the environmental impacts associated with the product's use?", and "Can factors be identified that improve the use phase from an environmental perspective and can these be translated to design decisions?" In order to gather reliable and valid data to answer these questions, two types of experiments were conducted: Control Experiments (in the form of Design of Experiments DOE (See Appendix A)), and Observational Studies.

The DOE studies were used to provided data on how different components and spray technologies (or combination of) affect energy use, water consumption and duration of product use. This was accomplished by relating existing and future variations in designs of shower and tapware products as factors. Energy and water use represented the response variables. The DOE design utilised controlled randomised trials where the factors were used to explain the variation in the response variables. The rationale for using DOE was to justify the findings for a larger population so design changes to products could reflect this.

The objective of the Observational Study was to develop and implement a shower recirculation system that enabled the environmental footprint to be quantified. A data recording device was embedded within this system that recorded the water and energy use every second during the shower cycle. In addition, a turbidity sensor provided data on when the user was washing and not washing to determine the efficiency of the system. Analysis of the data collected provided insights on the applicability of such systems, highlighting the barriers or success factors of eco-design projects at a system level.

Further details on the method for each experiment are provided in appendix A for cycles 1 and 2, and cycle 3 is provided in both appendix B (experiment method) and C (life cycle assessment method).

3.7 Data analysis process

The analysis section in Chapter 6 draws on recommendations and data analytical strategies by Yin (2014) and Saunders et al. (2009) as well as previous case study analysis such as Tingström and Kth (2007) and NPD action research analysis by Doevendans (2014). This section provides an overview of the analytical process. The data analysis process for the DoE experiments and LCA modelling completed in the action case studies are provided in Appendices A, B and C.

3.5.1 Preparing data

All data records from both the case study and action research study were stored in a database. This process including transcribing qualitative data from voice recorded interviews. A naming convention was formed as a quick reference system for each data record connecting them to a project or case.

Abbreviation	
S (n)	Stage
A (n)	Action Cycle (if appropriate)
Ob (n)	Observational Notes
In (n)	Interviews / Transcript
Q (n)	Questionnaire / Survey Data

For example, the file name "S2-A3-Ob3" represents observational notes from the third action research cycle during stage 2 (integration stage). The file name S1-Q(3) is a the 3rd questionnaire used in stage 1 (People and Processes).

For interviews, an additional naming system was formed to maintain anonymity in the results and analysis sections while being able to represent the individual's position in the organisation. The number (x) which corresponds to the individual name has been excluded from the thesis.

Abbreviation	**Department**
M (x)	Marketing
R (x)	Research and Development
E (x)	Engineering

I (x)	Innovation Management
D (x)	Industrial Design

Abbreviation	Description
(x) – t	Top Management
(x) – e	Extended Management
(x) – s	Senior in role
(x) – m	Middle in role
(x) - j	Junior in role

For example, the file name “S1-I(R001-S)” is an interview from Stage 1, with person “1” who is in the R&D team and in a senior role. “S2-A2-I(R003-t)” is an interview from Stage 2, during action research cycle 2 with person “3” in the R&D team in a top management role.

3.5.2 Analytical strategy

Often a challenge with mixed methods research designs is how to converge or merge data (Creswell, 2014). The action case study included experimentation and statistical analysis that produced quantitative data. This data was used to build relevant questionnaires and interviews to produce qualitative data from respondents involved in the R&D and NPD process. As an example, when an experiment concluded, the results were presented to a member of the R&D team, and they were asked how the results would impact the R&D process and practices. In addition, the researcher was able to collect participant observational data throughout conducting the experiment, noting strengths and weaknesses of any tools and techniques applied. Secondary qualitative data was generated during the cyclical analytical process of experimentation, quantitative analysis, interviewing and observing over a number of projects and involving multiple participants. This data was then converged with the qualitative data collected in the case study in the form of quotes, codes and themes. Table 18 details the “ground-up” analytical strategy (Yin, 2014) primarily applied using various inductive analytical activities including summarising, pattern matching, categorising, and explanation building as the primary techniques for analysing the primary case study.

TABLE 18 ANALYTICAL PROCEDURE

Case study analysis	Rationale
1. Review all data and summarise key points	Provide the researcher with an overview of the research and any major themes that are apparent
2. Link to literature	Data and annotations would be easy to identify and linked existing theory and possibly highlight a relationship
3. Compare and categorise key findings with respect to NPD and eco-type / eco-strategy	Allowed for predefined eco-design themes and their significance to emerge (forms a structured matrix that becomes the initial conceptual framework)
4. Identify patterns and relationships	Conversion of data to information through logical linking
5. Compress and order patterns in relevant categories	Identify causal links and relationships that would help identify both NPD and eco-design success factors for integration.
6. Expand on matrix using explanation building	Provide a deeper insight into why or how eco-design can be integrated. Compare findings with relevant body of knowledge and refine framework

3.6 Limitations of methodology

3.6.1 Reliability

Reliability is the term used to describe the degree in which the results of a study are free from errors and can be reproduced (Bryman & Bell, 2011). This provides trustworthiness and credibility of the outcomes. There are a number of procedures suggested by Creswell (2015) to improve reliability in a mixed methods study:

- Check transcripts to make sure they do not contain obvious mistakes during transcription
- Ensure there is no drift in the definition of codes
- Document procedures

- Cross-check codes developed by other researchers by comparing results that are independently derived

Table 19 summarises the actions taken to achieve reliability in this research.

3.6.2 Validity

Validity describes the accuracy of the findings of the study. The form of inquiry and investigation procedures of the proposed research requires a qualitative approach to determining validity. A number of procedures can be applied that can help researchers establish credibility of their study (Creswell & Miller, 2000).

The choice of the strategies and procedures is often based on the lens used by the researcher and their paradigm assumptions. The most relevant strategies are presented along with example of their possible use within this study. Table 19 describes how validity will be established.

TABLE 19 STRATEGIES AND PROCEDURES FOR ESTABLISHING RELIABILITY AND VALIDITY

Design Test	**Case Study (Company)**	**Embedded Action Case Study (User)**
Objective	*Integration of the most appropriate eco-design frameworks, models and tools into existing product development operational practices of a shower and tapware company*	*Applicability of eco-design tools and techniques that can be integrated into the development operational practices of a shower and tapware company*
Reliability: the extent to which the study is without and error and can be reproduced.	• Use of protocol • Single researcher (improves consistency) • Use of Likert scale in interviews and questionnaires	• Calibration of sensors (error checking in recording devices) • Apply ISO standards for collecting and analysing data where appropriate (i.e., ISO 14000 used to help companies address their environmental impact)
Internal Validity: The extent to which the causal relationships are justified	• Use of multiple sources of evidence within study (allowing for triangulation) • Comparison of findings across different projects (i.e., those conducted within the Action Case Study) • Clarify the bias of the researcher (self-reflection process) • Create in-depth narrative of the study by spending prolonged time in the field • Use peer review (both internal and external of organisation) to challenge findings and explore rival explanations	• Randomised trails • Careful selection of independent variables that are expected to have a large variation • Identification and elimination of noise within experiment • Use of significance when interpreting results • Reduce known but irrelevant sources of variation between units (Blocking)
External Validity: The extent to which the study can be generalised to a wider population (i.e., beyond the shower and tapware industry)	• Compare with known theory and empirical evidence on eco-design integration into NPD for other manufacturers of active products (outside of Shower and Tapware manufacturers)	• Compare with existing environmental studies on Design for Sustainable Behaviour

3.7 Ethical Considerations

Ethical considerations were guided by the Massey University code of ethical conduct for research. As the research involved human participants, it was necessary to apply for ethics approval. A full application was made and screened by the ethics committee. This was approved as low risk (Human Ethics Notification – 4000016509). However, the researcher is still responsible for the ethical conduct of the research, ensuring that:

All participants involved in the research are adults and are fully informed of the research

All personal details of individuals involved in the study that could identify them are removed

Physical and mental harm to individuals involved in the study is avoided.

While no ethical dilemmas were encountered in the study, the researcher made it general practice to inform the participants of the reasons for the research. All those who were involved in interviews and questionnaires preferred to remain anonymous in their responses. One of the reasons for this was to protect themselves from internal politics or organisational conflict (within other teams or individuals). Additionally, there was a requirement that confidential information used within this study remained protected, avoiding employee contractual repercussions for participants and the researcher.

3.8 Chapter Summary

Development of the research methodology involved considering the ontological position of the researcher, appraisal of various methodologies, and then logical linking of these to the chosen research design. A mixed method approach was chosen which included a case study with an embedded action case study. The research plan outlines how and when data was collected, stored and analysed. In Section 3.6, a number of strategies have been provided to address some of the limitations of the methodology surrounding reliability and validity.

4 Company Situational Analysis (Case study report)

4.1 Introduction to case study report

A study was conducted on the case company in order to gain an understanding of its NPD capability and environmental drivers.

The chosen company for the case study is based in Auckland, New Zealand. It is a medium sized company that produces showers, tapware and valves for domestic water use.

The company employs approximately 300 staff in Auckland, Australia, UK and China. They have a manufacturing facility in Auckland that produces and ships some of their products (proprietary) with the majority of products made (or assembled, packaged, and distributed) in China. The Design and Innovation Group are based in the Auckland headquarters and have a total of 20 staff across 4 different teams: Industrial Design, Marketing, New Product Development and Research and Development.

The organisational structure is shown in Figure 33. This structure did vary to a small degree over the duration of the study when individuals left or joined the company and new roles were created or removed.

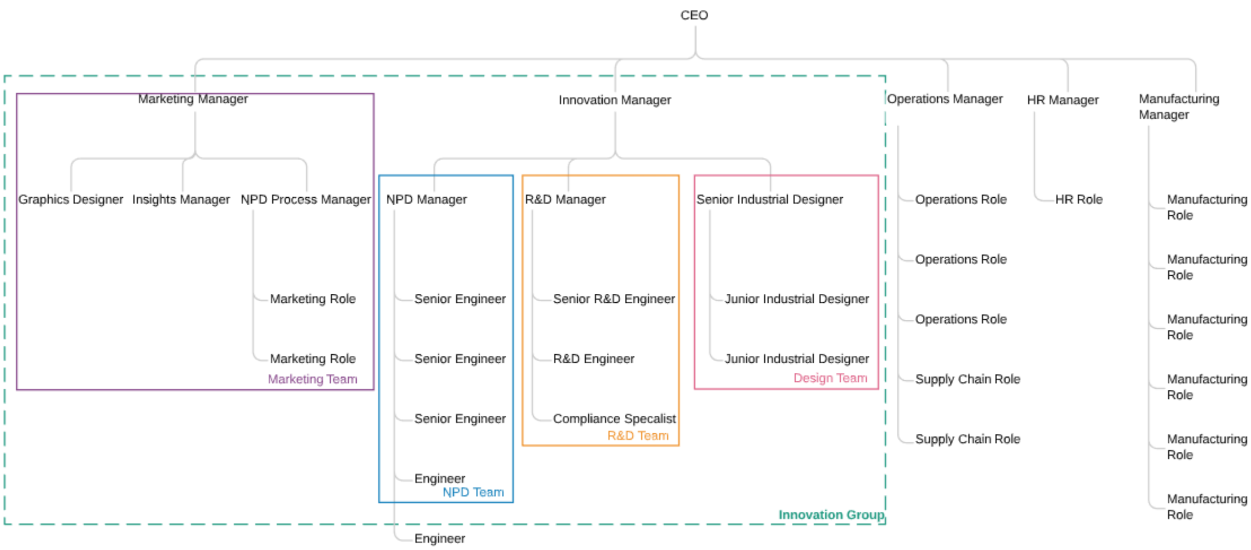

FIGURE 33 ORGANISATIONAL STRUCTURE

The case company has considerable product development inertia, allowing them to hold market share for two of their product types across multiple countries. They have established brand recognition and customer loyalty which are represented by high quality products. Design is an important influence within the organisation allowing them to consistently win prestigious design awards each year for new products.

The data collection procedures for the research outlined in Section 3.4.1 resulted in the following data:

- 23 pages of long interviews
- 13 pages of short interviews
- 26 pages of observational notes
- 44 pages of survey results
- 51 pages of meeting minutes (from NPD project presentations and gate meetings)

- 8 pages of planning and proposal reports from workshop
- 6 pages of LCA results
- 309 internal work emails.

The results are reported in six distinct parts within two main categories: NPD capability and environmental drivers (illustrated in Figure 34).

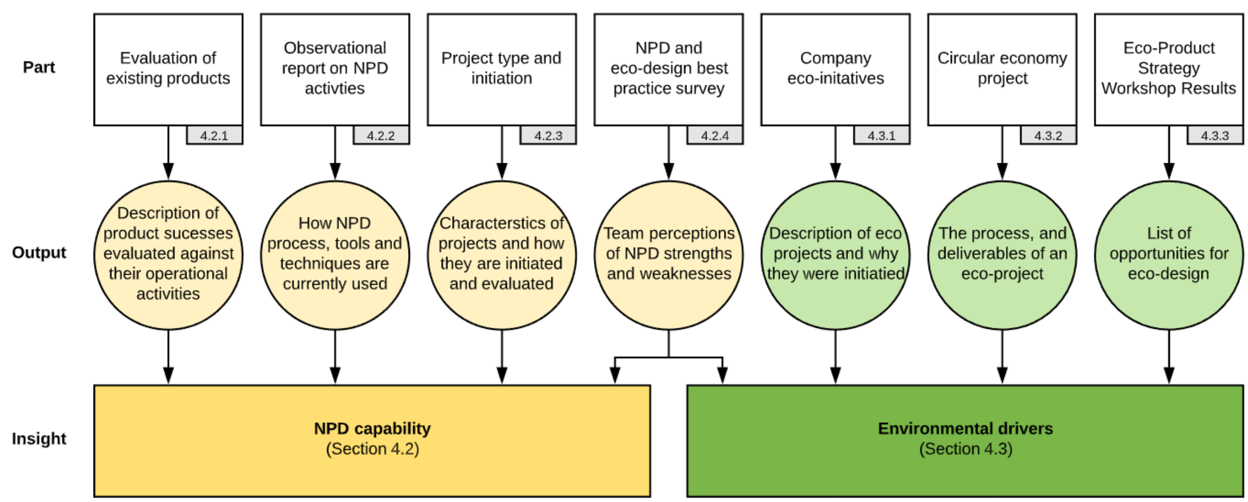

FIGURE 34 CASE COMPANY DATA COLLECTION (GREY BOX REFERS TO SUBJECTIONS OF THESIS)

4.2 NPD Capability

NPD capability is an organisation's inclination, aptitude and practices related to achieving specific objectives within the different elements of NPD best practice such as portfolio or project management. An organisation's capability will often determine how consistently it can deliver successful products and services (Mugge & Markham, 2013).

4.2.1 Evaluation of existing (and future) products

For the tapware product category, the majority of the company's products that have successfully made it to launch can be considered mainstream and tend not to differentiate on technology. However, their shower products are differentiated from competitors with respect to unique spray technologies developed by the company. The R&D team can spend anywhere between 2-10 years developing a different way to spray water. When this technology is ready, the NPD team develops a commercial product around it and a new shower product platform is launched; this allows for the development of many product variants that are sustained for many years. Nevertheless, the new spray technologies are often a variation on existing types (soft versus hard) accepted by existing markets; therefore, the products which emerge are not considered to be radical.

As part of this research, new products launched between 2016 and 2019 were plotted across an uncertainty matrix to illustrate the types (radical vs incremental) of innovations the company has focused on. The only radical product which successfully made it to launch occurred in 2011; however, this product was considered to be a failure and it was quickly discontinued. The product required consumable cartridges in order to function, and yet throughout the NPD process they did not evaluate the supply chain for these parts and therefore consumers were not able to obtain them easily. The Design and Innovation Manager and R&D Manager were individually questioned during short interviews as to what led to this outcome and what they could have done better. Both agreed that they had not considered the consumers' requirements with respect to the consumables during the NPD process. They supplied the cartridges to a bathroom store, an unlikely place for consumers to visit regularly, making it difficult for them to purchase them. Had they considered their customers' expectations better they may have been more likely to supply them in alternative retail locations such as a hardware store or supermarkets.

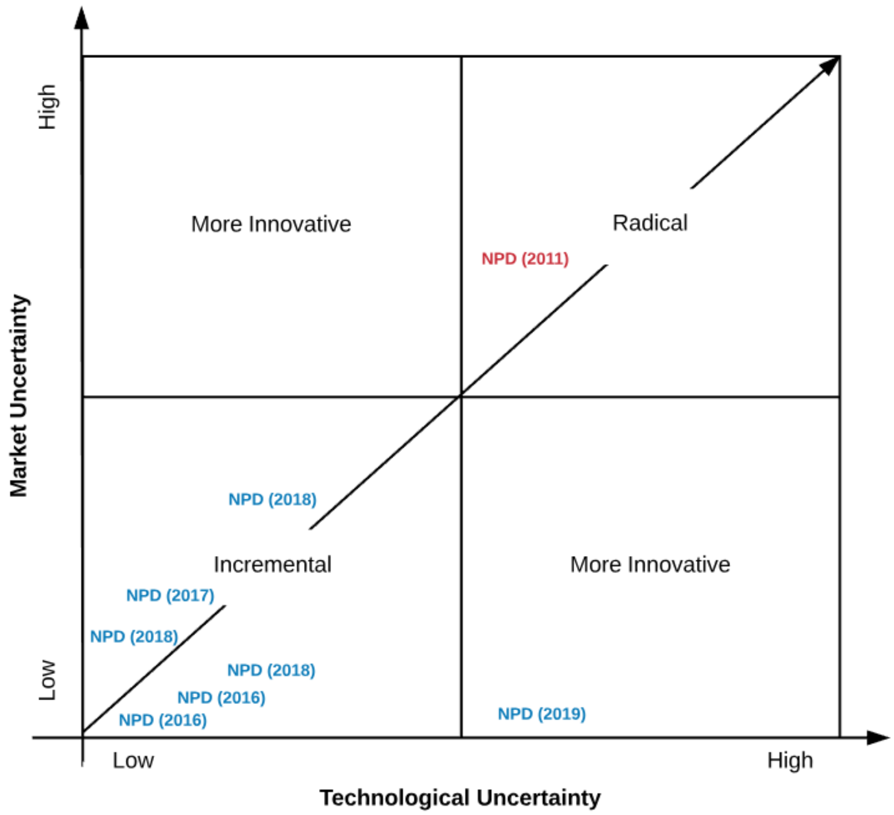

Figure 35 Product Uncertainty Matrix (Adapted from (Holahan et al., 2014))

Compared with their direct competitors, the company may be considered risk adverse, launching only shower and tapware product variants where they already have considerable experience. More specifically, they have not launched any digital products while their direct competitors have – this is primarily due to a lack of R & D experience in this area. Their new products tend to market the value of new experiences or trends in aesthetics rather than additional functionality or manufacturing expertise.

Products are designed and sold into multiple countries with different plumbing standards and constraints making them global products. The R&D team is responsible for ensuring new and existing products are updated to ensure compliance with these standards.

4.2.2 NPD activities

The following section describes the activities performed at a strategic and operational level. These are based on the observations and internal documentation over a three-year time period. Figure 36 provides a high-level overview on how the strategy informs the various activities that occur within their NPD.

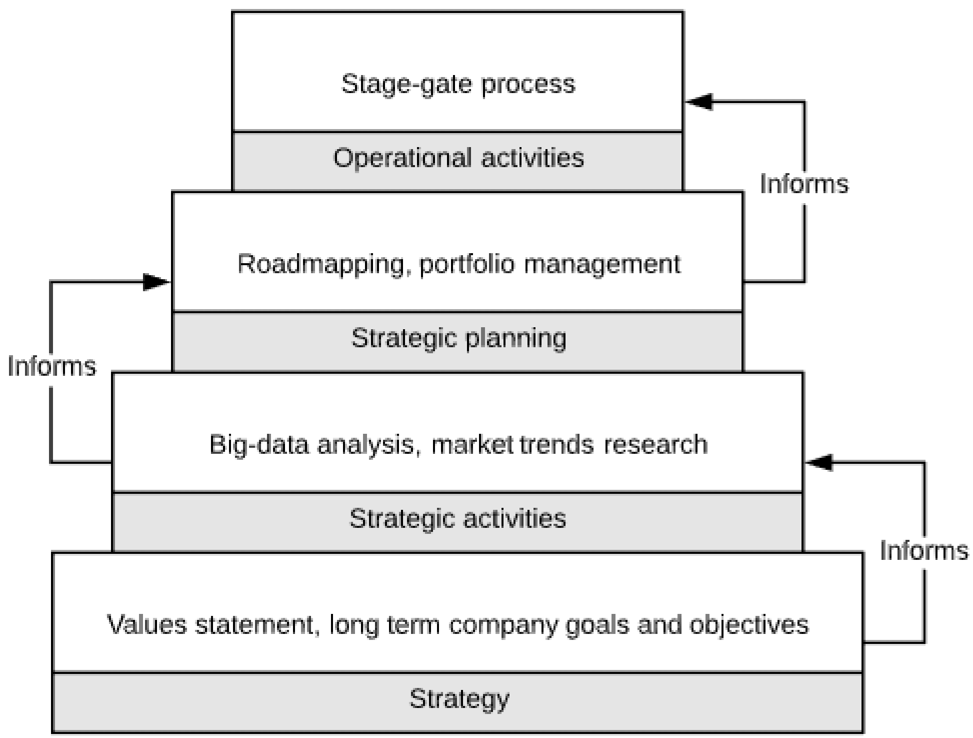

FIGURE 36 STRATEGY AND OPERATIONAL RELATIONSHIP

Strategy

The company has four value statements that represent what the company stands for and how those within the company should operate. The value statements have been excluded to preserve the anonymity of the company. It has defined goals and objectives; however, these are generic in nature (i.e., resembling brand slogans) rather than specific targets. There is no organisational direction or objectives other than a financial goal to be obtained within a specific time period. With respect to this goal, there appears to be no long-term formal plan to achieve it. The different business units (manufacturing, marketing, new product development, operations) do not work cohesively to plan their specific strategies.

Strategic activities

The company performs analysis and interpretation of big data and market trends that will impact the industry and identify broad areas they should be focusing on – this activity is conducted by a team at the CEO and director level. As an example of an output of this activity, the team identified the use of digital technology becoming more prevalent in the home (smart technology, internet of things). This information was relayed from the CEO to the product innovation executive with the aim of having the innovation team focus on new product development of digital technologies and their integration into existing products.

As another example of output from this activity, the team identified the fourth industrial revolution (known as Industry 4.0) as relevant and provided general terms on how their manufacturing processes needed to improve. This information was forwarded to the manufacturing executive to push at an operation level.

Strategic planning

Product development road-mapping is usually divided in quarters and covers an entire year. As with the strategic plan, this activity is done in isolation by the innovation group and does not include the other business units or experts (e.g., from Operations, Finance). Road-mapping provides a high-level snapshot of all the new product development projects currently in the pipeline. The organisation breaks its innovation into two distinct groups: 'global' and 'market specific'. Examples of global innovation include internal R & D projects, where technology is refined and packaged into a new product, or line extension projects where existing product development projects are 're-launched' to create variations of existing products to fill a gap in the market that relates to a small change in its characteristics (colour, size). Market specific innovation is the procurement and resell of products available from manufacturing partners. Consumers and resellers will highlight an opportunity which is picked up by the market specific manager, a draft proposal is formed, and then forwarded for approval by the operations team.

Operational activities

At an operational level there are many defined activities that occur in a structured sequence. The organisation uses a stage-gate model (Figure 37) for its new product development process, which has been refined over the past 30 years from ten stages to only four stages. This is claimed to "streamline the process" and make it less clunky for the operations team. In addition, it was thought this would speed up the development process allowing for faster NPD, a requirement of the organisation's business strategy. The NPD process manager described the process as "mostly followed".

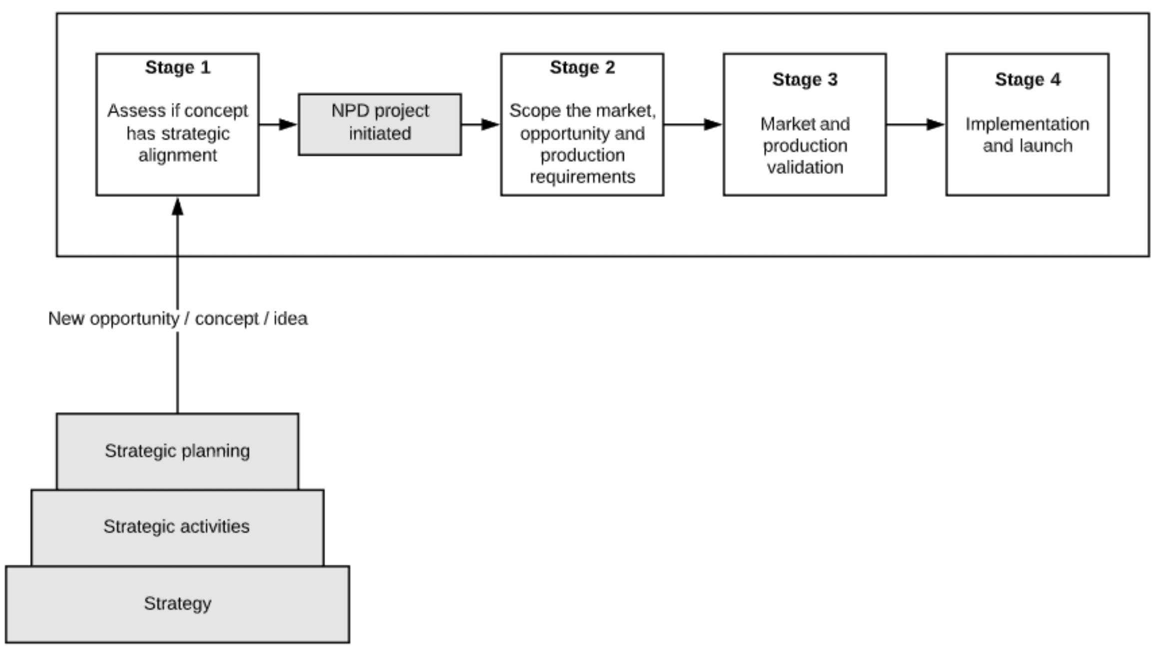

FIGURE 37 CASE COMPANY STAGE-GATE NPD PROCESS

Stage 1 is predominantly about validating a commercial opportunity that has been identified during strategic planning. This stage is primarily concerned with defining the potential NPD project in an opportunity statement. The statement describes the idea, how the product or opportunity might look, the markets it would be sold into, and initial supply or manufacturing considerations. Often a new idea moving through this stage will presented as a proposal to those in attendance at the Stage 1 gate meeting. If the idea is for a new product or technology, some artwork or a prototype may be demonstrated.

Stage 2 scopes the opportunity, defining in far more detail the market opportunity and scope. At this stage, an NPD project has been officially launched and resources have been allocated, which will include one or more engineers and industrial designers. Many technical descriptions of the NPD project must also be outlined at this stage including tooling, technical specifications and production scope. The documented purpose of the stage is stated as ‘outlining the NPD project and the opportunity that it is targeting’. These include:

- Seven tasks that scope the market opportunity and target customer group
- Seven tasks are intended to provide an understanding of the manufacturing requirements,
- Eight tasks are required to understand the product space with respect to the Voice of the Customer and added value,
- Three project management tasks provide a high-level project plan and resource allocation
- Three financial evaluation tasks provide an indicative investment and return.

While the process documentation states that the purpose of this stage ensures that development resources are used on projects with the highest strategic value, there are no formal tools or techniques used to allocate resources. Should the NPD project not make it to the next stage, this information is quantified and used to score the project; the information is stored in an ‘opportunities matrix’ which is used by managers to balance the portfolio of products with respect to resource and markets. If engineers or designers have available time for NPD projects, they will review this matrix and potentially reinstate a project.

The Stage 3 primary objective is to ensure that the NPD project meets customer and business objectives before capital is spent. This includes defining what the long-term financial commitment to the business is with respect to marketing and manufacturing. Market data that defines the size of the opportunity will then be used to define the production plan and volume required to meet that opportunity. At this stage many front-end activities are further defined such as design trends and user-centred research as well as identifying the competitor landscape and where the product in its current form would fit.

Stage 4 is described as a ‘two-gate phase’ yet the gates within this stage are unclear and not documented. The purpose of this stage is to execute the production and marketing plan that has been formalised in stage 3. As with Stage 3, there are front-end tasks such as determining freedom to operate with respect to patents and other intellectual property. Most other tasks listed within this stage relate to specific technical aspects being completed such as the creation of a Bill of Materials, and that product samples have been created, checked and approved.

The criteria at each stage of the process are task specific. Provided the tasks have been completed, the project can move from one stage to the next. This is further expressed in the implementation and management of ‘milestones’ within the process. Rather than gates that the project must pass through, the organisation identifies milestones which represent the project has met an objective (i.e., completed all tasks in list), rather than specific criteria such as product technical or financial requirements. In this approach, the process behaves more like a project planning tool and often fails to formally explore, screen, and evaluate new ideas into commercial products or services. For example, the task “idea generation” may be completed and therefore is marked as done – further progressing the project to achieve a milestone. However, there is no metric for idea generation that would allow them to evaluate how well this task was done, and if it was adequately completed to progress further. These tasks are discussed at 'gating meetings' which are held periodically (every 3 months) or when a new project requires initiation. These meetings are used as a point to talk through the progress of tasks for every new product development project at all stages, acting in part as a portfolio management tool. For each project, the task lists for each stage are worked through and many technical and financial documents are presented to those attending - some of the documentation can occasionally challenge the design requirements and successful outcomes of the project. If this occurs, the issues are discussed and debated by those in attendance and a go/no-go decision is made qualitatively. A behavioural rule of these meetings states that all those in attendance should be aligned with the decision and no-one should leave the meeting unhappy with the outcome or decision. Those usually required to attend are the heads of each department (i.e., Marketing, NPD, Operations, and Innovation); the project lead or engineers do not need to attend.

4.2.3 Project Initiation & Type

NPD Projects

Projects which enter the stage-gate process typically come from the 'global innovation management, and 'market specific procurement and resell' (see Strategic Planning). There is a much shorter development process specifically designed for the latter, which is essentially used to ensure that there is corporate alignment to the proposal and that the product or product range has included some financial and market assessment. This also allows the innovation team to track existing products and new products so there is a good understanding of the company's product portfolio. Ideas or concepts that formalise an NPD project typically come from previous killed projects (with justification to relaunch the project from a manager), R&D projects or from the marketing team that has identified an opportunity (discussed in Section 4.2.2). In a three-year time period, the innovation group performed two idea generation sessions. None of ideas led to formalised NPD projects. Therefore, the useful ideas come from only a select few within the company.

R&D Projects (and their relationship to NPD projects)

R&D projects often precede NPD projects. They can be launched by non-formal idea generation methods or by expert engineers performing blue sky development in-house. Sometimes R&D projects will be influenced by the strategic roadmap, directing the team to focus on areas of interest (e.g., integration of digital technology –discussed further in later in this section). Often when a prototype is developed or when the developed technology has some form that can indicate how it could be a commercial product, it will be assessed within the first stage of the NPD process (Figure 38). Provided some market and manufacturing opportunity is identified, a formal NPD project will be launched. The most common example of an R&D project developing to an NPD project is when a new type of shower spray is created. The organisation has developed a number of different spray technologies, and while the technology is very unique, it will always follow the same development pathway within the new product development process when packaging this technology into a new commercial product.

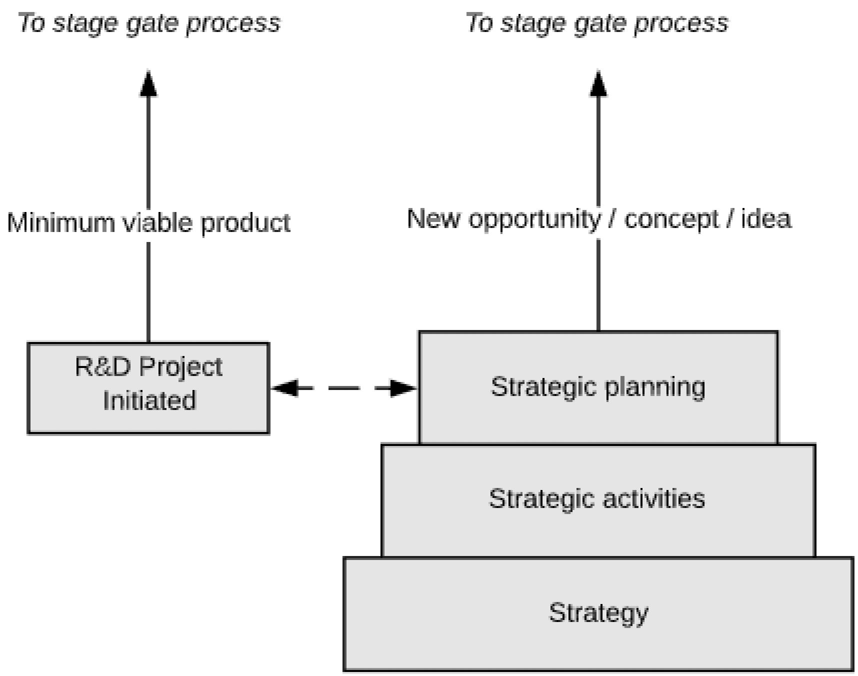

FIGURE 38 R&D PROJECT INITIATION

Other common R&D projects focus on evaluating existing technology to identify if it can be packaged into a new product or if it meets existing product standards. A typical example was the development and integration of digital technology and smart home ideas. Over the course of the study, several digital projects were initiated – none were successful in becoming NPD projects during the study. R&D projects are not communicated formally to the NPD team. The transfer of information is reliant on an R&D engineer approaching the head of Product Management to explain what they are working on. The head of Product Management considers that this approach needs to change, suggesting that "The projects that R&D are working on need to be scoped to determine their purpose or business opportunity, otherwise there is a potential that we are just wasting resources". Indeed, the process for managing R&D projects is different from NPD. A typical project R&D project follows its own macro level process as illustrated in Figure 39.

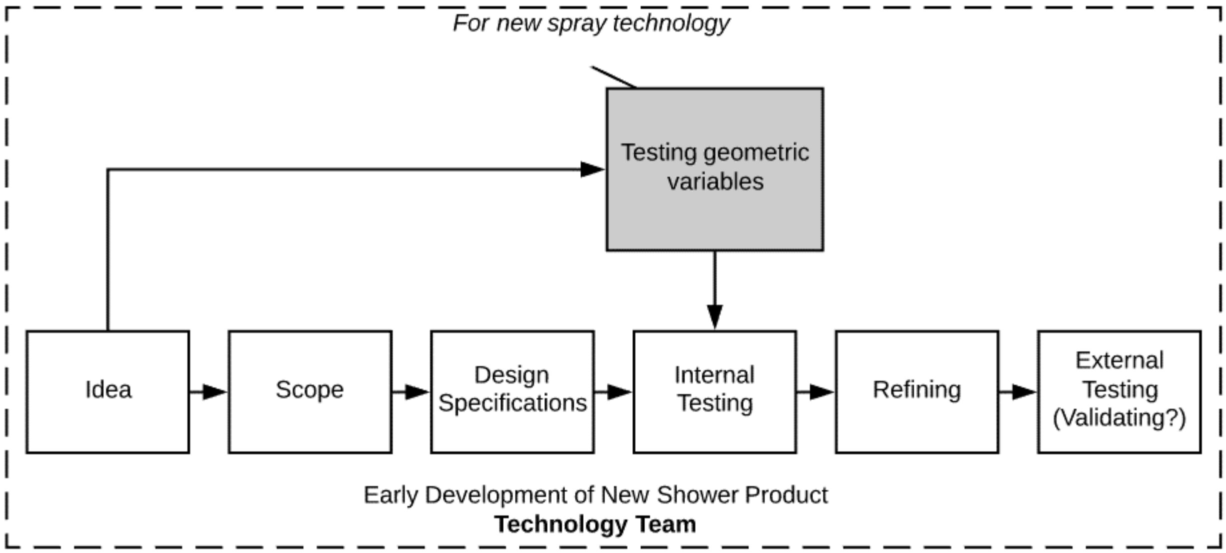

FIGURE 39 R&D PROJECT PROCESS

A common R&D project will identify different ways to spray water usually by colliding water droplets in a unique way that modify the feel and overall experience for the user. A less common R&D project investigates how digital technology can be embedded into existing products. Examples of these products include digital displays and interfaces, controls and sensors that allow the flow and temperature change and transmitting and recording systems that send feedback to the user. Currently no digital project has made it to commercial launch. Often these projects are not given the same level of market research into the demand, technical feasibility and overall resources compared to that of other projects. Evaluation is often done using 'gut feel', typically undertaken by the Head of the innovation group.

Pet Projects

NPD projects can also come from outside the design and innovation group. These projects are best described as "pet projects" since they tend to skip the early validation stages of the NPD process. Often these ideas come from senior management such as the CEO or a high-level manager. As an example, it was proposed to the CEO in late 2018 to launch a new line of product variants by purchasing a new piece of manufacturing equipment and integrating this into the manufacturing process. This project went ahead without identifying the market opportunity and performing some financial cost/benefit analysis. As a result, the company spent a large amount of capital and resources on initiating the project. When the project finally made it into the stage-gate process for evaluation they found that they did not have the demand to sell the units at the appropriate price point that would be required for the project to be a commercial success. At this stage it was too late to kill the project and it still went ahead. Another example was a tapware project which was initiated by an executive who thought it was simply a good idea. This was passed on to one of the senior product development engineers and industrial design experts who worked collaboratively for over a year developing this product. When the project was nearing a point where detailed design and technical requirements would be defined that would allow for manufacturing tasks to occur (known as a design freeze), it was only then evaluated against some market, technical and financial criteria. They quickly realised that there was no market for the product and that it had even less opportunity for success when considering other factors such as manufacturing capabilities for what was a radical design. The project was killed before significant capital investment was made; however, over a year of resources had been wasted on pre-development.

4.2.4 NPD Best Practice Survey

The NPD best practice survey was a discrete piece of research that occurred in the early stages of the case study. The purpose for conducting the study was to gather additional data on how individuals within the company believe they perform NPD activities compared to NPD best practice (as established by Kahn et al. (2006). The method for creating the survey and collecting responses is provided in the case study data collection procedures (Section 3.4.1). The results from the survey are descriptively summarised in this section. Any insights or key findings from the survey are triangulated with other sources in Chapter 6. There were 19 responses to the survey, which represents all members of the innovation group. Each element is briefly discussed while highlighting any trends or interesting responses. Overall, the results indicate that the innovation group do believe they have some best and poor practices. The full survey results are provided in Appendix E.

NPD Best Practice Survey Responses

Best practice looks at six elements of NPD – strategy, portfolio management, NPD process, culture and tools and metrics (Section 2.1). With respect to strategy and portfolio management, the respondents selected mostly answers that would suggest they are following poor NPD practices (Figure 40). Most agreed that there are either unclear NPD goals, or that the NPD goals are only clear in the silo team they are operating within. With respect to portfolio management, the company views NPD as short-term with most agreeing that they have poor practice with respect to project prioritization. Half of respondents claimed that managers' pet projects are ranked either highest or second highest (out of six choices) as the determinant of project selection and consider the process to be informal and flexible. However, many still claim that they balance their portfolio and have some regard for a mix of radical and incremental NPD.

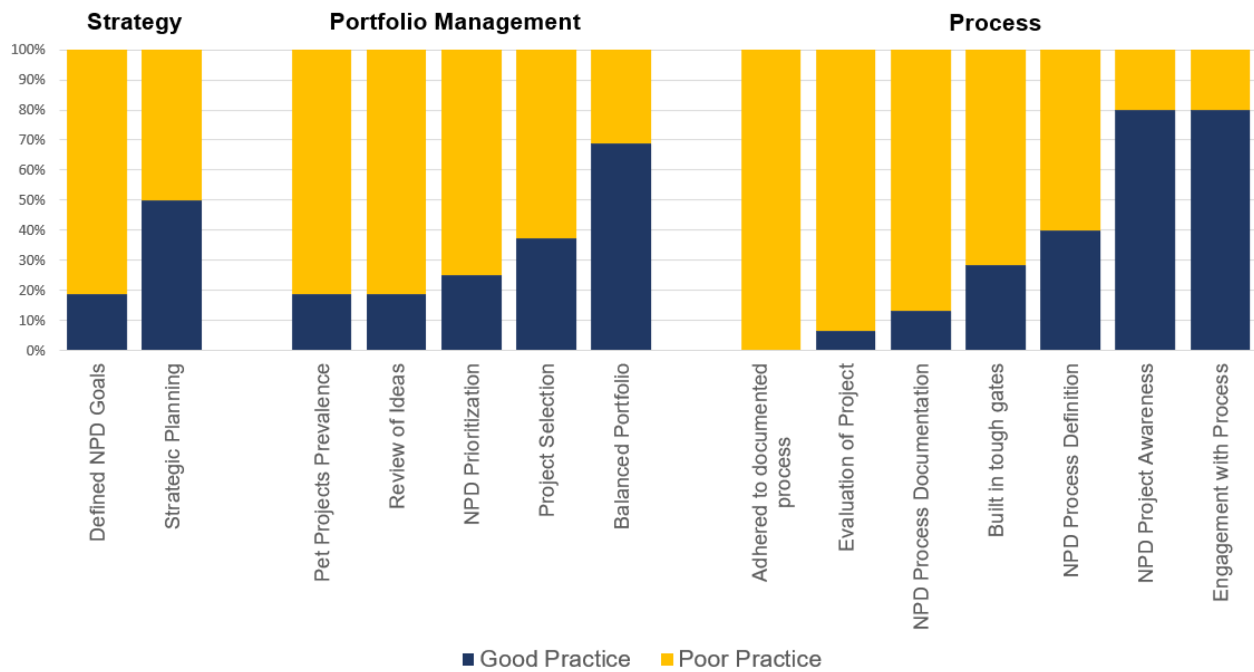

FIGURE 40 SURVEY RESULTS - STRATEGY, PORTFOLIO MANAGEMENT, PROCESS

With respect to process, the survey indicated that there is good awareness of the NPD process and most agreed that they are engaged with the process. However, most could not adequately describe the process, perhaps due to lack of documentation and visibility. All claimed that it could be readily circumvented with most claiming that it lacked "tough-gates" between each stage of the process.

The innovation group has a better opinion of their practices with respect to culture and the organisational structure. The teams have some cross-functionality, communicate well and has strong leadership for NPD projects. While the majority claimed that there was internal entrepreneurship, most agreed that they do not have the opportunity to work on their own projects. Most developers and middle managers stated that their focus was frequently directed towards non-NPD work.

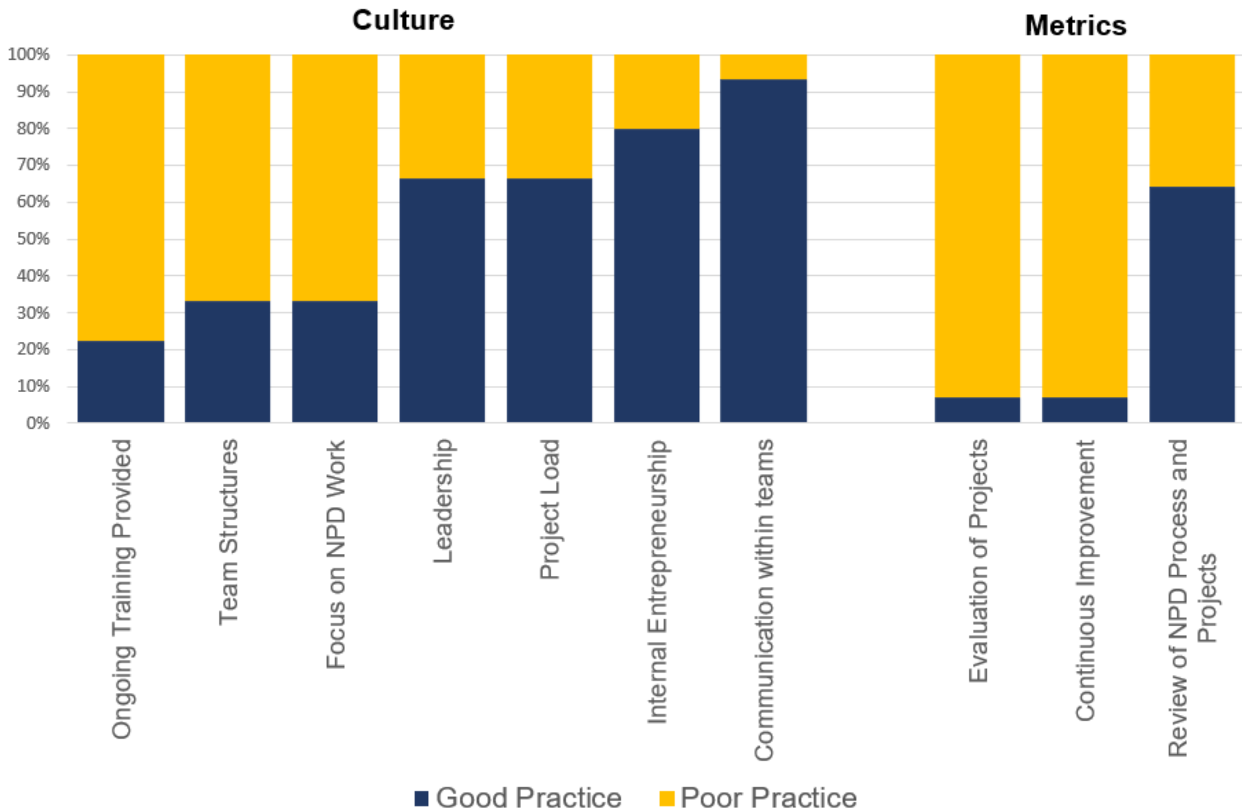

FIGURE 41 SURVEY RESULTS - CULTURE & METRICS

Most respondents selected answers that reflected poor practice within the metrics elements, indicating that they do not practice continuous improvement.

For tools and techniques the innovation group selected responses that suggest they are doing mostly poor practice. When asked if a project charter was used, 50% of respondents selected yes; however, when asked about important aspects that should be included in a charter (such as describing the value proposition for the customer and the features and requirements) many responded that they were not doing this. More than 50% responded saying they do have Idea Generation sessions; however, they also responded that they do not use any idea generation tools.

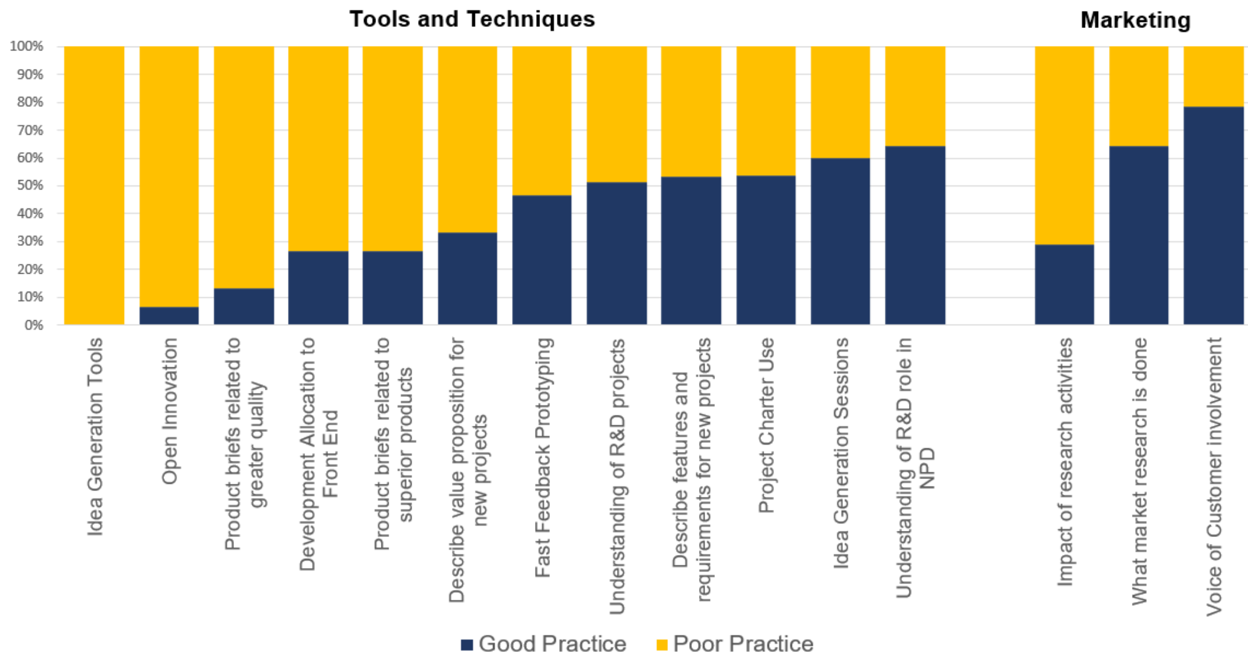

FIGURE 42 SURVEY RESULTS - TOOLS AND TECHNIQUES, MARKETING

Most respondents selected good practice with respect to market research. Most agreed that market research was being undertaken, and that this practice also included the voice of the customer; however, in a related question they indicated that these activities are not informing their NPD.

Eco-design survey responses

As with the NPD best practice survey, these responses have aggregated 'Strongly Agree' with 'Agree' and 'Strongly Disagree' with 'Disagree'. There was no neutral response option. The aggregated responses for agree/disagree for the first eco-design question are provided in Figure 43. The question asks the team to indicate what they believe prevents them from performing eco-design. It can be seen that the two most significant barriers the team identified were a lack of formalised eco-design plan and customers do not care [about environmental impacts of their products]. However, it can also be seen that the team considered that a lack of marketing budget and a lack of eco-design knowledge are preventing them from developing eco-products.

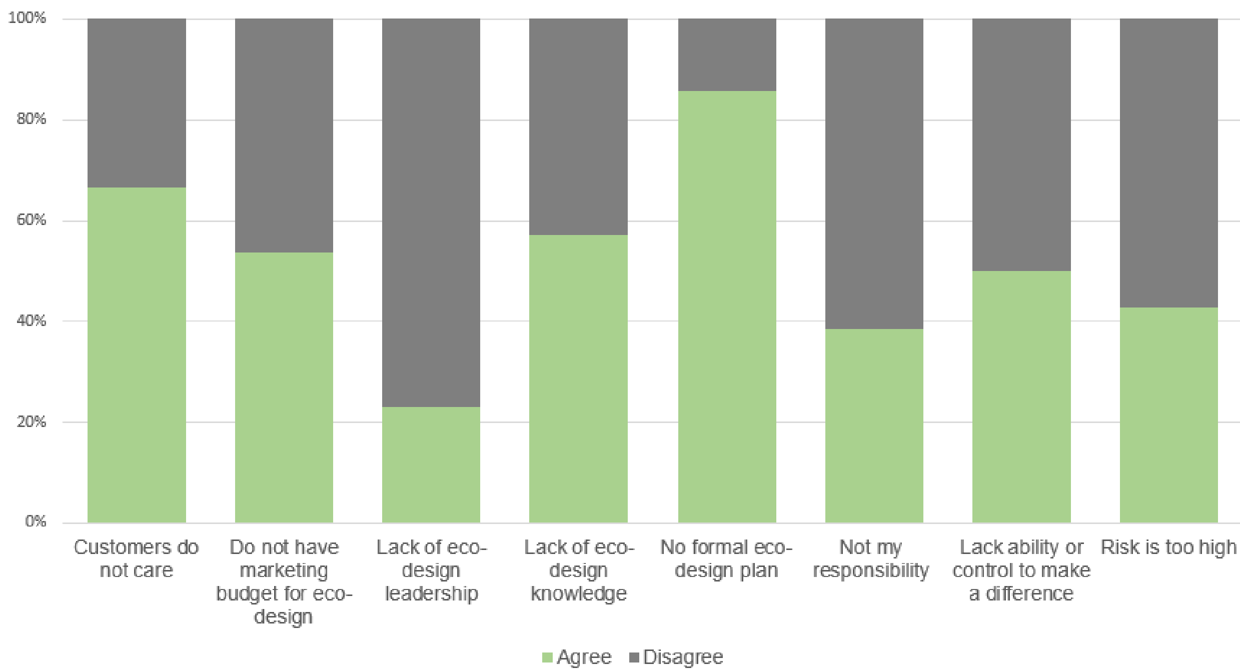

FIGURE 43 SURVEY RESULTS - ECO-DESIGN BARRIERS

The second eco-design question asked what type (class) of eco-design would be most appropriate for the innovation team to perform (Figure 44). Most agreed at some level that they should create new eco-products. These were described to the team as eco-products that have environmental performance at the forefront, which are marketed and sold as a better alternative to existing products. Ecosystem-based products and product-to-service models (such as Circular Economy) were collectively thought as less appropriate.

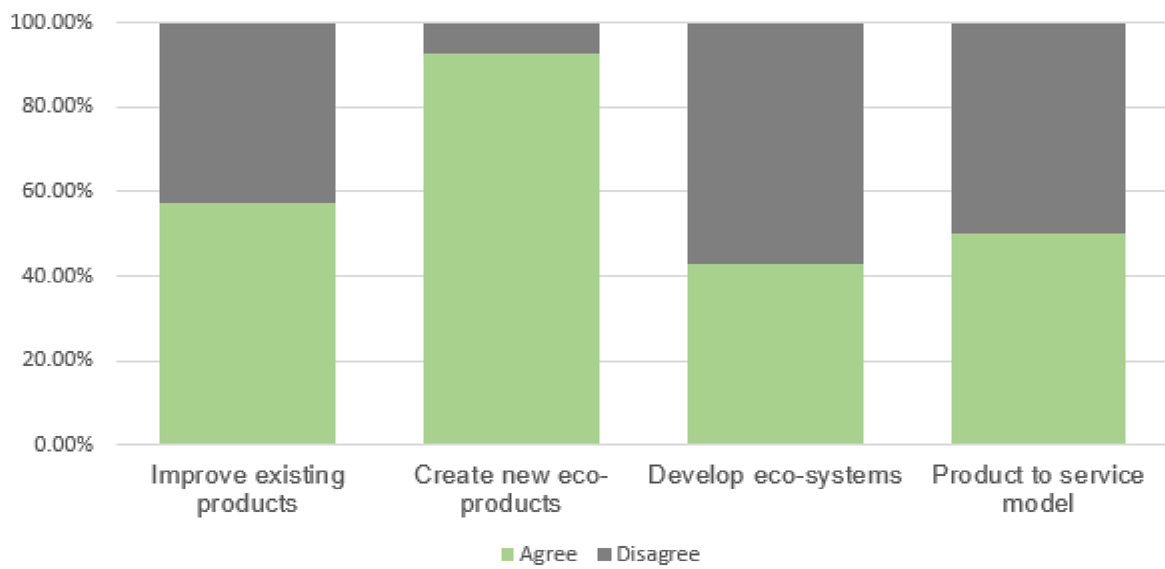

FIGURE 44 SURVEY RESULTS - ECO-INNOVATION TYPE

Question 3 asked the team to select the most appropriate answer to describe the current eco-design actions of the company (Figure 45).

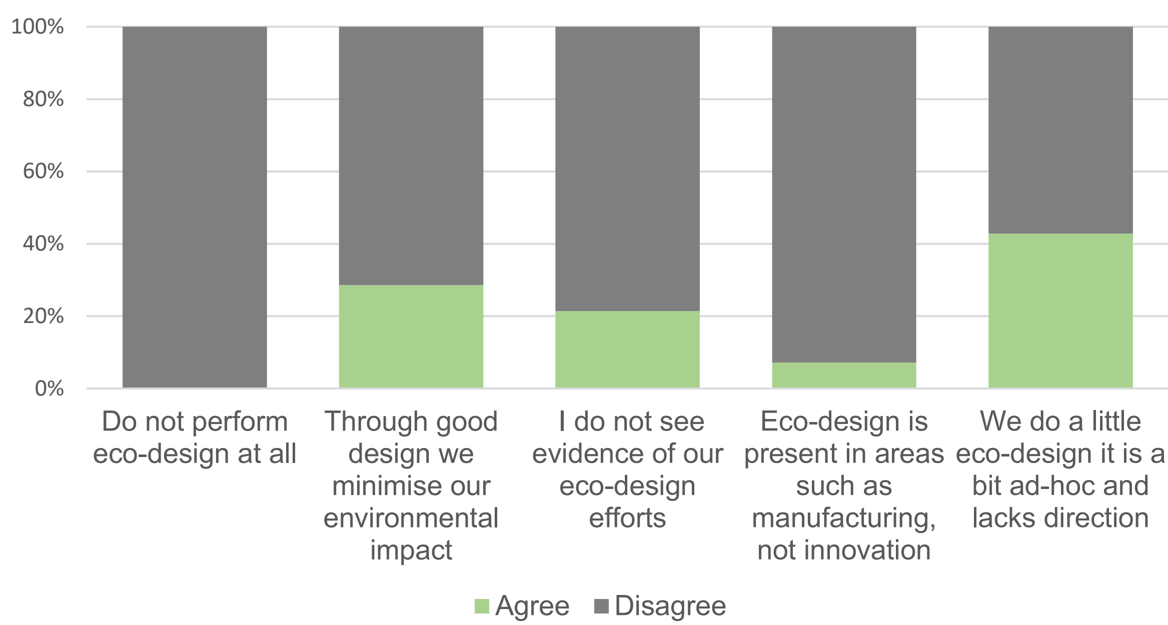

FIGURE 45 SURVEY RESULTS - ECO-ACTIONS WITHIN COMPANY

No-one within the team believed that they were not performing eco-design; however, most thought that it was ad-hoc and lacked direction – a result consistent with the first question where most believed the barrier to eco-design was a lack of formalised plan (Figure 43).

Question 4 asked the respondents to rank in order (5 highest, 1 lowest) which team could have the greatest impact on the eco-performance of products. This is used to weight the responses where the percentage of responses is multiplied by the rank (i.e., if 50% of respondents rank the industrial design team as having 25% impact on the eco-performance of products this produces a value 0.1. The result for each team is the sum of these weighted values (Figure 46). There was not strong agreement on which team has the greatest impact on the eco-performance of products.

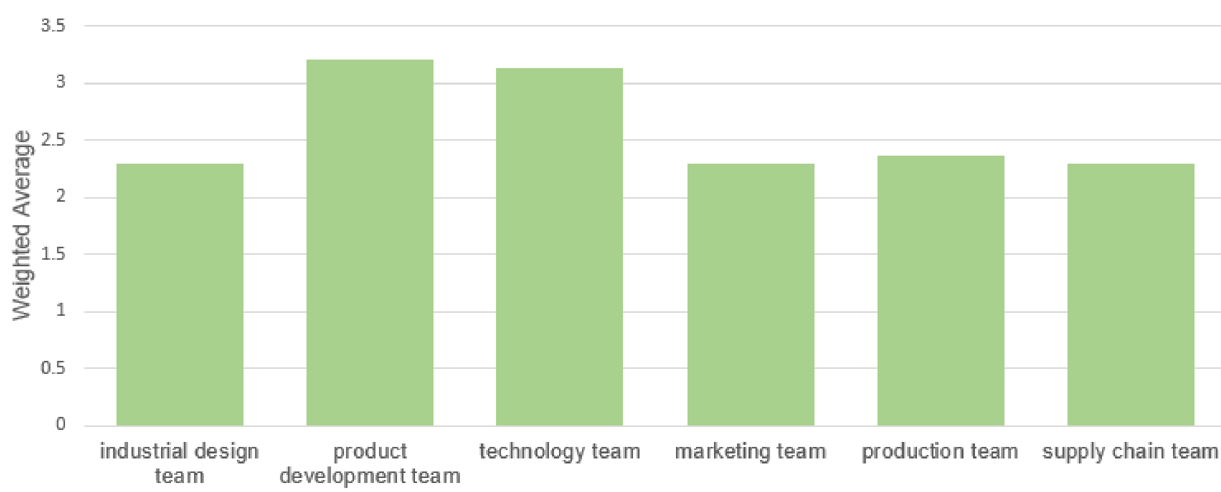

FIGURE 46 SURVEY RESULTS - TEAM LEVEL IMPACT

The fifth question asked the team to rank what they believed was the most appropriate metric for evaluating the environmental performance of new and existing products (Figure 47). Energy and flowrate were thought to be the most appropriate. Results of a full life cycle assessment was thought the third most appropriate. Average freight distance was thought the least appropriate.

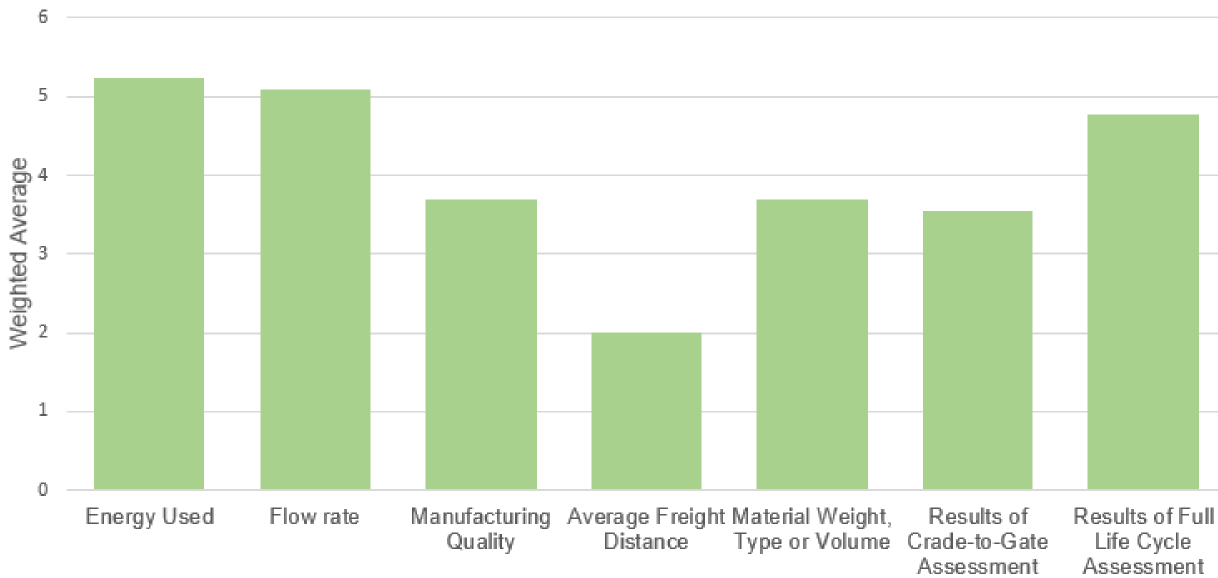

FIGURE 47 SURVEY RESULTS - BEST ECO-METRICS

Overall, the respondents collectively aligned on some environmental issues. However, it is clear that there is no definitive environmental goal that influences the team within these areas. In the final environmental directed question, "Does your organisation genuinely deliver environmental products", 35% of respondents chose to provide their own answer. Most of these answers reflected an opinion that they needed to do more to be able to genuinely deliver eco products with some recommending the need for a formalised environmental plan to enable change.

4.2.5 Summary of NPD capability

One of the most notable observations of the organisation's NPD capability is that their stage-gate process is either reported as not being followed or poorly executed. In a number of interviews, engineers and managers referred to the process as “only given lip-service” or “not always followed”. In addition, pet projects were reported to be prevalent and are only ‘picked up’ and terminated in later stages of the product development process. With respect to execution of the NPD process, there is a lack of evaluation criteria within the stages that might be described as tough-gates. Instead, the process acts only as a project management tool, with a number of tasks which require completion at each stage. In order to move from one stage to another, rather than a robust review process, the gating team subjectively debates the merits of the project to determine if there should be a go or no-go decision. There are also a number of front-end tasks that are occurring in later stages of the development process which could suggest that they are not doing ‘upfront homework’ to better define the business case and opportunity. The best practice survey results suggest that team has a good opinion of how they manage projects from idea to launch and this could reflect the comprehensive checklist of tasks that they have embedded in their process documentation.

There is evidence that they develop their products for a global market, particularly with respect to technical and quality aspects (i.e., plumbing standards). However, from a user experience perspective the customer research data that is intended to influence product development practice only comes from a local market which is then generalised to global markets. This is primarily due to a lack of resources or capability to do consumer product testing in other markets that they sell to (UK, Australia, US, China). Indeed, based on the best practice survey, many of the innovation group believe that, despite the input of user experience data that might represent the voice of the customer, this rarely impacts the design.

The other significant observation is that the R&D team and their projects appear to be mostly disconnected from the rest of NPD; it is only incremental NPD projects (i.e., products that they have experience with such as the development of a new shower spray technology) are they given further consideration and formalised. The process of identifying if an R&D project is a future NPD opportunity is completely reliant on the Head of Product Management's informal meetings with R&D engineers or the subjective evaluation completed by the Head of Innovation Group at the request of an engineer or middle manager.

4.3 Environmental drivers

4.3.1 Company eco-initiatives

There are a few activities which occur in different departments that are best described as eco or environmental initiatives. Each represents a situation where an opportunity to improve the environmental performance of some aspect of the business was identified, and a system or programme was put in place to address the problem. Improvement activities focused on environmental aspects were identified in four different business units: Human Resources, Manufacturing, Marketing and Operations.

Human resources have implemented an employee waste management system which separates out organics, plastics and paper. This is supported by ongoing training to ensure that staff are disposing of their waste in the appropriate bins. Another eco-initiative was the implementation of charging stations for all staff electric vehicles. This is intended to incentivise staff to purchase electric vehicles, allowing them to charge for free at work.

In **manufacturing,** the organisation removed lead-based products as lead is toxic to humans; the replacement is a silicone-based alternative which is more expensive but apparently better for the environment. Recognising the large quantities of water consumed during quality testing of new and development products, the **operations team** implemented a recirculating water system. This is intended for only freshwater testing of products and does not recirculate employee grey water.

With respect to **marketing**, the organisation recently began work on their first Environmental Product Declaration[3] with the assistance of an external partner that has experience with conducting Life Cycle Assessments. Initially they purchased a licence for LCA software with the intention to eventually use it within the NPD process. However, it was only ever used ad hoc and never in great detail. When faced with the cost of renewing the licence they could not justify continuation. This was also due to the lack of expertise that the staff has. They claim that it would take a very long time to become good at using the software, and even then, they would not know how to use it as well as the experts. They now prefer to have the third party do all of the LCA modelling for them since the quality and flexibility of the models would be more robust with fewer errors. In addition, they claim that in this way they would have access to all of the datasets not available with the standard licence. However, the company did see one drawback from this approach based on how the third-party company may not have a good appreciation for their supply chain or product knowledge. Therefore, communicating the data could become clunky, consequently slowing the LCA process to a point where decision support for design changes may not be delivered in a timely manner.

4.3.2 Circular economy project

With the popularisation and awareness of Circular Economy principles, and a desire to improve the efficiency of their production and supply chain, the company launched its first environmental project aimed at recovery and reuse of products. One of the senior engineers proposed to the CEO that stainless manufacturing of many of the parts for their products could open up opportunities in the area of recycling and reuse. Some existing parts are brass or plastics which are chrome plated, making their recovery and remanufacture technically unfeasible. The basis of

[3] Environmental Product Declarations (EPD) are transparent, verified and comparable information intended to communicate the life-cycle environmental impact of products. They are standardised by ISO 14025 and EN 15804.

the proposal was inspired by examples in the automotive industry where parts, which were generally just superficially worn but still had value, could be recovered, stripped back and restored to a new state through some type of manufacturing process and sold to a customer again. Using these principles as a starting point, a new project was initiated with the goal of producing a new product line with stainless steel as a substitute material for chrome-plated brass and plastic.

This project followed the four phases of NPD as described in section 4.2.1. Across all actors within the project there was an agreement on many of the drivers for this project:

- It provides an alternative to chrome plating - a manufacturing process which is expected to be prohibited in the future
- It provides an alternative to brass – trends show this material is becoming more expensive
- Material substitution provides capacity to recover and reuse parts
- It has potential to improve the company's green credentials.

During interviews with the project initiators, the objectives were stated to include:

- Manufacture internally (onshore) – as this would provide flexibility and control over the reprocessing and remanufacturing stage
- Primarily develop a new tapware product with an expectation to include stainless steel in an upcoming new shower product
- Solution needs to be designed for ease of disassembly and remanufacture

The project was developed over three years. It did not achieve the first objective. While it was designed to be remanufactured, no recovery program was officially planned or launched. Throughout development there were three major points that were raised that had some degree of influence over the project and its outcome.

Firstly, there was strong agreement between stakeholders that the existing operations team did not anticipate or were informed of the requirements for the project. When the project plan was communicated to other business units, there was evidence that there was room for interpretation of the goal and objectives of the project. This situation is reflected in Figure 48 where some of the secondary objectives became the main goal of the project such as the substitution of a material which was currently under economic threat, while other goals were primarily based on the bias of individuals in a position of great influence. Coming from a background of aesthetics and user experience, the innovation manager placed greater importance on these design aspects over any others.

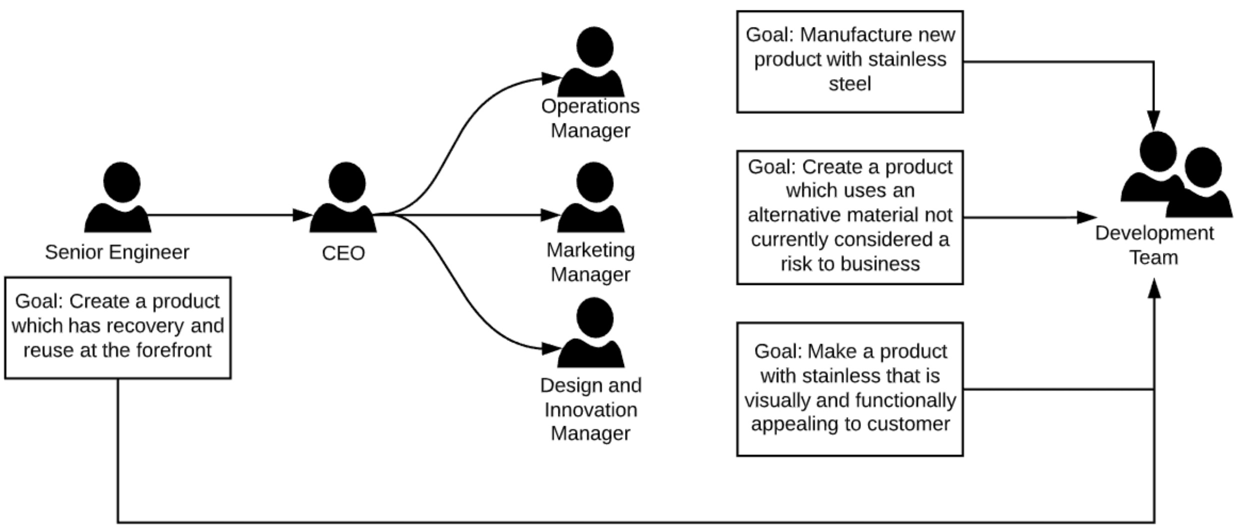

FIGURE 48 DIFFERENCE IN GOALS ACROSS DEPARTMENTS

One of the reasons for this lack of alignment was due to a perception that, as stainless steel was 100% recyclable, the responsibility of end-of-life of the product would not necessarily fall on the organisation to recover and repurpose – that there would always be an environmental saving due to the material property. Therefore, the need to recover and repurpose internally was not given adequate consideration. This is further reflected at every gating meeting, where the only evaluation this project received was with respect to scheduling and economic feasibility. There was no discussion or evaluation of the initial objectives throughout the gating meetings. As a result, it was decided to move the manufacturing offshore. A key stakeholder in the project stated "We are stuck in this old way of thinking; we move everything offshore mainly due to our need to achieve a faster return on investment. We are very short term focused".

Secondly, design changes occurred constantly throughout the project, and this slowed the development. While the product development engineers expected an iterative development process, many of the design changes were extreme which caused many of them to question how informed the project was. One of the senior NPD engineers stated that, "The design changes seem to be baseless and can only be an example of poor upfront scoping where we have not included the voice of the customer".

Lastly, when the project was completed a Life Cycle Assessment was initiated by the researcher to determine the environmental outcomes of the project with respect to manufacturing and end-of-life. The LCA indicated that across all relevant environmental impact categories the new product performed worse (see Appendix H for the full LCA).

The LCA results were presented at a seminar to the innovation team. It came as a complete surprise to most with many appearing to be rather upset at the results. The chief marketing officer responded at the end of the presentation by saying "this is very sobering". This is comparable to the example provided in section 4.2.1 where the company failed to provide replaceable cartridges for the new product. Both examples demonstrate a lack of upfront homework completed by the company leading to poor or failed products (regardless of the context e.g., eco-design).

4.3.3 Eco-product strategy workshop

In the early stages of the study, an in-house seminar was presented to the engineers, designers and managers from the product development team and was followed by a practical workshop. At the seminar, the researcher introduced the concept of Life Cycle Thinking and presented the results of an existing Life Cycle Assessment (LCA) study of a shower product (Institut Bauen und Umwelt e.V, 2011) to show how the use phase dominates the environmental impacts for this product category. This seminar also included details on the magnitude of the problem by highlighting important information from the literature review on household water and energy use and where this fits within the larger global problems such as water scarcity and global warming.

The subsequent workshop followed four distinct steps to generate strategies and then evaluate those at an operation level (Figure 49). The first step involved all of the innovation group working in teams to brainstorm new ways that shower and tap products or components could influence the use phase. Step two brought all the teams back together to discuss their ideas and evaluate them as a group. During this step some bad ideas were filtered out on a gut-instinct evaluation. An example of a bad idea was “creating a shower spray and product that people did not enjoy so they would spend less time showering”. While this idea may improve the environmental performance of the shower with respect to the use phase, the team agreed that the trade-off with respect to the commercial opportunity made it infeasible to pursue further.

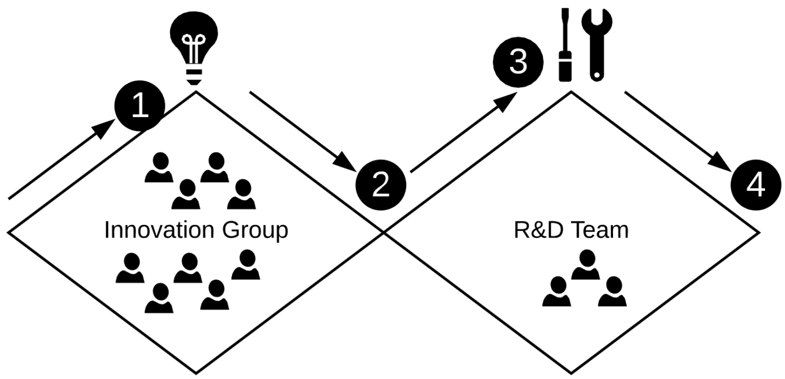

FIGURE 49 PRODUCT STRATEGY WORKSHOP DEVELOPMENT PROCESS

In the third step in the process, the R&D Team took all the ideas to the next idea generation phase. This was an inductive approach which asked, "What is required to test these ideas and what would the procedure look like", and "How would we implement so the results can inform our NPD practice?". Any design change that might impact the use phase needs to be quantified, yet there is a lack of data that would inform them if the decisions made would have a positive or negative impact on the environmental performance of the product. From this analysis, the R&D team concluded they needed to identify a method and practice for measuring and improving the use phase of their products. This method would allow them to test the generated ideas while refining an approach to eco-design, with the ultimate goal of improving their NPD practices. This was the beginning of the first action case study research cycle.

4.3.2 Summary of environmental drivers

The insights from the three activities related to Environmental Drivers (Figure 1) showed that the company's approach to addressing environmental issues within the organisation is unstructured. Different departments address environmental issues within their department ad-hoc or when they see an opportunity. While the company markets itself as a company that cares for the environment, there is no mandate from top management or formalised plan on how to achieve this, therefore there is no direction for each department or the company as a whole to follow. In the NPD best practice survey, the innovation team was asked what the most significant barriers were preventing the development of environmental products. Most considered that it was due to a lack of formalised plan. However, the second highest rating was the belief that environmental factors are of the least concern to their customers.

Observing the circular economy project from idea-to-launch provided data that helped linked the actions or behaviours of individuals and teams to the final outcomes of the project. While the data contributes to understanding the environmental drivers of the case company, it also provides an example of the operational practices of eco-design (at a material improvement focus) and its integration into NPD. The project demonstrates weakness in their front-end NPD activities as they failed to define a project brief that was communicated across different departments. This lack of front-end work has been observed in similar project (such as the cartridge project discussed in section 4.2.2).

In the innovation group there is an understanding of the environmental hot spots of their products and how life cycle thinking plays an important role in evaluating and improving products. There is an overwhelming agreement across the survey data, interviews and observations that the team believes that water and energy are the best method for evaluating the environmental performance of new and existing products, and that the technology and NPD teams are responsible for improving the use phase of the product. The use-phase workshop demonstrated that the team is prepared to address this phase; however, it was unclear as to what tools would be used to do this, how they would be applied and what the outcomes might look like.

4.4 Summary

This chapter has reported the results of the case study data. This provides information on the company's NPD capability. With respect to NPD capability, the company has had some NPD successes and failures. Best practice has been observed in strategic elements where they demonstrate clear objectives and goals. However, they have some operational weaknesses. Firstly, the stage-gate process isn't followed well. Pet projects are common as they are able to easily circumvent this process. The process also lacks metrics within the gates that would improve the go or no-go decisions when progressing from one stage to the next. Secondly, the voice of the customer is not well integrated into the product development process and often the company fails to understand the demands of different markets. Lastly R&D projects fall into a gap that exists between R&D and the stage-gate process and therefore fail to be formally evaluated at the conclusion of the project.

The environmental driver's section in 4.3 has reported on all known environmental initiatives that occurred during the case study. The company has no environmental plan and takes an ad-hoc approach to addressing environmental issues. The one NPD project that had environmental objectives at the forefront did not carry through to the final commercialised product. The innovation group acknowledges the use phase of their products is an environmental concern; however, there is no formal application of tools and techniques to address this.

The data reported in this chapter is combined with results from Chapter 2 in Chapter 5 and analysed in Chapter 6.

5 Embedded Action Case Study

5.1 Introduction

The action case study was undertaken at Stage 2 of the research (see Section 3.4). Here the researcher was embedded as a participant in the case; taking actions to implement user experiments, perform interviews and observe practices within the team and company based on those actions.

The results presented in this section follow the sequence of Plan, Act, Observe and Reflect. Each cycle informed the next cycle, enabling a logical progression to identification of the factors determining the effectiveness of eco-design practice as applicable (these are the technical and behavioural factors based on user data and analysis), and what is appropriate to implement (based on operational factors of the organisation).

The distinct experiments that were completed in each cycle generated academic papers that are reproduced in the appendices (Figure 50): the paper for Cycle 1 and 2 is in Appendix A, and the two papers for cycle 3 are given in Appendix B and Appendix C respectively. However, some analysis is required at different stages of the cycles, particularly when data collected in a cycle may inform the planning or act stages of the subsequent cycle. Therefore, to provide a logical progression from one cycle to the next, it is necessary for this chapter to report the narrative of the cycles rather than the distinct experiments or trials that were performed. This reporting process avoids over emphasising the product test results and instead focuses on data relevant to the research such as the actions to the outcomes of the experiments within NPD of the organisation (such as interviewee responses or a change in NPD practice).

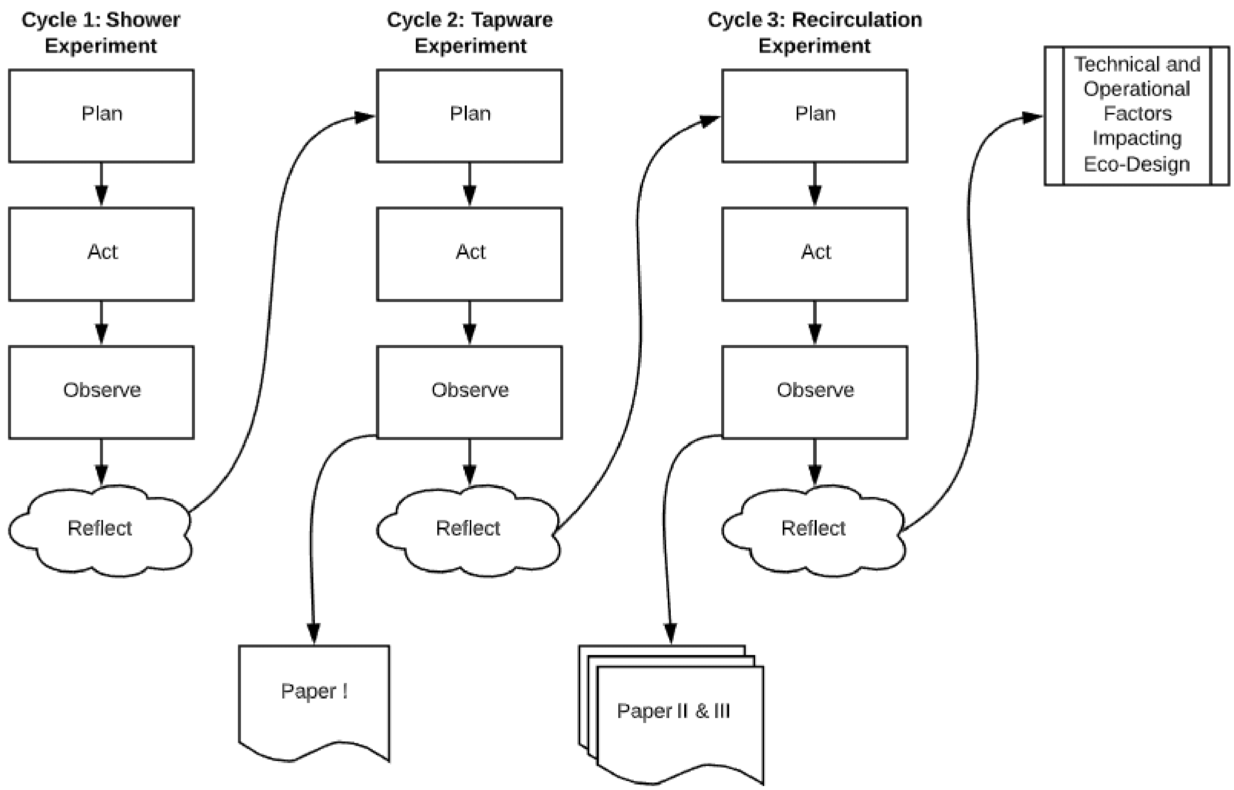

FIGURE 50 ACADEMIC PAPERS GENERATED FROM ACTION CYCLES

The cycles resulted in the follow data being collected:

- 26 pages of transcribed long interviews
- 9 pages of transcribed short interviews
- 18 pages of observational notes
- 25 pages of statistical data (Cycle 1)
- 32 pages of statistical data (Cycle 2)
- 54 pages of statistical data (Cycle 3)
- 6 pages of planning and proposal reports
- two LCA studies

5.2 Cycle one – shower product user study

Following the eco-product workshop strategy session described in Chapter 4 (Section 4.3), a number of product changes were identified that could improve a shower or tapware product's environmental performance with respect to the use phase. Some of these changes were components or systems that were already in existing products, such as different spray types that focus on the reduction of water but do not currently directly consider energy reduction or effectiveness. Many of the proposed changes could be represented as factors associated with the product design that can be experimented with to better understand what improvement (if any) can be made. After the workshop, the researcher worked closely with the R&D team to determine a method for not only testing to see if these variables could change the environmental performance of the product, but also provide opportunities for optimising the factors. The R&D team has traditionally applied a One Factor at a Time (OFAAT) method when testing products; however, the team realised that this method would not allow them to optimise for multiple factors. Design of Experiments (DoE) was proposed by the researcher as an alternative method that could be applied. One product development engineer in the team had experience with this tool and described it as an opportunity to improve their current practice: "We could just rush into some ad-hoc testing like we usually do, or we could do it the right way and have some robust results at the end of it". As a result, the team moved on to plan and design an experiment that followed a typical text-based DoE procedure.

Although a number of factors could have been included in the design, only two were chosen based on ease of implementation: Spray and Feedback. With respect to Spray, shower products can have unique sprays which disperse the water droplets to produce more coverage but with less water. Feedback relates to products which provide some prompt to the user regarding their use.

The goal of the experiment was to identify if, and what, spray type and feedback would reduce both the water and energy use.

The participants for the Shower Product User Study were identified. The use of social media and employee referrals from the case company generated a list of approximately 20 potential participants. However, finding willing participants who met the procedure requirement of a single user for the shower was difficult and somewhat unrealistic, and ultimately there were only two showers in the study that did not have multiple users. This resulted in monitoring and analysing five showers in different households that were used by a total of ten individuals. Participants were between the ages of 25 and 38, and of low to medium household income. There were eight males and two females.

A purpose build device (the datalogger) was constructed by the R&D team to measure and record data throughout the experiment. This device was subsequently installed in participants' showers (Figure 51).

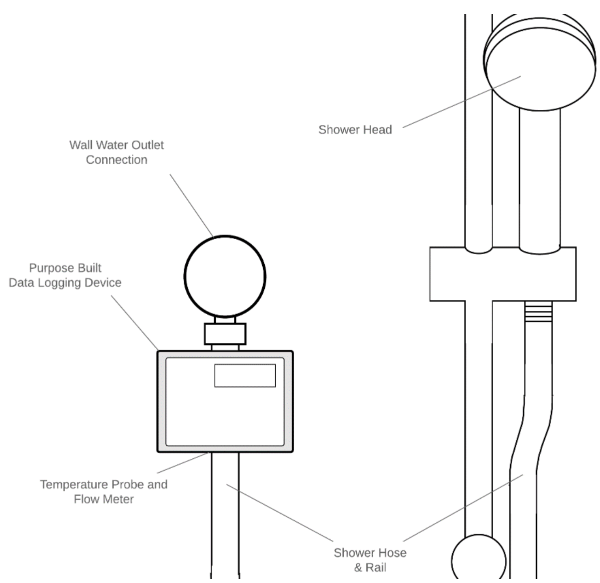

FIGURE 51 SHOWER INSTALLATION CONFIGURATION

The cost of the experiment included building the bespoke device (electronics, sensors, waterproof housing etc) but also purchasing the shower products to be tested; the latter totalled 15 units retailing between $135 and $300 each. Approval for these costs was obtained through submitting a proposal to the head of the innovation group that outlined the objectives of the experiment, timeframe, risks etc. The Head of Innovation and R&D Manager were both engaged throughout the planning and execution of the experiment and were eager to see the results of particular shower sprays included in the study, which they assumed to be environmentally superior to traditional sprays.

Act

It is necessary with a DoE to randomise the trials when testing every combination of factors and levels. As a result, every two weeks a new treatment was applied by returning to the household and changing the shower handset or adjusting the type of feedback that was presented to the user. The duration between treatments allowed a sufficient number of showers to be recorded and averaged to compensate for the variability in the shower activities (e.g., washing hair) and multiple users who would likely have different showering habits.

Observe

On completion of the experiment, the data was run through an omnibus test to identify what factors were statistically significant. This was ultimately used to validate if a change in water or energy was due to a change in one of the two factors. This information was graphed in a statistical software tool (minitab) and the results were presented to the innovation group.

Two key user-based insights were highlighted during the presentation. The first was that the spray type affected energy use. The sprays that were designed to save water, performed worse with respect to energy use. This was primarily due to the additional length of time spent per shower event using the water saving spray type, however other factors also influenced the increase (See Appendix A). If energy use is considered the most important environmental category for shower and tapware, then conventional spray technology is better from an environmental perspective than those currently developed by the company. This finding poses a challenge to most water care rating schemes where it is often recommended that a lower water star rating reduces use of hot water and associated energy costs. Secondly, when displaying feedback to the user when showering, the type of information provided to the user (or absence of) throughout a shower played an important role. For this study, users reduced their energy use when provided with information about whether they were a Low, Medium or High user (Use-scale display); in contrast, showing the monetary cost of the shower did not reduce the user's energy use.

After the presentation, interviews were conducted with the team to gain feedback. This feedback and observational notes collected during the first experiment were then used to review how DoE could be applied in future R&D projects. The goal was to determine how to improve the development of future products.

On the use of DoE itself, firstly, in the shower study there was a significant difference in energy use between the different spray types but no significant difference between the individual response variables that were used to calculate energy use (quantity of water, duration of shower, and temperature of water). Calculation of energy use may therefore be the most relevant variable to analyse in order to understand which spray type (or constituent components or technologies) is better from an environmental perspective. However, this variable does not provide enough information alone to know where the spray type itself could be improved. This is because different aspects of the design or technology may only impact one response variable (i.e., the impinging of the spray causes a decrease in temperature). Therefore, the water, duration and temperature variables should also be reported in the DoE results as they will provide more insight to the product developer and, hence, inform future NPD.

Secondly, the subjective experiences and needs of the different customers were not considered when planning the experiment. The purpose of taking a shower can be classified as functional (i.e., getting clean) or relaxing (or both at the same time to varying degrees), and existing commercial products provide alternative spray types oriented towards one or other of these experiences. The subjective experience of the participants could have varied from one treatment to another and thus affected the results, yet this aspect was not represented in the design of the experiment. In future experiments, it would be advisable to include an additional response variable or a covariant that assesses the user's experience of a shower treatment (for example, by using a survey to capture this qualitative data as with similar studies on showering (Adeyeye et al., 2017; Kuijer et al., 2013)).

Thirdly, conducting DoE in this way is difficult for shower products. It took a long time to collect the data as often only one data record could be recorded each day. It was also very time consuming for the R&D department as the longer the experiment ran, the more likely the conditions of the participant's environment or situation would change (away from home / not using their shower). The implication is that some product categories may be better suited for this type of experimentation than others (i.e., products which have a greater use greater use in a shorter time period).

With respect to the R&D process of the study, the first challenge highlighted was the ability to find participants. Typically, participants for similar studies done within the company (such as focus groups) are easily found through contacts of the Insights Manager. However, in this case they were unable to provide many willing participants. During the post-experiment interviews, two of the senior engineers suggested that this was because the experiment was being conducted in the bathroom, a space which is considered to be of a very personal nature.

The next challenge was that almost all of the engineers and managers found it very difficult to understand the results as they were conveyed. The graphs contained statistical information and terms that many of them were not familiar with. Only one engineer had previously been trained to use DoE and was able to easily comprehend the results. Most engineers had only performed 'One factor at a time' (OFAAT) experiments. Therefore, they were unfamiliar with the results produced by an omnibus test. In addition, some engineers were completely unwilling to comprehend the results from the study, stating that statistics were only useful for marketing purposes.

Finally, while many found the results interesting, they found it difficult to identify design decisions that could positively influence the environmental performance of the shower products. Many engineers believed that, because the results were linked to behaviours and subjective experiences of the users, there was little information that could be utilised in decision support.

Summary of findings (Part 1)

Users (applicability – greater behaviour and technical understanding)

- The thermodynamics of different sprays affect the energy use and subsequent environmental performance of a shower product
- If energy is the most important environmental category under consideration, then a conventional spray technology is better from an environmental perspective than those currently developed by the company
- Feedback to the user on their energy and water use has a measurable impact on energy and water use. The way in which this information is presented can determine if it is a positive or negative impact.

Summary of findings (Part 2)

Company (implementation – greater understanding of operational aspects of eco-design)

- Finding willing participants to perform experiments is difficult due to the personal nature of the bathroom
- Design of Experiments does work; however, it is not practical for this product category (showers) due to the time and resources required for the experimental work
- The factorial model will determine where in the NPD process it can be used to optimise the design (text based – later stage of development when a technology is being assessed, numerical based – early stages when different geometric variables are being tested (spray angle, number of nozzles)
- The experience of the user with respect to attitude or feelings should be analysed alongside the quantitative data on energy and water use
- Training on interpretation is needed
- Robust energy use and water use measurement tools are needed
- Decision makers find DoE hard to understand

Reflect

The R&D team had always planned to conduct further DoE experiments on other products. Tapware is also an active product category and contributes to water and energy use in the home. Compared with shower products, tapware is considered more functional, and therefore has the potential to avoid some of the challenges designers could face with respect to the associated subjective experiences of using products like showers. The team therefore decided to undertake a new experiment on tapware that would seek to identify a more practical methodology for conducting the experiments, with an experimental design that could drive obvious design choices and lead to improved tapware products from an environmental perspective.

5.3 Cycle two – Tapware product user study

Plan

The R&D team decided to run the tapware experiment in a corporate office to avoid earlier difficulties in finding willing participants. It was agreed that the use of a tapware product should be common across both home and office. A men's bathroom was selected that was used regularly by approximately 40 people.

The chosen factors to test were 'cartridge and 'flowrate'.

A cartridge is an internal component of a tap that allows for hot and cold-water delivery to be varied depending upon the handle position. In the early development stages of a new tapware product, alternative cartridges are evaluated and selected, and the tap design going forward will be optimised for this cartridge. Different cartridges could impact the environmental performance of the tap, and therefore could be an eco-design consideration for future products. Three cartridges were chosen: standard, progressive and 2-Step Eco. The standard cartridge has two degrees of freedom for delivery of water that control flow and temperature. The progressive cartridge only has a single degree of freedom, which controls both flow and temperature. The design of the progressive cartridge means that hot water is only delivered when the handle is turned beyond 90º. The 2-Step Eco cartridge is a modified standard cartridge designed to reduce water use by having a distinct restriction of the movement of the handle when the flow has reached 50% of its maximum flow: users who require a higher flow must then apply a greater force to move the handle beyond this restriction.

Taps can be flow-restricted easily using a range of components from original equipment manufacturers (OEMs). The flow restrictor can often impact the overall design of the tap as the body of the product may need to change to accommodate the size or shape of the component.

In the tapware industry, it is generally assumed that greater flow restriction equates to reduced water consumption per use.

One point of interest in the planning of the tapware experiment was the hardware changes that would be required to collect the information, and the new risks as a result. With the shower experiment, the recording device was positioned in line with the shower mixer and handset. For this new experiment it would need to be positioned under the sink. The datalogger would need to be capable of withstanding high static pressure when the tap was not in use. Should the plumbing leak, it could cause significant water damage to the area.

As per DoE guidelines, the trials to test the factors were randomized. It was decided that the entire sequence would run twice. It was expected that users would be unfamiliar with some of the designs and might use the tap in a less optimal way and this could negatively influence the results. In the first week the users would become accustomed to how to use the tapware (turn it on/adjust temperature), and this means that in week two it is more likely that genuine 'washing hand events' will be recorded.

Act

One of the notable differences when implementing the experiment was the ease of installation and trial management. Factorial changes for each trial were very easy to complete compared to the previous study. By using a communal facility, where there were multiple users, it meant that fewer data recording devices needed to be installed and managed but were still able to capture a large sample.

The experiment was also completed very quickly. It took six days to collect the necessary information, compared to the shower experiment which took several months.

An omnibus test was used to determine if the factors were significant. This information was graphed and presented to the innovation team.

Observe

As with the shower experiment, a number of observations were made from both a product user and operational perspective.

From a user perspective, it was found that varying the flow restriction had no effect on the quantity of either hot or cold water used for washing hands. Instead, users washed for a longer or shorter time depending on the flow restrictor, effectively using the same amount of water per wash regardless of the flow restrictor. This suggests that users require an optimum amount of water to wash their hands. With respect to the cartridge, it was found that users will be less likely to wash with hot water when a progressive cartridge is installed and are more likely to waste hot water using the alternative Standard and 2-Step cartridges since most users turn the handle to receive hot water, but do not wash long enough for the hot water to travel through the pipes and come out of the tap. This suggests that a Progressive Cartridge is environmentally superior as it wastes less energy based on the behaviours of users in this study because the users did not turn the handle far enough to access any hot water.

When presenting this information to the innovation team, there was agreement that the results were more robust, useful and easy to understand. This was due to the selected factors but also the product itself and the way users engage with it. Since a tap is considered more functional, the subjective experience was not seen as a variable that could influence the results – therefore there was more trust in the results.

One of the most interesting observations was how the eco-information was subjectively dismissed during discussion on how to develop a new tapware product. As part of an informal product development meeting (in addition to the post results meeting), the R&D team were given an opportunity to influence the cartridge selection for a new tap product that could ultimately impact the overall design. While it was agreed by all in the meeting that a progressive cartridge might be environmentally superior, this choice was overturned following a discussion about the users' preferences or aesthetics, purely based on opinion or what could be described as subjective interpretation of the customers' needs by those at the meeting. This discussion was not informed by any data related to the customers' needs.

<u>Summary of findings (Part 1)</u>

Users (applicability – greater behaviour and technical understanding)

- Flow restriction did not reduce water per use, users simply kept the tap on for longer and so used the same volume of water
- The type of cartridge used in the design significantly impacts energy and water use purely based on the way the user interacts with the product

<u>Summary of findings (Part 2)</u>

Company (implementation – greater understanding of operational aspects of eco-design)

- Experiments on products that are further removed from a 'good experience' and considered to be more functional yield more practical and easily understood results
- Environmental data that can be used in the decision-making process informing NPD need to be explicitly included and considered alongside other design criteria e.g., aesthetics, user experience.

Reflect

While the experiment provided more evidence that the DoE process had potential to identify the factors that could influence the use phase, it seemed that this may only be practical for tapware product or products which are more functional in design.

If one accounts for the subjective "relaxation" function of the shower where the length of the shower is an important aspect, would it be possible to design a shower product to reduce energy and water use whilst maintaining the duration of the shower? The R&D team decided this could be accomplished by taking a systems-based approach, extending the boundaries of the product system to include those that it interacts with i.e., the incoming water and outgoing wastewater systems. Acting on the insights and reflection from the first two cycles, the R & D team needed to identify an alternative method for addressing the environmental impacts associated with the use of hot water, without compromising on the user experience (such as reducing the flow of water or duration of shower). It was agreed by the team a systems-based approach could accomplish this.

5.4 Cycle three – recirculation system

Identify

Through formal discussions and previous documentation, the researcher found that the company had completed a number of R&D projects in the past on variations of these types of systems. A number of heat recovery products had been constructed and tested but none had been taken beyond an R&D project. In interviews the R&D manager explained that this was because the systems were deemed not commercially appealing as the financial incentive, in particular the related pay-off period for the customer, was too low. However, a review of the previous documentation of these projects indicated that there was only data on the technical system itself and its performance; there was no evidence of a business case evaluation and so it was difficult to validate if any robust assessment had in fact been completed.

One promising alternative to heat recovery is water recirculation, a system that the R&D team had not experimented with in the past. The R&D team decided to create and test a recirculation system with the goal to understand both the environmental performance of the system and identify the operational aspects that might impact the development of commercially viable system.

The process for designing, testing and comparing the two alternative systems followed three steps: constructing and testing of recirculation systems, user behaviour scenario modelling, and development of a comparative LCA (comparing the recirculation system and its performance of different recovery systems developed by the company in the past).

Act

The R&D team followed an informal process for developing the recirculation system:

1. A patent search was conducted to understand system fundamentals and the best method to recirculate water in a shower.
2. The team partnered with a relevant engineering firm with experience in water catchment, filtration and recirculation systems due to a lack of in-house knowledge in these areas.

This addressed knowledge gaps and provided vital information. In particular, it highlighted potential risks such as health hazards associated with hot wastewater, and performance trade-offs associated with shower water filtration such as maintenance of the filtration components which could impact the life of the system (and potentially the environmental performance) depending on how often these would require cleaning or replacing.

This led to the final prototype design illustrated in Figure 52.

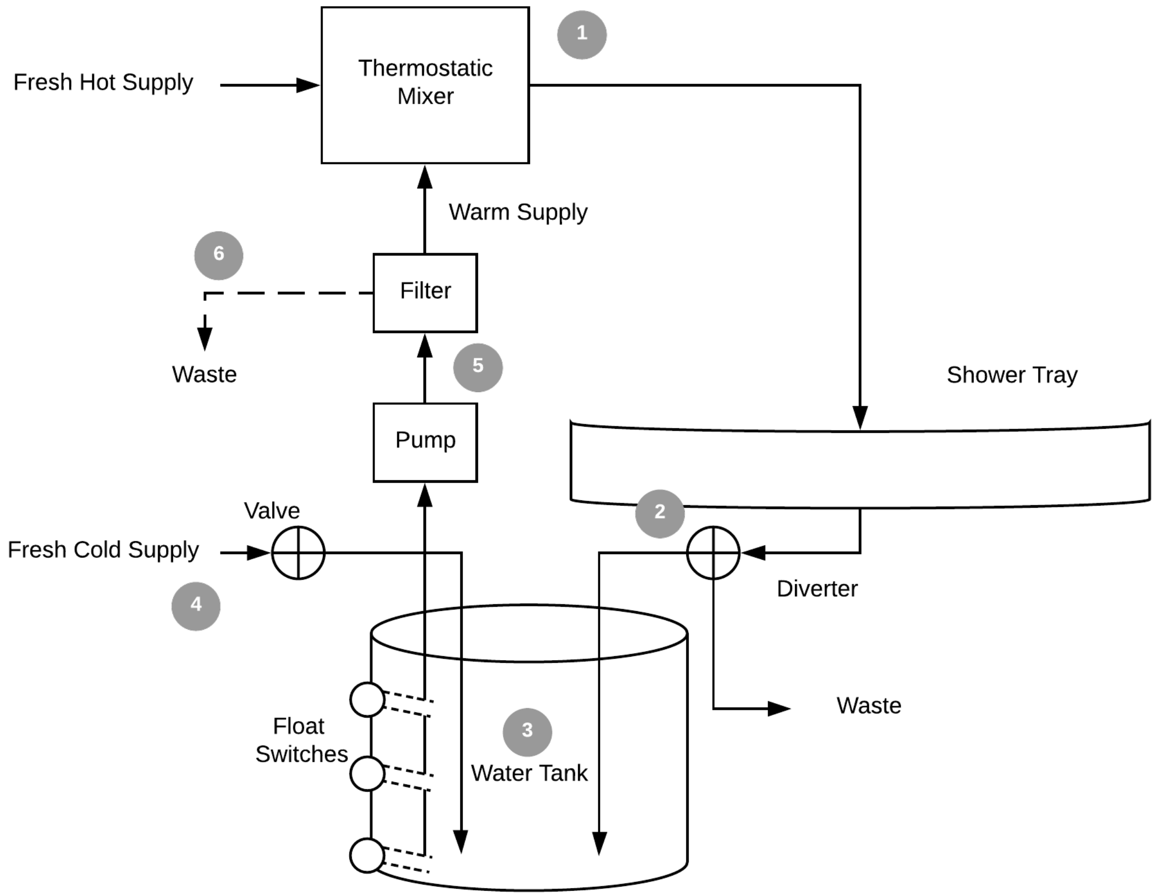

FIGURE 52 RECIRCULATION SHOWER SYSTEM

The process follows six stages in a semi-closed loop system. At the mixer (1), the incoming fresh hot supply (i.e., from a water heater) and recirculated water is managed by a thermostatic mixer that maintains a predefined temperature. This is flow restricted at 10 litres per minute. The water is directed to a showerhead which is then caught by the shower tray. A sensor detects the water turbidity and switches a value to divert the dirty water to waste (2). If clean water is detected it is diverted to the to the water tank. The water tank (3) acts as the systems cold water supply and buffer to prevent the system stalling should there be a lack of diverted waste shower water. This water level is maintained by series of electronic float switches. If the diverted water falls below a critical level, fresh cold water is delivered to increase the buffer (4). If the buffer tank indicates it is full, the diverter (3) begins sending all shower water to waste. A domestic household water pump (5) delivers the recirculated water from the buffer tank through an Ultrafiltration (UF) membrane filter in a crossflow configuration (6). This setup allows for solids to be continually flushed from the membrane surface though some water must be lost in the process. The crossflow was flow restricted at 0.5 litres per minute. The filtered recirculated shower water is delivered back to the mixer (1). All electronic switches, sensors, and motorized valves were managed by a microcontroller.

Several temperature sensors and flow meters were connected to the system at various points that allowed measurement of the energy and water recovery performance. A shower was simulated throughout the system by running the mixer at a fixed temperature. The system was trialled at 35ºC and 40ºC, both at a flow rate of 10 litres per minute. Each trial lasted approximately 10 minutes. In each trial the diverter was alternated every 2.5 minutes causing the system to respond to the change in recirculation flow and temperature until it reached a stable state. This alternating process is repeated several times allowing an average performance to be determined for each trial.

There was no pre-existing reliable or quantitative data on how much clean water exits the shower system for an individual shower i.e., water which could be recirculated and reused. Since a recirculation system typically only recirculates the cleanest water, the way in which people shower (time spent washing versus not washing) will affect how much water can be recirculated, and potentially the environmental impacts or savings associated with the use of the recirculated hot water.

Therefore, in a separate data collection exercise, turbidity sensors were installed in domestic household showers to monitor the washing behaviours of users. These sensors were positioned at the waste trap of the showers (Figure 53), allowing the data to be collected that determines when the user is washing or not washing.

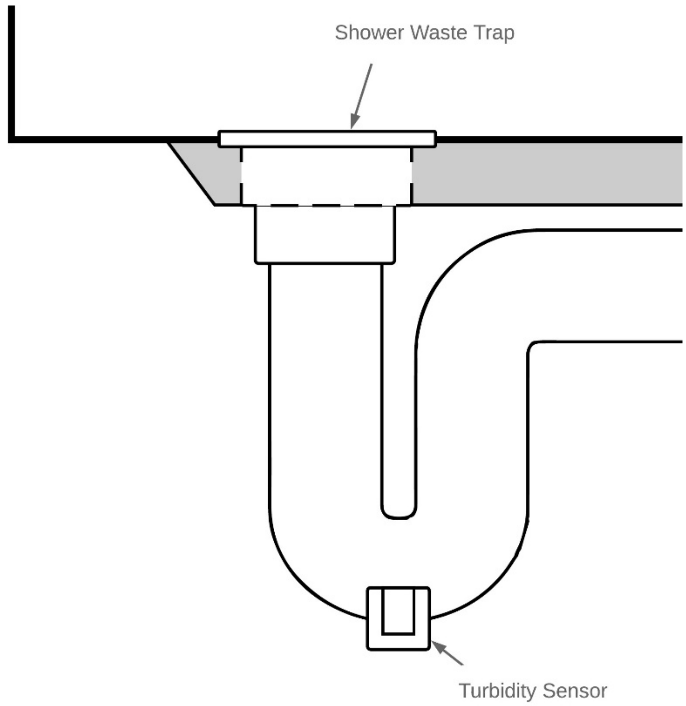

FIGURE 53 SHOWER WASTE TRAP

The turbidity sensors were installed in four shower units to provide a range of different showering situations. The first two were in a domestic household on a low-pressure system and the second two in a commercial office on a high-pressure system. The turbidity data collected for each shower event was analysed to identify a smaller number of “typical” washing scenarios for users. Applying the performance models from stage one (see Appendix B for more detail) provides a theoretical basis for how much water could have been recirculated for each of the different showering situations.

Observe

The full results of the trials are provided in Appendix B. In summary, in the recirculation experiment the flow and temperature of the shower were successfully maintained by the thermostatic mixer while the temperature of the buffer tank slowly increased as the shower water recirculated.

An example of a turbidity use profile from a domestic household is provided in Figure 54. By calculating energy and water use for the different profiles it was possible to determine best (least amount of energy used per shower event) and worst (greatest amount of energy used per shower event) cases.

These profiles were combined with the recirculation prototype performance test to provide a theoretical best and worst case that the system would perform at.

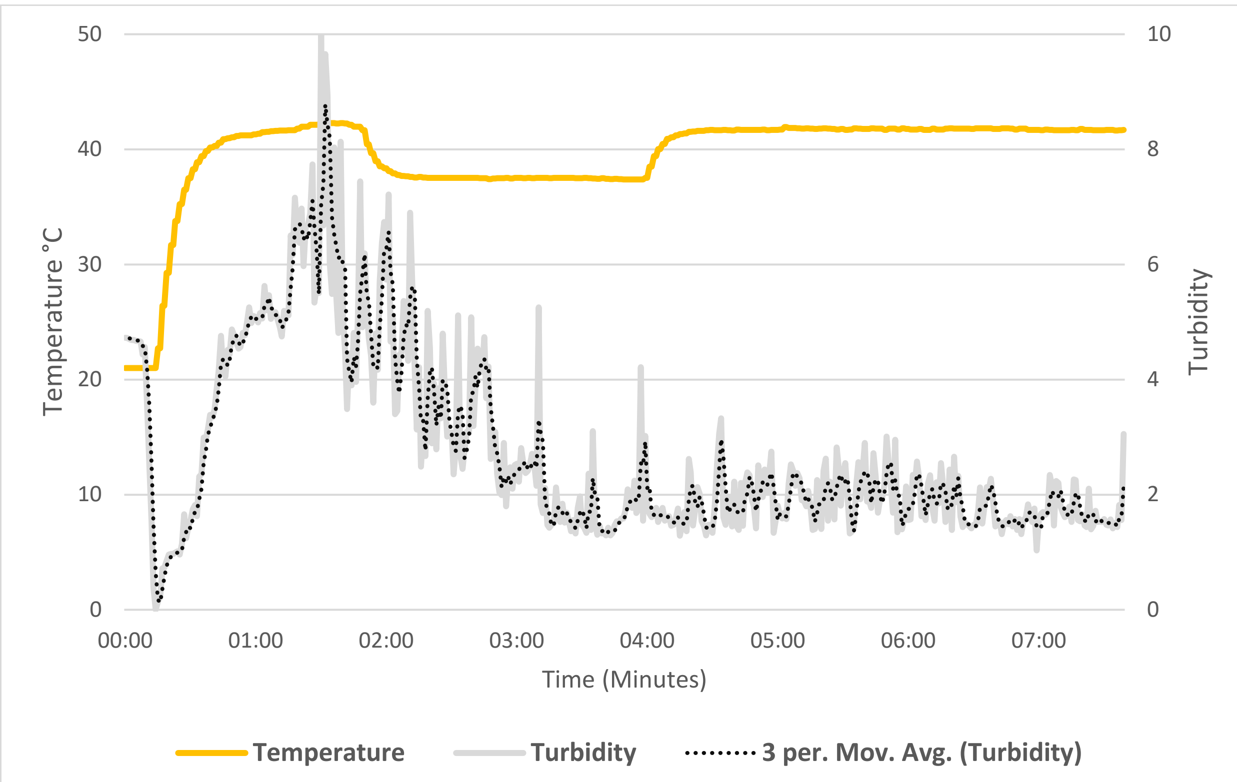

FIGURE 54 EXAMPLE OF USE PROFILE (TURBIDITY RECORDING)

The final step in the process was to complete an LCA to compare the environmental performance of the recirculation system to heat recovery systems that have been constructed and tested by the case company in the past. This LCA report is provided in Appendix C. This study was intended to provide decision support for the R&D team for strategic planning or prototyping, by informing which type of system level eco-innovation could provide the better environmental performance.

Figure 55 illustrates that across all the different systems, Climate Change and Fossil Fuel depletion (Resource use, energy carriers) and water scarcity are three of the hot spots. This is primarily due to the energy used to heat the hot water.

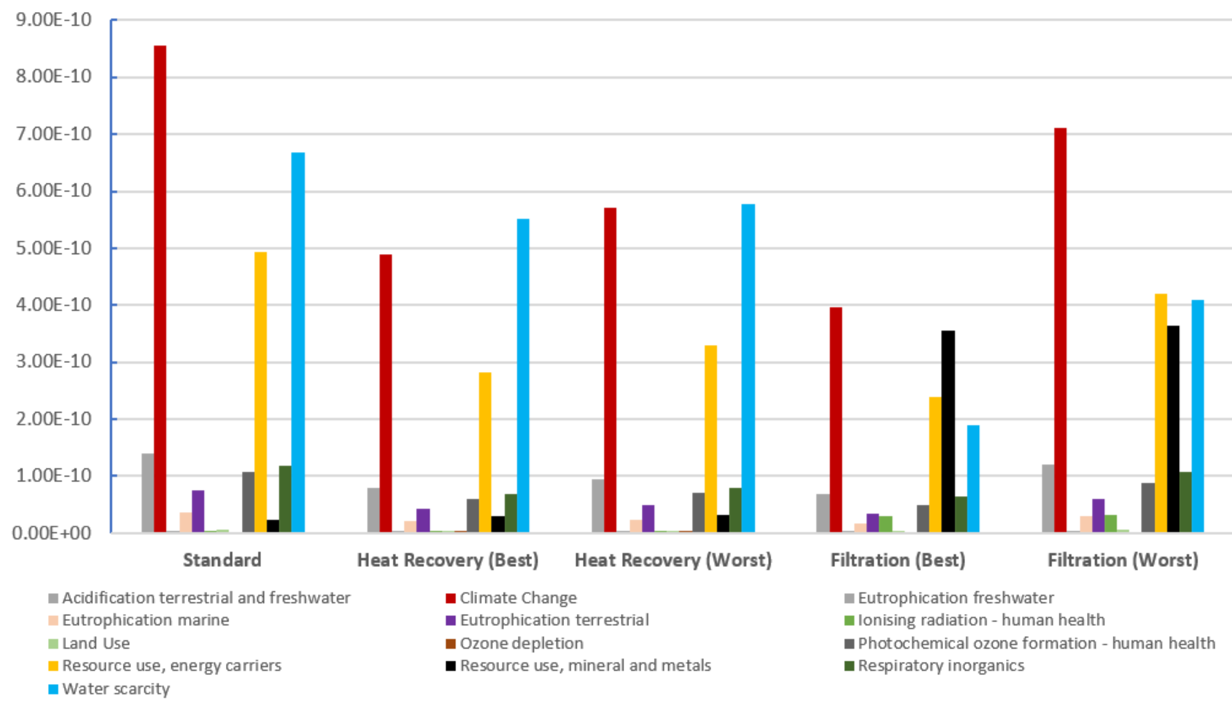

FIGURE 55 RECIRCULATION SYSTEM LCA RESULTS (ALL ENVIRONMENTAL IMPACTS) - EF 1.8 NORMALISED (GLOBAL EQUIVALENTS)

One of the most notable results is how the results change (or don't) across the different scenarios. With respect to climate change, the Standard scenario is very similar to the Filtration (Worst) scenario. Filtration (Best) demonstrates that, under optimal conditions, the recirculation system could reduce climate change emissions by approximately 50% compared to that of a normal shower. This was due to the interaction between the construction of the system and the behaviour of the users. The system was designed to collect a certain amount of water in the tank before recirculating, and this acted as a buffer to ensure a continuous flow of shower water between switching of fresh and recirculated water. This worked fine until the use profile was not compatible with the size of the buffer tank. A user would need to wash and not wash for a very specific amount of time in order to optimise the recirculation system. Since there would be a wide variety of user profiles, there is a possibility very little advantage could be gained – the environmental performance of the recirculation system could be as poor as the heat recovery system (as indicated by the Recirculation (Worst) results in Figure 53).

The LCA results also highlighted that, for the climate change impact category, the construction and function of the systems (i.e., materials, recirculation processes) were insignificant compared to the energy used to heat the water. Furthermore, additional energy was required for the filtration system as part of the cleaning process (post-use), contributing a considerable amount of climate change emissions over the life of the product (Figure 56).

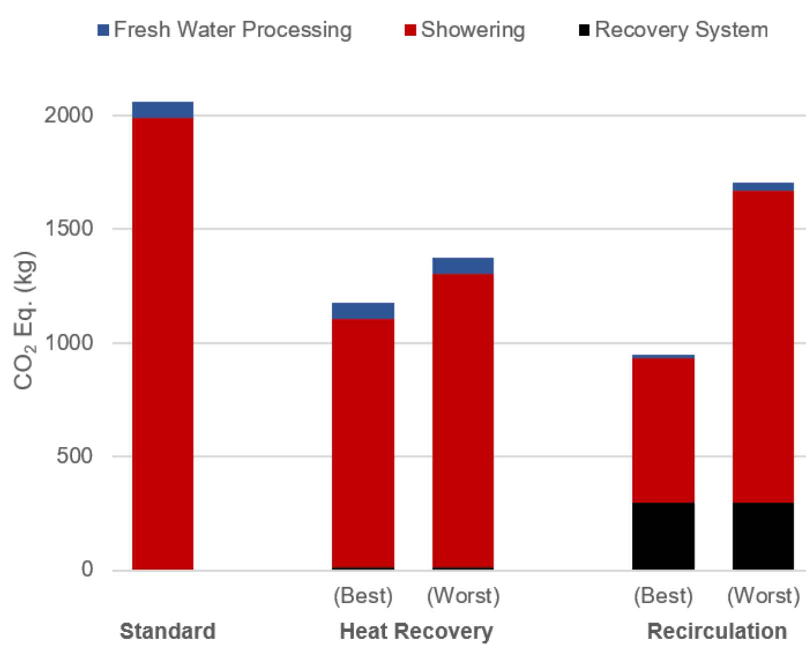

FIGURE 56 RECIRCULATION SYSTEM LIFE-CYCLE STAGES FOR CLIMATE CHANGE IMPACTS

When the results were formally presented to the Innovation group, the discussion that followed highlighted how critical LCA is at the system level of product development of eco-products. One of the NPD engineers stated, *"There's potential to not consider other parts of the life cycle, such as the cleaning and the impact it has, the LCA process has allowed us to quantify what the true benefits could be".*

During this presentation, a debate took place on the comparative performance between the prior projects on heat recovery systems and this recirculation system. There was a strong opinion that the heat recovery results must be incorrect as the R&D reports indicated that they performed better than what was modelled and presented. This is because the engineers had reported on effectiveness rather than efficiency of these earlier systems. Effectiveness measures how well they can recover energy losses based on the limitations of the system (i.e., in the case of temperature - water at 40ºC being passively transferred to water at 30ºC will only achieve a 5ºC change), while efficiency measures how much energy can be recovered from the total used (i.e., total heat loss of the water at 40ºC).

It was agreed across the team that the high cost associated with the recirculation system would need to reflect some kind of savings to the customer in order to add value. It was suggested that such a system could be marketed as a guilt-free solution for shower users, providing customers an opportunity to enjoy showering for as long as they like, with little harm to the environment. However, those involved in marketing claimed that the recirculation of water might reduce the experience factor since many may perceive recirculated water as unclean and less desirable for showering.

Summary of findings (part 1)

Users (Applicability – Greater behaviour and technical understanding)

- The showering profile affects the performance of the system. When utilising a buffer tank in the system, users who spend more time washing will show less improvement since water detected as dirty was not recirculated and instead discarded to waste.
- Subsystems share a relationship with the use profile – a specific design's' environmental performance depend on how users behave. In this design the buffer tank limited how much water could be recovered based on washing or not washing activity.
- Maintenance of the system can significantly impact the environmental performance as often additional hot water and cleaning solution is required.
- Various subsystems will impact the design. This includes the buffer tank mechanics, and the heat loses through pipework and the filter.
- A positive showering experience could be compromised due to the perception of washing in grey water

Summary of findings (part 2)

Company (Implementation – Greater understanding of operational aspects of eco-design)

- There is a need to standardise environmental performance testing
- Life Cycle Assessment is necessary to investigate whether there is a net environmental gain over the entire life of the product compared with conventional products
- System based eco-design may be difficult to market as customers may not see the value add in purchasing the system
- Lack of expertise in area of water filtration means that internal staff may not be able to adequately address some of the safety concerns of developing these systems

Reflect

One of the primary reasons the R&D team developed and tested the recirculation system was to identify and validate an alternative eco-product that could address the use phase. It was thought that by using a systems-based approach, environmental gains could be achieved despite the variability of users and their behaviours. However, this project demonstrated that this recirculation system might offer relatively little environmental gain depending upon how users behave in the shower. Finally, the comparison between the heat recovery and recirculation system demonstrated that in many cases it is best to focus on heat transfer rather than recirculation as get similar improvements environmentally.

5.5 Chapter Summary

The action case study, comprised of three experimental trials, provided information on the technical aspects and behavioural factors associated with products that affect their environmental performance. The observe and reflect steps of the cycles provided the opportunity to gather qualitative data from teams and employees that provide operational insights. DoE can be used as an effective tool to generate new environmental knowledge of products and their impacts; however, the practicality and reliability of the results is dependent upon the sample size and type of product. The value of the information from environmental testing diminishes when designers and engineers (or anyone reviewing the results) are unable to understand and interpret the results. The last cycle demonstrated that eco-design at a system level could be accomplished, however, there were many significant risks compared with the traditional products (showers and taps) that could not easily be addressed.

6 Analysis

This section analyses all the data presented in chapters 4 and 5. The process for analysing the data follows the procedures outlined in section 3.5.2 (Analytical strategy). The analytical process involved three activities: (1) summarising the data and linking to existing theory, (2) categorising, and (3) explanation building and narrative structuring (Figure 57).

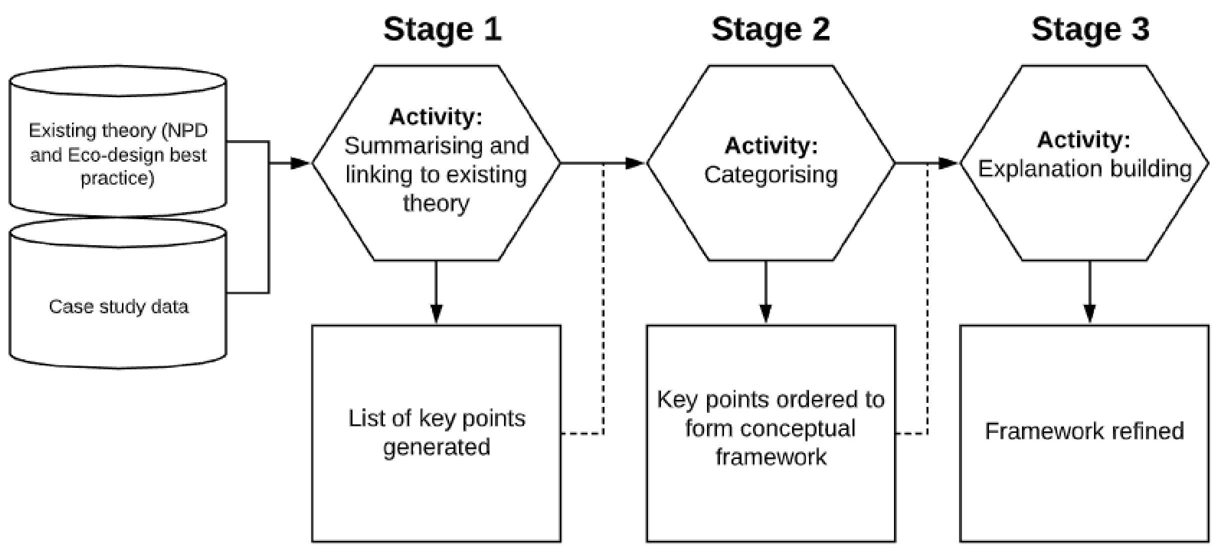

FIGURE 57 DATA ANALYSIS STAGES

6.1 Stage 1: Summarising

The purpose of this activity was to take long statements (i.e. from interviews) and compress them into shorter statements that recorded the main theme of what was said or observed (Saunders et al., 2009). In preparing the data (section 3.5.1), all notes, transcripts, and reports from data collection activities were combined into a single archive. The researcher read through the archive a number of times and noted key points. Knowledge of best practice eco-design and NPD (drawn from the literature in Chapter 2) was used to identify any relationships between the key points and existing theory that might need to be further explored (in subsequent analytical activities).

Identifying this relationship also assisted in determining if the key point could be a barrier or enabler to best practice eco-design integration. For key points that could not be linked to existing theory, assumptions were made as to whether they were a barrier or enabler based on the context and tone of different sources. The results are shown in Table 20.

TABLE 20 KEY POINTS FROM SUMMARISING STAGE

Key point	**Relationship to literature**	**Barrier / enabler**
Manufacturing has no strategy or future plan so they don't know how or where their products will be made	Company must have well defined environmental policy or strategy (Rodrigues, Pigossom, & McAloone, 2016)	Barrier
Company doesn't have capabilities in systems required for system design filtration / water reuse	Doing something new in both content and process Ulrich & Smallwood (2004)	Barrier
The company develop and market unique spray technology, eco sprays are not part of the development portfolio	Product portfolio have new products with potential for improving sustainability (Ussui & Borsato, 2013)	Barrier
The company conducted risk assessments. Some materials are economically a threat to future business - they want an alternative business model to mitigate this risk	Develop business, product and market strategies considering environmental trends (Rodrigues et al., 2016)	Enabler
Marketing, Manufacturing, Innovation - all doing their own thing without communicating to each other	Cohesive plan or process between departments (Barczak & Kahn, 2012)	Barrier
The engineers and designers believe they cannot make design choices that impact shower use - as this is subjective to the user	Take ownership of use stage (Rodrigues et al., 2016)	Barrier
Lack of criteria in NPD process	Subjective weighting / lack of robust evaluation at decision stage (Barczak & Kahn, 2012)	Barrier
Lack of environmental criteria in NPD process	Clearly define the environmental indicators and the methodology to be used during the gates (phase assessments) (Rodrigues et al., 2016)	Barrier
Design / aesthetics trumps eco criteria		Barrier
Ignoring/dismissing LCA results because it didn't favour earlier development decisions		
The engineers only know how to do One Factor at a Time (OFAAT), they don't understand DoE results, they don't trust them because they think they are not robust	Adapt eco-design tools through experimentation (Brones et al., 2017)	Barrier
They don't know how to conduct DoE or have the expertise to do it well	Build competency and training in organisation Ulrich and Smallwood (2004)	Barrier
Some projects are thought to have more value often when senior management is behind it. Funding to conduct benchmarking is more available for these projects	Motivating and educating on the importance of eco-design in both high and middle management (Tingström & Kth, 2007) There needs to be commitment, support and resources to conduct the activities related to eco-design (Rodrigues et al., 2016)	Enabler
Project briefs are poorly defined (or lack any definition). Lack of objectives, not formalised.	Sharp and early product definition to avoid scope creep and unstable specs, leading to higher success rates and faster to market (Cooper, 2018)	Barrier

Key point	Relationship to literature	Barrier / enabler
The engineers believe they can't do LCA well, but working with others allowed them to do this well by embracing the concept of collaboration with external companies	Establish cooperation programs and joint goals with suppliers and partners aiming to improve the environmental performance of products (Rodrigues et al., 2016)	Enabler
The company does not want to market the environmental benefits as they believe consumers do not value this	Elaborate and communicate recommendations to consumers on how to improve the environmental performance of the product during the use and end-of-life phases (Rodrigues et al., 2016)	Barrier
The company is not good at doing LCA so internally they can't build it into the NPD process	LCA is systematised (Rodrigues et al., 2016)	Barrier
The company believe they don't know how to engage with customers to use less water as there is currently no platform to do this		Barrier
R&D is siloed from NPD, they have their own process and do not formally engage with the NPD process (even in the early stages)	A common NPD process cuts across company groups (Barczak & Kahn, 2012)	Barrier
There is a lack of discipline in using the companies NPD process	Poor practice example there is no discipline in using the company's NPD process (Barczak & Kahn, 2012)	Barrier
The shower experiments take too long / more resources to conduct	Perform internal and external benchmarking of the environmental performance of products and/or eco-design best practices (Rodrigues et al., 2016)	Barrier
The company has flexible operational practices that allow them to act on new opportunities	NPD is flexible and adaptable to meet the varying needs of individual projects (Barczak & Kahn, 2012)	Enabler
The way in which they manage R&D resources and leverage their technical expertise allow them to create tools to conduct eco-design related benchmarking which builds competency and capability		Enabler
The integration of behavioural science and design decisions has potential to effectively support environmental consideration of shower and tapware products	Behaviour-changing devices need to be prototyped and user-tested to better understand their effectiveness and explore ethical considerations. Bhamra et al. (2011)	Enabler
Bathroom space is personal, difficult to benchmark		Barrier
Limited eco-schemes (WELLS and similar ratings) to guide their eco-npd, there is no incentive to go outside of this		Barrier
Tapware is purely functional; they can use the insights to make changes		Enabler
Believe that Eco-sprays or systems will compromise the experience of customers		Barrier

6.2 Stage 2: Categorising

To create a more meaningful connection to NPD theory, the key points were categorised to reflect their relationships to the NPD framework elements identified in the literature (Section 2.1). Since the element names and descriptions in the NPD literature differ to a small degree, this became an iterative activity (facilitated by affinity diagrams – an example is provided in Figure 58) involving revising categories and rearranging data in search of meaning and relationships of the key points.

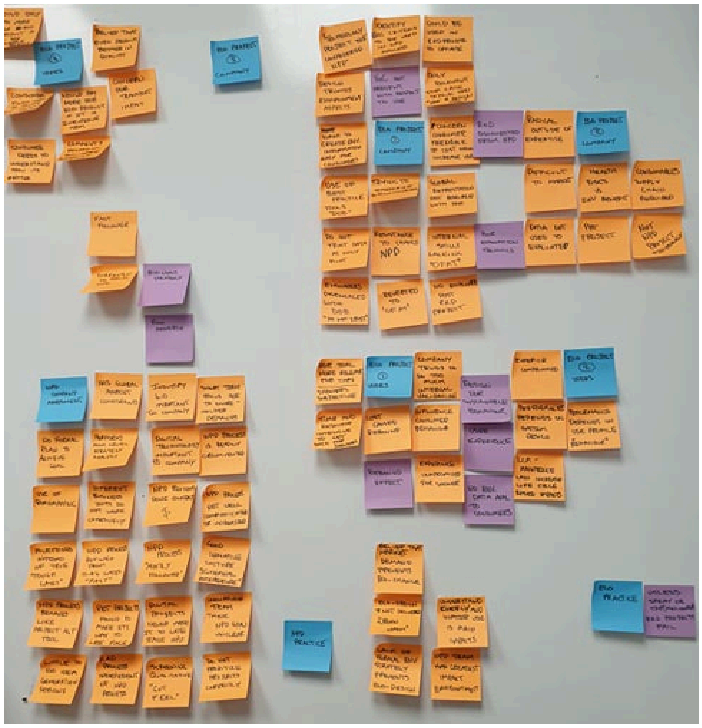

FIGURE 58 AFFINITY DIAGRAM EXAMPLE

Three significance changes were made to the key points during this process. Firstly, the key points were categorised under strategic NPD elements (Strategy, Technology Planning, Portfolio Management, Culture) and operational NPD elements (Process, Tools and Techniques, Project Definition and Market Requirements) (refer to Appendix J).

Secondly, it became clear that the categorisation of barriers and enablers could be linked with eco-design and rephrased to represent success factors (an example is provided in Figure 59).

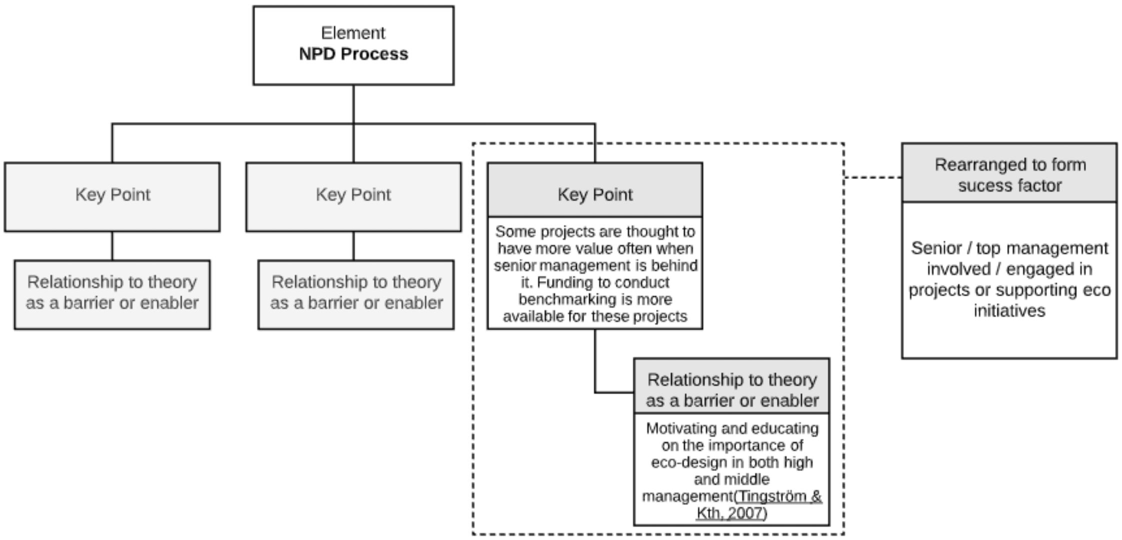

FIGURE 59 EXAMPLE TO SHOW PROCESS OF REPHRASING KEY POINT TO SUCCESS FACTOR

Lastly, one of the barriers to the integration of eco-design into NPD identified in the literature was how existing frameworks and models have thus far developed relatively separately (Section 2.5). In one iteration of categorisation, it was found that many of the key points (now rephrased as success factors) were specific to the different classes of eco-design (Stevels, 1999) (Section 2.2.1). For example, the success factors identified following analysis of the projects and outcomes of the action case study aligned with the Redesign and System class. The Circular Economy project from the case study data represented the Business Model class. Based on this emergent pattern and the known barriers to eco-design integration in different eco-design classes, the success factors were recategorized to reflect the 'Classes of Eco-design'. This created a matrix of success factors for NPD elements versus Classes of Eco-design (shown in Figure 60).

Key (significance)
Low | Medium | High | Very High

	CLASS 1	CLASS 2	CLASS 3	CLASS 4
Strategy				Adapting sustainable business models
				Cohesive plan between teams and departments
Technology Planning			Ability to collaborate with third party to fill knowledge / skill gaps	Manufacturing strategy that is communicated across the business
				Cohesive plan between teams and departments
Portfolio Management		Eco-products reflected in in portfolio	Need eco-product in portfolio	Eco-products reflected in in portfolio
	Decision makers are aligned	Decision makers are aligned	Senior / top management involved / engaged in projects or supporting eco initiatives	
Culture, Climate and Values	Decision makers are aligned	Decision makers are aligned		
	Senior / top management involved / engaged in projects or supporting eco initiatives	Willingness to take ownership of entire products life-cycle and make changes to improve hot spots	Willingness to take ownership of entire products life-cycle and make changes to improve hot spots	
		Senior / top management involved / engaged in projects or supporting eco initiatives	Senior / top management involved / engaged in projects or supporting eco initiatives	
NPD Process		Eco-design projects are included in a standardized NPD process	Eco-design projects are included in a standardized NPD process	NPD process is adhered to
				Senior / top management involved / engaged in projects or supporting initiatives
				Environmental criteria are defined, weighted and evaluated in NPD process
Quality of execution	Ability to collaborate with third party to fill knowledge / skill gaps	Ability to collaborate with third party to fill knowledge / skill gaps	Expertise in applying best practice eco-design benchmarking tools / methods	
			Eco-design benchmarking standards defined	
Link to market and key stakeholders		Ability to adapt marketing plan to communicate the added value of eco-design product changes / improvements	Ability to adapt marketing plan to communicate the added value of eco-design product changes / improvements	
Project and resource management	Ability to collaborate with third party to fill knowledge / skill gaps	Ability to collaborate with third party to fill knowledge / skill gaps	Highly skilled R&D team with strong technical capabilities in identifying and benchmarking eco-design opportunities	Flexible team, ability to adapt quickly to changes
		The ability to conduct best practice eco-design consumer tests that produce meaningful and robust results		Well defined scope, boundaries and upfront eco-design design requirements
		Highly skilled R&D team with strong technical capabilities in identifying and benchmarking eco-design opportunities		

FIGURE 60 INITIAL ANALYTIC FRAMEWORK OF RESEARCH

The success factors were given a different colour that represented significance (i.e., a common theme that appears to have had more of an impact at an operational level). These factors were categorised based on their description and best fit to different NPD elements. As can be seen in Figure 60, the culture category contained many of these significant factors. As the focus of the research was the operational practices (Section 3.1), it was decided that further analysis, as well as exploring the operational practices, should also examine the significance of culture as it related to these operational practices.

The result of these summarising and categorisation activities was the analytic framework shown in Figure 60.

6.3 Stage 3: Explanation building through narrative structuring

Often categorisation can fragment qualitative data and, in the process, the importance of subjective experiences or interpretations of the source are lost (Saunders et al., 2009). For example, the tone of a response in an interview or the context of a verbatim comment may provide more depth or richness to key points or patterns. It is this fragmentation and loss of data that can also make it more difficult to understand why a pattern or theme has emerged and therefore difficult to test if the current analytic framework is appropriate to address the objectives of the research.

The purpose of the following sections was to create a coherent story through narrative structuring that would represent each NPD element and the related success factors from the analytical framework. Due to the similarities of 'link to market key stakeholders' and 'project and resource management' in Figure 60, to improve the analysis these have been combined in section 6.3.3 (Project definition and market requirements).

This stage of analysis investigates the actions that participants in the study took, the consequences of those actions and the events that followed. The narrative was then compared against the appropriateness of the success factors and framework, highlighting areas for improvement that were addressed in a subsequent section (Section 6.4).

6.3.1 NPD process

As discussed in section 2.1.5, the NPD process is a sequence of activities in a structured process that take a product from idea to launch. Most top performing product development firms have a formal and disciplined process for doing NPD (Cooper, 2018; Markham & Lee, 2013). Key characteristics of an effective NPD process state that it should be common across different company groups (i.e. marketing, manufacturing, design) (Barczak & Kahn, 2012). The process should include defined criteria for evaluating NPD projects and should be adhered to. The early stages of the process should include performing upfront homework and testing (i.e. concept, product, market) (Cooper, 2018).

There was an identifiable formalised NPD process in the case company (section 4.2.1). This was well documented and visible. Many projects were observed moving through this process and the documentation and interviews supported the existence of, and adherence to, the NPD process. For example, in an NPD project for a new shower product which included a new spray technology it was clear that the marketing department was involved in the early stages of development; they performed consumer surveys, focus groups and used concepts or rapid prototypes to run consumer experiments to gain feedback on the experience that represented the voice of the customer. This data was analysed and fed back into the early stages of development, assisting R&D engineers with information that would help optimise the spray technology. In addition, the industrial design department was involved in this early stage of development. A spray technology is considered the engine of a shower product and is constrained by the required physical form of the product. This would include the design aesthetics (based on fashion trends), ergonomic and anthropometric data. Industrial design, R&D and marketing worked collaboratively together in the early stages of development in these projects to refine concepts, so the concepts aligned with customer and market requirements.

However, when the R&D department was working on projects that could be defined as more radical or breakthrough, an alternative process was observed. This process was unstructured, and often involved performing ad-hoc activities that lacked robust evaluation criteria and documentation. The R&D department segregated this process and projects going through it from other departments and worked in isolation. During the research study there were several different technology projects that went through this process that were categorised by the company as improvements projects, benchmarking projects or new technology:

- Improvement projects typically focused on step changes to an existing technology's efficiency or output that ultimately would create a new engine or internal mechanics of existing products. This could ultimately result in a replacement product or upgrade to existing products.
- The purpose of benchmarking projects was to measure the performance of competitor products or OEM (original equipment manufacturer) to answer various market and business case questions, which would be reported to the marketing department. This could be to learn how well a competitor product does compared to their equivalent or to qualify an OEM product for acquisition and rebranding.
- Technology projects lead to breakthrough developments. These projects explore radical new ideas outside the status quo of existing product platforms of the company. This process resembled closely the characteristics of the Fuzzy Front End (FFE) (Koen, Ajamian, Boyce, et al., 2002) as the nature of the work was chaotic and unscheduled and conducted by a small team from within the R&D department. Occasional projects were run by R&D individuals, allowing the individual to work outside of other formalised projects that they would be involved in. This created flexibility in delivery dates and allowed creative ideas to emerge. The measure of progress of the project or generalizable objectives was to develop a proof-of-concept or strengthen existing concepts. These projects did not enter the NPD process, and the R&D manager was responsible for tracking and funding these projects from an R&D budget.

This separate process for more radical projects enabled an innovative environment for the R&D department. However, the projects were often overlooked by other departments or, in extreme cases, treated as unmanageable risks that should be killed off. <M003-S> worked actively to identify the senior stakeholders who had pet projects and used financial tools, market demand analysis, brand alignment and other measures to remove them from the NPD development portfolio. However, there was evidence that R&D projects other than pet projects were sometimes considered in the same frame of reference. If other departments got involved too early, this would result in an R&D project being terminated or failing to be fully explored. There were examples of projects where a proof-of-concept would be demonstrated to a manager outside of R&D who would dismiss the future value based on subjective knowledge of the market demand and that the proof-of-concept did not align with the existing product range.

The projects completed in the action case study are examples of technology projects going through this R&D process. To the best of the department's knowledge, no type of environmental projects had thus far explored the use phase in detail for the purposes of developing new technology or concepts that could improve the environmental impact of showering. There was a need to better understand what environmental tools could be applicable, and how those tools can be adapted to fit within the R&D process, an aspect understood to impact the successful integration of eco-design (Brones et al., 2017). The informal and undisciplined nature of the work allowed for the R&D department to try eco-design strategies (Brezet & V. Hemel, 1997; Roy, 2016) in combination with the voice of the customer based on the principles of Design for Sustainable Behaviour (Wever, van Kuijk, & Boks, 2008).

Many insights on eco-design implementation were obtained through these projects (discussed further in Section 6.3.2). In particular, it was observed that the technology developments and final results of these projects met the same fate as other non-eco-design related R&D technology projects: they were overlooked and then dismissed by top management. In an interview, <R002> agreed that the eco-projects followed the same pattern as other R&D work:

"The problem is that there is no buy-in from decision makers, such as top management, in the R&D process"

This is in contrast to the research findings regarding the new projects that proceeded through the official NPD process where there was strong evidence of top management support and involvement. For successful eco-design integration, there needs to be commitment, support and resources to conduct the activities related to eco-design (Rodrigues et al., 2016). If those eco-design activities only occur in the FFE process and don't make it into the NPD process, this could go some way towards explaining the absence of good environmental products within the organisation.

<R002> went on to say that, even if there was action on a radical new product based on the findings from the eco-design projects, the NPD process would likely not adapt well:

"It's designed for products we know and do well at. We've got good practice at commercialising the same kind of product and our process has been orientated to support this type of incremental development".

This statement could also explain in part why there was a lack of tough-gates and or criteria on which NPD projects are judged. During gate review processes, there were clear deliverables that needed to achieved before moving to the next stage (in the form of a checklist); however, criteria that would define a go/no-go decision for both financial and qualitative aspects were not clear – perhaps because it was not needed to support the kinds of projects that went through this NPD process. Instead, decisions were made based on casual conversations and gutfeel during gating meetings. This can be considered poor NPD practice and can negatively impact NPD projects and their outcomes (Barczak & Kahn, 2012), and yet for incremental innovations the organisation has mostly a good record of delivering successful new products. In rare cases, <M001-S> stated that, when a project steps into the unknown, the process isn't able to manage risk fast enough, and claimed that they were often having to backtrack to deal with problems that should have been picked up in earlier stages of the process.

When asked why environmental criteria was absent from the gate meetings and NPD process documentation process, <M001-S> responded:

"We need a stronger lens upfront on what that could be and even have perhaps a more robust discussion upfront around how we could include environmental criteria without compromising cost or other metrics."

This demonstrates a prioritization of classical business measures and an unwillingness to include environmental criteria based on the perceived lack of rigour of those measures. However, Rodrigues et al. (2016) recommend that environmental criteria be clearly defined in the gating process and the methodology for measuring eco-indicators should be included as part of the gate review. Yet from an R&D perspective it is argued that the process for projects should be flexible and less formalised (Cooper, 2006).

It is reasonable to conclude that some adaptation of the NPD process is required for eco-design technology projects. In particular, there needs to be a formal connection between the R&D FFE and established NPD processes which involves gaining buy-in from key decision makers. This may then facilitate moving the project through to the next stage of development where it can be provided with a more detailed and integrated analysis. Also, the NPD process needs to be adapted to include eco-design criteria at gates that evolve as the organisation gathers more environmental knowledge on its products and users.

6.3.2 Quality of execution

This section focuses on the product development tools and techniques the team applied and how well they were executed. The organisation used a variety of tools at different stages of the product development process. These tools were commonly used in incremental projects and included project management tools such as Critical Path and simulation tools within CAD to optimise component designs and improve them for manufacturing. At the **front end of development**, both the marketing and new product development teams implemented tools and techniques to gain insights on the voice of the customer and performed creative sessions to identify or evaluate new product opportunities. These included focus groups, ethnographic studies and surveys. These are tools and techniques considered to be best practice NPD that drive new product success (Cooper, 2018; Markham & Lee, 2013).

R&D projects are classified as both **technology** and **breakthrough** projects. When it came to **technology projects**, the tools were more varied. For improvement projects, specific performance modelling and simulation software was used to evaluate existing technology and make improvements to the overall design. For benchmarking projects, they conducted experiments with sometimes customised equipment and physical tools that allowed data collection and analysis of variables that would define some criteria for evaluation.

For **breakthrough projects** where the objective was to develop a new spray technology, the R&D team had a history of creating custom tools to assist with technology development:

"When it comes to prototyping, a very traditional technique is to design something, create it, then look at what works and what doesn't, then take that into the next prototype iteration. This can be slow and costly." – <R001-S>

Instead, they developed 'flexible prototypes' that allow them to change and receive feedback on a number of variables on a single 'super prototype'. Then, during testing and iteration, they tried to bring in the voice-of-customer as much as possible to avoid wasting time on features that never get noticed.

One technique used to improve these products from an environmental perspective is to design the technology to operate at the lowest possible flow rate. The flowrate for a new spray was sometimes defined in the project brief. However, it was treated as an ideal or target rather than as a constraint. They also included the voice-of-the-customer in this process (through product and concept testing), and the user feedback ultimately defined the acceptable flowrate.

How the user experiences the product is important for designers as it must meet their needs, desires and capabilities (Niedderer, Clune, & Ludden, 2017; Norman, 2013). Therefore, the way in which the user interacts with a product will ultimately impact its design (human-centred design). De Medeiros et al. (2018) note that product-user interaction plays a fundamental role in generating more (or less) environmental impact during product usage, and many practitioners have identified tools and techniques that can assist designers in exploring ways of improving product-user interaction from an environmental perspective (Coskun, Zimmerman, & Erbug, 2015). The projects conducted during the action case study are examples of the R&D department exploring this product-user interaction and analysing the relationship between the product design (components, ergonomics, and mechanics) and the way users interact with it. The goal was to better understand that relationship and how it impacted the use phase from an environmental perspective.

The DoE techniques applied in this process were effective in providing insights that could be used for future technology projects that could benchmark existing products with respect to their use phase or provide design considerations for environmental improvements.

As an example, <R001-S> was concerned that if you were to use an *eco-feedback approach* (Bhamra et al., 2011) the type of feedback may cause rebound effects:

"If shown a monetary value per use they might perceive this as small and increase their use as a result"

The first DoE experiment substantiated this concern by demonstrating that the type of feedback does play a role in increasing or decreasing use (section 5.1, Appendix A). Another insight from the second DoE experiment proved valuable and was reviewed during an informal meeting on cartridge types for tapware products. When asked what was being considered when looking at these results, <R003-T> explained:

"The results of the experiment provided some credence to the theory that progressive cartridges save energy"

However, the results of the study were not formally considered in the decision process regarding which cartridge to take forward in the design process. Instead, <R002> argued that the design change would be aesthetically unappealing:

"The aesthetic design is more important and those with the authority to include such changes are in a design orientated position"

It was also highlighted that, for these DoE experiments, there was a lack of data points that would give the results more rigour, particularly for the shower experiment. When asked what needs to be done going forward with this approach, <R002> suggested more data sources were needed. This statement was supported by <R003-T>:

"The sample size was too small. We need experiments conducted in different regions all over NZ but even then, that would only represent NZ and we design for global markets" – <R003-T>

This statement suggests that the R&D department recognises that the behaviours of users and the way they interact with the product will change based on region or geographical location. It was agreed across the R&D department that conducting the experiments yielded practical results, but the need to complete them on a large scale would involve considerably more time and resources. The anticipated cost made it unappealing to continue with this line of experimentation:

"We had to incentivise people to participate in the experiment then if you include the cost of the test equipment – this was also high to design, build and maintain and then there is additional cost to install and collect the data – somehow we would then have to do this worldwide" – <R003-T>

R003-T suggested that, even if they had the funding to continue, they probably wouldn't and instead would opt to collect metadata (such as through integrated smart digital products) and learn about product-user interaction through observation rather than experimentation. However, in similar studies elsewhere, it has been noted that small-scale experiments are better than none at all since they may contribute additional information to the environmental assessment tools (such as LCA). This can lead to more valid interpretation and recommendations of the use phase (Daae & Boks, 2015).

There was also a lack of understanding of the results of research coming from the R&D and other departments. With a lack of understanding also came a lack of trust. Designers, and managers with an engineering background could understand the statistics behind the method but did not appreciate the inclusion of behavioural science as part of the design considerations for improving the environmental performance of a product – they considered it too subjective, "fluffy", lacking rigour, and out of place for product development. However, when optimising the experience of a new product, tools were used to gain knowledge of the subjective experiences of the users which were typically extremely variable. Yet these particular data collection tools and final results seemed to carry more weight with engineers, designers and managers and were often integrated into the design process:

"You got us on that one. All quality testing is done that way. Material, mechanical and functional performance testing with customers are all completed on a small scale and integrated into the development process, but, when it comes to environmental testing we seem to think small-scale isn't good enough – <R002>

So why did acceptance of the legitimacy of the quality testing results not extend to the environmental results? One possible explanation is the recognition of the significance of market and customer requirements by the innovation team, a recognition that does not extend to environmental considerations. <R003-T> stated that it is common knowledge that consumer experience plays a critical role in sales, pointing out that hotels rank shower experience as one of the top important factors for repeat customers and linking this to flowrate. In contrast, <R001-S> proposed that customers do not have a good awareness of the environmental impact of using their products:

"I'm often disappointed with consumer's attitudes, I've always believed we've pushed out more than is accepted. One of the problems is that the true cost to the environment is not reflected in water use and flowrate"

This implies that marketing and consumer awareness may influence the tools and techniques used to address the use phase. If it is believed that customers do not care about environmental improvements related to the use phase, then the NPD and R&D teams may be less likely to implement related tools and techniques to address these environmental impacts.

For products that have an active use phase, many case studies have demonstrated successful design interventions to improve the environmental based impacts of the product through applying behavioural science insights to improve the use phase of the product (Polizzi di Sorrentino, Woelbert, & Sala, 2016). Typically these products are functional (electrical appliances such as refrigerators, dishwashers) (Bhamra et al., 2011). For the action case study in this research, the techniques used to analyse the use phase appeared to be more effective when targeting a more functional product, and better received by the innovation group. However, when the products were experience based (such as for shower products), there was more opposition and challenges associated with accepting the results of experiments using these techniques.

In the third experiment (recirculation system trials in section 5.3), the objective was to create an eco-design system where it was initially believed the subjective experiences of the users would not be a factor (for example, savings would depend on the performance of filtration not how users showered).There are many different types of filtration systems that could work for a recirculation system, and LCA allows for optimisation by quantifying the environmental impacts of those alternative filtration systems over the lifetime of the shower system.

During the recirculation experiment and data collection phase, different use profiles based on shower behaviour were created for LCA modelling. This is an important consideration for LCA where the use phase varies based on user behaviour (Daae & Boks, 2015; Polizzi di Sorrentino et al., 2016). One of the key insights gained from the LCA study was the impact shower behaviour had on the overall life cycle-based environmental impacts of the recirculation system. If the user showered for a longer period of time, the environmental improvements gained by using a recirculation rather than conventional shower system would be high. However, if the user had shorter showers, perhaps more functional showers, then the environmental improvements would be very small over the lifetime of the recirculation compared with conventional shower system. In fact, the environmental benefits would be similar to heat recovery systems that would be a fraction of the cost to the user. Thus, the user's behaviour considerably impacts the environmental performance of the assessed system.

It is well established that LCA is an effective eco-design tool used to improve the environmental performance of products (Boks & Stevels, 2003) and, when formalising this within the NPD process, can contribute important insights in environmental projects (Johansson, 2002; Pigosso et al., 2013; Poudelet, Chayer, Margni, Pellerin, & Samson, 2012). In the circular economy project (section 4.3.2), LCA was instrumental in measuring and reporting on the life cycle-based impacts of their material choice for this project – and provided some insight and pathways to ensuring true environmental improvements were achieved in material choices and recovery programs. However, the organisation experienced key challenges in implementing LCA within the design process, and in particular conducting LCA studies using the specialist LCA software:

"For the thousands that it cost each year we would need to be using the software a hell of a lot to justify the cost. We would also need to train a few people on how to use it and even then, we wouldn't really know how to use it well" - <R003-S>

This implies the organisation found that LCA is difficult to learn and implement and, as a result, it was not utilised enough throughout the process. These findings are consistent with other eco-design integration studies (Baumann et al., 2002; Devanathan et al., 2010),

After a year of maintaining the LCA software licence, the organisation decided to contract LCA work out or ask environmental questions of experts and simply be charged for the hours. While this does present some cost benefits, it could make it more difficult to systemise LCA and lacks the embedded integration of the NPD process (Tingström & Kth, 2007; Ussui & Borsato, 2013) that would result in a meaningful impact.

LCA is often most useful at late stages of the NPD process or applied retrospectively at the end of product development (for example, to produce an Environmental Product Declaration) when detailed product specifications are available (Baumann et al., 2002). Due to the highly specific data requirements for undertaking an LCA, it is therefore limited in its ability to assist in early stages of development (such as in the FFE) (Baumann et al., 2002; Devanathan et al., 2010). Much research has been dedicated to the development of alternative approaches that can use or combine analytical estimation methods and qualitative data to assist in decision support for these early stages (Devanathan et al., 2010; Dewulf et al., 2006; Lofthouse, 2006). However, in this research LCA was applied effectively in the recirculation project and provided vital decision support in the FFE development of a systems-based approach to showering. Using LCA, it was established that the major impacts associated with this system were the relationship between how users showered (i.e., length of time spent washing vs not washing), the overall design and method of recirculation (i.e., size of recirculation tank, flowrate, quantity of water recovered) and the filtration system (i.e., effectiveness and life in service). LCA was a necessary and useful tool in this analysis.

In the action case study, the tools and techniques applied provided sufficient information to support improving the life cycle-based environmental impacts of showers and taps. However, it was found that for LCA and other tools to be effective, practitioners (engineers and designers) need to become more competent in using the environmental experiments and acknowledge the relationship between consumer behaviour and environmental impacts when interpreting the results. The use of any tools should be grounded in LCT based principles, so the outcomes are focused on environmental hot spots in the lifecycle (such as the use phase). In addition, the experiments on the use phase are useful, even if they are not fully representative of different geographical regions. The results of these types of experiments need to be recognised as legitimate by decision-makers.

6.3.3 Project definition and market requirements

Good project and product definition is considered to be a major success factor in NPD (Cooper, 2018). This will ensure the project stays on track, avoids scope creep and communicates the objectives for the project.

Project definition was completed by the organization for technology and NPD projects over the duration of the study, and how well this was executed played a critical role in the development time and outcomes for projects. There was a lack of previous project documentation that showed good examples of clear upfront concept description that included defining the goals and objectives. This impacted the outcomes of eco-design projects such as the Circular Economy product. For the Circular Economy project, there was evidence was evidence that the goal and objectives of the project were poorly defined. Engineers and designers developed the product with the expectation that it would be refurbished on-site and spent a significant amount of development time working on design changes that would allow for ease of disassembly. However, other departments developed their own description of the product and purpose and independently created marketing and manufacturing plans. These applied traditional financial tools with a narrow lens that considered the costs associated with a linear product development life cycle (rather than the circular approach initially proposed). A "one pager" document was created for this project that defined the criteria. However, when asked what criteria were used as a primary reference for the development of the project, two different answers emerged. The marketing department did not make the connection of the material choice, recovery process and environmental savings.

"I think if you went right back to the stage where we define the criteria I don't think we would have been really clear that one of the core objectives was that it had to be an material perceived to be an environmental improvement, I think that story evolved" – <M001-T>

One of the senior engineers that was briefed by the R001-S on the project stated that goals were very clear from the beginning:

"I had to create a new tapware product that provides the ability to reuse the materials at the end of life, we had to keep the parts and body modular and try to replace many of the traditional manufacturing processes with the use of stock and third party parts" - <E-001-S>

<R003-T> suggested that one of the reasons for this disconnect was how the criteria were defined for each department. Engineers were taking a life-cycle thinking approach, defining the value based on recovery and reuse. Marketing applied a short-term thinking approach, and defined criteria based on return on investment. There did not appear to be a single cohesive product definition that was communicated across all departments.

Another example where product definition was not clearly stated upfront concerned the technology projects on products that recover heat from a shower system. The R&D team would define constraints on how well the system should perform with respect to size, installation and maintenance, and spent most of their time maximizing efficiency of the heat recovery mechanics. However, there was little attention paid to the effectiveness of the overall product concept and the added value it would give customers from a combined economic and environmental perspective.

An added benefit of having a well-defined concept or product definition is that it will place more emphasis on the front-end homework stages (Cooper, 2018). In the process of defining the benefits and value proposition to be delivered to the customer, it will highlight where there is a lack of information of the preceding development stages such as 'Opportunity Identification and Analysis'. During an interview, <E001-S> claimed that poor upfront scoping was a problem as often he received design changes that made him question if any scoping had been done at all:

"I keep getting significant design changes, swivel to traditional then fatter to thinner and then they change their mind again and change it back, so it sounds like they don't actually know what the product is supposed to be" - <E001-S>

It was observed that the organization conducted customer research that would help define the design specifications; however, this was not well integrated into the design process. This finding is consistent with the NPD survey where most respondents claimed that the customer insight research did not impact their development activities (section 4.2.1).

For most projects, flowrate was defined as a key performance criterion – and this was usually identified through customer research. However, the same customer research was very clear that this criterion was based on an economic value proposition and did not represent environmental awareness from consumers. And the experiments conducted in the action case study provided evidence that flowrate alone is not a good environmental criterion but that other environmental criteria could be derived for shower and tapware products (Section 5.5). However, a significant barrier to including these more representative environmental criteria for new products is how to link them to perceived value to the customer.

In summary, it is necessary to have a clear project brief at the start of a new project. For eco-projects it is important that the scope, objectives and deliverables are communicated consistently throughout different teams and departments that are involved in the project. Furthermore, there should be more engagement with customers to better understand their needs and build this into the development process. If customers are not environmentally aware of the benefits of eco-additions to new or existing products, then it becomes difficult to justify the need (Dewulf, 2013).

6.3.4 Culture

The culture of the organisation played a critical role in the outcomes of the different studies throughout this thesis. The case study situational analysis (Chapter 4) demonstrated the importance that the organisation places on the culture and climate and its effect on NPD success. The organisation has built in a number of core values that reflect their overall business strategy and objectives that are expressed in the day-to-day activities of NPD. The culture and climate of an NPD organisation has been linked as a determinant for successful product development and both a strategic and operational level (Berchicci & Bodewes, 2005; Cooper, 2012; Markham & Lee, 2013) and existing research has outlined various NPD success factors in this area (Anderson, 2017; Barczak & Kahn, 2012; Cooper et al., 2004).

Many of the culture success factors were observable throughout the study. Top management was engaged with the NPD process and innovation, employees were motivated and aligned with the organisational values. Culture and Climate of the organisation ranked highest in the Situational Analysis NPD survey (Section 4.2.4), with most answering that the teams have cross-functionality with good communication and strong leadership for NPD projects. Some of the cultural success factors which support the integration of eco-design into NPD (Berchicci & Bodewes, 2005; Johansson, 2002; Tingström & Kth, 2007) were also observed. There were environmental champions at a product development level of the organisation and a strong eco-design 'mind-set' within the innovation group to include environmental consideration as part of their day-to-day activities. This attitude had driven a number of environmental initiatives that cut across the different parts of the business such as employee waste management, recirculation system projects within the R&D team, and removal of hazardous materials in their product processes. While these may not be good examples of eco-design *per se*, they demonstrate a drive to manage the environmental impacts across different parts of the business.

However, despite a high-level commitment to the environment by the business, the culture and values regarding eco-design and the integration of environmental consideration into NPD were not as clear. This was first highlighted in an interview with <M001-T> who was asked if there was good awareness of environmental issues and what can or should be done at a product development level:

"I think it is confused, I think there is real pockets of heightened awareness and real interest - and frustration on the inability to pervade through to the culture and be really meaningful".

<M001-T> suggests that, despite a number of environmental product development projects including those often initiated or supported by the CEO, there is still no alignment on what the environmental philosophy is and how it plays a role in NPD success. This position was supported by <R001-S> who expressed that, in order for environmental product development to succeed, there was an outstanding need to make sustainability part of the culture.

This lack of alignment on eco-design has three main influencing factors which were expressed throughout the study: individual employee attitudes, customer attitudes and the consideration (or not) of the product use phase (Figure 61).

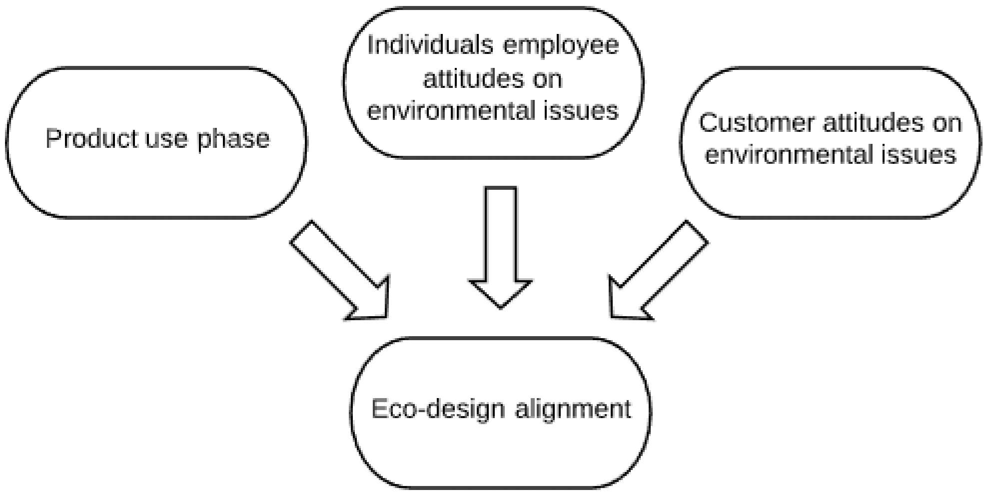

FIGURE 61 INFLUENCING FACTORS ON ECO-DESIGN COMPANY ALIGNMENT

Regarding **individual employee attitudes**, <M001-S> stated that there were individual employees in a position to derail environmental initiatives, and suggested:

"You can always find someone at the back of the room who thinks sustainability is rubbish and we shouldn't bother."

<R002> proposed that there were social and physiological factors inhibiting action on eco-design and suggested that, regardless of whether employees have a positive approach to addressing environmental issues, most people within the organisation are unable to comprehend the environmental threat and the change required by the organisation to counter that threat:

“Most people think that you just need to recycle a little bit and that’s their contribution complete. So when they are sourcing components or making decisions that’s how they are thinking – they are not thinking about the bigger picture and certainly not addressing the elephant in the room”

Similarly, the existing values and product strategy of the organisation with respect to ‘good design’ plays a role in an individual’s perception of eco-design. The organisation has built a reputation for developing products that are aesthetically pleasing and consistently celebrates their awards. In the action case study, the tapware experiment presented the organisation with an opportunity for a design change that could compromise the aesthetics but improve the environmental performance of the product. This change was quickly dismissed in favour for retaining the aesthetic appeal. <R003-S> stated that:

“The ultimate decision maker has a passion for design and aesthetics, not the environment”

There was also a perception that top management did not support eco-design. For example, on presentation of the LCA results for the circular economy project, many were shocked at the negative outcome with respect to the environmental impact of what they had perceived to be a good choice. Despite the researcher outlining initiatives that could improve the environmental profile, there was a significant lack of subsequent action from top management to take anything forward. In a follow up discussion with <M002> they claimed that this was typically for the organisation:

“This is the kind of culture we have built. We gather information, analyse it, and present it to the decision makers but then we fail to see any action.”

<R001-S> proposed that a pathway to aligning the organisation would be to create and implement an environmental strategy and plan with clear goals and objectives from an environmental perspective. The best practice NPD survey results (Section 4.2.1) illustrated that the innovation group believed that a lack of environmental strategy was the greatest barrier to producing eco-

products. This is supported by the literature that states that strategic planning is considered to be fundamental to the long-term success of any NPD organisation (Kahn, Kay, Slotegraaf, & Uban, 2013a; Markham & Lee, 2013), and that NPD organisations should define long term objectives of innovation and environmental sustainability (Brones et al., 2017; Rodrigues et al., 2017). In implementing such a strategy, Brones et. al (2017) recommend a number of actions or pathways that could be taken to achieve this.

Regarding the **product use phase** and its impact on culture, the philosophy had been that if the company was developing products which use less water, then there was an environmental benefit. Many of the company's shower products are designed to improve the experience of showering through spraying the water in a different way, which also happens to require less water. Water rating schemes provide the platform for promoting water efficiency and environmental savings to their customers. However, from a Life Cycle Thinking perspective a singular focus on use of less water is too simplistic. It is recommended that eco-design strategic planning should be based on life cycle thinking principles (Brones et al., 2017; Pigosso et al., 2014). As demonstrated in the action case study, energy and duration of use are other factors that contribute to the environmental impact of shower and tapware products across different environmental impact categories (such as carbon emissions) – yet there is no platform for acknowledging these aspects and their role in reducing environmental impacts. In fact, one of the Design of Experiment studies highlighted that traditional shower sprays tend to use less energy on average. <R001-S> argued that:

"From an environmental perspective we could just be developing traditional needlejet sprays but there is less added value for the customer. People still have to buy your product, so your environmental strategy and the products you develop need to be economically sustainable as well".

This perception was shared by <M001-T> who suggested that there is a balance and trade-off to develop products that deliver a great experience to users while also delivering wider environmental savings through restricted water use.

When presenting the action case study results to the engineers, the researcher made clear that there are design changes that can improve the use phase of their products. However, when questioned on how they might implement those changes, most engineers still believed that they lacked the ability to influence this area. They stated that they would rather focus on stages they know they can directly impact in design (such as manufacturing and end-of-life) and leave the use phase for the customer to manage.

The **customers' attitudes** also played a contributing factor in the organisational culture and lack of eco-design alignment. In an interview, <R001-S> explained it was still unclear on how to orientate the eco-design strategy so customers would see the added value:

"We could go for the completely polarised approach so it's obvious for customers"

This "polarised approach" would draw on the eco-design classes, developing products that have eco-design at the forefront or developing systems that recycle and recover water and energy. However, many employees stated in interviews that the environmental savings for these products and systems alone are not enough to gain customer buy in. <M001-T> believed there needed to be an economic value and that the environmental benefits should be 'tagged to' this economic value. Other employees believed that customers simply lacked a good awareness of environmental issues:

"We would need to conduct a marketing campaign that clearly outlined to customers how the use phase of showering impacts the environment so we could generate real buy-in and added value for such products, we just don't have the resources or marketing budget to do that" - <M003-S>.

In conclusion, culture has a significant impact on the operational activities. There is a lack of alignment across departments on what the environmental priorities are, particularly at a top management level where there is little or no support for addressing environmental hot spots (such as the use phase). Consumers have also played a role in the culture of the organisation. As identified in section 6.3.2, teams were less likely to implement eco-design tools and techniques or act on environmental knowledge if they believed consumers did not care about this aspect. This has influenced other engineers, designers and decision makers, creating a poor eco-mindset where environmental initiatives or improvements are not a priority, or they are actively excluded from the NPD process.

6.4 Improvements to framework

Through the narrative structuring and explanation building process described in Sections 6.1 to 6.3, it became clear that three aspects of the initial framework required further consideration: (1) the varying relevance of different NPD elements for each class of eco-design, (2) the relationship between culture and the success of NPD, and (3) tailoring of the success factors to be more directly applicable to specific products.

Firstly, nothing significant emerged from the narrative structuring that would suggest that best practices need to differ between the different **classes of eco-design**. However, it was found that the characteristics of NPD best practice could be equally applied to eco-design projects. As an example, a characteristic of NPD best practice is to create a well-defined product description to communicate the goal and objectives of an NPD project to engineers, designers, managers and other practitioners or decision makers. Its absence can slow development though scope creep or back tracking (Cooper, 2018). The case study company tended not to develop well-defined product descriptions, and this particularly created ambiguity in eco-design projects where staff failed to identify the agreed purpose of the project and instead made decisions based on assumptions or limited environmental knowledge. Therefore, the lack of good NPD practice had an impact on the successful integration of eco-design in the company.

Secondly, the **significance of culture** and its impact on the NPD process became more apparent as the research progressed. The analysis indicated that environmental criteria should be included within the NPD process. However, when eco-design tools and techniques were used in the action case study to investigate the environmental impacts of products, their results were often challenged by staff who expressed doubt on the robustness and reliability of their results. This was particularly evident when quantifying the environmental impacts associated with the product use phase. For project definition and market requirements, there was no platform or marketing strategy that linked to the perceived customer value of eco-design of active products, and therefore any metrics or project definitions (that might define 'eco-added value' for the customer) were not possible.

While all these operational points are individually significant within each element, they also share links with the culture of the organisation. Furthermore, decision makers and top management appeared to be disengaged from R&D environmental initiatives and lacked alignment on how to perform eco-design. This allowed managers within the NPD process to make more subjective decisions or exclude important environmental criteria that might address the use phase based on their own bias or conflicting values. This also impacted the environmental mind-set of engineers, designers, influencing the type of tools they used and leading to a lack of confidence in the likely success of new environmental initiatives that were outside the norm (i.e., considered radical). Without an eco-culture embedded in the organisation, the use phase was not adequately considered in the product development process and project definition. Regardless of the tools and techniques applied to address the use phase, the results are likely to be overlooked or easily dismissed.

Lastly, many of the **success factors** in the analytical framework did not seem appropriate or provide enough clarity to enable a shower and tapware manufacturer to realise tangible environmental improvements in their product development. As an example, an initial success factor stated, “Senior Top-Management involved / engaged in projects or supports eco-initiatives”. However, simply supporting all environmental projects may cause shower and tapware manufacturers to not focus on the use phase and instead drive projects that seem more achievable but ultimately may have little impact on the life cycle-based impacts or produce no net environmental benefit. Some success factors also seemed in conflict with existing best practice theory NPD and eco-design. For example, when exploring the factor “Ability to adapt marketing plan to communicate the added value of eco-design product changes / improvements”, the narrative explained that this was not appropriate when the use phase was the life cycle priority. It would require an expensive and significant study of users to see how their behaviour changed. There was no budget for such a monumental undertaking since there is no platform or environmental scheme that would assist them in demonstrating the added value to customers. This factor can be categorised as external to the organisation; as such, they may be influenced by government policy or public pressure, but the company can do little to influence them.

As a result of these insights, the framework was revised to a simplified representation (Figure 62) and the success factors were recategorized and rephrased (Table 21). The framework is referred to as the ‘STeP framework’ (**S**hower and **T**apware **e**co-design **P**roduct framework) in the remainder of the thesis.

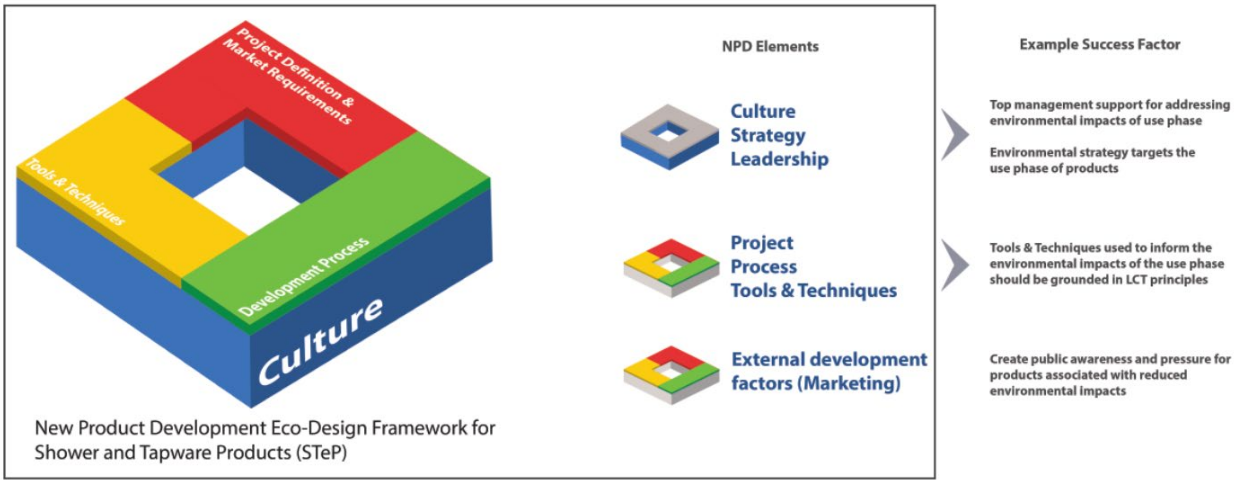

FIGURE 62 NEW PRODUCT DEVELOPMENT ECO-DESIGN FRAMEWORK FOR SHOWER AND TAPWARE PRODUCTS (STEP)

Table 21 can be used to analyse the NPD processes of shower and tapware manufacturers for changes that would be required to successfully integrate eco-design into their NPD practice. It could be linked with existing NPD audit tools (e.g. Barczak and Kahn (2012) NPD practice audit) to identify weak points in their NPD or changes that need to occur in different elements to support the integration of eco-design.

These success factors have also been used to support the operationalisation of the STeP framework and the proposed conceptual model for the FFE of NPD for shower and tapware (Section 6.5)

TABLE 21 FACTORS AND JUSTIFICATION FOR ECO-DESIGN INTEGRATION INTO NPD OF SHOWER AND TAPWARE PRODUCTS

	Success Factor	Justification
Culture, Strategy, Leadership	Environmental strategy targets the use phase of products	Most environmental impacts occur in the use phase, and so resources should be focussed on environmental goals and objectives related to the use phase
	Top management support for addressing environmental impacts of use phase	Top management determines whether eco-design projects succeed or fail
	LCT education across different departments to ensure alignment for eco-design initiatives	Poor understanding of the life cycle-based impacts of shower and tapware products, and subjective interpretation of causes of environmental impacts
Project, Process, Tools and Techniques	R&D development process should cut across other divisions of NPD	Lack of buy-in from decision makers when at opportunity identification and analysis stages of R&D and NPD
	Tools and techniques used to inform the environmental impacts of the use phase should be grounded in LCT principles	Environmental impacts in the use phase generally dominate the overall life cycle-based environmental impacts of the product
	Innovation group acknowledges the relationship between consumer behaviour and environmental impacts	Knowledge generated in this area needs to guide the NPD process
	Core competency in conducting environmental experiments that include both DfSB and LCT principles to gain new product knowledge	A need to generate reliable and valid results that can lead to new product concepts/ideas or existing product improvements
	Clearly defined upfront product description which is communicated across organization	Prevent subjective interpretation of the goal and objectives of the product or concept (across different departments/functions)
	LCA included in evaluation of new concepts or prototypes that address the use phase	Must quantify all additional components and systems that impact the use phase to ensure true environmental benefits for consumers
	Development of benchmarking and standards when testing environmental concepts/prototypes/ideas	Required as environmental criteria in evaluation stages of development
	Core competency in marketing environmental concepts which target improvements in the use phase	A need to create value with consumers from R&D environmental product and concept developments
External Influencing Factors	Create public awareness and pressure for products associated with reduced environmental impacts	Consumers not willing to pay extra or do not see value in such products / concepts (lack of demand)

Success Factor	Justification
Influence external standards or policy (i.e., Government) with respect to environmental impacts associated with the product	Lack of rating scheme for environmental impacts of shower and tapware products other than water (i.e., energy).

6.5 Proposing an NPD process model for the Fuzzy Front End (FFE)

This study has shown that the eco-design projects observed during this research are located at the front end of the design process i.e., the fuzzy front end. This is reflected in the success factors (particularly for the operational elements of NPD such as Project, Process, Tools and Techniques) where all have a strong relationship to the FFE (Table 22).

TABLE 22 SUCCESS FACTORS AND RELATIONSHIP TO FRONT-END

Success Factors (Project, Process, Tools and Techniques)	Relationship to FFE
R&D development process should cut across other divisions of NPD	R&D is considered the **front-end** of NPD
Tools and techniques used to inform the environmental impacts of the use phase should be grounded in LCT principles	Tools and techniques used to inform design decisions should occur in the **front-end**
Innovation group acknowledges the relationship between consumer behaviour and environmental impacts	Consumer research should inform **early design** decisions
Core competency in conducting environmental experiments that include both DfSB and LCT principles to gain new product knowledge	Experiments that gain new knowledge can initiate **new** eco-product ideas
Clearly defined upfront product description which is communicated across organization	Usually included in a project brief as part of the **front-end** development activities
LCA included in evaluation of new concepts or prototypes that address the use phase	Concepts and prototypes are part of **front-end** development
Development of benchmarking and standards when testing environmental concepts/prototypes/ideas	Concepts and prototypes are part of **front-end** development
Core competency in marketing environmental concepts which target improvements in the use phase	The ability to market the concept implies the voice-of-customer research activities should occur

In proposing an NPD process model that would operationalise the STeP framework relevant NPD Process modes are presented in Table 23. A summary of the front-end NPD processes reviewed in chapter 2 is presented in Table 23.

TABLE 23 FRONT END PROCESS MODELS (OVERVIEW)

Table 23 Front End Process Models		
Author	**Model**	**Differentiating characteristics**
(Khurana & Rosenthal, 1998)	Fuzzy Front-End Model	Does not distinguish between technology projects and NPD projects. Activities within stages resemble traditional stage-gate models. Front-end activities grounded in strategic fit/portfolio management practice
(Reid & De Brentani, 2004)	Fuzzy Front-End Information Flow and Decision-Making Process: Discontinuous Innovations	An abstract perspective of the fuzzy front end and the way in which information flows to decision makers. Focus on managing discontinuous innovation projects which originate in an environment that is disconnected from an organisations NPD process
(Cooper, 2006)	Technology Stage Gate	Iterative between stages but ultimately sequential. Utilised as an operational blueprint or roadmap that generalises and prioritises technology projects in preparation for entering the NPD process. Traditional business measures used to evaluate new technology development opportunity.
(Koen et al., 2012)	New Concept Development Model	Interrelated activities (the stages) are non-sequential. The model focuses on how activities and understanding the relationship with the engine (the organisation culture and strategy) and uncontrollable influencing factors (consumers, market)

The eco-design projects observed in this research were often non-sequential in their development process, as ideas evolved from iteration and in response to influence from other strategic development activities (such as opportunity analysis and consumer (product user) engagement). The culture of the organisation also impacted the activities within the NPD process. This included how the company perceived the demand for environmental considerations as being linked to the attitudes of consumers. The process activities, culture and the outside influences (i.e., consumers, policy/regulations) were all interconnected. Based on these characteristics of the company NPD process, the New Concept Development Model (NCD Model) (Koen et al., 2012) presented in section 2.3.1 seems most appropriate for implementation in the company: it is described as a relationship model, not a linear process, and new ideas are expected to evolve iteratively across the five elements of the model.

Therefore, based on this research, the NCD model was adapted to account for the STeP success factors. The adaptation, referred to as the "Eco-Design Process for Active Products" (EcoAP) model, is proposed and shown in Figure 63. How the framework and success factors of the STeP framework align with the model have been listed in the 'Engine' and 'Influencing Factors'. The principle behind the Influencing factors is that they are uncontrollable by the organisation; however, awareness of what these are and their impact on NPD efforts or performance needs to be understood by the organisation as it can better inform stages of the NPD development (i.e., public pressure or policy when assessing a new eco-opportunity). The 'Engine' lists the high-level strategy and culture the company should be attempting to embed to support eco-design within the fuzzy front-end of NPD. The relationship between the engine and the activities or stages that occur within the Eco-AP model are further explained in section 6.5.1 and section 6.5.2. Finally, 'Opportunity Identification' and 'Opportunity Analysis' are combined with a new stage known as 'Opportunity Development' and this adaptation is discussed in Section 6.5.3.

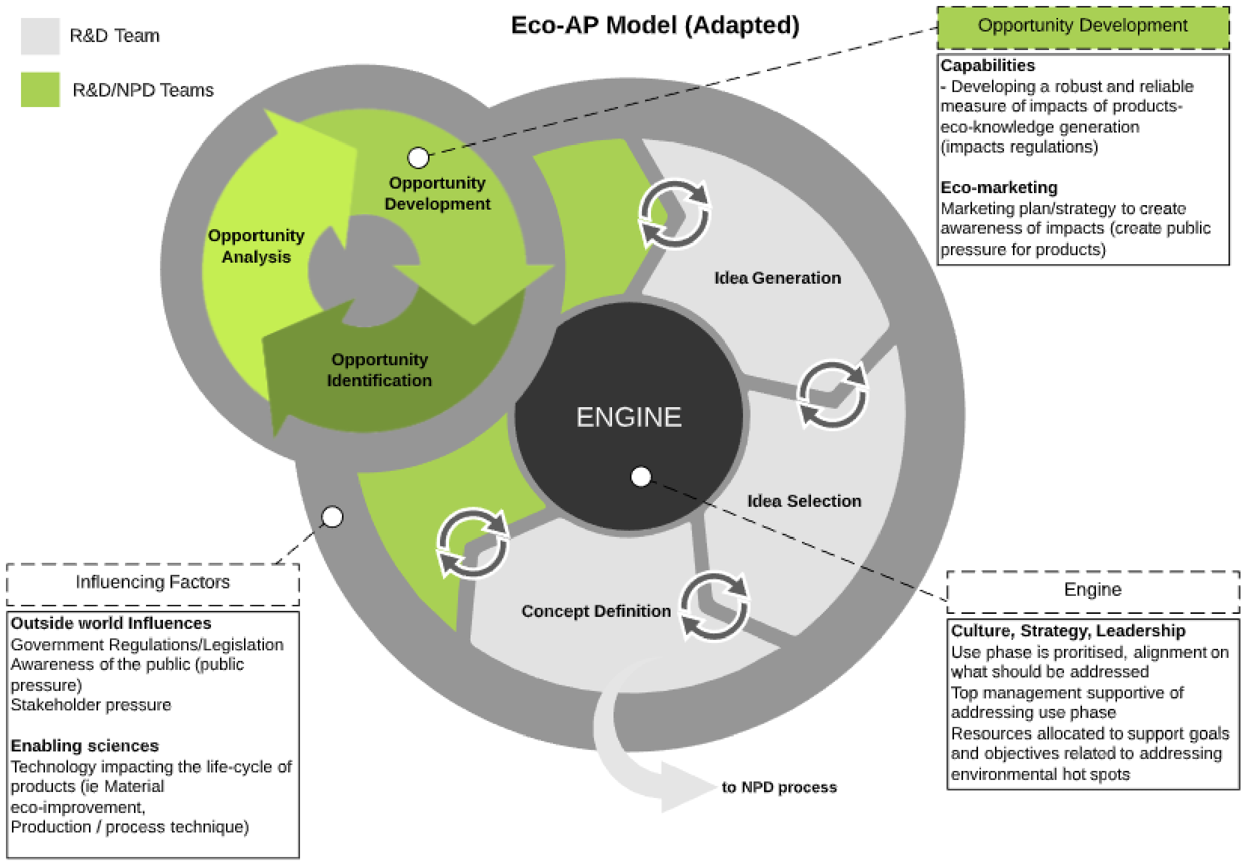

Figure 63 Eco-AP Model (Adapted from Koen et al. (2012))

6.5.1 The engine alignment

Strategy, leadership and culture impact many of the NPD elements and influence all divisions of an organisation (Barczak & Kahn, 2012). A well-defined strategy provides the organisation with goals and objectives which will determine the priorities of technology and market direction (Anderson, 2017) – success factors that ultimately impact the front-end process and R&D projects. A product development project must have strategic alignment with the business and strong leadership in order for it to succeed. Often R&D projects inherently have high risks and significantly longer time horizons that require ongoing support from senior management to continually drive the opportunity (Koen, Ajamian, Boyce, et al., 2002). This also requires a culture that is supportive of an ambiguous and chaotic development process. Teams and individuals must deal with more uncertainty that would otherwise be expected from an incremental project.

The engine explains the relationship between the activities within the EcoAP model and the culture of the organisation. For successful EcoAP there should be clear alignment on the environmental priorities of the organisation and top management support to drive environmental R&D projects. More specifically, for producers of active products top management needs to be supportive of addressing what is typically the environmental hot spot – the use phase. Furthermore, they need to be prepared to back projects that approach addressing the use phase from less traditional methods and processes - such as DfSB.

Idea generation and enrichment in the early stages of development is the activity that generates, develops and matures a concrete idea (Koen, Ajamian, Boyce, et al., 2002). It is recommended to include human centred activities that would help understand the customer with respect to their needs or desires, so that ideas are developed from their viewpoint (IDEO, 2019). Design Thinking is an example of an NPD process (discussed in Section 2.1.5) that focuses on human-centred product development providing practitioners with behavioural tools and techniques to analyse and interpret consumer behaviour. However, from an active product perspective there is risk that a customer's preference on function and experience, may conflict with efficiency and other environmental impacts associated with its use. DfSB must therefore be integrated into the idea generation and enrichment stages of development to maintain product consumer requirements on function and experience while mitigating environmental impacts associated with use. This would require employees to have an ability to conduct environmental experiments that allow them to gain new knowledge on consumer behaviour with respect to the use phase and allow this new information to impact design decisions through to final concept. Human behaviour can be complex, and therefore complex tools (such as DoE) are necessary to measure, analyse and optimise the use phase.

Idea selection in the front-end is described as the formal process where the development team will look at a very limited amount of information about an idea to decide if further resources should be committed. Product developers typically use solution requirements to formally evaluate the idea or rank it against others. Solution requirements can be defined with respect to technical, legal, social and environmental constraints/criteria. To assist product developers in this selection process, a number of eco tools and methods are available including Design for the Environment (DfE) and Life Cycle Assessment (LCA) (Fitzgerald, Herrmann, Sandborn, & Schmidt, 2005). DfE tools, such as those based on checklists, are easy to implement but are very subjective and not particularly insightful in guiding improvements. LCA is commonly thought of as unsuitable for early design processes due to the limited information available about the product at that stage in the design process (Devanathan et al., 2010). However, for active products this is not necessarily always the case. When considering eco-design at a system level, LCA is necessary to quantify the environmental impacts associated with the overall design – particularly at the early stages of development. This is supported by the findings in section 6.3.2 where LCA was found to necessary and useful in the early development of a recirculation system. The impact of various sub-systems and how they perform with respect to the overall design can significantly vary the life cycle-based impacts. Combining sensitivity analysis with the results across multiple impact categories (i.e., Energy, Water,) useful data can be generated. This data can be used to support decisions so significant that when reaching a stage of final design many of the major environmental hot spots should already be optimised (i.e., the efficiency of the system under normal conditions of use).

The NCD model defines **concept definition** as the final activity prior to exiting the FFE to the rest of the product development process. At this point in the process the project champion needs to present a compelling case on the business opportunity to gatekeepers within the NPD process. These gatekeepers will follow guidelines to determine if the project should proceed through the NPD process (e.g. stage-gate) or if it should continue iteration within the NCD model (Koen, Ajamian, Boyce, et al., 2002). A weakness of this transition between the NCD model and stage-gate models is that both typically lack environmental criteria or the ranking of environmental criteria against other criteria is subjective, and they are often not given much weighting in the evaluation of new projects. Existing eco-design models attempt to address this by recommending the inclusion of environmental criteria to evaluate projects (Pigosso et al., 2011; Rodrigues et al., 2016); however, they often make a generic recommendation rather than recommending inclusion at a specific point – such as in a front-end process. As a result, the recommendations often lack precision in their explanation of integration (Jefferson Hynds et al., 2014). Therefore, during concept definition robust and quantitative environmental criteria, based on LCA or other tools based on LCT principles, must be included and evaluated. These should give no room for subjective interpretation of the purpose or aim of the project by individuals and teams in different departments. This would require the gatekeepers to have a sound understanding of LCT and LCA so more objective decisions can be made. The insights from the shower and tapware case study suggest that by not doing so their impact categories and life cycle stages could be ignored. As an example, they may just focus on reducing the impact category 'water use' since this is the way it has always been done.

6.5.2 Opportunity Development adaptation

The Opportunity Identification and Analysis stages in the conceptual model represent the business case evaluation of a proposed new project (Koen et al., 2012). Identification often precedes the Idea Generation stage (Koen, Ajamian, Boyce, et al., 2002) and involves activities that highlight opportunities the company might want to pursue. This is often driven by the strategic goals of the organisation and includes formal activities that map future scenarios (such as fore-sighting) and less structured techniques such as ‘water-cooler’ conversations (Dewulf, 2013). Opportunity Analysis applies tools and techniques such as focus groups, market studies or scientific experiments that translate the technology opportunity into a business opportunity where risks and strategic fit can be measured. This is in contrast to NPD opportunity assessments where evaluation of the commercial opportunity may result in a go-no/go decision (Högman & Johannesson, 2013); the opportunity stages are intended to be more explorative and inform the project and guide further development. As an example, the stage may highlight the need to obtain more information or complete additional experimentation that would further reduce uncertainty.

Within the original NCD model, Koen (2002) recommends building a multifunctional team including marketing and R&D experts to conduct an opportunity analysis. This analysis will assess the business capability and competency. Successful ideation and analysis in incremental innovations often requires leveraging an organisation’s capabilities to develop commercial opportunities (Ulrich & Smallwood, 2004). These capabilities are particular strengths of an organisation which are based on competences (e.g. R&D resources, marketing and sales force) and resources (materials, manufacturing), and how well these fit with the needs of a new product or concept (Cooper, 2012). However, a weakness of the Koen (2012) NCD model is that it fails to consider the development of organisational capabilities for the opportunity identification and analysis stages for breakthrough projects/innovations. For discontinuous innovation or breakthrough projects, capabilities often need to emerge or be developed by the organisation (Miller, 2013). This capability develops over time as an organisation becomes more competent at the activity.

To accommodate the external success factors in the STeP framework, an additional activity is proposed to be included in the part of the EcoAP model referred to as Opportunity Development. Rather than a new technology project being driven by outside influences on the organisation (government regulations, consumer demand), this activity would produce new capabilities within the organisation that create new opportunities. An example of how this capability could develop is provided in Figure 64.

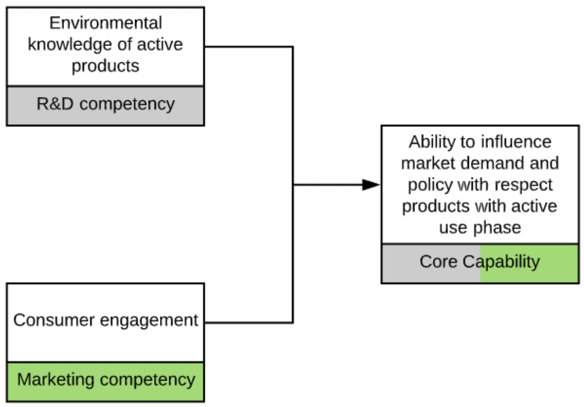

FIGURE 64 CAPABILITY DEVELOPMENT WITHIN PROCESS

In this example, new knowledge and skills on how to address the environmental impacts of the use phase is developed within the organisation. As an example, performing user experiments and conducting LCAs, the case company was not only able to gain new environmental knowledge, but started to develop new expertise in gathering this information. When combined with existing expertise in consumer engagement and marketing, a new core capability emerges that enables the organisation to influence market demand and government policy. In the case of shower and tapware products, the marketing team could include a brochure along with the product that informs the customer on how to use the product responsible (i.e., not taking long hot showers). This information could be representative of studies the organisation has performed (such as the DoE user studies) demonstrating environmental awareness, engagement and expertise. In addition, the organisation could use the studies to influence government policy and create new pressure for alternative products or systems (i.e., requirements that new product have functions that informs the user of energy use).

6.5 Chapter summary

This chapter has described the analytical process that resulted in an initial framework (Section 6.1). The first stage of this process has summarised all data collected to for the key points from the research allowing an analytical framework to form. The explanation building and narrative structuring investigated these points identifying themes and key findings that helped refined the framework. One of the most notable findings was the significance of culture and its impact on eco-design integration. The framework was refined and led to a simplified representation for the integration of eco-design into NPD for shower and tapware products (Figure 62, the STeP framework). Alongside this framework, a number of success factors (Table 21) were identified that are required to successfully integrate eco-design into NPD practice. This framework and success factors can be used to audit the companies NPD activities to identify changes that need to occur in different elements to support the integration of eco-design.

Finally, consideration of how to operationalise the framework has led to proposing a new NPD model (Figure 63) for the early design of active products (Eco-AP). This model adapts the NCD model aligning the engine with the cultural significance of the framework. The model includes a major adaptation by including opportunity development, where the activity is designed to produce new capabilities within the organisation that create new opportunities.

7 Conclusions

This chapter concludes the study by recapitulating the aims of the study (Section 7.1), research questions and how those research questions have been addressed (Section 7.2). Key findings are identified and discussed in the context of existing knowledge and theory (Section 7.3).

Lastly, the wider implications of the study results are discussed, and recommendations are given for future research (Section 7.4).

7.1 Recapitulating the aims of the research

Shower and tapware products contribute significantly to a household's environmental footprint but, although this is generally known, very few environmental improvements have been made in products that are commonly available for use in homes. All the improvements (or new products) that have been developed to address life cycle based environmental impacts of shower and tapware products to date can be considered niche, commercially unfeasible and not mainstream. At the same time, of the frameworks, models and tools that are available to drive eco-improvements for these and similar products, many are too generic to provide pragmatic guidance for practitioners. There is also a recognisable disconnect between eco-design and NPD that leads to difficulties in integration of eco-improvements into mainstream product development. In response to these issues, the purpose of this study was to determine how environmental considerations could be better integrated into the product development practices of shower and tapware manufacturers.

The study adopted an embedded case design that applied an action research methodology within a shower and tapware manufacturing company. This approach provided both distance recording (observing within the case study) and participatory interactions (participating as part of the case study team), enabling data to be collected from both the primary (the case company) and secondary (product users) units of analysis. The primary data collection techniques included structured observations, field notes, interviews and experiments. The data was analysed using a systematic process involving categorising and explanation building through narrative structuring. This yielded an analytical framework that led to the development and refining of success factors that can drive eco-design integration into the NPD practices of shower and tapware manufacturers. Key findings from this process are discussed in this chapter with respect to the research questions.

7.2 Review of research questions

7.2.1 Research Question 1

When applied in the shower and tapware industry, are current eco-design frameworks, models and tools used within existing NPD frameworks and processes fit for purpose?

The NPD literature provides the fundamental tools (in the form of frameworks, models and tools) that underpin successful product development. Despite the wide variation across industries, products, services and markets, many of the fundamentals are relevant across most sectors. The shower and tapware industry are no exception. The future growth of the organisation relies on having an informed strategy, knowledge of the markets they want to target, having a portfolio of products that meet the demands of customers, and a process that improves decision making in development and reduces uncertainty.

Although they have developed largely independently of NPD, the most popular eco-design frameworks models and tools (Brones et al., 2017; Naga Vamsi Krishna et al., 2015; Pigosso et al., 2014) attempt to take the same approach as adopted in NPD theory, identifying elements of product innovation (i.e. Process, Portfolio Management, Marketing) and proposing generalisable eco-design practices that, at first glance, look applicable to shower and tapware manufacturers. However, a review of research investigating specific operational practices (in the form of processes and/or analytical techniques) suggested that they are too broad and lack guidance for practitioners (Section 2.2). This is due to the large variation in technical and functional characteristics of different types of products that ultimately create significant differences in environmental impacts. For example, Jefferson Hynds et al. (2014) state that many of these practices are too general (e.g. “Ensure top management commitment” or far too broad (e.g. recommending hundreds of different eco-practices regardless of their relevance).

Key Finding 1: The NPD fundamentals that underpin successful product development are generic across different product categories, including shower and tapware products. However, the integration of eco-design, frameworks, models, tools and techniques into NPD must consider the unique product characteristics of different types of products and associated environmental impacts in order for them to be useful and effective.

Shower and tapware manufacturers have received little attention with respect to improving the life cycle based environmental impacts of their products and integration of eco-design into their NPD processes. There are also no useful examples of mainstream shower and tapware products that are distinguished by a focus on their environmental credentials. As active products, an environmental hot spot of showers and taps is the use phase (in particular, due to water use and greenhouse gas emissions from heating water); although water use is widely recognised as having an environmental impact, other impacts (such as climate change) have largely been ignored. The literature provides several generic product strategies under different frameworks (e.g. Eco-Classes, Design for Sustainable Behaviour) that could facilitate consideration of the use phase in NPD, yet there is little to guide practitioners on how these strategies can be operationalised and successfully integrated into current NPD practice. Boks et al. (2020) propose this is particularly the case when working in the front end of product development, known to be the most important stage to address environmental impacts associated with the use phase of an active product (as discussed in Section 2.4.1).

7.2.2 Research Question 2

Can a more effective framework be developed and refined for a manufacturer of shower and tapware products to support integrating eco-design into their NPD operations?

Evidence to address this question was gathered from literature, and from the case study and the action case study. This led to development and refinement of a prototype framework (STeP Framework) (Section 6.4) that is tailored to support the integration of eco-design into the NPD operations for a manufacturer of shower and tapware products. The operationalisation of this framework has identified a front-end model (Eco-AP) that would be most effective at supporting integration of eco-design into the NPD operations of shower and tapware products (Section 6.5).

Key Finding 2: Culture is the foundation for successful eco-design integration into NPD of shower and tapware products

The results of the case study demonstrated that an individual within an organisation can intend to integrate eco-design practices into the NPD processes but, unless there is agreement within a team and/or across the different departments in the company, there is unlikely to be progress. The circular economy project (Section 4.3.2) is an example of a project where an individual's eco-design objectives were overwhelmed by other economic and manufacturing priorities. There was also evidence that even if an eco-design project progresses at a team level, there may be other teams (perhaps in different departments) or top management that do not agree with the need or value of the eco-design project. This was evident in the action research case studies (discussed in Section 6.3.4) where the R&D team trialled eco-design tools and techniques that would address the use phase; however, the results of the experiments were met with scepticism and distrust by other teams and top management, and their integration into the NPD process was ultimately overthrown.

Unless top management is aligned and supporting of eco-design integration, then it may not be possible to overcome individuals who oppose eco-design changes and ultimately environmental efforts will not be successful. An example was provided in section 6.3.4 where it was claimed that there was always someone within the company that was able to disrupt environmental initiatives. Furthermore, it was claimed that consumer attitudes also influenced the culture of the company with respect to integration environmental consideration into product development. If it was believed that consumers did not care, then it was more difficult to justify environmental improvements or embed this consideration in the NPD process. The STeP framework was therefore developed with culture as the foundation (Figure 65).

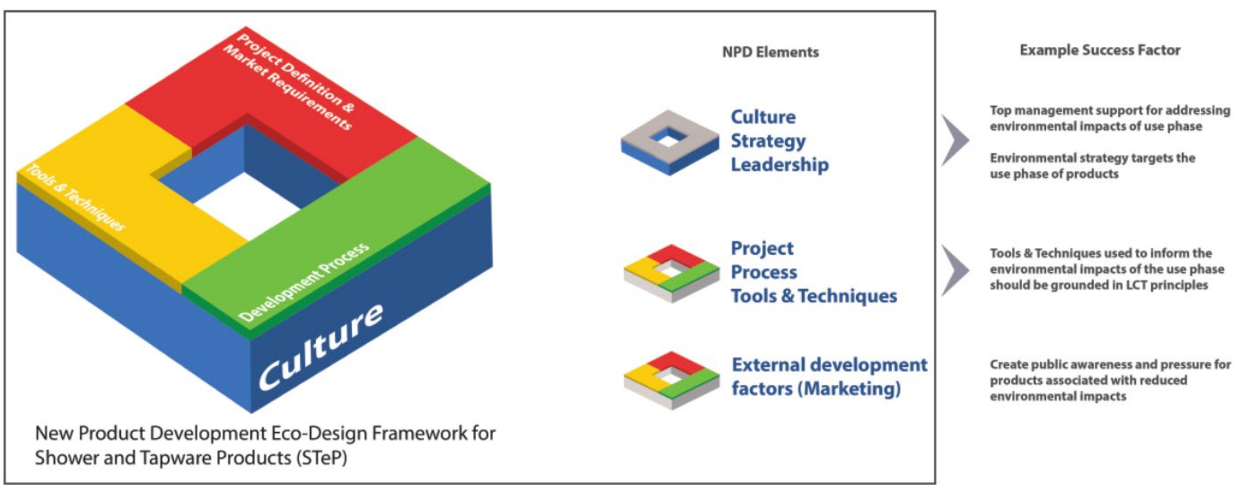

FIGURE 65 FRAMEWORK FOR INTEGRATION OF ECO-DESIGN INTO NPD OPERATIONS OF SHOWER AND TAPWARE MANUFACTURE (STEP FRAMEWORK)

This finding is supported by literature, but there is some disagreement due to the context and complexity of environmental issues and having an 'eco-mindset'. With respect to culture and NPD more generally, Cooper et al. (2004) state that culture is one of the most important drivers of successful NPD. McLean (2005) found that a positive culture is related to creativity and entrepreneurship within an organisation. Ulrich et al. (2009) linked culture to strategic aspects such as portfolio management, and operational aspects such as leadership, communication and customer connectivity. In this research, many positive cultural aspects were observed in the company: the case study showed the company had strong leadership, great communication, and supported creativity within innovation and design. However, when it came to eco-design, the company culture was not always supportive.

Key Finding 3: Culture must embed an effective 'eco-mindset'

There was evidence that teams and individuals within operations had an eco-mindset. They were performing ad-hoc environmental improvements within their operations and processes such as recycling schemes and waste reduction in processing (section 4.3.1). However, the product design team thought that their department was already doing all they could by attempting to reduce in-use water flow as much as possible in the development process. Yet water reduction was often considered an economic indicator (reduced flow therefore reduced cost for the customer) rather than an environmental performance indicator, and so trade-offs were made based on the value add for the customer. As an example, a senior engineer designed a shower product so the lowest possible flow restrictor could be used; however, when the design was finally trialled with customers, the flow wasn't high enough for customers to buy the product and as a result they increased the flow rate beyond anything in their current product range. This led to creation of possibly one of the worst environmental products in their range (Section 4.3). There were many more examples identified in section 6.3.4 where eco-design was excluded based on the engineer's perception or subjective knowledge that the customers did not value environmental performance in the same way as the individual staff, team or company. This type of eco-mindset allowed them to discount or ignore environmental objectives within the product development process. Tingström and Kth (2007) suggest the problem with this mindset is that it causes companies to simply develop the products to an environmental standard that is based on current customers' requirements. This short-term strategy is not sustainable: customers are becoming more environmentally aware of the life cycle-based story associated with the products they buy, use and dispose of, and therefore companies need to adopt a long-term product strategy to look beyond what the customers value in the present and instead design for the future. With this type of eco-mindset, the company can create opportunities that support the development of future eco-products that make tangible environmental improvements. This eco-mindset must also acknowledge the relationship between consumer behaviour and environmental impacts, as well as provide an opportunity for 'Design for Sustainable Behaviour' (DfSB) knowledge to influence design decisions (as discussed in Section 6.3.4). This requires alignment and collaboration between design teams and marketing to create future opportunities where the value add of DfSB can be effectively communicated to the customer.

Key Finding 4: The effectiveness of the framework requires consideration of the product users in order to identify appropriate tools to address technical and behavioural factors related to life cycle-based eco-design integration

By including product users as an additional unit of analysis in the research, useful data was collected and analysed that provided insights on the applicability of specific tools and techniques to address the use phase (Figure 66).

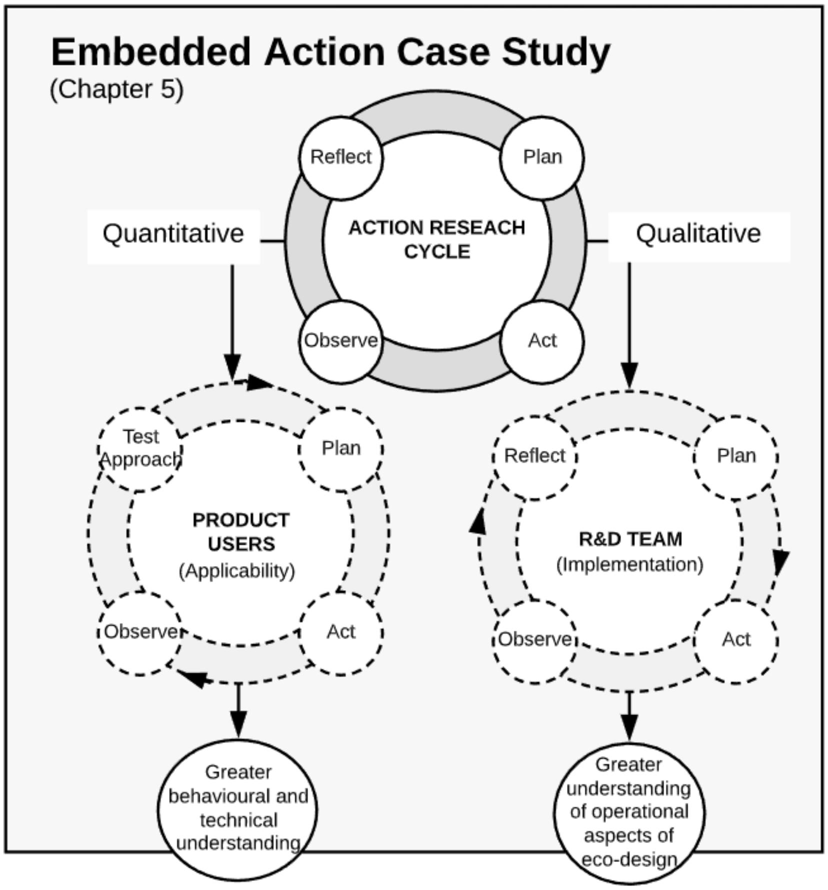

FIGURE 66 EMBEDDED ACTION CASE STUDY

Other eco-design frameworks typically have not done this. Instead, frameworks based on case studies will analyse data collected from studying people within an organisation and refine or form a framework based on a company (or multiple companies) as the unit of analysis (Brones et al., 2017). Alternatively, a deductive approach is taken where a framework will be established based on expert opinion and then tested in a company to validate it (Pigosso et al., 2014). Often, these frameworks attempt to generalise the applicability of the proposed framework, presumably to widen the relevance to multiple industries, products or companies. There are exceptions such as the S³ Framework (Miranda, Pérez, Borja, K. Wright, & Molina, 2017) that was developed specifically for smart products (physical products with embedded electronics); however, they did not include analysis of product users in their framework.

By including product users in the scope of this study, new insights were gained that informed development of the STeP framework. An example is how different showering habits can impact design decisions. The company had traditionally relied on standards and guidelines to improve the environmental impacts of its products. That is, reducing the flow rate means reducing the customer's environmental impact and therefore all products can be orientated to support this single eco-design goal. However, as previous discussed in Section 5 the action case study showed that water flow restriction had no impact with the results demonstrating that functional users require a minimum amount of water to adequately complete washing. Therefore, simply reducing the flow for a functional user would mean that user is just going to a take longer time to wash and use approximately the same total amount of water. Alternatively, if the user is an experiential customer, their experience may be detrimentally affected, and the customer may move to alternative products and services in order to get the desired experience.

It was only though careful implementation and experimentation with product users in the action case study that the company was able to develop a method for understanding what changes can be made to the design of a new product when people and how they interact with the product is taken into consideration. If the company simply applied existing DfSB intervention strategies (Bhamra et al., 2011) without experimenting with the users, they would be inclined to make design changes with traditional standards and guidelines in mind (such as flow-rate). The changes would not necessarily deliver environmental improvements. Therefore, the organisation needs to embed environmental experimentation to discover behavioural insights of the users so DfSB intervention strategies can be more effective.

7.2.3 Research Question 3

For manufacturers of shower and tapware products, how can environmental considerations be integrated into the front-end product development process of NPD?

It is well recognised that the early design stages (the front-end of the NPD process) is the most influential with regards to a product's environmental performance (Baumann et al., 2002; Dewulf, 2013). Many eco-design tool developers claim to have addressed this by developing tools and techniques that can be integrated into a typical front-end NPD process (Gremyr, Siva, Raharjo, & Goh, 2014; Huisman, Boks, & Stevels, 2003; Miranda de Souza & Borsato, 2016). However, as discussed in Section 2.2, it is still widely accepted that eco-design integration in the front-end of NPD is poorly applied (Baumann et al., 2002; Boks et al., 2020; Dewulf, 2013). Baumann et al. (2002) claim that this is due to engineers' and designers' inability to select the most appropriate tools to integrate, and also their lack of knowledge about how to implement them correctly. Dewulf (2013) suggests is it less about the tools, and more a failure in implementing the front-end process correctly.

Key finding 5: Successful eco-design integration into NPD for shower and tapware products requires an iterative front-end model that develops new knowledge and outcomes rather than commercialisation deadlines

It is well understood that traditional processes do not work for unconventional projects (Cooper, 2006). The traditional NPD process (i.e., the gated NPD process) is for predictable projects, where the deliverables are easily defined and well understood. For the case study company this could be making a standard tap where the only real difference is the aesthetics (shape/form). However, in the case study company, even for R&D projects such as developing a new spray technology (Figure 67), the traditional process still accommodated this type of product design: the product is using the same materials which are formed by the same manufacturing processes, and ultimately delivers the same experience or function to the customer. Also, NPD, design and marketing teams are involved alongside the R&D team from the beginning of the project, and early on they start to form some high-level objectives for the new technology. In many cases, before a spray is fully developed, designers have already chosen what the product would look like. The teams in the company have moved through this process for many years, developing many new spray technologies and commercial products. The traditional process has been refined to support this type of development, allowing products to be developed to a pre-defined standard.

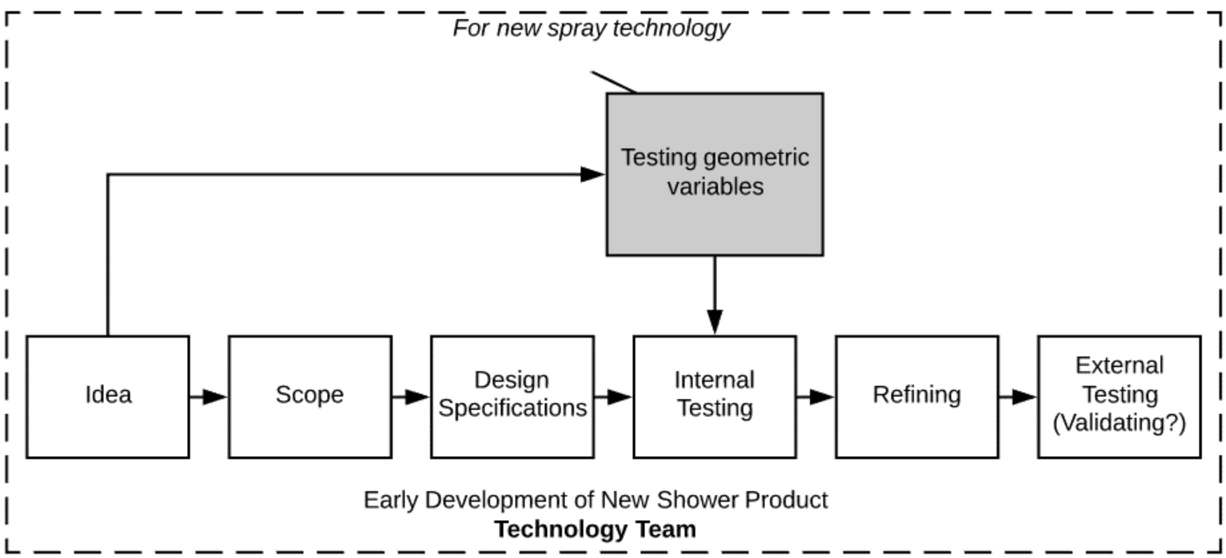

FIGURE 67 EARLY DEVELOPMENT OF NEW SHOWER PRODUCT PROCESS

The circular economy project (Section 4.3.2) followed this traditional process and yet was not effective in achieving the goals of the project. While the project produced a commercial solution, it did not achieve some of the originally defined deliverables (e.g., onshore manufacturing and refurbishment). Within the traditional NPD process there were specific tasks to perform, and these tasks were assigned (following conventional practice) to teams or individuals across design, NPD and manufacturing etc. However, this was a unique project, with unique requirements, and these were often not recognised in the process. As a circular economy project, the company should have been thinking about longer-term supply chain and manufacturing strategies. This would require looking beyond their short-term strategy many years into the future to understand the repercussions of recovering the product, refurbishing and selling it again. This would have an impact on decisions in the process that are commonly driven by short-term financial measures. The company did achieve what their actions set out to do; to put another product on the market. The gated NPD process assisted in doing so. It provides a well refined process that helps the company develop commercial solutions to a standard. However, when they were trying to go beyond that standard and achieve more (such as in the circular economy project), the gated NPD process simply brought them back down to the standard.

There were evidence R&D projects within the company where the objective was not designing a new shower spray type, represented the true fuzzy-front end of their NPD. These R&D projects were described as radical when project deliverables were focused on strengthening a prototype, gaining new knowledge, and creating new capabilities or generating minimal viable products. The R&D team had the freedom to take any idea (regardless of source) and develop it. They were not bound by market assessments and commercialisation deadlines that might prevent the project from being initiated. As a result, it was possible to explore eco-design ideas, and the eco-projects that subsequently formed were well beyond traditional eco-improvements (such as flow restriction, or material usage); they integrated DfSB product strategies (Bhamra et al., 2011) and systems level designs (J. C. Brezet & C. v. Hemel, 1997). The process was iterative, building new eco-knowledge from project to project that could ultimately lead to new products or concepts. However, these outcomes typically did not go beyond the R&D process. Often R&D projects would reach a certain point where new knowledge was reported or a tangible minimal viable product was achieved. The project did not enter the gated NPD process and the technology, knowledge or concept would be set aside while the team's activities would be prioritised elsewhere. A formalised stage or gate that would allow these projects to transfer from one process to the next did not exist. In section 6.5 an evaluation of front-end NPD process models identifies the Koen (2002) NCD model as the most appropriate and with some significant adaptations to the model the new model attempts to address this gap by aligning the NPD process and FFE. In addition, the adapted model (Eco-AP – Figure 68) promotes more collaboration between teams on R&D projects in the opportunity development stage. This early inclusion creates interest and participation across different departments (as discussed in Section 6.3.1). This structure supports the findings in Section 6.3.2 that a clear project brief at is needed at the start of a new eco project. The scope, objectives and deliverables that are commonly defined in a project brief need to be communicated consistently throughout different teams and departments that are involved in the project. Lastly, one of the more significant adaptations to the NCD process is the inclusion of an additional stage that builds eco-design capability and expertise that can be used to influence government policy and drive market demand (section 6.3.3). As engineers and designers conduct more environmental experiments and assessment (such as LCA and DoE) their knowledge and expertise of eco-design could be used to influence consumer perceptions. As an example, if a specific design is quantified to save water and energy based on user behaviour and is successfully marketed as a legitimate and important eco consideration by consumers, the engineers and designers can genuinely address one of the environmental hotspots of that product.

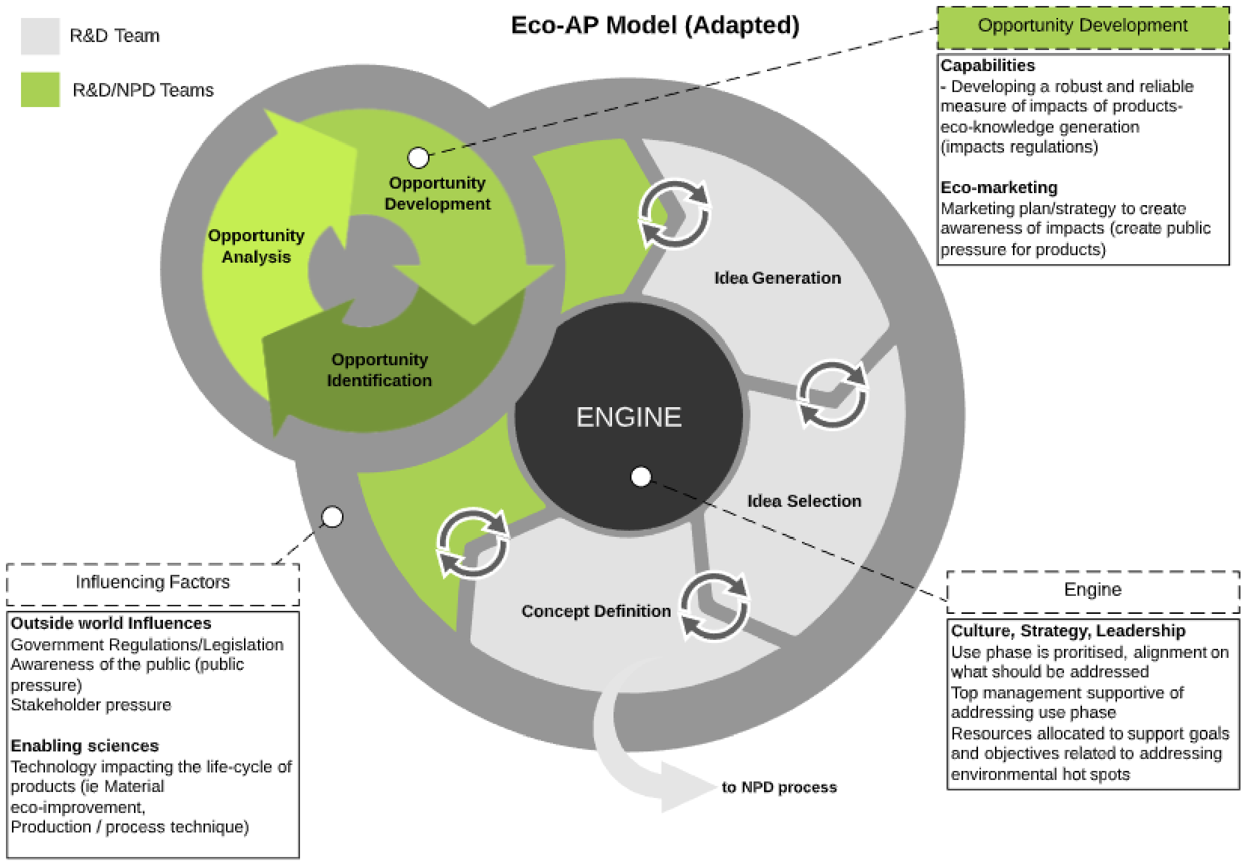

FIGURE 68 ECO AP-MODEL

7.3 Contributions to discipline and practice

Contribution to discipline explains how the study has contributed to an established theory or body of knowledge, while contributions to practice explains how the study provides a greater understanding on how to implement the knowledge in the real world.

Since this study has cut across two subject areas where researchers have operated largely within their own silos (as discussed in the literature review Section 2.1 and Section 2.2), the contributions of this research are discussed at the intercepting point between these two bodies of knowledge: the integration of New Product Development and Eco-design.

7.3.1 Contributions to the theory about integration of New Product Development and Eco-design

While there is some overlap between the NPD and eco-design bodies of knowledge, it is important to recognise that NPD theory is mainstream whilst eco-design is more specialised; the former addresses a wide range of product aspects (health and safety, quality, production, portfolio management, strategy) whereas the latter focuses on the environmental aspects of products, projects or outcomes. This study has investigated how to better integrate the two bodies of knowledge as a mechanism for facilitating eco-design to become more mainstream. The most recent NPD frameworks which have attempted to integrate eco-design (or Sustainable Innovation) discuss the approach from a product level and focus on describing various tools and techniques that a company can apply through a series of tiers as they become leaders in sustainable innovation. And Barczak and Kahn (2012) rank the NPD elements of process and tools as more important than culture. In contrast, this study has demonstrated that this approach is inadequate, and supports the calls of Tingström and Kth (2007), Baumann et al. (2002) and Brones et al. (2017) who recommend that such integration frameworks should drive the organisations to first embed an eco-mindset, environmental strategy and strong eco-capability in order for any eco-tools and techniques to be effective.

Jefferson Hynds et al. (2014) claim eco-design frameworks, models and tools are too broad and lack guidance when integrating eco-design into NPD practice. Acknowledging this observation, this study has specifically not considered transferability to other industry contexts and, as a result, the outcomes (framework and model) are industry relevant for NPD practitioners of the shower and tapware industry. In contrast, the NPD body of knowledge acknowledges it is not possible to cover the full range of specific practices and processes for all industries and focuses on identification of the principles and practices that underpin success (Anderson, 2017). However, while the study outputs (such as the STeP framework and EcoAP model) are applicable to integrating eco-design into NPD in a specific industry, the methodology, in particular use of action research cycles, perhaps provides an example of how a company can use a structured process to identify relevant principles and practices from the eco-design body of knowledge and integrate them effectively into the operational elements of the NPD process in an organisation.

This study has also shown a strong link between eco-design projects and front-end technology projects as defined by Cooper (2006). Dewulf (2013) calls for a greater emphasis on integrating eco-design at the front-end by considering both strategic (doing the right things) and operational (doing things right) aspects of NPD. This study aligns with Dewulf (2013) by recognising the impact of the front-end innovation activities on successful eco-design integration and proposing adaptations to an existing NPD model (NCD model) to support front end integration of eco-design.

7.3.2 Contributions to the practice of New Product Development and Eco-design integration

Based on the overall findings of the study, a framework (STeP) has been developed that provides guidance and recommendations for Shower and Tapware manufacturers to integrate eco-design into its NPD practices. Other companies (such as other shower and tapware manufacturers) could potentially benefit from this framework given its industry relevance (as discussed in section 7.5). However, caution is advised when implementing the STeP framework in other industries as its usefulness and applicability may deteriorate when used outside of the industry sector for which it was developed.

Firstly, the STeP framework provides a complementary addition to similar NPD frameworks (Barczak & Kahn, 2012) that define good practice NPD (success factors) by focusing on the integration of eco-design into NPD. A company can use the list of accompanying success factors to identify any gaps in their current NPD practice that might prevent them from successfully integrating eco-design.

Secondly, a systemisation of the STeP framework is proposed that embeds the success factors into a front-end NPD process model (Eco-AP process model). The model creates a strong relationship between the operational activities (i.e., Idea Generation, Selection and Project Definition) and the strategic aspects (Culture, Strategy and Leadership). This is necessary in a process model for eco-design of active products since the strategic aspects will strongly influence the success of the project at an operational level. An additional operational step has been identified in this study that should be included in the process, and which is not currently found in front-end process models. This is defined as Opportunity Development where rather than the company allowing their eco-design project selection and development to be only influenced by external factors, they instead create new eco-opportunities. This is accomplished by developing an eco-capability where companies can identify environmental impacts of new or existing products, work on ways to address those impacts, and develop competency in marketing to raise awareness of those impacts so that consumers see the value of the new product(s).

Thirdly, the study provides an example of how a company producing active products can identify appropriate tools and apply them to improve the environmental performance of their products. The use of DoE provided the ability to assess the behaviours of users and provided a method for understanding what changes can be made to the design of a new product when people and how they interact with the product is taken into consideration. More generally, the use of tools (such as DoE and LCA) performed for different projects demonstrated that practicality and appropriateness depend largely on the product category or type of product under investigation (i.e., improvement vs system change). However, this study does provide examples of tools that could be effective for products beyond shower and tapware (such as other active products) and contributes to the call to identify appropriate eco-design tools for the front-end of NPD (Figure 69).

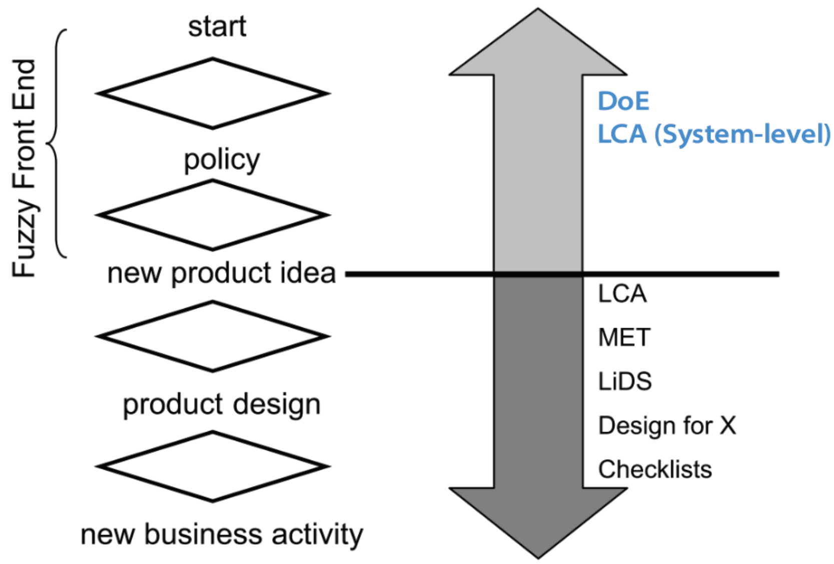

FIGURE 69 IDENTIFICATION OF TOOLS FOR FUZZY FRONT END (ADAPTED FROM (BOKS ET AL., 2020))

7.3.3 Contributions to shower and tapware industry

As discussed in Chapter 2, the environmental impacts of shower and tapware over the life of the product can accumulate and result in a significant portion of a household's footprint. There are research organisations dedicated to quantifying these impacts, which influence government policy. These policies produce standards that define how the product should perform, consumer labelling to inform customers of the environmental impacts of the product and customer incentive schemes that influence purchasing of specific products. All these aspects will impact the decisions of product developers at a strategic and operational level. This study provides new insights and quantified results that could be used by government and other research institutions to better understand – and influence - the environmental impacts of shower and tapware products.

Firstly, the study provides supporting evidence to the Koeller and Gauley (2010) position that flow restriction is not a sufficient measure of environmental impacts of the use phase of shower and tapware products. Restricting the flow in the DoE experiments had little impact on total water use as users washed for longer with a 5-litre compared to an 8-litre flow restriction, suggesting that users need an optimum amount of water to complete the function. In addition, the study also revealed that some cartridges designed to save water in fact have the opposite effect while also using considerably more energy than the alternatives.

Secondly, the study contributes to a greater understanding of sustainable consumption associated with product use of showers and tapware. Studies which investigate the relationship between a consumer product and user attitudes, habits and behaviours have largely focused on purchasing behaviours (Bhamra et al., 2011). This study contributes to the expanding discussion on what behavioural factors influence the use of active products such as showers and tapware.

7.3.4 Progressing the research: implementation of framework and model

As discussed in sections 2.2 and 2.3, one of the common problems of most eco-design frameworks is that they are too broad and lack guidance for practitioners (Brones et al., 2017; Jefferson Hynds et al., 2014). This study addresses the former criticism by remaining focused on the shower and tapware industry to avoid defining practices that are too generalised to be of any use. Regarding the latter criticism, guidance for practitioners has been defined in the form of what processes and practices should occur when implementing eco-design within NPD (section 6.5).

While strictly outside the scope of the present study, it is also useful to reflect on the process for implementation of the framework and model to assist designers, engineers and managers attempting to integrate these practices into the business (known as the soft-side of eco-design).

In a critical review of the soft-side of eco-design, Brones et al. (2017) recommended a combination of top-down and bottom-up strategic management to integrate eco-design, and propose a transitional framework for change management. This transitional framework was applied and tested in an action research case study with principles that are categorised with similar NPD elements to the STeP framework (Strategic, Tactical, Operational) developed in this study. Drawing on the literature on change management best practice (section 2.1.4) and this eco-design transitional framework (Brones et al., 2017), a process guideline for the implementation of the STeP framework is proposed in Box 4.

Box 4. A proposed implementation of the STeP framework

Step 1: An eco-design champion takes the risk

This requires a designer, engineer or middle manager (likely positioned in the front-end of product development) to incorporate the practices and principles stated in the Eco-AP process model into their existing design process. This person will be task-driven and focused on addressing environmental issues within product development. They will need to have conviction and be willing to push the boundaries of the status quo with respect to addressing the use phase of the company's products.

Step 2: Learning and generating new knowledge

The engineers and designers who have adopted the model will be tasked with generating new environmental knowledge and will apply tools and techniques to inform the environmental impacts of the use phase (such as DoE). Repeated implementation of these tools and techniques will generate or identify design factors that can be built into prototypes and products.

Step 3: Advocate results

This step demonstrates the value that design changes can have from a social, environmental, and economic perspective to the teams and individuals in other departments. The goal is not necessarily to have them adopt the practices but adapt the new environmental knowledge into their existing practice.

For example, the marketing team could begin to report on the results to consumers. The purpose of this step is to educate rather than to sell product.

Step 4: New criteria are formalised

With educated consumers and design knowledge of what factors improve the use phase, true value has been created. Consumers will want products that are designed to engage them to reduce water and energy. As part of best practice NPD, new criteria that reflect the consumer needs will be established in the NPD process requiring such design factors be integrated into products. Practices to generate and incorporate this knowledge become standardised.

Step 5: Management realigns environmental vision

This step requires management to identify what aspects of their environmental strategy or Environmental Management System (EMS) requires change to align with the practices performed at the mid-manger and worker level. This could mean standardising new eco-tools currently being applied in product development (i.e., LCA, DoE, Life Cycle Mapping) and establishing funding for eco-projects, environmental promotional material and any other resources required to support the initiatives being driven by eco-design champions.

To evaluate how successful the implementation of the STeP framework and eco-design model has been, managers could continually audit their performance with respect to the success factors provided in Section 6.4. The guidelines present a simplified and generalised best-case scenario for implementation. It is likely that several possible pitfalls or challenges will be faced by the company that will require they remain flexible and adopt new practices. For example, there would likely be resistance to change when implementing new practices, and individuals and teams may not be willing to adopt them. Top management thus should support – and not lead - these initiatives and allow this process to develop from the ground up. It is also likely that individuals and teams may select the easier environmental problems to address. For example, it may be easier to address the use phase of tapware than showers (see section 5.3). Managers and eco-champions need to consider the trade-offs at this point and ask questions such as, “While this may not address the worst environmental impacts within our product range, does this help align the company culture towards addressing the use phase?”

In section 6.5.2 the opportunity adaptation of the Eco-AP model was introduced.

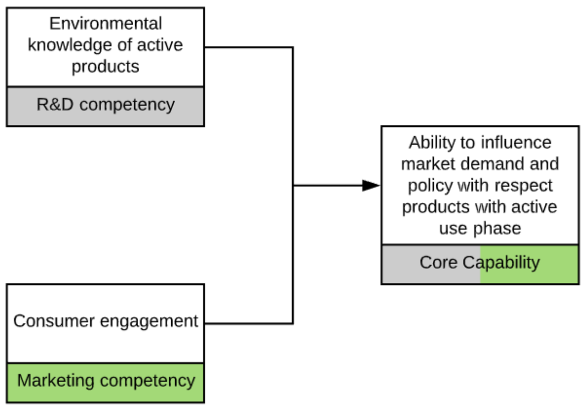

FIGURE 70 CAPABILITY DEVELOPMENT WITHIN PROCESS

Figure 70 illustrated that through product testing and consumer engagement a core capability would emerge that would allow companies to influence market demand with respect to eco products. As discussed in section 2.1.2, when developing core NPD capabilities, organisations should determine if they have the right people with the relevant expertise and knowledge (Ulrich & Smallwood, 2004). In addition, it is important that NPD teams are cross functional and allow customers to become an integral part of NPD development (Barczak & Kahn, 2012). Typically, the people involved in such projects are engineers, industrial designers, and other experts that would be classified under the subject area of engineering or business. However, to develop this capability would require an understanding of behaviours, thoughts and feelings of consumers (Niedderer et al., 2017; Norman, 2013). This subject may require expertise in a field of study outside of engineering or business, such as psychology. Before undertaking these eco-design projects, organisation could consider if it is necessary to include people beyond the field of engineering and business for project success (such as psychologist) and include them in the NPD team.

While it is possible that the guidelines proposed here may assist in the implementation of the framework and model, as it has not been tested there is no empirical evidence to support it. This is merely a proposal based on contemporary organisational change theory (Beer et al., 1990). As discussed in section 2.1.4, the foundation knowledge on organisational change lacks valid framework, provides contradictory advice and is commonly based on unchallenged assumptions (Todnem By, 2005). Therefore, caution is advised when adhering to these recommendations. Further research is required to determine a valid process to implement the model that draws on insights from behavioural psychology and organisational change and leadership studies.

7.4 Generalisability

Generalisability is an important consideration as it determines how the findings of a case study can be applied beyond that case study. It is the extent to which the results of a study are generalisable to other situations or groups. In this case, the primary aims and objectives were to gain insight of how to integrate eco-design practices, principles and concepts into the practices of one specific shower and tapware manufacturer. As this was only a single case study, it is necessary to determine the external validity when considered in the context of other shower and tapware manufacturers. A commonly recognisable way of doing so would be statistical generalisation. An inference (how eco-design integration should occur) is made about a population (the shower and tapware industry) based on a sample (a single or multiple cases). However, Yin (2014) recommends that the case study should not be considered the sample, but rather the opportunity to shed empirical light about a theoretical concepts or principles that describe lessons learned that are generalisable to the wider population. Arguably, then, the insights gained could be generalised to a wider set of industries. Generalisation to two wider sets of stakeholders is discussed in Sections 7.4.1 and 7.4.2.

7.4.1 Generalisability to the shower and tapware industry

Individual manufacturing companies have certain skills, expertise or capabilities that are unique to the company. This could mean that a shower and tapware manufacturer may have differing barriers or enablers (with respect to NPD and eco-design) to that of its competitors. However, different shower and tapware manufacturers all produce products that use water and energy, the product users interact with the product, and their behaviours ultimately impact the environmental footprint. Therefore, since the research design (Chapter 3) and theoretical propositions (Appendix E) for this research have been grounded in NPD and eco-design theory, there is an expectation that the underlying drivers of other shower and tapware manufacturers innovation efforts will still be the same.

The literature review for this research (Section 2.4) indicated there is a lack of shower and tapware products which demonstrate the application of life cycle-based eco-design within the shower and tapware industry. This suggests that manufacturers of these products do not have the knowledge, skills, motivations, or strategic direction to develop such products.

Therefore, at a basic level, and using a bottom-up approach to eco-design integration (Brones et al., 2017), many of the tools and techniques in this study could be used by different shower and tapware manufacturing companies to better inform the design team on the environmental impacts of shower and tapware products, and provide relevant examples of eco-product strategies that can be applied in their NPD.

At a more sophisticated level, the STeP framework and Eco-AP model in this study provides the top-down approach to make strategic and operational changes to drive eco-design. They highlight that the culture needs to be influenced to support eco-design efforts, and the process must adapt to the unique characteristics of shower and tapware eco-design projects. For proposed eco-design projects to be successful, they must be able to create eco-value with consumers. These characteristics are all applicable to other shower and tapware companies.

7.4.2 Generalisations beyond the shower and tapware industry

While there is evidence that the STeP framework is generalisable to other manufacturers of showers and tapware products, it is more difficult to examine its relevance to all products. However, it may be considered most relevant to those product categories where the use phase is considered the most significant in terms of life cycle-based environmental impacts. As discussed in Section 2.4 these are often described as "active products". Active products can be further categorised as experiential or functional. Both these types may be suited to the STeP framework. Some producers of active products that are considered purely functional (e.g. televisions, washing machines, vacuum cleaners) have made significant improvements in addressing the use phase (Roy, 2016).

Personal transport vehicles (such as cars) are also an active product. Car manufacturers have been under increasing government pressure to comply with carbon reduction policies and, as a result, there has been a rise in the manufacture of fuel efficient and electric vehicles (Sovacool, Rogge, Saleta, & Masterson-Cox, 2019). While a car's primary purpose by definition is functional (for transporting) (Soanes & Stevenson, 2005), a car can also be categorised as experiential. Like taking a shower to relax and feel good, many people will use a car for similar reasons (Mokhtarian, Salomon, & Singer, 2015). Driving a car can be for adventure seeking, escaping to a different environment, a buffer between other (stressful) activities or finding independence. Manufacturers recognise this and add luxury features to cars to improve the overall experience. This means users enjoy the driving experience more, and are more likely to spend more time driving (Lenderman, 2010).

Car manufactures are addressing the use phase (US Congress Subcommittee on Energy and Resources, 2007) by introducing more fuel efficient cars including hybrids and electric vehicles. Efficiency is determined by benchmarking using standard units (i.e., quantity of fuel used to travel 100km). This efficiency could be increased further by encouraging various driving behaviours (Beusen et al., 2009; McIlroy & Stanton, 2017). Research on this aspect has followed a similar methodology to the action case study approach of this research: researchers have performed experimentation and trials in different driving scenarios to determine the impact on the response variables (energy) when varying a number of factors (i.e., visual and haptic eco-feedback to the user). It is likely that some of the insights have influenced design of mainstream car products (e.g., optimising displays so the most effective feedback information is built into the car dashboard to improve driving efficiency). However, this approach still isolates experience and efficiency and could have created sub-optimisation of the two. For example, a car may have features that improve its efficiency when driven as a mode of transport such as a regular drive from home to work. Eco-feedback (e.g., providing live feedback of how their acceleration is impacting fuel efficiency) can influence the driver to accelerate or slow down more consistently, perhaps saving fuel per kilometre. However, if the driver is using the car for a leisure drive (i.e., for the purposes of hearing the roar of the engine, feeling the force of the driver seat by suddenly accelerating or taking in the sights of a long country drive while driving at speed) suggests that the efficiency features may not have an effect. The efficiency improvements that are built into a car (i.e., feedback displays) are designed to interact with a particular type of user or profile. This example has parallels with the findings in the shower study. People had different showering habits – some users preferred higher flow rates, others significantly increased the heat, and some had spray preferences. The showering habits reflected what they needed to do to have a better experience in the shower. The spray types designed to reduced water and energy use overall did not necessarily improve the efficiency of the product, and in some cases, they performed worse than conventional sprays.

Therefore, outside of the shower and tapware industry, the STeP framework and success factors are likely to be most applicable to manufacturers of active products where there is a mismatch (or conflict) between products that require optimisation of both experience and efficiency. Designers of active products that have little user interaction may still find the STeP framework useful, particularly when it is necessary to embed an eco-mindset into the organisation. However, the applicability may diminish as the focus moves further away from products (or services) where the user interaction has less or no impact on the magnitude of the environmental impacts of the product over its life cycle (conceptualised in Figure 71)

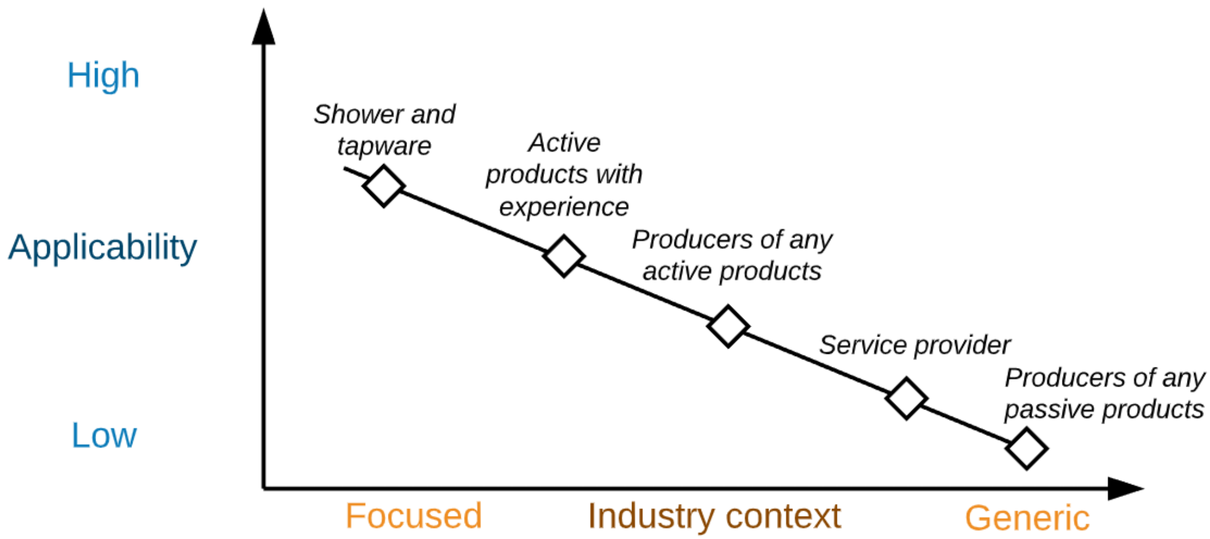

FIGURE 71 CONCEPTUALISING THE APPLICABILITY OF THE STEP FRAMEWORK IN OTHER INDUSTRIES

7.5 Future research recommendations

Based on the research results, three future research recommendations are proposed. Firstly, future research should test the STeP framework in other shower and tapware companies to determine if culture is always the main success factor. This future research should also test the operationalisation of the STeP framework. As mentioned, manufacturers should avoid force-fitting product development projects into an NPD model and future adaptations to the model may be necessary. However, what those changes might be, can only be identified through application of the model in other studies.

Secondly, while the framework identifies culture to be a significant factor, this study has not examined how best to change the organisation to adopt practices that would enable success in eco-design in the shower and tapware or any other industry context. This was outside the scope of this study. As there is a lack of valid research on the subject of organisation change management (see Section 2.1.4), this could present a future opportunity for research (i.e., how to best promote and standardise eco-design behaviours and practices within NPD business structures).

Thirdly, future studies should test the STeP framework and EcoAP model in a context beyond the shower and tapware industry. The STeP framework and success factors which provide an approach for integrating eco-design into the NPD practices of shower and tapware may be applicable to other industries or products where the use stage is a contributing factor and is impacted by different types of users (experiential or functional) (as discussed in section 7.5). Research should also validate the applicability beyond products with a dominant use stage (i.e., passive products) to determine if these products are less likely to need the STeP framework (as discussed in section 7.4.2). This would help validate the findings of the study.

Lastly, the experimental trials undertaken as part of the action research study contributed to a better understanding of the environmental impacts of shower and tapware products. It would be worthwhile to apply this knowledge in future projects on eco-design shower and tapware. The outcomes of this research could provide further insights into the design of shower and tapware products with improved environmental profiles.

7.6 Concluding remarks

This research identified the disconnect between NPD and eco-design both in the literature and in practice as a barrier to development of more environmentally sustainable products. Also, recognising that many eco-design frameworks, models and tools are too broad to be useful, this research focused specifically on the shower and tapware industry to investigate the recognised disconnect between NPD and eco-design.

The study is unusual in that its research design included two units of analysis: the case company (organisation) and the product users (user behaviour). This led to unique insights that are reflected in the final STeP framework and Eco-AP model be useful and effective. Effective eco-design culture and 'eco-mindset' was also found to be a determinant of successful eco-design integration which is represented as the foundation of the STeP framework. The culture must allow consideration of the product users in order to identify appropriate tools to address technical and behavioural factors related to life cycle-based eco-design integration. The operationalisation of the framework is represented in the Eco-AP model which supports the generation of new knowledge and insights rather than commercialisation deadlines.

The researcher believes that these findings will contribute to improvement of the integration of environmental aspects into product development for showers and tapware, and potentially other active products.

8 References

Abrantes, R., & Figueiredo, J. (2014). Feature based process framework to manage scope in dynamic NPD portfolios. *International Journal of Project Management, 32*(5), 874-884. doi: 10.1016/j.ijproman.2013.10.014

Acaroglu, L. (2017). The Disruptive Design Approach. from http://unschools.co/method/

Adams-Bigelow, M. (2006). Rejoinders to "Establishing an NPD Best Practices Framework". *Journal of Product Innovation Management, 23*(2), 117-127. doi: 10.1111/j.1540-5885.2006.00187_5.x

Adeyeye, K., She, K., & Baïri, A. (2017). Design factors and functionality matching in sustainability products: A study of eco-showerheads. *Journal of Cleaner Production, 142*(Part 4), 4214-4229. doi: 10.1016/j.jclepro.2016.11.143

Aguardio. (2019). Aguardio. from https://www.aguardio.com/

Aibar-Guzmán, C., & Somohano-Rodríguez, F. M. (2021). Do consumers value environmental innovation in product? *Administrative Sciences, 11*(1). doi: 10.3390/admsci11010033

AIMC4. (2014). Lessons from AIMC4 for cost-effective fabric-first low-energy housing (pp. 19). H+H UK Ltd: Stewart Milne Group.

Amphiro. (2019). Amphiro Website.

Anderson, Jurgens-Kowal, T., Atherton, S., Verhaeghe, J.-J., Rodriguez, C., Dworaczyk, K., & Fix, J. (2020). *Product Development and Management Body of Knowledge: A Guidebook for Training and Certification, Second Edition*

Anderson, A. M. (2017). *Product development and management : body of knowledge*: Chicago, IL : PDMA, [2017].

Axor Design. (2020). Axor Starck Collection. from https://www.axor-design.com/bath/products/collections/axor-starck-organic

Barczak, G., & Kahn, K. B. (2012). Identifying new product development best practice. *Business Horizons, 55*(3), 293-305. doi: 10.1016/j.bushor.2012.01.006

Baumann, H., Boons, F., & Bragd, A. (2002). Mapping the green product development field: engineering, policy and business perspectives. *Journal of Cleaner Production, 10*(5), 409-425. doi: https://doi.org/10.1016/S0959-6526(02)00015-X

Beal, C., Stewart, R. A., Huang, T., & Rey, E. (2011). SEQ residential end use study. *Journal of the Australian Water Association, 38*(1), 80-84.

Becker, B. (2006). Rethinking the Stage-Gate process—A reply to the critics.: Management Roundtable.

Beckley, J. H., Paredes, M. D., & Lopetcharat, K. (2012). *Product innovation toolbox : a field guide to consumer understanding and research*: Hoboken : John Wiley & Sons, 2012.

Beer, M., Eisenstat, R. A., & Spector, B. (1990). Why change programs don't produce change. *Harvard Business Review, 68*(6), 158-166.

Berchicci, L., & Bodewes, W. (2005). Bridging environmental issues with new product development. *Business Strategy and the Environment, 14*(5), 272-285. doi: 10.1002/bse.488

Beusen, B., Broekx, S., Denys, T., Beckx, C., Degraeuwe, B., Gijsbers, M., . . . Int Panis, L. (2009). Using on-board logging devices to study the long-term impact of an eco-driving course. *Transportation Research Part D Transport and Environment, 14*, 514-520. doi: 10.1016/j.trd.2009.05.009

Bhamra, T., Lilley, D., & Tang, T. (2011). Design for Sustainable Behaviour: Using Products to Change Consumer Behaviour. *Design Journal, 14*(4), 427-445. doi: 10.2752/175630611X13091688930453

Bigelow, A. (2005). First results from the 2003 comparative performance assessment study (CPAS) *PDMA handbook of new product development* (2nd ed., pp. 546—566). Hoboken, NJ: John Wiley and Sons, Inc.

Björk, E., & Ottosson, S. (2007). Aspects of consideration in product development research. *Journal of Engineering Design, 18*(3), 195-207. doi: 10.1080/09544820600675966

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering, 33*(5), 308-320. doi: 10.1080/21681015.2016.1172124

Boehm, B., Egyed, A., Kwan, J., Port, D., Shah, A., & Madachy, R. (1998). Using the WinWin spiral model: a case study. *Computer*(7), 33.

Boehm, B., & Turner, R. (2005). Management Challenges to Implementing Agile Processes in Traditional Development Organizations. *IEEE Software, 22*(5), 30-39.

Boeijen, A. v., Daalhuizen, J., Zijlstra, J., & Schoor, R. v. d. (2013). *Delft design guide : design methods*: Amsterdam : BIS Publishers, [2013].

Boks, C. (2006). The soft side of ecodesign. *Journal of Cleaner Production, 14*(15–16), 1346-1356. doi: http://dx.doi.org/10.1016/j.jclepro.2005.11.015

Boks, C., Diehl, J. C., & Wever, R. (2020). Sustainable Product Design, Engineering and Management Education for Industrial Design Engineering. *13th CIRP International Conference on Life Cycle Engineering*.

Boks, C., & Stevels, A. (2003). Theory and practice of environmental benchmarking in a major consumer electronics company. *Benchmarking: An International Journal, 10*(2), 120-135. doi: 10.1108/14635770310469653

Boks, C., & Wever, R. (2007). *Design for Sustainability in the Fuzzy Front End*.

Braa, K., & Vidgen, R. (1999). Interpretation, intervention, and reduction in the organizational laboratory: a framework for in-context information system research. *Accounting, Management and Information Technologies, 9*(1), 25-47. doi: https://doi.org/10.1016/S0959-8022(98)00018-6

Bradbury, H. (2015). *The SAGE Handbook of Action Research*. London: SAGE Publications Ltd.

BRANZ. (2006). Designing Homes for Climate Change.

Brezet, & Hemel, V. (1997). *Ecodesign: a promising approach to sustainable production and consumption.* Paper presented at the UNEP, Paris.

Brezet, J. C., & Hemel, C. v. (1997). *Ecodesign : a promising approach to sustainable production and consumption*: Paris : UNEP, c1997 1st ed.

Brick, C., Sherman, D. K., & Kim, H. S. (2017). “Green to be seen” and “brown to keep down”: Visibility moderates the effect of identity on pro-environmental behavior. *Journal of Environmental Psychology, 51*, 226-238. doi: 10.1016/j.jenvp.2017.04.004

Brones, Carvalho, d., & Zancul, d. S. (2014). Ecodesign in project management: a missing link for the integration of sustainability in product development? *Journal of Cleaner Production, 80*, 106-118. doi: http://dx.doi.org/10.1016/j.jclepro.2014.05.088

Brones, Carvalho, d., & Zancul, d. S. (2017). Reviews, action and learning on change management for ecodesign transition. *Journal of Cleaner Production, 142, Part 1*, 8-22. doi: https://doi.org/10.1016/j.jclepro.2016.09.009

Bryman, A. (2016). *Social research methods* (5th ed ed.): Oxford University Press.

Bryman, A., & Bell, E. (2011). *Business research methods* (3rd ed ed.): Oxford University Press.

Camilleri, M., French, L., Pollard, A., Saville-Smith, K., Faser, R., Rossouw, P., & Jowlett, J. (2006). Energy Use in New Zealand Households.

Charter, M., & Chick, A. (1997). The Journal of Sustainable Product Design - Editorial. (1), 5-6.

Chatman, J. A., & O'Reilly, C. A. (2016). Paradigm lost: Reinvigorating the study of organizational culture.

Chialin, C. (2001). Design for the Environment: A Quality-Based Model for Green Product Development. *Management Science, 47*(2), 250.

Christensen, C. M. (Producer). (2013). Clayton Christensen: Disruptive innovation. Retrieved from https://www.youtube.com/watch?v=rpkoCZ4vBSI

Coelho, C. R. V., & McLaren, S. J. (2013). Rethinking a product and its function using LCA—experiences of New Zealand manufacturing companies. *The International Journal of Life Cycle Assessment, 18*(4), 872-880. doi: 10.1007/s11367-012-0526-4

Cooper, R. (2016). Agile-Stage-Gate Hybrids. *Research Technology Management, 59*(1), 21-29. doi: 10.1080/08956308.2016.1117317

Cooper, R., Edgett, S., & Kleinschmidt, E. J. (2004). Benchmarking best NPD practices-I: Culture, climate, teams and senior management's roles are the focus of this first in a 3-parts series. *Res. Tech. Manag., 47*, 1-16.

Cooper, R. G. (2006). Managing Technology Development Projects. *Research-Technology Management, 49*(6), 23-31. doi: 10.1080/08956308.2006.11657405

Cooper, R. G. (2011a). Perspective: The Innovation Dilemma: How to Innovate When the Market Is Mature. *Journal of Product Innovation Management, 28*(s1), 2-27. doi: 10.1111/j.1540-5885.2011.00858.x

Cooper, R. G. (2011b). *Winning at new products : creating value through innovation*: New York : Basic Books, [2011]]]]]><![CDATA[>
<![CDATA[Fourth edition.

Cooper, R. G. (2012). New Products *The PDMA Handbook of New Product Development* (pp. 1-34): John Wiley & Sons, Inc.

Cooper, R. G. (2014). What's Next? After Stage-Gate. *Research Technology Management, 57*(1), 20-31. doi: 10.5437/08956308X5606963

Cooper, R. G. (2018). The drivers of success in new-product development. *Industrial Marketing Management*. doi: https://doi.org/10.1016/j.indmarman.2018.07.005

Cooper, R. G., & Sommer, A. F. (2020). New-Product Portfolio Management with Agile. *Research-Technology Management, 63*(1), 29-38. doi: 10.1080/08956308.2020.1686291

Coskun, A., Zimmerman, J., & Erbug, C. (2015). Promoting sustainability through behavior change: A review. *Design Studies, 41*, 183-204. doi: https://doi.org/10.1016/j.destud.2015.08.008

Creswell, & Miller. (2000). Determining Validity in Qualitative Inquiry. *Theory Into Practice*(3), 124.

Creswell, J. W. (2014). *Research design : qualitative, quantitative, and mixed methods approaches*: Thousand Oaks : SAGE Publications, c2014 4th ed.

Creswell, J. W. (2015). *A concise introduction to mixed methods research*: SAGE.

Creswell, J. W., & Creswell, J. D. (2005). Mixed Methods Research: Developments, Debates, and Dilemmas. In R. A. Swanson & E. F. Holton (Eds.), *Research in organizations : foundations and methods of inquiry* (pp. 459). San Francisco, CA: Berrett-Koehler.

Creswell, J. W., & Plano Clark, V. L. (2007). Part of chapter:4 Choosing a mixed methods design pp: 62-79 & Part of Ch:7 Analyzing data in mixed methods research pp: 128-135. In J. W. Creswell & V. L. Plano Clark (Eds.), *Designing and conducting mixed methods research* (pp. 62-79). Thousand Oaks, Calif: SAGE Publications.

Daae, J., & Boks, C. (2015). Opportunities and challenges for addressing variations in the use phase with LCA and Design for Sustainable Behaviour. *International Journal of Sustainable Engineering, 8*(3), 148-162. doi: 10.1080/19397038.2015.1010630

Davis, K., & Rose, C. (2013). *60 minutes. [electronic resource]*: Columbia Broadcasting System.

De Medeiros, J. F., Da Rocha, C. G., & Ribeiro, J. L. D. (2018). Design for sustainable behavior (DfSB): Analysis of existing frameworks of behavior change strategies, experts' assessment and proposal for a decision support diagram. *Journal of Cleaner Production, 188*, 402-415. doi: 10.1016/j.jclepro.2018.03.272

Dekoninck, E. A., Domingo, L., O'Hare, J. A., Pigosso, D. C. A., Reyes, T., & Troussier, N. (2016). Defining the challenges for ecodesign implementation in companies: Development and consolidation of a framework. *Journal of Cleaner Production, 135*, 410-425. doi: https://doi.org/10.1016/j.jclepro.2016.06.045

Desso. (2016). Desso - Circular Economy. from http://www.desso.com/c2c-corporate-responsibility/circular-economy/

Devanathan, S., Ramanujan, D., Bernstein, W. Z., Zhao, F., & Ramani, K. (2010). Integration of sustainability into early design through the function impact matrix. *Journal of Mechanical Design, Transactions of the ASME, 132*(8), 0810041-0810048. doi: 10.1115/1.4001890

Dewulf. (2013). Sustainable Product Innovation: The Importance of the Front- End Stage in the Innovation Process *Advances in Industrial Design Engineering*: Intech.

Dewulf, W., Willems, B., & Duflou, J. R. (2006). Estimating the environmental profile of early design concepts. In D. Brissaud, S. Tichkiewitch & P. Zwolinski (Eds.), *Innovation in Life Cycle Engineering and Sustainable Development* (pp. 321-334). Dordrecht: Springer Netherlands.

Doevendans, J. T. (2014). *Implementing Lean in a seasonal horticulture sector : theoretical and practical suitability in the NZ pipfruit industry : a thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy at Massey University, Palmerston North, Manawatu, New Zealand*: Massey University.

Driessen, P. H., Hillebrand, B., Kok, R. A. W., & Verhallen, T. M. M. (2013). Green New Product Development: The Pivotal Role of Product Greenness. *IEEE Transactions on Engineering Management, 60*(2), 315-326. doi: 10.1109/TEM.2013.2246792

Efeoglu, A., Møller, C., Sérié, M., & Boer, H. (2014). *Design thinking: characteristics and promises*.

Eggink, W. (2016). *Disruptive Design Techniques*.

Ellen MacArthur Foundation. (2017). Circular Economy Overview. from https://www.ellenmacarthurfoundation.org/circular-economy/overview/concept

Estruch, A., Vila, C., Siller, H. R., Romero, F., & Abellan, J. V. (2016). *Enabling innovative concurrent engineering and collaborative manufacturing in extended enterprises.* Paper presented at the 2008 IEEE International Technology Management Conference, ICE 2008.

Evrard, D., Rejeb, H. B., Zwolinski, P., & Brissaud, D. (2021). Designing immortal products: A lifecycle scenario-based approach. *Sustainability (Switzerland), 13*(6). doi: 10.3390/su13063574

Farel, R. (2013). Action research in practice. *Proceedings of the International Conference on Engineering Design, ICED, 2 DS75-02*, 63-72.

Fitzgerald, D. P., Herrmann, J. W., Sandborn, P. A., & Schmidt, L. C. (2005). *Environmental Objectives for New Product Development Decision-Making*. Department of Mechanical Engineering and Institute for Systems Research. University of Maryland, College Park, MD 20742, USA.

Frame, B., Gordon, R., & Mortimer, C. (2010). *Hatched : the capacity for sustainable development*: Christchurch, N.Z. : Landcare Research, 2010.

Garnevska, E., McLaren, S., & Hiroki, S. (2014). Yealands wine group: Balancing business and sustainability. *International Food and Agribusiness Management Review, 17*(4), 237-257.

Gehin, A., Zwolinski, P., & Brissaud, D. (2008). A tool to implement sustainable end-of-life strategies in the product development phase. *Journal of Cleaner Production, 16*, 566-576. doi: 10.1016/j.jclepro.2007.02.012

Gleick, P. H. (2014). *The World's Water : The Biennial Report on Freshwater Resources*. Washington: Island Press.

Graetz, F., Smith, A., Rimmer, M., & Lawrence, A. (2010). *Managing organisational change* (3rd Australasian ed ed.): John Wiley and Sons Australia, Ltd.

Granato, D., & Ares, G. (2013). *Mathematical and statistical methods in food science and technology*: Chichester, West Sussex, UK : John Wiley & Sons Inc., 2013.

Gremyr, I., Siva, V., Raharjo, H., & Goh, T. N. (2014). Adapting the Robust Design Methodology to support sustainable product development. *Journal of Cleaner Production, 79*, 231-238. doi: http://dx.doi.org/10.1016/j.jclepro.2014.05.018

Griffin, A. (1997). PDMA Research on New Product Development Practices: Updating Trends and Benchmarking Best Practices. *Journal of Product Innovation Management, 14*(6), 429-458. doi: https://doi.org/10.1111/1540-5885.1460429

Grohe. (2020). Water Saving Innovations.

Halecker, B. (2015). Action case study - A research strategy based on abduction for relevant and rigorous management research. *International Journal of Business Research, 15*(4), 23-32.

Hallstedt, S. I., Thompson, A. W., & Lindahl, P. (2013). Key elements for implementing a strategic sustainability perspective in the product innovation process. *Journal of Cleaner Production, 51*, 277-288. doi: http://dx.doi.org/10.1016/j.jclepro.2013.01.043

Hansgrohe. (n.d.). Pontos AquaCycle Webpage.

Harry, B. (2011). The Importance of Feedback in Software Development. from msdn.microsoft.com

Hassi, L., & Wever, R. (2010). *Practices of a "green" front end of innovation; A gateway to environmental innovation*.

HeatBack. (2016). Heatback. from http://www.heatback.co.nz/the-product

Henrich, M. (2009). *Water End-use Efficiency Project (WEEP) - A Case Study*. Paper presented at the SB07 NZ Conference: Transforming our Built Environment, Auckland, New Zealand.

Henricks, M. D., Young, M., & Kehoe, E. J. (2020). Attitudes toward Change and Transformational Leadership: A Longitudinal Study. *Journal of Change Management, 20*(3), 202-219. doi: 10.1080/14697017.2020.1758529

Högman, U., & Johannesson, H. (2013). Applying stage-gate processes to technology development—Experience from six hardware-oriented companies. *Journal of Engineering and Technology Management, 30*(3), 264-287. doi: http://dx.doi.org/10.1016/j.jengtecman.2013.05.002

Holahan, P. J., Sullivan, Z. Z., & Markham, S. K. (2014). Product development as core competence: How formal product development practices differ for radical, more innovative, and incremental product innovations. *Journal of Product Innovation Management, 31*(2), 329-345. doi: 10.1111/jpim.12098

Horrell, Shekar, & McLaren. (2020). USE OF DESIGN OF EXPERIMENTS TO OPTIMISE THE ENVIRONMENTAL PERFORMANCE OF CONSUMER PRODUCTS: A CASE STUDY OF SHOWERS AND TAPWARE IN NEW ZEALAND. *Proceedings of the Design Society: DESIGN Conference, 1*, 1911-1920. doi: 10.1017/dsd.2020.269

Horrell, M., Tunnicliffe, M., & McLaren, S. (2020a). *Development and performance testing of a system-based eco-shower*.

Horrell, M., Tunnicliffe, M., & McLaren, S. (2020b). *The use of LCA in early design to optimise the environmental performance of active product systems*.

Huisman, J., Boks, C. B., & Stevels, A. L. N. (2003). Quotes for environmentally weighted recyclability (QWERTY): Concept of describing product recyclability in terms of environmental value. *International Journal of Production Research, 41*(16), 3649-3665. doi: 10.1080/0020754031000120069

Hume, A., & Mortimer, C. (2011). The Life Cycle Management (LCM) Pilot Project: Enablers and barriers to adoption. Wellington, New Zealand: Ministry of Economic Development.

IDEO. (2019). What is Design Thinking? , from https://www.ideou.com/blogs/inspiration/what-is-design-thinking

Institut Bauen und Umwelt e.V. (2011). Environmental Product Declaration as per ISO 14025 for hand showers Croma 100 and Crometta 85. Panoramastraße, Berlin.

Issa, I. I., Pigosso, D. C. A., McAloone, T. C., & Rozenfeld, H. (2015). Leading product-related environmental performance indicators: a selection guide and database. *Journal of Cleaner Production, 108, Part A*, 321-330. doi: http://dx.doi.org/10.1016/j.jclepro.2015.06.088

Jallon, R., Blais-Ouellette, S., & Valette, A. (2015). Domestic water recycling apparatus and fluid contamination detection system therefor: Google Patents.

Jefferson Hynds, E., Brandt, V., Burek, S., Jager, W., Knox, P., Parker, J. P., . . . Zietlow, M. (2014). A maturity model for sustainability in new product development. *Research Technology Management, 57*(1), 50-57. doi: 10.5437/08956308X5701143

Johansson, G. (2002). Success factors for integration of ecodesign in product development: A review of state of the art. *Environmental Management and Health, 13*(1), 98-107. doi: 10.1108/09566160210417868

Johnson, R., & Lipp, A. (2007). Cognitive Mapping: A Process to Support Strategic Planning in an Academic Department. *Group Decision and Negotiation, 16*, 43-60. doi: 10.1007/s10726-006-9031-0

Jolliet, O., Saade-Sbeih, M., Shaked, S., Jolliet, A., & Crettaz, P. (2015). Inventory Analysis of Emissions and Extractions *Environmental Life Cycle Assessment* (pp. 57): CRC Press.

Jreissat, M., Isaev, S., Moreno, M., & Makatsoris, C. (2017). Consumer Driven New Product Development in Future Re-Distributed Models of Sustainable Production and Consumption. *Procedia CIRP, 63*, 698-703. doi: https://doi.org/10.1016/j.procir.2017.03.314

Jugend, D., Pinheiro, M. A. P., Luiz, J. V. R., Junior, A. V., & Cauchick-Miguel, P. A. (2019). Achieving environmental sustainability with ecodesign practices and tools for new product development *Innovation Strategies in Environmental Science* (pp. 179-207).

Kahn, K. B., Barczak, G., & Moss, R. (2006). PERSPECTIVE: Establishing an NPD Best Practices Framework. *Journal of Product Innovation Management, 23*(2), 106-116. doi: 10.1111/j.1540-5885.2006.00186.x

Kahn, K. B., Kay, S. E., Slotegraaf, R., & Uban, S. (2013a). *The PDMA handbook of new product development.*: Hoboken, N.J. : Wiley, ©2013 Third edition.

Kahn, K. B., Kay, S. E., Slotegraaf, R., & Uban, S. (2013b). *The PDMA handbook of new product development. [electronic resource]*: Hoboken, N.J. : Wiley, ©2013 Third edition.

Kapiti Coast District Council. (2014). River Recharge Scheme. from http://www.kapiticoast.govt.nz/Your-Council/Projects/Water-Supply-Project/River-Recharge-Scheme/

Khurana, A., & Rosenthal, S. R. (1998). Towards Holistic "Front Ends" In New Product Development. *Journal of Product Innovation Management, 15*(1), 57-74. doi: 10.1111/1540-5885.1510057

Kim, H., Cluzel, F., Leroy, Y., Yannou, B., & Yannou-Le Bris, G. (2020). Research perspectives in ecodesign. *Design Science, 6*, e7. doi: 10.1017/dsj.2020.5

Koeller, J., & Gauley, B. (2010). Sensor-Operated Plumbing Fixtures - Do They Save Water? (pp. 11). California: California Energy Commission.

Koen, P. A. (2004). The fuzzy front end for incremental, platform and breakthrough products and services. *PDMA Handbook*, 81-91.

Koen, P. A., Ajamian, G. M., & Boyc, S. (2002). Fuzzy Front End: Effective Methods, Tools, and Techniques. In P. Belliveau, A. Griffin & S. Somermeyer (Eds.), *The PDMA Toolbook for New Product Development*. New York: John Wiley & Sons Inc.

Koen, P. A., Ajamian, G. M., Boyce, S. D., Clamen, A., Fisher, E. S., Fountoulakis, S. G., . . . Seibert, R. F. (2002). Fuzzy Front End : Effective Methods , Tools , and Techniques (Vol. 1, pp. 5-35).

Koen, P. A., Bertels, H. M. J., & Kleinschmidt, E. (2012). Effective Practices in the Front End of Innovation *The PDMA Handbook of New Product Development* (pp. 115-134): John Wiley & Sons, Inc.

Kotter, J. P. (2007). Leading change: Why transformation efforts fail. *Harvard Business Review, 85*(1), 96-103.
Kuczmarski, T. D. (2006). Rejoinders to "Establishing an NPD Best Practices Framework". *Journal of Product Innovation Management, 23*(2), 117-127. doi: 10.1111/j.1540-5885.2006.00187_3.x
Kuijer, L., De Jong, A., & Van Eijk, D. (2013). Practices as a Unit of Design: An Exploration of Theoretical Guidelines in a Study on Bathing. *ACM Transactions on Computer-Human Interaction (TOCHI), 20*(4), 1-22. doi: 10.1145/2509404.2493382
Kuo, T. C., Tseng, M.-L., Lin, C. H., Wang, R.-W., & Lee, C.-H. (2018). Identifying sustainable behavior of energy consumers as a driver of design solutions: The missing link in eco-design. *Journal of Cleaner Production, 192*, 486-495. doi: 10.1016/j.jclepro.2018.04.250
Kutz, M. (2007). *Environmentally conscious mechanical design*: Hoboken, NJ : John Wiley, c2007.
Lallana, C., Krinner, W., Estrela, T., Nixon, S., Leonard, J., & Berland, J. M. (2001). Sustainable water use in Europe (Vol. 2). Copenhagen,: European Environment Agency, Kongens Nytorv 6, DK-1050 Copenhagen K.
Ledwith, A., Perks, H., & Nicholas, J. (2011). New product development best practice in SME and large organisations: theory vs practice. *European Journal of Innovation Management, 14*(2), 227-251. doi: 10.1108/14601061111124902
Lenderman, M. (2010). *Experience the Message: How Experiential Marketing Is Changing the Brand World*: McClelland & Stewart.
Lenfle, S., & Loch, C. (2011). Lost roots: How project management came to emphasize control over flexibility and novelty. *California Management Review, 53*(1), 32-55.
Lilley, D. (2009). Design for sustainable behaviour: strategies and perceptions. *Design Studies, 30*(6), 704-720. doi: https://doi.org/10.1016/j.destud.2009.05.001
Lofthouse, V. (2006). Ecodesign tools for designers: defining the requirements. *Journal of Cleaner Production, 14*(15–16), 1386-1395. doi: http://dx.doi.org/10.1016/j.jclepro.2005.11.013
Loh, M., & Coghlan, P. (2003). Domestic Water Use Study in Perth, Western Australia 1998-2001. Water Corporation of Australia.
Lu, T. (2007). *Research of domestic water consumption: a field study in Harbin, China.* (Master of Science), Loughborough University, United Kingdom.
Maccioni, L., Borgianni, Y., & Pigosso, D. C. A. (2019). Can the choice of eco-design principles affect products' success? *Design Science, 5*. doi: 10.1017/dsj.2019.24
Malte, S., & Manuel, L. (2021). Ecodesign—A Review of Reviews. *Sustainability, 13*(315), 315-315. doi: 10.3390/su13010315
Mandalios, J. (2013). RADAR: An approach for helping students evaluate Internet sources. *Journal of Information Science, 39*(4), 470-478. doi: 10.1177/0165551513478889
Markham, Mugge, P., & Tucker, R. (2014). *Traversing the Valley of Death: A practical guide for corporate innovation leaders*.
Markham, S. K., & Lee, H. (2013). Product Development and Management Association's 2012 Comparative Performance Assessment Study. *Journal of Product Innovation Management, 30*(3), 408-429. doi: 10.1111/jpim.12025
McGee, C. (2013). Your Home - Energy. from http://www.yourhome.gov.au/
McGlade, J., Werner, B., Young, M., Matlock, M., Jefferies, D., Sonnemann, G., Aldaya, M., Pfister, S., Berger, M.,Farell, C., Hyde, K., Wackernagel, M., Hoekstra, A., Mathews, R., Liu, J., Ercin, E., Weber, J.L., Alfieri, A., Martinez-Lagunes, R.,Edens, B., Schulte, P., von Wirén-Lehr, S., Gee, D. (2012). Measuring water use in a green economy, A Report of the Working Group on Water Efficiency to the International Resource Panel: UNEP.
McGrath, M. E., Anthony, M. T., & Shapiro, A. R. (1992). *Product development : success through product and cycle-time excellence*: Boston : Butterworth-Heinemann, c1992.

McIlroy, R. C., & Stanton, N. A. (2017). *Eco-driving : from strategies to interfaces*: Taylor & Francis, CRC Press.

McLean, L. D. (2005). Organizational Culture's Influence on Creativity and Innovation: A Review of the Literature and Implications for Human Resource Development. *Advances in Developing Human Resources, 7*(2), 226-246. doi: 10.1177/1523422305274528

Metz, P., Burek, S., Hultgren, T. R., Kogan, S., & Schwartz, L. (2016). The path to sustainability-driven innovation. *Research Technology Management, 59*(3), 50-61. doi: 10.1080/08956308.2016.1161409

MFE. (2020). Choosing water efficient products. from https://www.mfe.govt.nz/fresh-water/we-all-have-role-play/choosing-water-efficient-products

Miller, C. W. (2013). Getting Lightning to Strike *The PDMA Handbook of New Product Development* (pp. 135-153).

Ministry for the Environment. (2016). About fresh water in New Zealand. from http://www.mfe.govt.nz

Miranda de Souza, V., & Borsato, M. (2016). Combining Stage-Gate™ model using Set-Based concurrent engineering and sustainable end-of-life principles in a product development assessment tool. *Journal of Cleaner Production, 112*, 3222-3231. doi: 10.1016/j.jclepro.2015.06.013

Miranda, J., Pérez, R., Borja, V., K. Wright, P., & Molina, A. (2017). Sensing, smart and sustainable product development (S 3 product) reference framework. *International Journal of Production Research*, 1-22. doi: 10.1080/00207543.2017.1401237

Modern Plant. (2015). Save water, energy and money with Grohe's Powerbox. from http://www.modernplant.ie/company-news,content/

Mokhtarian, P., Salomon, I., & Singer, M. (2015). What Moves Us? An Interdisciplinary Exploration of Reasons for Traveling. *Transport Reviews, 35*. doi: 10.1080/01441647.2015.1013076

Mugge, P., & Markham, S. K. (2013). An Innovation Management Framework *The PDMA Handbook of New Product Development*.

Mulder, K. (2017). *Sustainable Development for Engineers : a Handbook and Resource Guide* (First edition ed.): Taylor and Francis.

Naga Vamsi Krishna, J., Aditya, S., & Shashikantha, K. (2015). Development of a framework for green product development. *Benchmarking: An International Journal, 22*(3), 426-445. doi: 10.1108/BIJ-06-2014-0060

NERI. (2006). Energy Used in NZ Homes. from http://www.physics.otago.ac.nz/eman/hew/ehome/energyuse.html#

Nidumolu, R., Prahalad, C. K., & Rangaswami, M. R. (2009). Why sustainability is now the key driver of innovation. *Harvard Business Review, 87*(9).

Niedderer, K., Clune, S., & Ludden, G. (2017). *Design for Behaviour Change: Theories and practices of designing for change*.

NIWA. (2017). Bin 2.5 Supply and demand of potable water. from https://www.niwa.co.nz/climate/urban-impacts-toolbox/toolbox-trays/second-tray-assess-the-likely-hazard/bin-25-supply-and-demand-of-potable-water

Norman, D. A. (2013). *The design of everyday things* (Revised and expanded edition ed.): Basic Books.

Notargiacomo, R. (2006). Rejoinders to "Establishing an NPD Best Practices Framework". *Journal of Product Innovation Management, 23*(2), 117-127. doi: 10.1111/j.1540-5885.2006.00187_2.x

Oh, M., Shin, J., Park, P. J., & Kim, S. (2020). Does eco-innovation drive sales and technology investment? Focusing on eco-label in Korea. *Business Strategy and the Environment, 29*. doi: 10.1002/bse.2565

Orbsys. (2020). Orbital Systems Website.

Oreg, S., & Berson, Y. (2019). Leaders' impact on organizational change: Bridging theoretical and methodological chasms. *Academy of Management Annals, 13*(1), 272-307. doi: 10.5465/annals.2016.0138

Otto, K. N., & Wood, K. L. (2001). *Product design : techniques in reverse engineering and new product development*: Upper Saddle River, NJ : Prentice Hall, c2001.

Pereira, L. S., Cordery, I., & Iacovides, I. (2009). *Coping with water scarcity : addressing the challenges*: [Dordrecht] : Springer, c2009 New rev. and extended ed.

Peters, L. S. (2006). Rejoinders to "Establishing an NPD Best Practices Framework". *Journal of Product Innovation Management, 23*(2), 117-127. doi: 10.1111/j.1540-5885.2006.00187_1.x

Pigosso, D. C. A., & McAloone, T. C. (2015a). *Ecodesign maturity model as a framework to support the transition towards iso 14.001:2015 certification.* Paper presented at the Proceedings of the International Conference on Engineering Design, ICED.

Pigosso, D. C. A., & McAloone, T. C. (2015b). *Supporting the development of environmentally sustainable PSS by means of the ecodesign maturity model.* Paper presented at the Procedia CIRP.

Pigosso, D. C. A., McAloone, T. C., & Rozenfeld, H. (2014). *Systematization of Best Practices for Ecodesign Implementation*. Paper presented at the International Design Conference, Dubrovnik, Croatia.

Pigosso, D. C. A., Rozenfeld, H., & McAloone, T. C. (2013). Ecodesign maturity model: A management framework to support ecodesign implementation into manufacturing companies. *Journal of Cleaner Production, 59*, 160-173. doi: 10.1016/j.jclepro.2013.06.040

Pigosso, D. C. A., Rozenfeld, H., & Seliger, G. (2011). Ecodesign Maturity Model: criteria for methods and tools classification. In G. Seliger, M. M. K. Khraisheh & I. S. Jawahir (Eds.), *Advances in Sustainable Manufacturing: Proceedings of the 8th Global Conference on Sustainable Manufacturing* (pp. 241-245). Berlin, Heidelberg: Springer Berlin Heidelberg.

Polizzi di Sorrentino, E., Woelbert, E., & Sala, S. (2016). Consumers and their behavior: state of the art in behavioral science supporting use phase modeling in LCA and ecodesign. *international journal of life cycle assessment*(2).

Poudelet, V., Chayer, J. A., Margni, M., Pellerin, R., & Samson, R. (2012). A process-based approach to operationalize life cycle assessment through the development of an eco-design decision-support system. *Journal of Cleaner Production, 33*, 192-201. doi: 10.1016/j.jclepro.2012.04.005

Poulikidou, S., Björklund, A., & Tyskeng, S. (2014). Empirical study on integration of environmental aspects into product development: Processes, requirements and the use of tools in vehicle manufacturing companies in Sweden. *Journal of Cleaner Production, 81*, 34-45. doi: 10.1016/j.jclepro.2014.06.001

Rajesh, S., Daniel, C. S., & Park, C. W. (2001). Cross-Functional Product Development Teams, Creativity, and the Innovativeness of New Consumer Products. *Journal of Marketing Research, 38*(1), 73.

Reid, S. E., & De Brentani, U. (2004). The Fuzzy Front End of New Product Development for Discontinuous Innovations: A Theoretical Model. *Journal of Product Innovation Management, 21*(3), 170-184. doi: 10.1111/j.0737-6782.2004.00068.x

Reim, W., Lenka, S., Frishammar, J., & Parida, V. (2017). Implementing Sustainable Product–Service Systems Utilizing Business Model Activities. *Procedia CIRP, 64*, 61-66. doi: https://doi.org/10.1016/j.procir.2017.03.130

Remmen, A., Jensen, A. A., & Frydendal, J. (2007). *Life cycle management : a business guide to sustainability*: United Nations Environment Programme.

Renström, S., Selvefors, A., Strömberg, H., Karlsson, I.C.M.*, Rahe U. (2013). *Target the use phase! Design for sustainable behaviour*. Paper presented at the The 6th International Conference on Life Cycle Management, Gothenburg.

Rijsberman, F. R. (2006). Water scarcity: Fact or fiction? *Agricultural water management*.

Roberts, P. (2005). *Yarra Valley Water: 2004 residential end use measurement study*: Yarra Valley Water Melbourne, Australia.

Rodrigues, V. P., Pigosso, D. C. A., & McAloone, T. C. (2017). Measuring the implementation of ecodesign management practices: A review and consolidation of process-oriented performance indicators. *Journal of Cleaner Production, 156*, 293-309. doi: 10.1016/j.jclepro.2017.04.049

Rodrigues, V. P., Pigossom, D., & McAloone, T. (2016). *Process-oriented performance indicators for measuring ecodesign management practices.* Paper presented at the Proceedings of International Design Conference, DESIGN.

Rossi, M., Papetti, A., Marconi, M., & Germani, M. (2019). A multi-criteria index to support ecodesign implementation in manufacturing products: benefits and limits in real case studies. *International Journal of Sustainable Engineering, 12*(6), 376-389. doi: 10.1080/19397038.2019.1575926

Rossi, M., Taisch, M., & Terzi, S. (2012, 18-20 June 2012). *Lean product development: A five-steps methodology for continuous improvement.* Paper presented at the 2012 18th International ICE Conference on Engineering, Technology and Innovation.

Roy, R. (2000). Sustainable product-service systems. *Futures*(3-4), 289.

Roy, R. (2016). *Consumer product innovation and sustainable design. [electronic resource] : the evolution and impacts of successful products*: London : Routledge, Taylor & Francis Ltd, 2016.

Roy, R. K. (2001). *Design of experiments using the Taguchi approach : 16 steps to product and process improvement*. New York ; Chichester: John Wiley & Sons.

Royce, W. W. (1987). Managing the development of large software systems: concepts and techniques. *Proceedings of the 9th International Conference: Software Engineering*, 328.

Sakellariou, E., Karantinou, K., & Poulis, K. (2014). Managing the global front end of NPD: Lessons learned from the FMCG industry. *Journal of General Management, 39*(2), 61-81.

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research methods for business students*: Harlow, England ; New York : FT/Prentice Hall, 2009 5th ed.

Schein, E. H. (2004). *Organizational culture and leadership* (3rd ed ed.): Jossey-Bass.

Schneider, B., Ehrhart, M. G., & Macey, W. H. (2013). Organizational Climate and Culture. *Annual Review of Psychology, 64*(1), 361-388. doi: 10.1146/annurev-psych-113011-143809

Shahbazi, S., & Jönbrink, A. K. (2020). Design Guidelines to Develop Circular Products: Action Research on Nordic Industry. *Sustainability, 12*(9), 3679.

Shahmohammadi, S., Steinmann, Z., King, H., Hendrickx, H., & Huijbregts, M. A. J. (2019). The influence of consumer behavior on energy, greenhouse gas, and water footprints of showering. *Journal of Industrial Ecology, 23*(5), 1186-1195. doi: https://doi.org/10.1111/jiec.12858

Sheldon A. Buckler. (1997). The Spiritual Nature of Innovation. *Research Technology Management, 40*(2), 43.

Silverstein, D., Samuel, P., & DeCarlo, N. (2009). *The innovator's toolkit. [electronic resource] : 50+ techniques for predictable and sustainable organic growth*: John Wiley & Sons.

Singh, P. K., & Sarkar, P. (2019) Eco-design approaches for developing eco-friendly products: A review. *Lecture Notes in Mechanical Engineering* (pp. 185-192).

Soanes, C., & Stevenson, A. (2005). *Oxford dictionary of English* (2nd ed., rev. / edited by Catherine Soanes, Angus Stevenson ed.): Oxford University Press.

Sobek Ii, D. K., Ward, A. C., & Liker, J. K. (1999). Toyota's principles of set-based concurrent engineering. *Sloan Management Review, 40*(2), 67-83.

Sommer, A. F., Hedegaard, C., Dukovska-Popovska, I., & Steger-Jensen, K. (2015). Improved Product Development Performance through Agile/Stage-Gate Hybrids. *Research Technology Management, 58*(1), 34-44. doi: 10.5437/08956308X5801236

Sovacool, B. K., Rogge, J.-C., Saleta, C., & Masterson-Cox, E. (2019). Transformative versus conservative automotive innovation styles: Contrasting the electric vehicle manufacturing strategies for the BMW i3 and Fiat 500e. *Environmental Innovation and Societal Transitions, 33*, 45-60. doi: https://doi.org/10.1016/j.eist.2019.02.004

Standards New Zealand. (2003). Plumbing and drainage *Part 1: Water services* (Vol. 4.4.1). Australia: SAI Global Ltd.

Steam Whistle. (2013). Steam Whistle's Green Initiatives. from http://www.steamwhistle.ca/ourbeer/greenInitiatives.php

Stevels, A. (1999). Integration of EcoDesign into business, a new challenge. *Proceedings First International Symposium on Environmentally Conscious Design & Inverse Manufacturing*, 27.

Tanco, M., Viles, E., Ilzarbe, L., & Alvarez, M. J. (2008). Is design of experiments really used? A survey of Basque industries. *Journal of Engineering Design, 19*(5), 447-460. doi: 10.1080/09544820701749124

Tingström, J. A., & Kth, S. f. i. t. o. m. M. M. O. (2007). *Product development with a focus on integration of environmental aspects.* (Doctoral Thesis), KTH, Stockholm. Retrieved from http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edsswe&AN=edsswe.oai.DiVA.org.kth.4289&site=eds-live&scope=site Available from EBSCOhost edsswe database.

Todnem By, R. (2005). Organisational change management: A critical review. *Journal of Change Management, 5*(4), 369-380.

Toyota. (2009). Prius and the Environment. from https://www.toyota.co.uk/new-cars/prius/index.json

Tromp, N., Hekkert, P., & Verbeek, P.-P. (2011). *Design for Socially Responsible Behavior: A Classification of Influence Based on Intended User Experience* (Vol. 27).

Tukker, A., Emmert, S., Charter, M., Vezzoli, C., Sto, E., Munch Andersen, M., . . . Lahlou, S. (2008). Fostering change to sustainable consumption and production: an evidence based view. *Journal of Cleaner Production, 16*(11), 1218-1225. doi: https://doi.org/10.1016/j.jclepro.2007.08.015

Ullman, D. G. (2016). *The mechanical design process*: New York, NY : McGraw-Hill Education, [2016]]]>
<![CDATA[Fifth edition.

Ulrich, D., Allen, J., Smallwood, N., Brockbank, W., & Younger, J. (2009). Building culture from the outside in. *Strategic HR Review, 8*, 20-27. doi: 10.1108/14754390910990955

Ulrich, D., & Smallwood, N. (2004). Capitalizing on Capabilities. *Harvard Business Review, 82*, 119-127, 138.

Unilever. (2000). Table Detergents - Towards a More Sustainable Future. from https://www.unilever.com

Unschool. (2020). UNEP and Disruptive Design Partnership Program. from https://anatomyofaction.org/

US Congress Subcommittee on Energy and Resources. (2007). *Hybrid cars : increasing fuel efficiency and reducing oil dependence : hearing before the Subcommittee on Energy and Resources of the Committee on Government Reform, House of Representatives, One Hundred Ninth Congress, second session, July 20, 2006*: Washington : U.S. G.P.O. : For sale by the Supt. of Docs., U.S. G.P.O., 2007.

Ussui, P. R. S., & Borsato, M. (2013). *Sustainability Indicators for the Product Development Process in the Auto Parts Industry*. Paper presented at the ISPE International Conference on Concurrent Engineering.

van Oorschot, K., Sengupta, K., Akkermans, H., & van Wassenhove, L. (2010). Get Fat Fast: Surviving Stage-Gate® in NPD. *Journal of Product Innovation Management, 27*(6), 828-839. doi: 10.1111/j.1540-5885.2010.00754.x

Verworn, B., Herstatt, C., & Nagahira, A. (2008). The fuzzy front end of Japanese new product development projects: Impact on success and differences between incremental and radical projects. *R and D Management, 38*(1), 1-19. doi: 10.1111/j.1467-9310.2007.00492.x

Veryzer Jr, R. W. (1998). Discontinuous Innovation and the New Product Development Process. *Journal of Product Innovation Management, 15*(4), 304-321.

Vokins, M. (2019). Hansgrohe Welcomes Sustainability. *DesignInsider*.

Water Footprint Network. (2016). National water footprint explorer. from http://waterfootprint.org/

Wever, R., van Kuijk, J., & Boks, C. (2008). User-centred design for sustainable behaviour. *International Journal of Sustainable Engineering, 1*(1), 9-20. doi: 10.1080/19397030802166205

Wise, T. P., Daniel, R., & Livingston, M. M. (2015). *Agile Readiness : Four Spheres of Lean and Agile Transformation* Retrieved from http://MASSEY.eblib.com.au/patron/FullRecord.aspx?p=1897127

Wißotzki, M. (2018). The notion of capability in literature *Capability Management in Digital Enterprises* (pp. 27-39).

Yeung, A., & Ulrich, D. (2020). Book highlight—Culture: Shaping the right priorities and behaviors in the ecosystem. *Global Business and Organizational Excellence, 39*(3), 55-61. doi: 10.1002/joe.21994

Yin, R. K. (2014). *Case study research : design and methods*: Los Angeles : SAGE, [2014]

Zbicinski, I. (2006). Product Design and Life Cycle Assessment. Uppsala: Baltic University Press.

Appendix A

USE OF DESIGN OF EXPERIMENTS TO OPTIMISE THE ENVIRONMENTAL PERFORMANCE OF CONSUMER PRODUCTS: A CASE STUDY OF SHOWERS AND TAPWARE IN NEW ZEALAND

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Abstract

Eco-tools and techniques often lack guidance and a robust methodology for improving the environmental performance of products with an active use phase. A case study was undertaken to investigate the role of Design of Experiments (DoE) in providing insights to improve the environmental performance of two product categories with active use phases: showers and tapware. The results show how varying the components can reduce energy use and demonstrated how DoE can be used as an objective method for optimising a products environmental performance when user behaviour can influence the results.

Keywords: ecodesign, sustainable design, design process, active products, design of experiments

1. Introduction

Pressures from environmentally conscious consumers have led manufacturing companies to explore opportunities to develop products and systems with environmentally superior characteristics (Sousa and Wallace, 2006). This requires companies to identify relevant environmental criteria to guide the product development process (Sousa and Wallace, 2006), and use these criteria to assess alternative materials for components, modify the design so that it has an improved environmentally profile (Lenox, 2000), and/or create alternative products fulfilling the same function(s). To assist product developers in this process, a number of eco tools and methods are available including Design for the Environment (DfE) and Life Cycle Assessment (LCA), which can be used at various stages in New Product Development (NPD) (Fitzgerald et al., 2005). DfE tools, such as those based on checklists, are easy to implement but are very subjective and not particularly insightful in guiding improvements. Quantitative tools such as LCA are not only time consuming and costly, but tend to be unsuitable for early design processes due to the limited information available about the product at that stage in the design process (Devanathan et al., 2010). In particular, for companies developing products with an environmentally dominant use phase, the existing approaches are often inadequate. These types of products are described as "active products", and often the majority of environmental impacts are associated with energy consumption during the use stage of the product's life cycle (Jolliet et al., 2015).

The task of addressing the future use phase in the design of a consumer product might be difficult for a company when there is more than one variable contributing to the environmental impacts associated with the use phase: these variables may not be obvious and need to be "discovered" by the designers. This discovery involves identifying the factors of the product's design (such as its shape, weight, interface) that affect the product's environmental impacts in its use phase. Furthermore, there may be a lack of empirical evidence that quantifies the environmental improvements when modifying a design to account for consumers' behaviour. As an example, a consumer survey study found a correlation between design factors of showers (i.e. spray type, colour, shape) and the user experience (Adeyeye et al., 2017). The study concluded that user experience and perceptions of the shower under different types of showerheads can significantly contribute to the use phase of the product - how enjoyable a product is for the user can determine how much it gets used. This suggests that companies need to develop an awareness of the factors influencing the environmental impacts associated with the use of their products in order to improve or innovate new products that do actually reduce overall environmental impacts (Herring and Roy, 2007).

Use of existing eco-tools has had limited relevance for active of products, as often these tools do not explicitly consider variability in how the user interacts (or potentially interacts) with the product or the influence of this behaviour on the magnitude of environmental impacts at the use stage (Wever et al., 2008). Generally existing environmental assessment approaches to support NPD (Renee et al., 2007, Boks and Stevels, 2003, Wever et al., 2008) either do not consider the environmental impacts related to human-product interactions or do so superficially, and there is a lack of guidance and robust methodologies for conducting this type of benchmarking (Lin et al., 2017). Studies which do address sustainable consumption tend to focus primarily on purchasing behaviours rather than the use of the product (Bhamra et al., 2011). This suggests that a new approach is needed to complement existing eco tools and provide companies with a practical method for addressing multiple variables (components, materials, user interfaces) that ultimately affect the environmental performance in the use phase of the product.

Design of Experiments (DoE) is one of the most popular benchmarking tools in product development since it commonly applied within Total Quality Management (TQM), an approach to support the improvement of manufacturing processes (Kutz, 2007). It has already been recognised as relevant in the context of environmental management as it can help minimise waste generation during the manufacturing phase of a product's life cycle (Kutz, 2007). A key component of TQM processes is some form of experimentation to test how the input variables from a device, component or manufacturing process affect the response variables that need to be optimised. DoE is considered to be the most effective experimentation tool when considering multiple input variables for a product system (Tanco et al., 2008, Roy, 2001). DoE avoids the misleading results that are often found in alternative experimentation methods such One Factor at a Time (OFAAT) and Randomised Control Trials (RCT), where the results only yield first order responses and ignore interactions between factors (Kutz, 2007). One study showed that most manufacturing companies applying DoE were those doing Research and Development projects (Tanco et al., 2008); however, the majority of manufacturing companies still apply inferior tools such as OFAAT (Granato and Ares, 2013). Kutz (2007) recommends that the DoE can also be used to optimise the environmental performance of a product, so the design is more useful and efficient in its use. This is supported by Gremyr et al. (2014) who emphasise that DoE used within the context of sustainable product development should aim to support the front end of product development by considering the full life cycle of the product, including the use phase. Furthermore, a case study has shown that DoE can be applied in a user-centred design to optimise a product's aesthetics, based on systematic statistical modelling of user-experience feedback from customers (Lin et al., 2017).

Inspired by Kutz (2007) and Gremyr et al (2014), in this research a DoE industrial case study was undertaken to investigate improvement in the environmental performance of the use phase of an active consumer product, and provide insights into whether the DoE approach could be used more generally to support eco-design in New Product Development. A shower and tapware manufacturing company was selected for the case study. The company is based in Auckland, New Zealand; it has a considerable share of the market in New Zealand and Australia, and a growing presence in the United Kingdom and North America. The company sells a wide range of different shower and tapware products with varying spray technologies and user interfaces that are representative of variables that can be optimised to improve the environmental performance. Two individual DoE experiments were set up; (1) different shower products used in domestic household showers, and (2) various tap designs used in a corporate office bathroom. The process for designing and conducting the experiments followed four distinct stages: 'Generation of Ideas and Factors', "Development of case study", "Undertake case study" and "Interpretation of the results and analysis". The following sections follow this structure to describe the study and its results.

2. Case Study

2.1. Stage One: Generation of Ideas

An in-house seminar and practical workshop was attended by the engineers, designers and managers from the product development team. At the seminar, the researcher introduced the concept of Life Cycle Thinking and presented the results of an existing Life Cycle Assessment (LCA) study of a shower product (Institut Bauen und Umwelt e.V, 2011) to show how the use phase dominates the environmental impacts for this product category. Teams brainstormed design factors that could influence the use phase of shower products, with a few of the generated design factors selected as appropriate to test in an experiment. They were chosen based on two aspects: ease of application and low risk in conducting the experiment. With respect to ease of application, the factors needed to be able to be relatively easily applied and tested in a household with minimal requirements for additional plumbing. With respect to risk, all equipment and components needed to be pressure rated to New Zealand plumbing standards and fitted professionally to the shower or bathroom to prevent permanent damage to the house from leaks or flooding. For the shower experiment the selected factors were: 'Spray Type' and 'Feedback to User'. For the tap experiment, the chosen factors were 'Cartridge Type' and 'Flow Rate'. In both experiments, the factors have levels representing the variations in the factor being tested (meaning all factors used are text-based rather than numeric). For the shower experiment, the factor 'Spray Type' had three levels: 'Luxury Spray A', 'Luxury Spray B' and 'Conventional'. The factor 'Feedback to User' had three levels: 'No Feedback', 'Usage Scale' and 'Monetary Cost'. For the tapware experiment, the factor 'Cartridge Type' had three levels: 'Progressive', '2-Step Eco' and 'Standard'. The factor 'Flow Rate' had two levels: '5 Litre' and '8 Litre'. These factors and levels are described in more detail in the following sections.

2.2. Stage Two: Development of case study

The second stage of the process established a protocol for conducting the DoE experiments to identify and reduce nuisance variables. Two aspects were identified as significant to this experiment. A single shower unit can have multiple users where one user cannot clearly be distinguished from another one, so the response data may misrepresent the situation. Ideally it would be preferable to conduct the shower experiment using shower units that had only a single user. Similarly, the tapware experiment required that bathrooms with multiple basins would require all taps to follow the treatment order in parallel. The nuisance variables thought to be worthwhile including in the DoE and mitigating were ambient temperature and humidity in the shower room since this could impact the duration and temperature of the shower; however, due to excessive humidity saturation, the electronic sensor used to collect this data malfunctioned in some shower units and therefore these data had to be omitted from the final analysis. All shower units were pressure tested by the researcher prior to the experiment to ensure all had a high-pressure water supply (at least 200 kPa) to avoid misleading results from comparing low and high-pressure water systems. The purpose-built recording device (Figure 1) could be fitted between the shower hose and elbow of any rail system shower in a household. It recorded the primary response variables: Water Volume, Temperature, Duration and Energy on a flash memory card. Energy is calculated based on the thermal energy required to heat the volume of water per shower (based on the other response variables). These variables reflect what a shower and tap product consume when in use. For this calculation ambient temperature was assumed to be 15^{o}C. Water flow and temperature were recorded as analogue and digital signals. A real-time clock was included in the device to record duration of each shower event. This same device was adapted for the tapware experiment by adding an additional flowmeter, and temperature probe for the separate hot and cold inlets. Each unit was calibrated using a Center 370 RTD Temperature Probe and GPI Industrial Grade Electronic Flow Meter. As shown in Figure 1, the ‘LCD Display’ and ‘Use Scale’ were positioned in the shower to provide the user with information during their shower. The ‘LCD display’ can show numerical values while the ‘Use Scale’ has two sets of LED lights to indicate the low, medium and high use for energy (red) and water (blue).

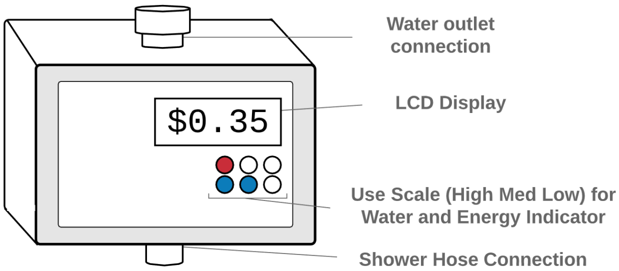

Figure 1. Purpose Built Recording Device

2.3. Stage Three: Undertake Pilot Studies

2.3.1. Experiment 1 - Showers

Method

The first task was to identify participants for the shower study. The use of social media and employee referrals from the case company generated a list of approximately 20 potential participants. However, finding willing participants who met the procedure requirement of a single user for the shower was difficult and somewhat unrealistic, and ultimately there were only two showers in the study that did not have multiple users. This resulted in monitoring and analysing five showers in different households that were used by a total of ten individuals. Participants were between the ages of 25 and 38, and of low to medium household income. There were eight males and two females. Once the participants had been chosen, the researcher installed the datalogger into each household's shower. The general purpose of the experiment was explained to the participants; however, no further information was given to avoid influencing the results.

Table 1. Shower Experiment Factors and Levels

	Factor 1: Spray Type	Factor 2: Feedback to User
Level 1	Luxury Spray A	No Information
Level 2	Luxury Spray B	Energy and Water Usage (Low, Medium, High)
Level 3	Conventional	Cost Information

The multifactorial test design is shown in Table 1. Three types of existing spray types were used in the experiment. Luxury spray technology works by colliding water jets to form a larger coverage area with water droplets for a shower: Luxury Spray B provides greater coverage than that of traditional sprays, and Luxury Spray A does the same but uses a radically different method for creating the water droplets. The ‘Feedback to User’ factor provided real-time information to the user about their current shower. Energy and water use were indicated using a low, medium and high LED light display referred to as the ‘Use Scale’. Cost showed the user how much their shower cost in cents; additionally, when the shower was turned off a total cost for the month was shown. The cost calculation used a conservative estimation based on one of the lowest possible energy prices in New Zealand and assumed an 85% energy efficiency of hot water heating and supply.

Every two weeks a new treatment was applied by returning to the household and changing the shower handset or adjusting the type of feedback that was presented to the user. This change was based on the randomised treatment order in Table 2. The duration between treatments allowed a sufficient number of showers to be recorded and averaged to compensate for the variability in the shower activities (e.g. washing hair) and multiple users who would likely have different showering habits.

Table 2. Treatment Order for Shower Experiment

StdOrder	Spray Type	Consumption
1	Luxury Spray A	No Display
2	Luxury Spray A	LED Display
3	Luxury Spray B	LED Display
4	Luxury Spray B	No Display
5	Conventional	Cost Display
6	Luxury Spray A	Cost Display
7	Conventional	No Display
8	Luxury Spray B	Cost Display
9	Conventional	LED Display

Results

The records of showers for all the households were averaged for each treatment. Figures 2 show the fitted means of all households for the response variable of interest. An Omnibus test was used to explain the variance to determine if a factor was statistically significant (where p-values < 0.05 are considered significant). The baseline comparison is the first level of each factor. Figure 2 (A) shows the effect on Temperature for the factors ‘Spray Type’ and ‘Display Type’. The ‘Conventional Spray’ had a lower Temperature than both the Luxury Sprays but none of the differences were found to be statistically significant. The ‘Display Type’ had a significant effect on Temperature with a p-value of 0.04. Compared to no feedback, the ‘Cost’ display was associated with a temperature increase of 0.14ºC but this was not significant. The ‘Use Scale’ was associated with a temperature reduction of 0.48 ºC when compared to no display and this was significant (p-value 0.014). In summary, the Use-Scale influenced a reduction in temperature while the other factors and levels did not have a significant impact.

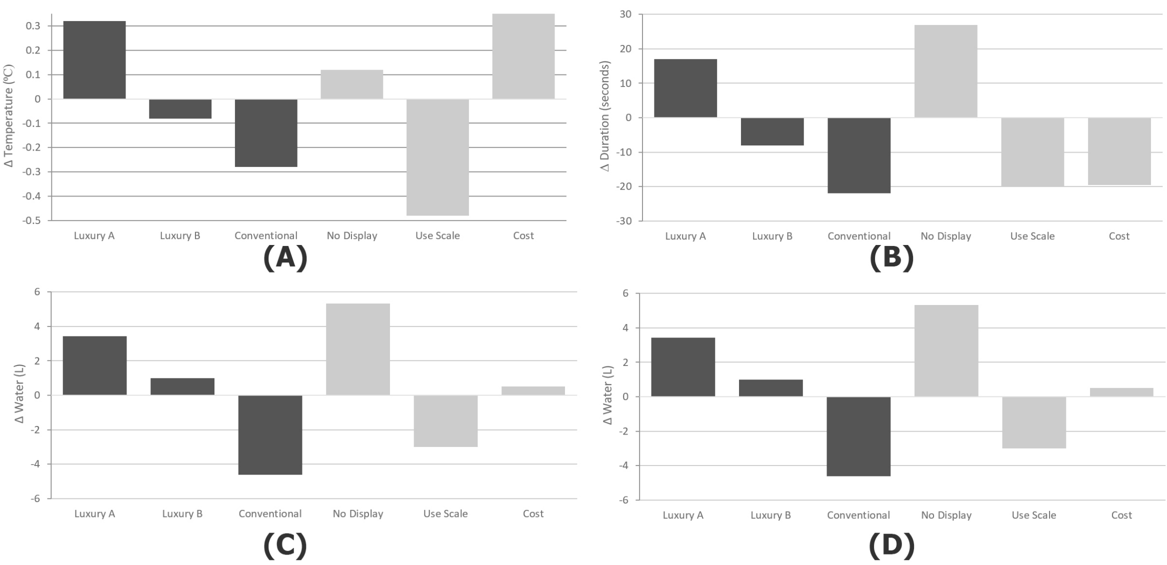

Figure 2. Showers - All factors response

Figure 2 (B) shows that, on average, the ‘Conventional Spray’ reduced the duration of the shower; however, this was not significant. An absence of any display was associated with an increased shower duration by 30.7 seconds and this was significant (p-value 0.036). Figure 2 (C) shows the response for Water. There was weak evidence (p-value 0.078) that spray type affected the total volume of water used per shower. The absence of a display indicated some increase in water usage compared to the Use-Scale and Cost factors however these were no statistically significant. Figure 2 (D) shows the response for Energy. ‘Spray Type’ was significant (0.049 p-value) while ‘Display Type’ was not. The Luxury-A showerhead was estimated to use 461 KJ more than the mean of all showers (8% increase); however, this was not significant (0.061 p-value). There was a weak interaction between ‘Luxury-A’ and ‘No-Display’ with a p-value of 0.094 that estimated an increase of 580KJ of energy (10% increase).

2.3.2. Experiment 2 Tapware

Method

The tapware experiment was run in a corporate office in Auckland, New Zealand. A men’s bathroom was selected that was used regularly by approximately 40 people. Recording devices were installed under two basins. Two taps were installed on to the basins; these taps were flexible in their design which enabled the researcher to change the internal and external components throughout the experiment. The factors and levels chosen for this experiment are shown in Table 3.

Table 3. Tapware Experiment Factors and Levels

	Factor 1: Cartridge Type	Factor 2: Flow Restriction
Level 1	Progressive	5 L / min
Level 2	2-Step Eco	8 L / min
Level 3	Standard	

A cartridge is an internal component of a tap that allows for hot and cold water delivery to be varied depending upon the handle position. The standard cartridge has two degrees of freedom for delivery of water, which controls flow and temperature, while the progressive only has a single degree of freedom, which controls both flow and temperature. The design of the progressive means that hot water is only delivered when the handle is turned beyond 90^{o}. The 2-Step Eco cartridge is a modified standard cartridge designed to reduce water use by having a distinct restriction of the movement of the handle when the flow has reached 50% of its maximum flow: users who require a higher flow must then apply a greater force to move the handle beyond this restriction.

Taps can be flow-restricted easily using a range of components from original equipment manufacturers (OEM). The flow restrictor can often impact the overall design of the tap as the body of the product may need to change to accommodate the size or shape of the component. In the tapware industry, it is generally assumed that lower flow restriction equates to reduced water consumption per use which is then reflected in most water saving and labelling schemes.

The multifactorial design and run order for the tapware experiment is shown in Table 4.

Table 4. Treatment Order for Tapware Experiment

StdOrder	Cartridge Type	Flow Restriction
1	Progressive	5 L / min
2	2-Step Eco	5 L / min
3	Progressive	8 L / min
4	Standard	8 L / min
5	Standard	5 L / min
6	2-Step Eco	8 L / min

The week before the experiment, all combination of tap modifications were introduced into the bathroom without recording. This was to avoid collecting data in the subsequent week where the users were experiencing the new design for the first time. For the experiment itself, a new combination was applied each day at approximately 12noon. Over six days 473 “washing hands” records were collected from all treatments. Since both hot and cold temperatures and flow were individually measured, it was not considered necessary to calculate energy use as it was assumed that the quantity of hot water used was representative of energy use. The response variables for the tap experiment were: Duration, Cold Water Use and Hot Water Use. An additional final response variable was calculated (PercentWaste) which represented any hot water that was drawn into the pipes but did not reach the tap and instead cooled to ambient temperature.

Results

The fitted means shown in the following graphs are the average of washing events for both taps for the response variable of interest. An Omnibus test was used to explain the variance to determine if a factor was statistically significant. Unless mentioned otherwise, no interactions between factors were found to be significant. Figure 3 (A) shows that the ‘Cartridge Type’ had no significant effect on the response Duration. However, there was weak evidence (p-value 0.181) that using a higher flow reduced Duration. Flow had no statistically significant effect on Cold and Hot water use (Figure 3 C & D). However, ‘Cartridge Type’ was statistically significant for both Cold and Hot water use. Using a Progressive cartridge was associated with an increase in cold water use by 78.1 mL (p-value 0.003) and decrease in hot water use by 102 mL (p-value < 0.001).

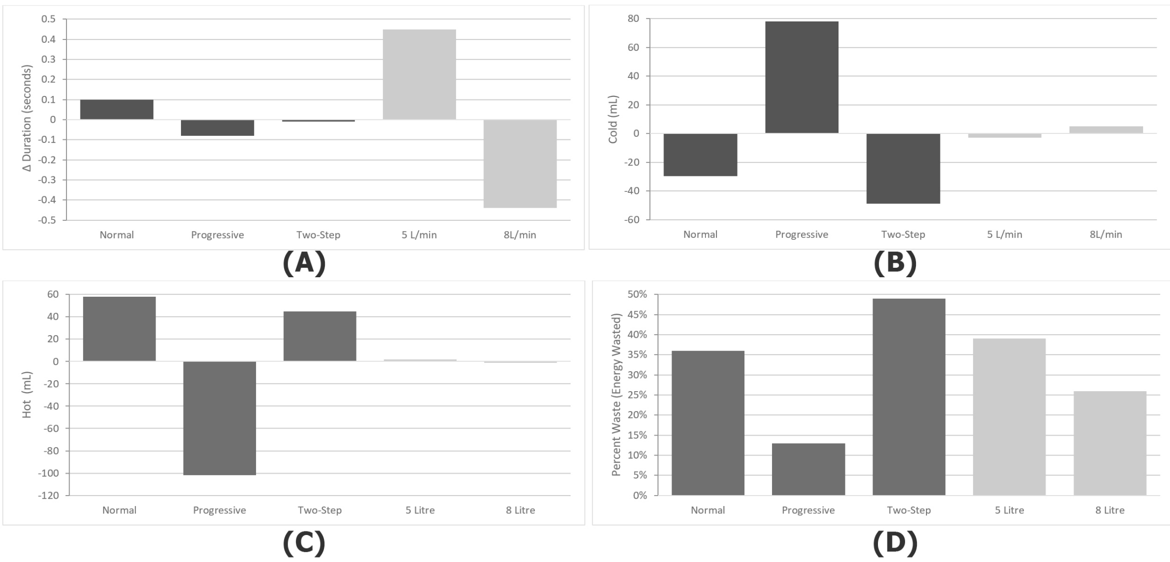

Figure 3. Tapware - All factors response

For PercentWaste (Figure 3 D), ‘Cartridge Type’ was statistically significant (p-value < 0.001). Flow was also found to be significant (p-value < 0.001), but there was a significant interaction between Cartridge and Flow (p-value 0.040) which suggests the wasted energy (for heating water) increases when the cartridge distributes less hot water per washing hand event. This can be explained by the fact that a larger volume of hot water is more likely to travel through the pipes to the user than a smaller volume of water over the same time period.

2.4. Stage Four: Interpretation of results

In the first experiment on showers, Spray type was shown to affect energy use of shower products while water volume, duration and temperature were not affected by Spray type. This finding poses a challenge to most water care rating schemes where it often recommends that a lower water star rating reduces hot water and associated energy costs. When displaying information to the user of a shower product, the type of display (or absence of a display) throughout the shower plays an important role. For this study, users responded positively by reducing their energy use when provided with information about whether

they were a Low, Medium or High user (Use-scale display); in contrast, showing the monetary cost of the shower did not reduce the user's energy use.
The second experiment presented some evidence that varying the flow restriction had no effect on the quantity of either hot or cold water used for washing hands. Instead, users washed for a longer or shorter time depending on the flow restrictor, effectively using the same amount of water per wash regardless of the flow restrictor. It was found that users will be less likely to wash with hot water with a Progressive Cartridge, and are more likely to waste hot water using the alternative Standard and 2-Step Cartridge since most users turn the handle to receive hot water, but do not wash long enough for the hot water to travel through the pipes and come out of the tap. This suggests that a Progressive Cartridge is environmentally superior as it wastes less energy based on the behaviours of users in this study.

3. Discussion

On the use of DoE for improving the environmental impacts of active products, firstly DoE provided the inherent ability to assess the behaviours of users and their related impact on the response variables. As an example, in the shower experiment there was evidence that information provided back to the user about their showering did influence their use of energy and, based on the type of feedback, it can produce a positive or negative response (displaying use information as a scale had a positive effect on energy use while showing the cost of the shower produced a negative effect on energy use). The tapware experiment demonstrated that varying components size, and position influenced the user's energy consumption. The DoE has therefore provided a method for understanding what changes can be made to the design of a new product when people and how they interact with the product is taken into consideration.

Secondly, DoE provides decision support when the subjective experiences and needs of different customers may impact the results and insights. Active products can be functional and experiential. As an example, the purpose of taking a shower can be classified as functional (i.e. getting clean) or relaxing (or both at the same time to varying degrees), and existing commercial products provide alternative spray types oriented towards one or other of these experiences. Simpler statistical tools often aggerate the all the results across participants which can lead to inaccurate results, however DoE addresses this by arranging experimental units into blocks (Blocking). Since different users or groups of users have different parameters for use, Blocking allows the practitioner to look at how those individual users respond to changing of the factors. To better inform designers in this area it would be advisable to include an additional response variable or a covariant that assesses the user's experience. For example, in the shower experiment a survey could have been used to capture this qualitative data.

Thirdly, the practicality of conducting DoE in this way depends upon the product category. Producers need to be clear on what their objectives are for undertaking a DoE and the time required to do so. As an example, in the shower study it took a long time to collect the data as often only one data record could be recorded each day, while typically over 100 data records could be collected in the same time period for the tapware study. The implication is that some product categories are better suited for this type of experimentation than others i.e. those products that are used relatively frequently, and where user benefits are purely functional. Therefore, producers need to be aware of the practicality of varying DoE designs and match their expectations with realistic time horizons.

Validation of experiment results was difficult since most of the factors (Spray Type, User Feedback, Cartridge) analysed were non-numerical. At the end of a DoE experiment it is often necessary to translate the factorial design into the product development or manufacturing process to determine if the design is effective (Kutz, 2007). A DoE design that contains numeric factors allows the practitioner to develop a model for optimising the product design that reflects the ideal response based on varying all the factors and levels. This optimal product design could then be created and tested to validate the results of the DoE. Since this study applied non-numeric based factors mostly, it did not easily allow for this validation and this could diminish the usefulness of the results depending on how far along the product is within the NPD process. Furthermore, the decision support tools derived from this study are likely to be only relevant for a later stage of the development process, providing a method for benchmarking and varying the design of the product. To improve DoE for use in early design stages could be to further break down a part or technology to reflect its numerical components as additional factors. Using the shower study as an example, by replacing Spray Type with number of spray nozzles, size of the water jet and angle of the water collision it would allow the practitioner to identify a new spray type that has the least environmental impact. Its common practice for design engineers to create prototypes and trial them on customers to obtain formative feedback and adjust the design accordingly. Therefore, the DoE design could identify an optimum point where the experience is maximised, and the environmental impact is at its minimum.

4. Conclusions

Embedding environmental considerations into the product development process of active consumer products can be difficult for practitioners. This is particularly challenging when there are multiple factors to consider and where user behaviour may influence the environmental impacts associated with the product's life cycle. This study has demonstrated that DoE can be used as an objective method for obtaining new environmental insights in this area, and has led to recommendations for use of DoE in future experiments to support the NPD process. The factors and levels in a DoE experiment need to be carefully selected to reflect the stage of the product development process or type of NPD project. NPD projects can typically be categorised as radical or incremental (Slater et al., 2014). In the context of a shower product, a radical project could be the development of a new spray technology where the product developer can use modelling and prototyping techniques in the early stages of development to modify the waterjet size, amount and speed. Since these are variables that could ultimately impact the use phase of the product, there is an opportunity to implement DoE using numerical factors to optimise the design for active use. However, when implementing DoE in an incremental project it may be more appropriate to use text-based factors and levels. In this type of project, the objective is to provide an environmental point of reference and comparison of products, components or technology; this comparison may be used to support material and part selection during the later stage of the NPD process when the design specifications are being formalised. Common decision support tool for material and part selection implemented during the NPD process are Pugh Charts and Weight Factor Matrix (Otto and Wood, 2001, Ulrich and Eppinger, 2012).

In the shower study, the attitudes or feelings of the participants were not recorded as each combination of factors and levels were tested. This led to a realisation that it is important to include qualitative data in the DoE design when the user benefits of the product are not purely functional. This could involve recording response variables that are both quantitative (energy use of the prototype) and qualitative (experience of the customer) so that the final analysis can include consideration the correlation or trade-offs between them. One of the obvious limitations of the study is the small sample of active product categories. Therefore, the implications for the use of DoE to inform the design process may not be representative of all active products.

Acknowledgements
This research is funded and supported by Callaghan Innovation [grant number MTVN1503]

References

Adeyeye, Kemi, Kaiming She, and Abderrahmane Baïri. 2017. "Design factors and functionality matching in sustainability products: A study of eco-showerheads." Journal of Cleaner Production 142 (Part 4):4214-4229. doi: 10.1016/j.jclepro.2016.11.143.

Bhamra, Tracy, Debra Lilley, and Tang Tang. 2011. "Design for Sustainable Behaviour: Using Products to Change Consumer Behaviour." Design Journal 14 (4):427-445. doi: 10.2752/175630611X13091688930453.

Boks, Casper, and Ab Stevels. 2003. "Theory and practice of environmental benchmarking in a major consumer electronics company." Benchmarking: An International Journal 10 (2):120-135. doi: 10.1108/14635770310469653.

Devanathan, S., D. Ramanujan, W. Z. Bernstein, F. Zhao, and K. Ramani. 2010. "Integration of sustainability into early design through the function impact matrix." Journal of Mechanical Design, Transactions of the ASME 132 (8):0810041-0810048. doi: 10.1115/1.4001890.

Energy Saving Trust. 2013. At Home With Water. London: Department of Environment Food and Rural Affairs.

Energy Saving Trust. 2018. "How to reduce my energy consumption." Energy Saving Trust. http://www.energysavingtrust.org.uk/home-energy-efficiency/home-appliances.

Fitzgerald, D P., J W. Herrmann, P A. Sandborn, and L C. Schmidt. 2005. University of Maryland, College Park, MD 20742, USA.

Font Vivanco, David, René Kemp, and Ester van der Voet. 2016. "How to deal with the rebound effect? A policy-oriented approach." Energy Policy 94:114-125. doi: 10.1016/j.enpol.2016.03.054.

Granato, Daniel, and Gaston Ares. 2013. Mathematical and statistical methods in food science and technology: Chichester, West Sussex, UK : John Wiley & Sons Inc., 2013. Bibliographies

Non-fiction.

Gremyr, Ida, Vanajah Siva, Hendry Raharjo, and Thong Ngee Goh. 2014. "Adapting the Robust Design Methodology to support sustainable product development." Journal of Cleaner Production 79:231-238. doi: http://dx.doi.org/10.1016/j.jclepro.2014.05.018.

Herring, Horace, and Robin Roy. 2007. "Technological innovation, energy efficient design and the rebound effect." Technovation 27:194-203. doi: 10.1016/j.technovation.2006.11.004.

Institut Bauen und Umwelt e.V. 2011. Environmental Product Declaration as per ISO 14025 for hand showers Croma 100 and Crometta 85. Panoramastraße, Berlin.

Jolliet, O., M. Saade-Sbeih, S. Shaked, A. Jolliet, and P. Crettaz. 2015. "Inventory Analysis of Emissions and Extractions." In Environmental Life Cycle Assessment, 57. CRC Press.

Kutz, Myer. 2007. Environmentally conscious mechanical design, Wiley series in environmentally conscious engineering: Hoboken, NJ : John Wiley, c2007. Non-fiction.

Lenox, Michael. 2000. "An Assessment of Design-for-Environment Practices in Leading US Electronics Firms." Interfaces 30 (3):83-94.

Lin, K. Y., A. P. I. Yu, P. C. Chu, and C. F. Chien. 2017. "User-experience-based design of experiments for new product development of consumer electronics and an empirical study." Journal of Industrial and Production Engineering 34 (7):504-519. doi: 10.1080/21681015.2017.1363089.

Murray, Cameron K. 2013. "What if consumers decided to all 'go green'? Environmental rebound effects from consumption decisions." Energy Policy 54:240-256. doi: 10.1016/j.enpol.2012.11.025.

Otto, Kevin N., and Kristin L. Wood. 2001. Product design : techniques in reverse engineering and new product development: Upper Saddle River, NJ : Prentice Hall, c2001. Bibliographies

Non-fiction.

Renee, Wever, Boks Casper, Marinelli Thomas, and Stevels Ab. 2007. "Increasing the benefits of product-level benchmarking for strategic eco-efficient decision making." Benchmarking: An International Journal (6):711. doi: 10.1108/14635770710834509.

Roy, Ranjit K. 2001. Design of experiments using the Taguchi approach : 16 steps to product and process improvement. New York ; Chichester: John Wiley & Sons.

Slater, S. F., J. J. Mohr, and S. Sengupta. 2014. "Radical product innovation capability: Literature review, synthesis, and illustrative research propositions." Journal of Product Innovation Management 31 (3):552-566. doi: 10.1111/jpim.12113.

Sousa, Ines, and David Wallace. 2006. "Product classification to support approximate life-cycle assessment of design concepts." Technological Forecasting and Social Change 73 (3):228-249. doi: http://dx.doi.org/10.1016/j.techfore.2004.03.007.

Tanco, Martin, Elisabeth Viles, Laura Ilzarbe, and María Jesus Alvarez. 2008. "Is design of experiments really used? A survey of Basque industries." Journal of Engineering Design 19 (5):447-460. doi: 10.1080/09544820701749124.

Tiefenbeck, Verena, Thorsten Staake, Kurt Roth, and Olga Sachs. 2013. "For better or for worse? Empirical evidence of moral licensing in a behavioral energy conservation campaign." Energy policy.

Ulrich, Karl T., and Steven D. Eppinger. 2012. Product design and development: New York : McGraw-Hill/Irwin, c2012

5th ed. Bibliographies

Non-fiction.

Wever, Renee, Jasper van Kuijk, and Casper Boks. 2008. "User-centred design for sustainable behaviour." International Journal of Sustainable Engineering 1 (1):9-20. doi: 10.1080/19397030802166205.

Appendix B

Environmental development and performance testing of a system-based eco-shower

Mike Horrell, Dr Mark Tunnicliffe, Dr Sarah McLaren

Abstract

Product development companies seeking to reduce the environmental impacts associated with showers have developed systems that can recover energy and water through recirculation of the wastewater. However, there are many challenges faced by NPD practitioners when developing these systems. NPD teams must address the inherent risk of prototyping systems that need to manage wastewater potentially containing viruses and bacteria harmful to humans and there is a lack of empirical data on what designs, or combination of key components (such as filters), yield the greatest environmental improvements. This paper reports on a study that followed an R&D team in a shower and tapware company through the NPD process of designing a recirculation system. The study showed it is possible to avoid the inherent human health risks associated with prototyping recirculation systems and still obtain enough information on energy and water use to determine the system performance of the investigated design. It also highlighted the need to include user behaviour in performance testing to improve the accuracy and reliability of the results.

1.0 Introduction

In the residential sector, household carbon emissions (HCE) comprise all the carbon emissions associated with a domestic household. The majority of these emissions generally arise from the use of energy, and in particular energy for lighting, appliance use and heating. The distribution of energy use across different household activities varies in different households and countries (Camilleri et al., 2006; McGee, 2013; NERI, 2006). However, a number of studies have shown that the most significant contributor of HCE in many western countries is hot water heating (Beal, Bertone, & Stewart, 2012; Beal, Stewart, Huang, & Rey, 2011; Lu, 2007; Nakagami, Murakoshi, & Iwafune, 2008; Wong, Mui, & Zhou, 2017). Even in countries with a high proportion of renewable energy sources, the small contribution of fossil fuels used to heat hot water represents a significant environmental problem needing improvement (The Energy Efficiency and Conservation Authority, 2019).

As illustrated in Figure 1, the use of showers and taps make up approximately 50% of water use in Western countries.

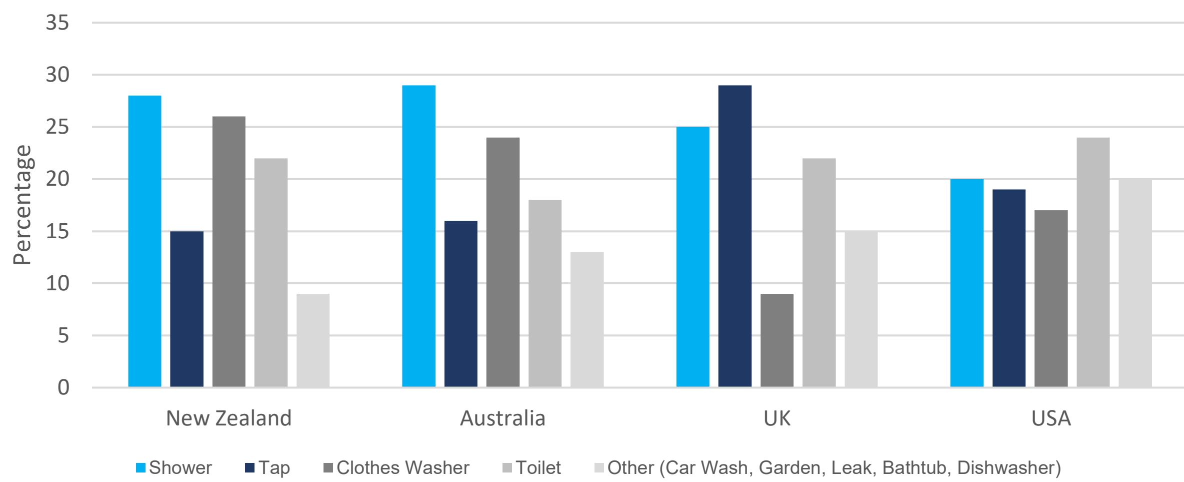

Figure 1 Water use by micro-component
(Butler & Memon, 2006; European Environment Agency, 2012; Henrich, 2009; Roberts, 2005)

A number of producers of shower and tapware products have conducted environmental evaluations of their products (Institut Bauen und Umwelt e.V, 2011), and some have attempted to reduce their environmental footprints by designing products with reduced water flows (Adeyeye, She, & Baïri, 2017). However, depending on the behaviour of users, this reduced water flow could have little impact on reducing energy, and the related HCE, in the use phase of the shower or tapware product (Gauley & Koeller, 2017; Horrell, Shekar, & McLaren, 2020). Users can require an optimal amount of water to complete washing and will simply wash for longer if the water flow is restricted. An alternative eco-design approach, based on life cycle thinking, is to extend the product system to include consideration of the other systems that it interacts with (van Hemel, Hemel, & Delft, 1998). This is known as a ‘re-think’ eco-design strategy (Charter & Chick, 1997) that proposes stepwise environmental improvements can be made.

In applying ‘re-think’ to shower and tapware products, designers and engineers would look beyond efficiency at the point of delivery of water and consider management of the incoming and outgoing water. The approach includes the design of and interaction between sub-systems; for example, how is water being filtered, pumped, heated, consumed, and then discarded. This provides engineers and designers with an opportunity to ‘rethink’ the entire system and create and implement new ideas to improve its overall environmental performance.

Three types of alternative water management systems have been developed and commercialised: (1) passive heat recovery, (2) active heat recovery and (3) recirculation. Examples have been provided in Table 1.

Table 1 Eco-shower systems examples

Name	**Category / Type**	**Reference**
HeatBack	Passive Heat Recovery	HeatBack (2016)
EcoPlus Hot Water Heat Pump System	Active Heat Recovery	Rheem (2020)
Orbital System	Recirculation	Orbsys (2020)
EcoVea	Recirculation	Reveeco (2011)
Pontos Aqua Cycle 2500	Recirculation	Hansgrohe (2020)

Passive heat recovery systems are a device that transfers the outgoing hot wastewater heat of a shower to the incoming fresh. The common method for achieving this is through separating the hot and cold water by a material that has a high thermal conductivity (i.e. copper). Generally, the maximum amount of energy that can be recovered is the difference between the energy of the hot water and the energy of the cold. If the ambient temperature of the cold water is 20°C and a user has a shower at 40°C, then the maximum energy the system can recover will be based on an equilibrium temperature of 30°C. A disadvantage of the system is that it is difficult to clean the waste cavity or pipes used in thermal transfer. As biofilm and other waste build up around the pipe, the thermal conductivity decreases resulting in a decrease in system performance (Hua, 2005). However, while difficult to maintain, they are relatively easy to construct and install (Timea, Rusu, & Dan, 2010).

Active heat recovery systems improve on the efficiency of heating the incoming fresh water. They commonly replace electric or gas water heating systems for the entire home. The system works by drawing in ambient heat from the air and absorbing it using a refrigerant inside an evaporator coil while cooled, dehumidified air is exhausted. The heated refrigerant is then pumped through a compressor that further increases the temperature. A copper condenser coil transfers the heat from the refrigerant to fresh cold water (as with the passive heat recovery system). Under favourable conditions (such as warm ambient air) this method can save up to 70% of the energy required for a shower (Clark & Williamson, 2001). Compared with passive heat recovery systems, they require approximately the same time and effort to install; however, the parts required to construct and assemble these systems are much more expensive to manufacture compared to that of passive heat recovery systems.

Recirculation systems focus on recovering the hot water that would normally be lost down the drain and transferring it back to the user to be reused. The technology includes processes for cleaning the water and managing any heat losses. Some systems claim to save up to 80% of energy required for a shower (Orbsys, 2020; Reveeco, 2011). Such systems are much less common than passive and active heat recovery and this could explain why very little information exists on the technology. Since recirculation systems are based on recovery and reuse of both water and energy, they have the potential to significantly outperform heat recovery systems in most situations. However, unlike heat recovery systems, recirculation systems include reuse of wastewater which can contain contaminants harmful to humans (Harris, Hoffman, & Mazac, 2001). Indeed, one of the more popular commercial recirculation systems states that the water recirculated is not safe for users to ingest while showering (Orbsys, 2019). The technological solution to this problem is to filter the water prior to recirculating it, and there are several alternative filtering systems and recovery processes (i.e. detecting and discarding very dirty water or recirculation of all water) in existence. These different technologies can have a big impact on the efficiency and, ultimately, the overall energy recovery performance of the system.

Recirculation systems are a promising approach to improving the life cycle-based impacts of showers. However, there are many challenges manufacturers may face when developing them. Firstly, there is significant inherent risk in prototyping these solutions due to potential health risks associated with recirculating wastewater (due to bacteria and viruses) – both for the company's development team and test subjects. Traditional shower systems have not had to consider this aspect during development of new products as wastewater is always outside the scope. Secondly, there is a lack of empirical data on what designs, or combination of key components (such as filters) yield the greatest environmental improvements. Therefore, at the early stages of development (idea generation, idea selection) it is difficult to identify and evaluate what designs or components should be prototyped and tested, potentially slowing development or wasting time testing undesirable solutions. Lastly, it is unclear what competences are required by a company when developing these types of solutions. Since recirculation systems may fall under a different industry domain (i.e. wastewater filtration, or fresh water supply), the required skills and knowledge to develop these types of systems may not be available in a company whose focus is developing shower and/or tapware products.

Comparing the different systems-based approaches suggests that recirculation systems require additional research to better understand and address the challenges associated with design of recirculation systems as faced by shower and tapware manufacturers.

A case study was undertaken to investigate these challenges. The case company is a leading New Zealand based shower and tapware manufacturer with approximately 300 employees. The researcher was embedded in the research and development (R&D) team and worked collaboratively in a new technology project to perform a detailed technical investigation of a proposed recirculation technology. This work is part of a larger study where the overall methodology is based on action research (Halecker, 2015).

The case company has had experience developing heat recovery systems but does not have a commercial solution available to customers. At the time of the study, the R&D team had little knowledge of recirculation systems and had never designed, prototyped or tested such a system; the purpose of their project was to determine the technology feasibility of recirculation systems. This case study research required identification and mitigation of risks during prototyping and testing while obtaining adequate information (i.e. from experimental trials) that could be used to inform future commercial solutions in this area. This research also aimed to identify what development internal capabilities would be required to prototype and potentially commercialise a recirculation system.

2.0 Method

The method had two stages: (1) design and construction of a recirculation system and (2) user performance modelling.

This required the construction of two different test systems. The first system was a recirculation system. Instead of testing with users, a simulated shower was trialled that allowed gathering of data on how the system performs under different conditions. For validity the data representing these conditions would require human occupants, but the R&D team considered the health risks associated with recirculating dirty shower water too high to perform actual user trials. Therefore, a system was constructed for the purposes of gathering data on turbidity of the used shower water only. The second system collected test data from user experimental trials that measured and recorded how users shower (i.e. washing, not washing, duration in shower, temperature). The data from both systems was then combined to provide a theoretical understanding of how the system would perform under realistic conditions.

2.1 Stage 1 – design and construction of recirculation system

The R&D team followed an informal process for developing the recirculation system. It started with a simple patent search to understand the fundamentals of the system and to develop a basic understanding of how best to recirculate the water in a shower. As the team lacked expertise and knowledge in filtration of shower water, they decided to partner with an engineering firm with experience in water catchment, filtration and recirculation systems. This enabled them to address knowledge gaps and provided vital information that led to an awareness of the aspects of shower water filtration systems that would need to be addressed. It was realised that maintenance of the filtration components could be significant as it could affect the life of the system (and potentially the environmental performance), depending on how often the different parts would require cleaning or replacing.

This ultimately led to the final prototype design illustrated in Figure 1.

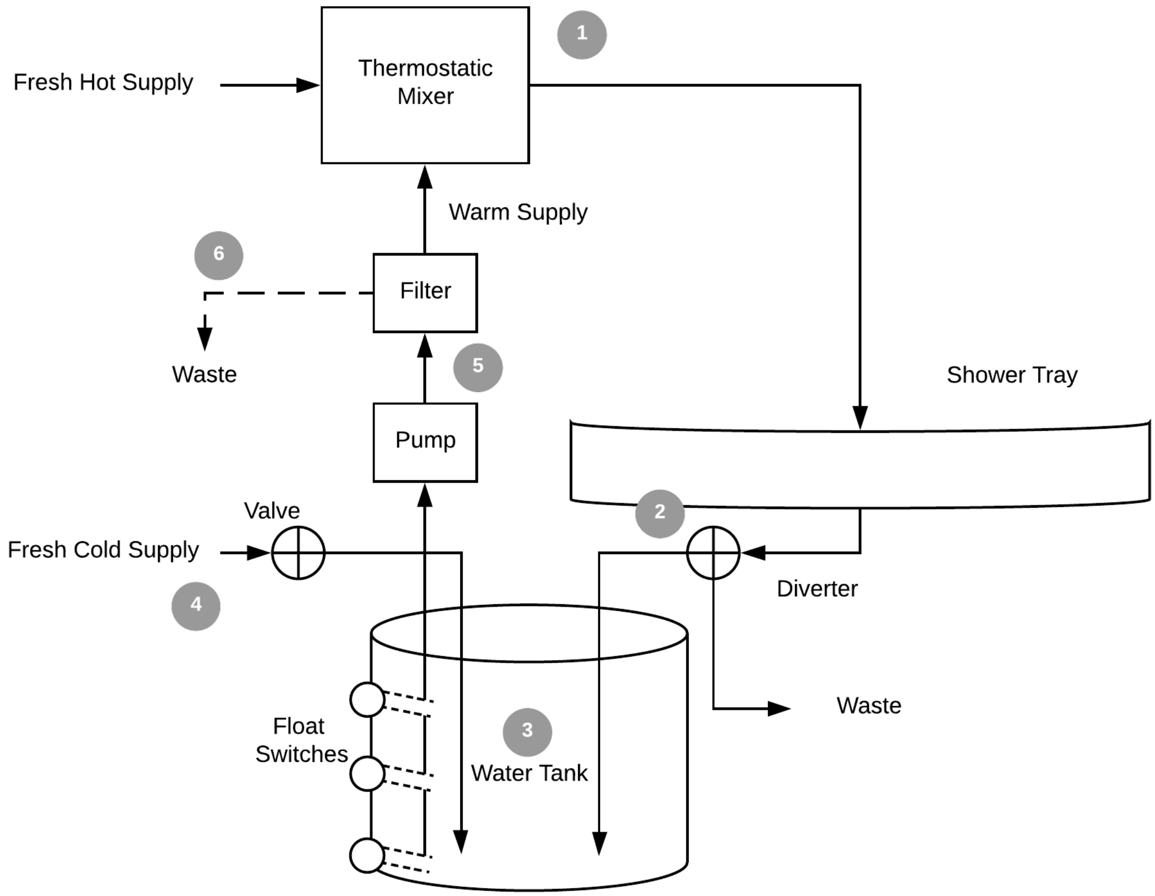

Figure 2 Recirculation Shower System

The process follows six stages in a semi-closed loop system. At the mixer (1), the incoming fresh hot supply (i.e. from a water heater) and recirculated water is managed by a thermostatic mixer that maintains a predefined temperature. This is flow restricted at 10 litres per minute. The water is directed to a showerhead, and the water is subsequently caught by the shower tray. A sensor detects the water turbidity and switches a valve to divert the dirty water to waste (2). If clean water is detected, it is sent to the water tank. The water tank (3) acts as the system's cold-water supply and also as a buffer to prevent the system stalling should there be a lack of diverted waste shower water. The water level in the water tank is maintained by a series of electronic float switches. If the diverted water falls below a critical level, fresh cold water is delivered to increase the buffer (4). If the buffer tank is full, the diverter (3) begins sending all shower water to waste.

A domestic household water pump (5) delivers the recirculated water from the buffer tank through an Ultrafiltration (UF) membrane filter in a crossflow configuration (6). Solids are continually flushed from the membrane surface using some of the recirculated water, which then goes to waste. The crossflow was flow restricted at 0.5 litres per minute. The filtered recirculated shower water is delivered back to the mixer (1). All electronic switches, sensors, and motorized valves are managed by a microcontroller.

Several temperature sensors and flow meters were connected to the system at various points that allowed measurement of the energy and water recovery performance. The microcontroller reports these measurements every second on an output window. A showering event was simulated by running the mixer at a fixed temperature. The system was trialled at 35ºC and 40ºC, both at a flow rate of 10 litres per minute. The system can have two stable states depending on where the water is being diverted. The first stage is where shower water has been diverted consistently to fill the buffer tank. The second state all shower water is discarded down the drain forcing the buffer storage tank to empty and causing the system to rely only on the fresh incoming water. In each trial, the diverter was alternated every 2.5 minutes to determine the length of time required for the recirculation flow and temperature to reach a stable state. This alternating process is repeated several times allowing an average performance to be determined for each trial.

The calculation used to determine energy used and recovered throughout the trial was:

Equation 1 Energy Storage in Heated Water

$$E = c_p \, dt \, m$$

where

E=energy (kJ)

cp=specific heat of water(4.2kJ/kg)

dt=change in temperature

m=mass of water (kg)

2.2 Stage 2 – user performance modelling.

Since a recirculation system typically recirculates the cleanest water, the way in which people shower (time spent washing vs not washing) will impact how much water can be recirculated. Monitoring the washing behaviours of users in the shower is possible via a turbidity sensor. The sensor applied in these trials was a thermometric TSD-10 turbidity sensor and positioned at the waste trap of a shower (Figure 2). It works by measuring light between a volume of water. As soap and other dirt particles in wastewater block light, it decreases the light that can be detected, indicating a decrease in water clarity.

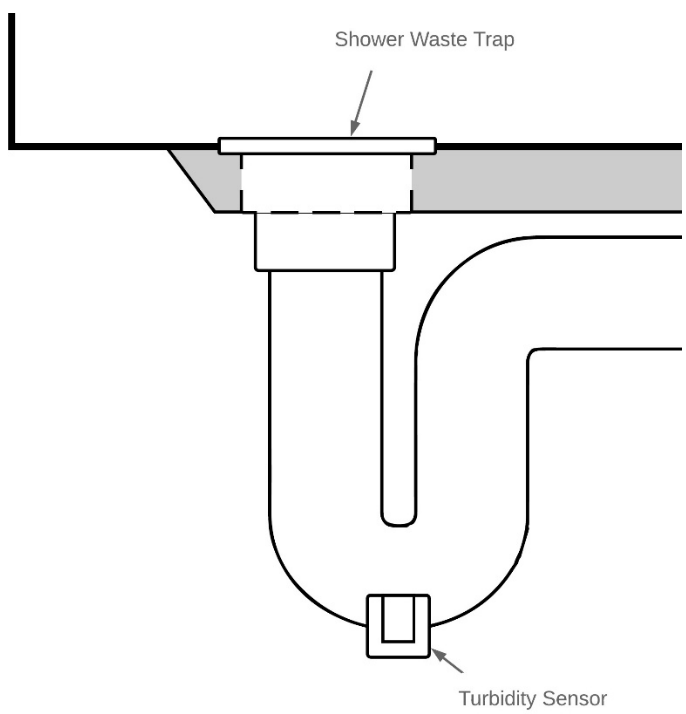

Figure 3 Shower Waste Trap

These sensors were connected to a datalogger unit that also recorded temperature, flowrate and duration.

The dataloggers were installed in four shower units to provide a range of different showering situations. The first two were in a domestic household with a low-pressure water system and the second two in a commercial office with a high-pressure water system. Figure 3 is an example of how existing shower systems were retrofitted with the required hardware All units recorded showering over a two-week period. In total, 25 shower events were recorded across all four shower units.

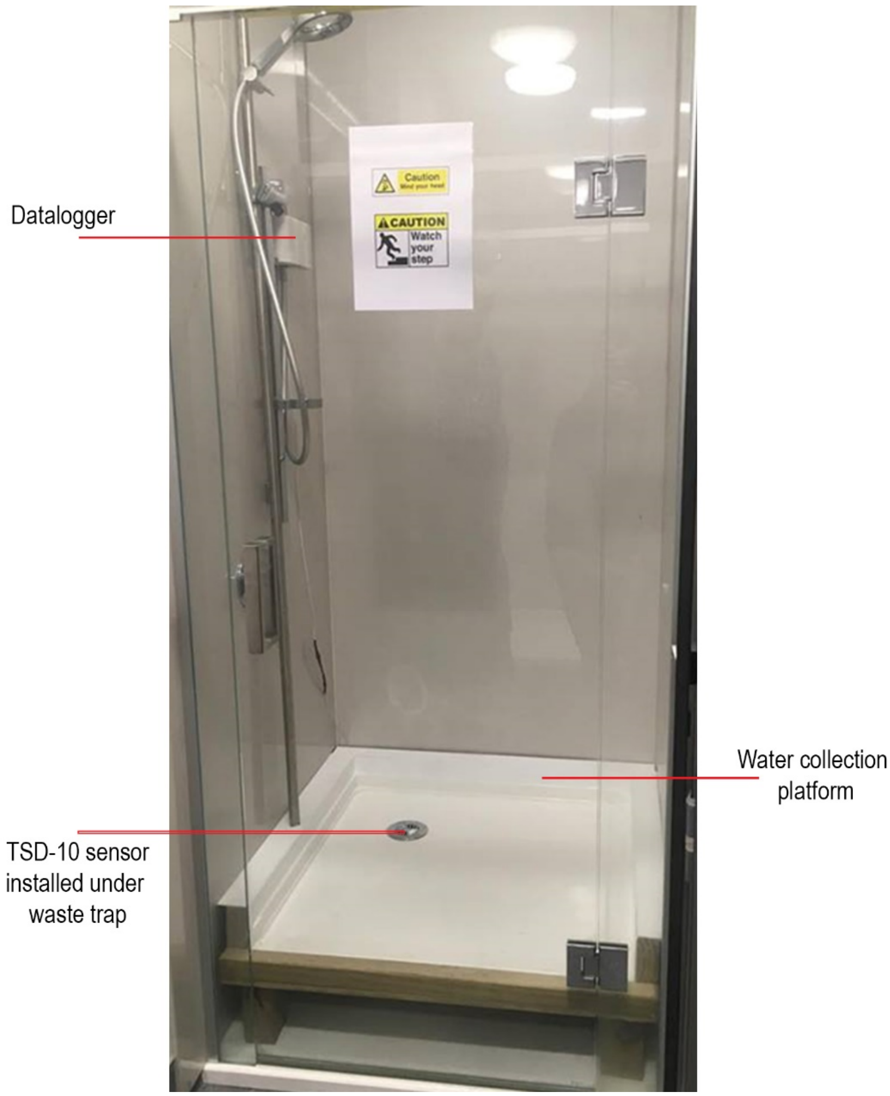

Figure 4 Typical example of turbidity sensor install

3.0 Results

Results are reported in three sections; the first reports on the results of the performance testing, the second provides the user modelling results and the last section combines the data from the first two to provide the theoretical performance scenarios.

3.1 Recirculation system

An example of the performance results from the trials are shown in Figure 5 at 9 litres (L) per minute for 8.3 minutes.

During performance testing, the cold-water temperature remained at 18 °C. The flow and temperature of the shower were successfully maintained by the thermostatic mixer while the temperature of the buffer tank slowly increased as the shower water was recirculated.

The heat losses of the system to the environment were 3.5ºC for the 35ºC shower trial and 7.5ºC for the 40ºC shower trial. These losses were presumed to be through water droplets and air (from shower head to shower platform), pipes, hoses and the casing of the membrane filter (as these were not insulated).

Figure 4 shows that in the first trial, the buffer tank reaches a stable state at 208 seconds. At this point in time, the diverting valve activated, and the quantity of water in the buffer tank began to decrease. When it reached a critically low point (at 271 seconds), it was topped up with cold water and the buffer tank temperature began to drop.

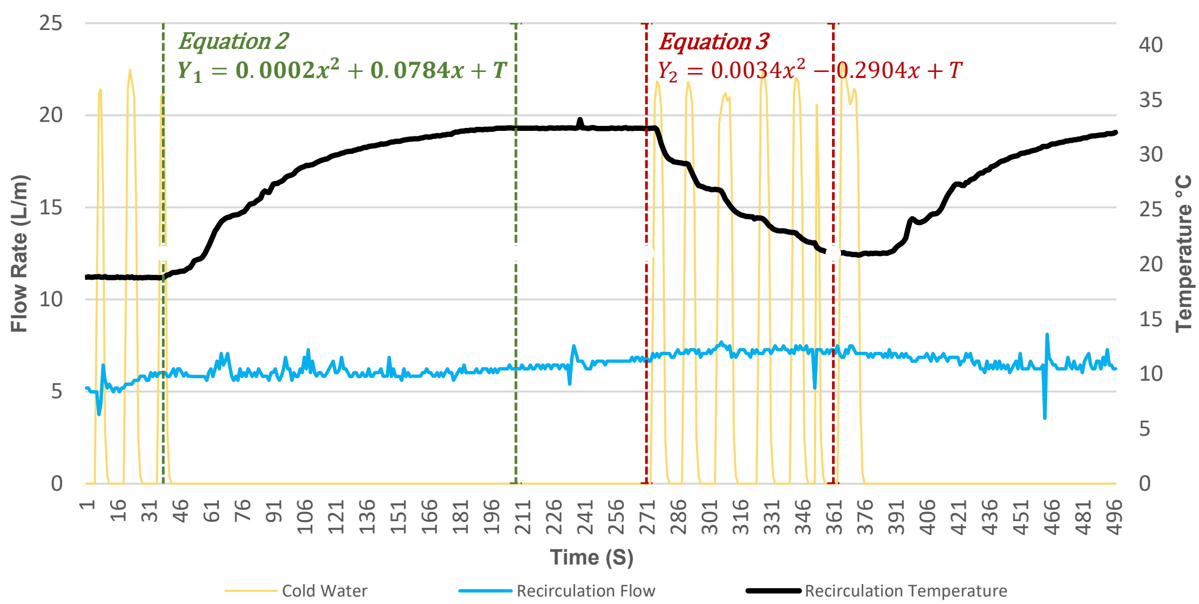

Figure 5 Simulated Shower at 40 ºC at 9 L / min

The simulated shower trial provides the temperature change of the buffer tank when it is increasing:

Equation 2 Temperature Increase Trial 1

$$Y_1 = 0.0002x^2 + 0.0784x + T$$

and when it is decreasing:

Equation 3 Temperature Decrease Trial 1

$$Y_2 = 0.0034x^2 - 0.2904x + T$$

$$x = time\ index$$

$$T = tank\ temperature\ at\ initial\ change$$

The same process was applied to the 35ºC trial. This led to the following equations:

Equation 4 Increase in Temperature Trial 2

$$Y_1 = 0.0008x^2 + 0.2015x + T$$

Equation 5 Decrease in Temperature Trial 2

$$Y_2 = 0.001x^2 - 0.2098x + T$$

The trial also provided information on how the long buffer tank lasts under these conditions before cold water is added. For the 35ºC trial, the tank can provide warm recirculated water to the shower continuously for 92 seconds (at an average of 6.45 litres per minute). Under the 40ºC trial it can run continuously for 76 seconds (at an average of 7.84 litres per minute). During the 40ºC trial, the recirculated shower water system was able to fill the buffer tank beyond its operating limits; as a result, approximately half of the shower water that could have been recirculated during this time was instead diverted to waste.

Equation 1 was applied to the output results to find the energy required to heat a mass of water. The equation is applied for every data entry (every second) of water that was recirculated, and water that exits the shower handset. These results are totalled for both recirculated energy and shower energy. The difference is the performance of the system (E_{total}).

Equation 6 Energy Total

$$E = c_p \, dt \, m$$

$$E_{shower} = \frac{4.2kJ}{kg}(T_{shower} - T_{cold})\, m$$

$$E_{recirc} = \frac{4.2kJ}{kg}(T_{recirc} - T_{cold})\, m$$

$$E_{total} = E_{shower} - E_{recirc}$$

As an example of its use, for the 40ºC trial 4.4MJ is required to heat the shower water from time 37 to 361 seconds. Under this recirculation scenario the energy saved could be as high as 2.0MJ (45%) if the system recirculated continuously after reaching a stable state. However, this does not necessarily represent the best or worst performance of the system since the test scenario does not represent the different behaviours of the user (washing vs not washing) that could impact the system.

3.2 User modelling

Of the 25 showering events recorded, 4 were selected to represent different washing scenarios (two from each of the high and lower water pressure systems). This selection was done by first grouping common showering patterns (time of day, length of shower) to represent a single user for each group. The second part of selection visually compared these groups of shower events and identified obvious differences in showering behaviour or patterns between each event. However, as all these showering units are used by more than one person, the differences could be due to individuals showering differently, or an individual showering differently each day. A single shower event has been selected from each group to represent a different scenario (i.e. a showering pattern).

A high-resolution graph of a selected shower event is provided for each shower group (Figure 4 to Figure 7). For this analysis, water turbidity values between 10 and 0 represents clarity of water (0 clear, 10 unclear dirty water). A moving average has been added to the turbidity line plot to reduce noise for easy of reading. Due to the programming and mechanics of the turbidity sensor it is only able to reliably measure once water begins passing over it. When a shower begins, it takes approximately 2-3 seconds before this occurs. Therefore, turbidly data at the beginning of each shower were ignored in all calculations.

The first scenario (Figure 6) illustrates the participant showered for approximately 8 minutes at 40 °C. They spend the beginning of their shower washing. It appears they lowered the temperature of their shower during rinsing, then increased it for the rest of the duration of their shower. Half their shower duration is spent washing.

The second scenario (Figure 7) the participant showers for approximately 10 minutes. They shower at a lower temperature than the first scenario (36 °C). There appear to be at least two distinct washing events where the turbidity has peaked.

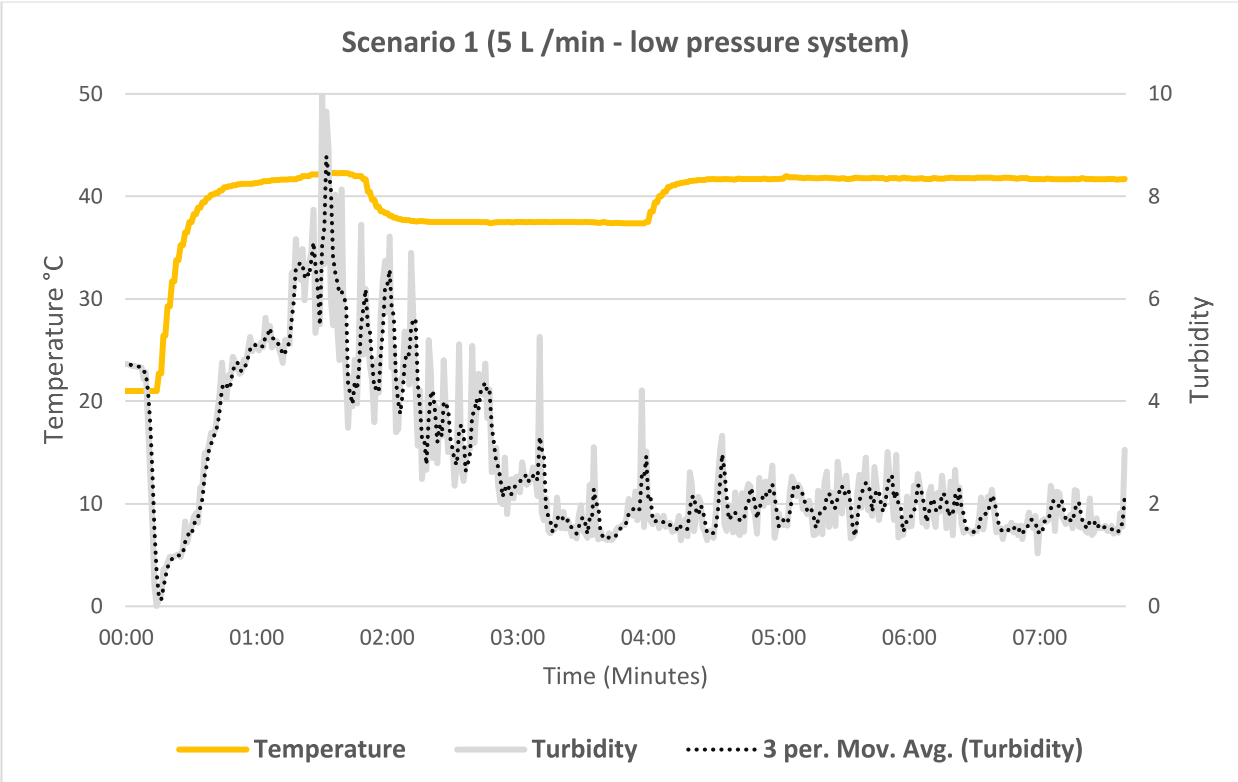

Figure 6 Shower Use Scenario 1

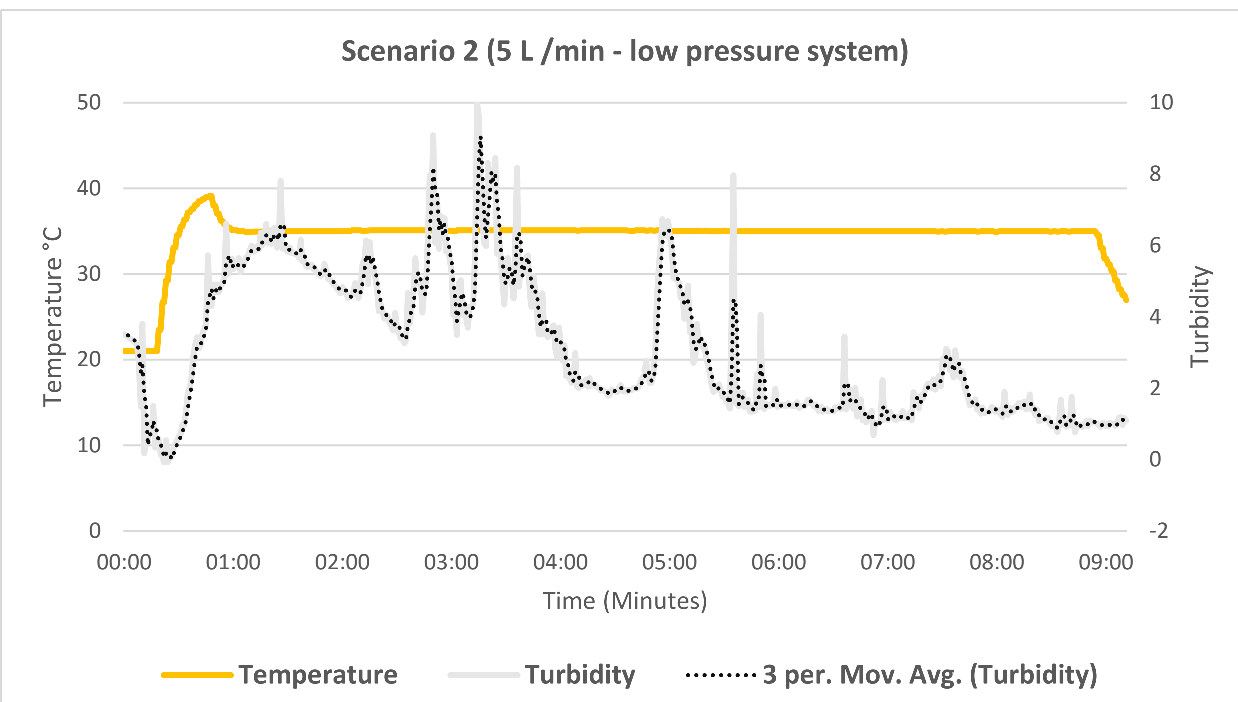

Figure 7 Shower Use Scenario 2

The participant in Scenario 3 (Figure 8) showers for approximately 12 minutes and appears to have at least 4 short washing events throughout their shower. Their average shower temperature is 39 °C.

The last scenario (Figure 9) the participant has a shower for approximately 7 minutes at a temperature of 36°C. There are two distinct washing events closer to the middle of the shower suggesting the person spent almost 3 minutes in the shower before washing.

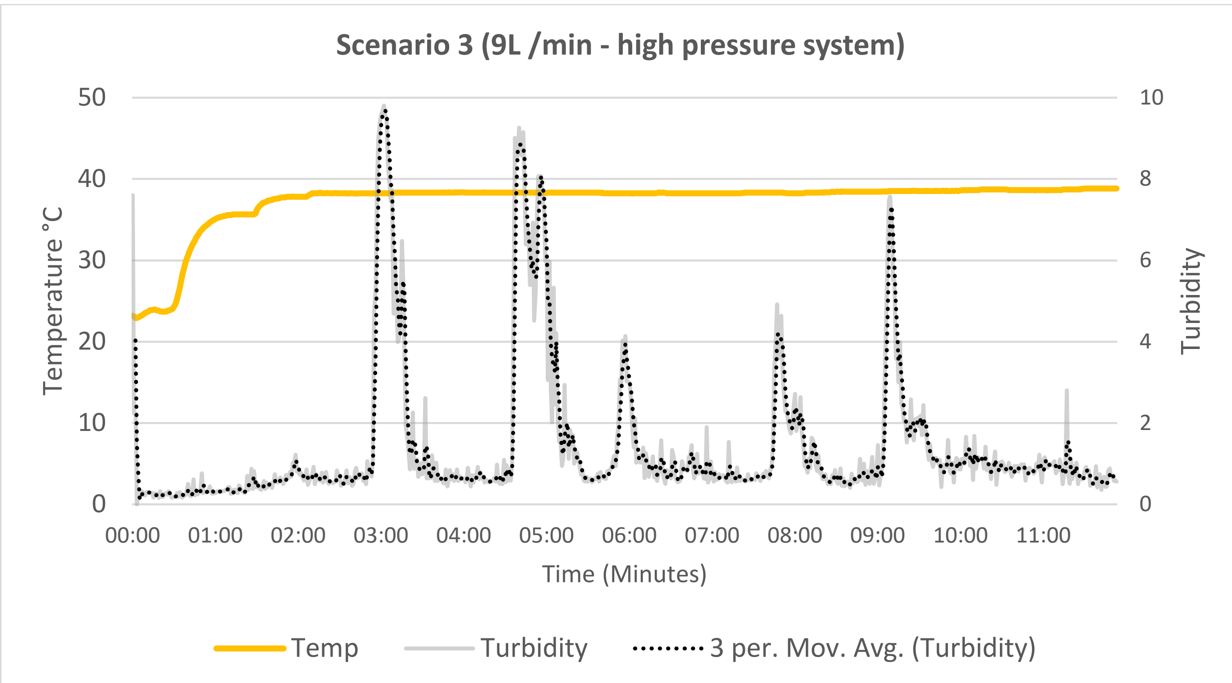

Figure 8 Shower Use Scenario 3

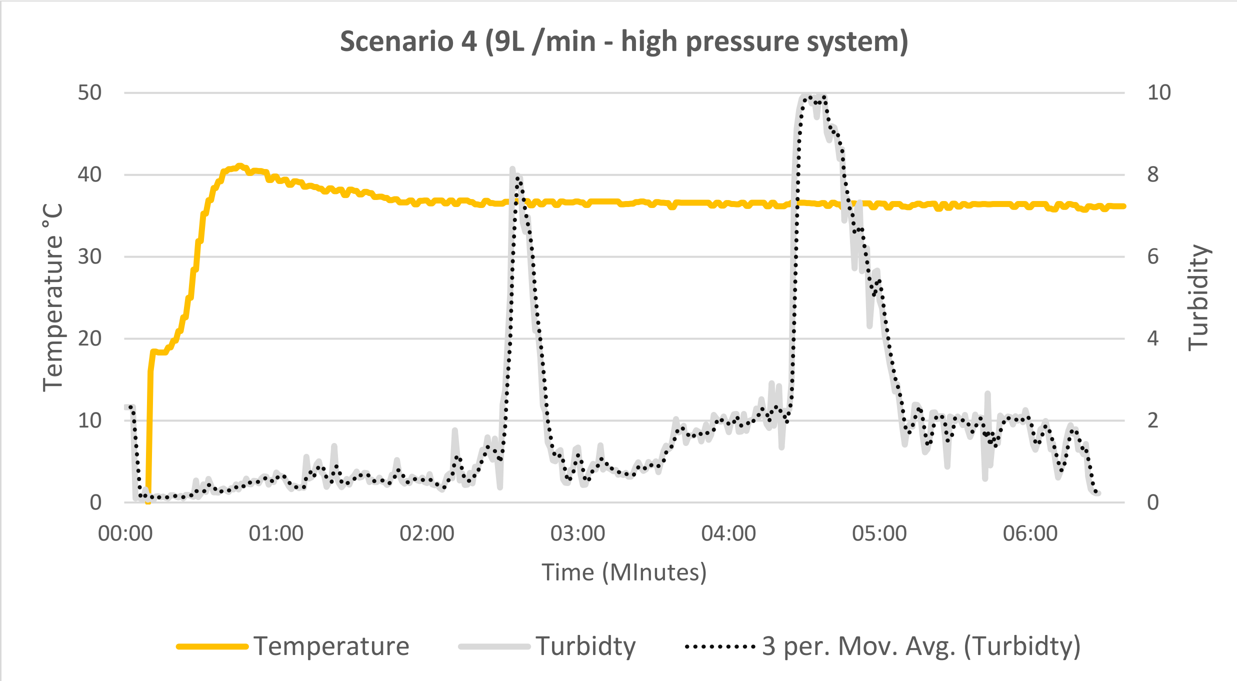

Figure 9 Shower Use Scenario 4

3.3 Use scenarios

The equations in section 3.1 describe how the system performs under standard operating conditions. However, the user trials (section 3.2) demonstrate that there are a range of operating conditions. Due to the turbidity spikes, it is possible to model when a person is washing or not washing. Combining this with the equations in section 3.1, it is possible to model how the system would perform under the different conditions. This is accomplished by applying the same energy calculation process in section 3.1 where temperature values are substituted for those in the use scenarios. To determine how the energy savings should be calculated, the study assumes if the participant is washing (or rinsing), the system is not recirculating water, otherwise shower water is recirculated back to the participant.

Equation 2 and Equation 3 are applied to shower scenarios that operate at close to 40 ºC (Scenarios 1 and 3) while Equation 4 and Equation 5 are applied to scenarios that operate close to 35 ºC (Scenarios 2 and 4).

A theory-based energy calculation explains how the system performs under these scenarios. The results are provided in Table 1. Under these different scenarios the system could recover as high as 51% and as low as 18% energy of a shower (the calculated performance in Table 2).

Table 2 Theory-based use scenario performance results

Scenario	Equation	Total Energy (MJ)	Recovered Energy (MJ)	Performance Recovered (MJ)/Total (MJ)	Water (Litres)
1 - 5 L /min (40 ºC)	Equation 2 Equation 3	2.3	1.0	43%	32.3 (8.3 sent to waste)
2 - 5 L /min (35 ºC)	Equation 4 Equation 5	2.2	0.4	18%	43.1 (19.7 sent to waste)
3 - 9L /min (40 ºC)	Equation 2 Equation 3	5.3	2.7	51%	91.3 (20.1 sent to waste)
4 - 9L /min (35 ºC)	Equation 4 Equation 5	4.2	1.9	45%	58.3 (16.6 sent to waste)

4.0 Discussion

Two general topics are addressed in this section: the results of the experimental trials, and the insights related to prototyping and testing of eco-shower systems.

Experimental trials

The results demonstrate that different shower scenarios will impact the performance of the system. This is due to the behaviour of users while showering (washing vs not washing) and the system's inability to accommodate different extremes.

Firstly, as noted in the performance trial, half of the water that could be recirculated was instead diverted to waste. This is because the buffer tank reached its operating limit. This occurs when the flow of recirculating warm water entering the tank exceeds the flow of recirculated water being sent to the mixer. In this situation, any additional water that could have been recovered is instead diverted to waste. This is most evident in scenarios 2 and 3, where the participant spends more time under the shower not washing than washing. The buffer tank water is only drained completely when dirty water has been detected in the system for a sustained duration. The implication is that the size of the buffer tank should be increased for users who spend relatively more time not washing than washing in the shower. However, it should also be noted that this will only be beneficial if some sustained washing occurs at the end of the shower. If not, a full buffer tank would never get used – any recovered warm water would be discarded at the end of the shower.

Secondly, the temperature at which the participant chooses to shower also contributes to changes in performance. Since the buffer tank must start cold, the cooler the shower temperature the longer it takes for the buffer tank to reach a stable temperature. Therefore, more mains heated water is required at the mixer. This is one of the reasons why scenario 4 performs worse than scenario 3. Scenario 2 is an extreme of this state of operation. Since the flowrate is significantly lower than scenario 4, the buffer tank only ever achieves a slight increase in temperature. The implication of this is a smaller buffer tank is best (as it would reach its optimal temperature sooner). However, this finding conflicts with the first finding where the buffer tank is not able to accommodate the users who spend less time washing.

Lastly, the behaviour of participant 3 provides the best performance of the scenarios. Since they spent shorter durations washing or not washing, the buffer tank was often at its optimum temperature and water volume.

Prototyping and testing

It was found that collaboration with other companies was necessary during development of the prototype recirculation system as the case company and R&D team lacked the internal expertise in filtration technology required for the recirculation system. Filtration is one of the most important sub-systems for recirculation systems since it is intended to remove biological hazards for the users. Had the project not called on the expertise of external R&D, internal development would have required more time and resource to achieve the same result (assuming it was achievable at all).

Secondly, the results of the study demonstrated that the behaviour of users has a significant impact on the performance of the system. The size of the buffer tank limited the system's performance in some situations and improved it in other situations. It is reasonable to conclude that the best solution is one where the recirculation systems are flexible and can adapt to the different showering behaviours of users. For example, the buffer tank could be designed to vary in size based on what the user is doing throughout the shower.

Lastly, the method for prototyping and testing of the system meant that the participants were not exposed to potential biological hazards associated with recirculation of wastewater during the experiments. Instead, the R&D team simulated the performance of the recirculation system by quantifying the amount of water coming out of the shower that was clean enough to be recirculated or that was too dirty and had to go to waste. Using this approach, the team also avoided the additional resources required for quality testing the water but, at the same time, gained enough information to decide if the system and its design was worth pursuing.

5.0 Conclusions

This study has demonstrated it is possible to avoid the inherent human health risks associated with prototyping recirculation systems while still obtaining enough information to determine the system performance of the proposed design. To accomplish this, designers and engineers should identify ways of modelling user behaviour that can be applied to recirculation shower performance models tests. However, it would still be necessary to determine how effective the recirculation system is at removing bacteria and viruses by recirculating dirty shower water from a participant. This is beyond the scope of this study.

By combining the information of both trials (performance testing and user scenario modelling) it was possible to identify specific system components (and combination thereof) that had significant impact on the systems (such as the buffer system). Thus, it informed designers and engineers what improvements to focus on in the next iteration of the system.

The development process highlighted the technical capabilities required to develop recirculation systems (such as knowledge and implementation of water filtration technologies and integrated mechatronic systems). In addition, the development team must have the ability to safely undertake experimental trials with potential users of the system. This can allow the team to better understand user behaviour, and design flexible and smart systems to accommodate the insights gained.

One of the obvious limitations of the study was the small number of participants. The user modelling experiments are highly unlikely to represent all possible scenarios across different regions or countries. The study could be repeated with a wider cross-section of a population that could identify representative sets of temperature, flowrates and washing behaviours, and these could be used to better inform R&D efforts.

Acknowledgements

This research was funded and supported by Callaghan Innovation [grant number MTVN1503] and the Dick and Mary Early Scholarship in Technology.

References

Adeyeye, K., She, K., & Baïri, A. (2017). Design factors and functionality matching in sustainability products: A study of eco-showerheads. *Journal of Cleaner Production, 142*(Part 4), 4214-4229. doi: 10.1016/j.jclepro.2016.11.143

Beal, C., Bertone, E., & Stewart, R. (2012). Evaluating the energy and carbon reductions resulting from resource-efficient household stock. *Energy and Buildings, 55*, 422-432. doi: https://doi.org/10.1016/j.enbuild.2012.08.004

Beal, C., Stewart, R. A., Huang, T., & Rey, E. (2011). SEQ residential end use study. *Journal of the Australian Water Association, 38*(1), 80-84.

Butler, D., & Memon, F. A. (2006). Water consumption trends and demand forecasting techniques. In D. Butler & F. A. Memon (Eds.), *Water demand management* (pp. 1-26): London : IWA Publishing, 2005.

Camilleri, M., French, L., Pollard, A., Saville-Smith, K., Faser, R., Rossouw, P., & Jowlett, J. (2006). Energy Use in New Zealand Households.

Charter, M., & Chick, A. (1997). The Journal of Sustainable Product Design - Editorial. (1), 5-6.

Clark, S., & Williamson, A. (2001). Domestic Hot Water Options and Solutions. Christchurch, New Zealand: University of Canterbury.

European Environment Agency. (2012). Energy efficiency and energy consumption in the household sector. Denmark.

Gauley, B., & Koeller, J. (2017). Shower-Based Water Savings Flow Rate vs. Duration vs.Volume: MaP.

Halecker, B. (2015). Action case study - A research strategy based on abduction for relevant and rigorous management research. *International Journal of Business Research, 15*(4), 23-32.

Hansgrohe. (2020). Pontos AquaCycle 2500 Brochure. Germany.

Harris, Hoffman, & Mazac. (2001). Reducing Contamination by Improving Household Wastewater Treatment: Blackland Research Centre Water Sciences.

HeatBack. (2016). Heatback. from http://www.heatback.co.nz/the-product

Henrich, M. (2009). *Water End-use Efficiency Project (WEEP) - A Case Study*. Paper presented at the SB07 NZ Conference: Transforming our Built Environment, Auckland, New Zealand.

Horrell, M., Shekar, A., & McLaren, S. (2020). USE OF DESIGN OF EXPERIMENTS TO OPTIMISE THE ENVIRONMENTAL PERFORMANCE OF CONSUMER PRODUCTS: A CASE STUDY OF SHOWERS AND TAPWARE IN NEW ZEALAND. *Proceedings of the Design Society: DESIGN Conference, 1*, 1911-1920. doi: 10.1017/dsd.2020.269

Hua, L. (2005). *Heat exchanger development for waste water heat recovery.* (Master of Mechanical Engineering), University of Canterbury, Christchurch, New Zealand.

Institut Bauen und Umwelt e.V. (2011). Environmental Product Declaration as per ISO 14025 for hand showers Croma 100 and Crometta 85. Panoramastraße, Berlin.

Lu, T. (2007). *Research of domestic water consumption: a field study in Harbin, China.* (Master of Science), Loughborough University, United Kingdom.

McGee, C. (2013). Your Home - Energy. from http://www.yourhome.gov.au/

Nakagami, H., Murakoshi, C., & Iwafune, Y. (2008). *International Comparison of Household Energy Consumption and Its Indicator*.

NERI. (2006). Energy Used in NZ Homes. from http://www.physics.otago.ac.nz/eman/hew/ehome/energyuse.html#

Orbsys. (2019). Orbital Systems Operator Manual.

Orbsys. (2020). Orbital Systems Website.
Reveeco. (2011). Ecovea Technology. from http://www.reveeco.com/technology.html
Rheem. (2020). EcoPlus Hot Water Heat Pump System. from https://rheem.co.nz/products/home/heat-pump-water-heating/ecoplus-hot-water-heat-pump-system
Roberts, P. (2005). *Yarra Valley Water: 2004 residential end use measurement study*: Yarra Valley Water Melbourne, Australia.
The Energy Efficiency and Conservation Authority. (2019). Hot water systems. from https://www.eeca.govt.nz/standards-ratings-and-labels/equipment-energy-efficiency-programme/products-under-the-e3-programme/measures-under-consideration/hot-water-systems/
Timea, G., Rusu, T., & Dan, V. (2010). Technological Variations for Domestic Waste Water Heat Recovery. *ProEnvironment Promediu, 3*(6), 313.
van Hemel, C. G., Hemel, v., & Delft, T. U. (1998). *EcoDesign Empirically Explored: Design for Environment in Dutch Small and Medium-sized Enterprises*: Boekhandel MilieuBoek.
Wong, L.-t., Mui, K.-w., & Zhou, Y. (2017). Carbon Dioxide Reduction Targets of Hot Water Showers for People in Hong Kong. *Water, 9*(8), 576.

Appendix C

The use of LCA in early design to optimise the environmental performance of active product systems

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Abstract

Manufacturers looking to reduce the environmental impacts of their products can apply state-of-the art environmental assessment tools, such as Life Cycle Assessment (LCA), to assist design engineers in decision support. However, LCA is often thought to be unsuitable for use early in the design process due to the limited information available about the product at that stage. A case study was undertaken to investigate the application of LCA early in the design of a shower system. The study followed the early development and optimisation of the shower system and all related sub-systems (such as filtration systems and management of the incoming and outgoing water and energy). The results demonstrated that LCA can provide robust results and reliable decision support even when there is limited data available. The manufacture and maintenance of the additional subsystems required to recirculate wastewater were found to be insignificant across most environmental impact categories when compared with the energy required to heat water over the life of the system - which dominated the life cycle-based impacts for all the water recovery systems modelled. Furthermore, it was found necessary to include human-centred behavioral factors in the assessment – and it is likely that this will be an important consideration for studies of other active product systems. Overall, it was found that use of LCA early in the design process is, in fact, possible and is pivotal in providing engineers with environmental information so that informed eco-design decisions can be made for active product systems.

1. Introduction

Life Cycle Assessment (LCA) has been used extensively to quantify the environmental profile of products. When applied correctly, it can support designers and engineers in manufacturing companies by providing detailed information on the environmental impacts of a product at different parts of its life cycle, supporting both improvements to existing products and driving the development of new sustainable products (Silva, 2012).

In product design, it can be helpful to distinguish between active and passive products (Hassi & Wever, 2010). An active product consumes something (often energy) in its use, while a passive product will typically not consume anything in its use (Jolliet, Saade-Sbeih, Shaked, Jolliet, & Crettaz, 2015). For an active product, often the use stage will dominate the life cycle-based environmental impacts associated with the product, and this is particularly true for active products with a high power demand and high frequency of use (such as kettles, hairdryers and showers) (WRAP, 2010). When considering how to improve the environmental performance of products with a dominate use phase, decisions made at the front-end of the development process can ultimately determine how the product will be used (for example, its frequency of use and power demand). However, there are very few environmental tools that systematically provide support for NPD practitioners at the front end of development (Boks & Wever, 2007; Hassi & Wever, 2010).

This study focuses on two challenges identified at the front end of development for active products: (1) use of LCA to support product development decisions, and (2) addressing user behaviour when modelling the use phase.

Firstly, product development decisions can be both strategic ‘Doing the Right NPD’ and operational ‘Doing NPD Right‘ (Anderson, 2008). ‘Doing the Right NPD’ often involves selecting projects from an idea or concept bank, based on strategic direction or the need to balance product portfolios (Cooper & Edgett, 2010). Criteria used in this selection process may include technical feasibility, company capability (and competency) and commercial opportunity. Manufacturers looking to reduce the environmental impacts will include environmental performance in their project selection criteria. Completing a stand-alone LCA may provide some insights for new product development, although more accurate quantification of the actual impacts will not be possible until the end of the project when more information is available.

'Doing NPD Right' may involve integration of decision support tools such as LCA into the NPD process. Integrating LCA in this way is often only useful when detailed information about the product is known i.e. at the later stages of the NPD process. But, at these later stages, the information on the product's environmental profile may not provide much decision support as the product is already largely developed. However, if LCA is used early in the NPD process, such studies can require considerably more effort than traditional measures used in decision making because the scope of decision-making is wider (Fitzgerald, Herrmann, Sandborn, & Schmidt, 2005). As an example, when selecting a material, usually the decision is based on quality or technical specifications (defined by customer wants and needs), traded off against other performance measures (often unit cost), at an early stage in the design process. But, there are often no simple trade-offs involved in evaluating the environmental performance of different materials. Alternative materials may have entirely different manufacturing processes, be required in different amounts, create different wastes, and have different end-of-life scenarios. To find out which is best, detailed data needs to be collected and modelled. Therefore, the use of LCA at the early stages of development often requires more assumptions in the modelling, and needs to be rechecked through additional modelling at later stages development when the design is finalised (Vezzoli, 2018).

The second challenge this study focuses on is related to LCA when user behaviour is a consideration. An emerging area in environmental product innovation is Design for Sustainable

Behaviour (DfSB). This focuses on how users interact with a product and the effect this has on its environmental footprint (Bhamra, Lilley, & Tang, 2011). This is important for active product LCA studies as it may decrease uncertainty in modelling of the use phase (Daae & Boks, 2015). For example, an LCA study on shower handsets assumed users spent only two minutes in the shower at a global average temperature of hot water supply in a home (50ºC) when modelling the use phase (Institut Bauen und Umwelt e.V, 2011). However, other studies have shown that users will vary the duration, temperature and flowrate when using different types of shower handsets (Adeyeye, She, & Baïri, 2017; Horrell, Shekar, & McLaren, 2020). If the use phase dominates this product, and secondary data (averages) or assumptions do not closely match the actual use profile it can cause significant error in the results.

The purpose of this study was to address these two challenges. This was done by undertaking an LCA of a shower recirculation system for a shower and tapware manufacturer in Auckland, New Zealand, at the front end of the product development process, and integrating behavioural data into the LCA scenarios to represents different use profiles.

2. LCA Methodology

2.1 Goal and Scope Definition

The goal of the LCA was to quantify the life cycle-based environmental impacts of showering using a standard shower and an alternative heat and/or water recovery shower system. This included the processing and supply of water to the domestic home and use of the shower system.

The functional unit for the study was a (hypothetical) New Zealand household of two people that each took a 5-minute shower every day at 40°C with a flow rate of 10 litres per minute over 10 years.

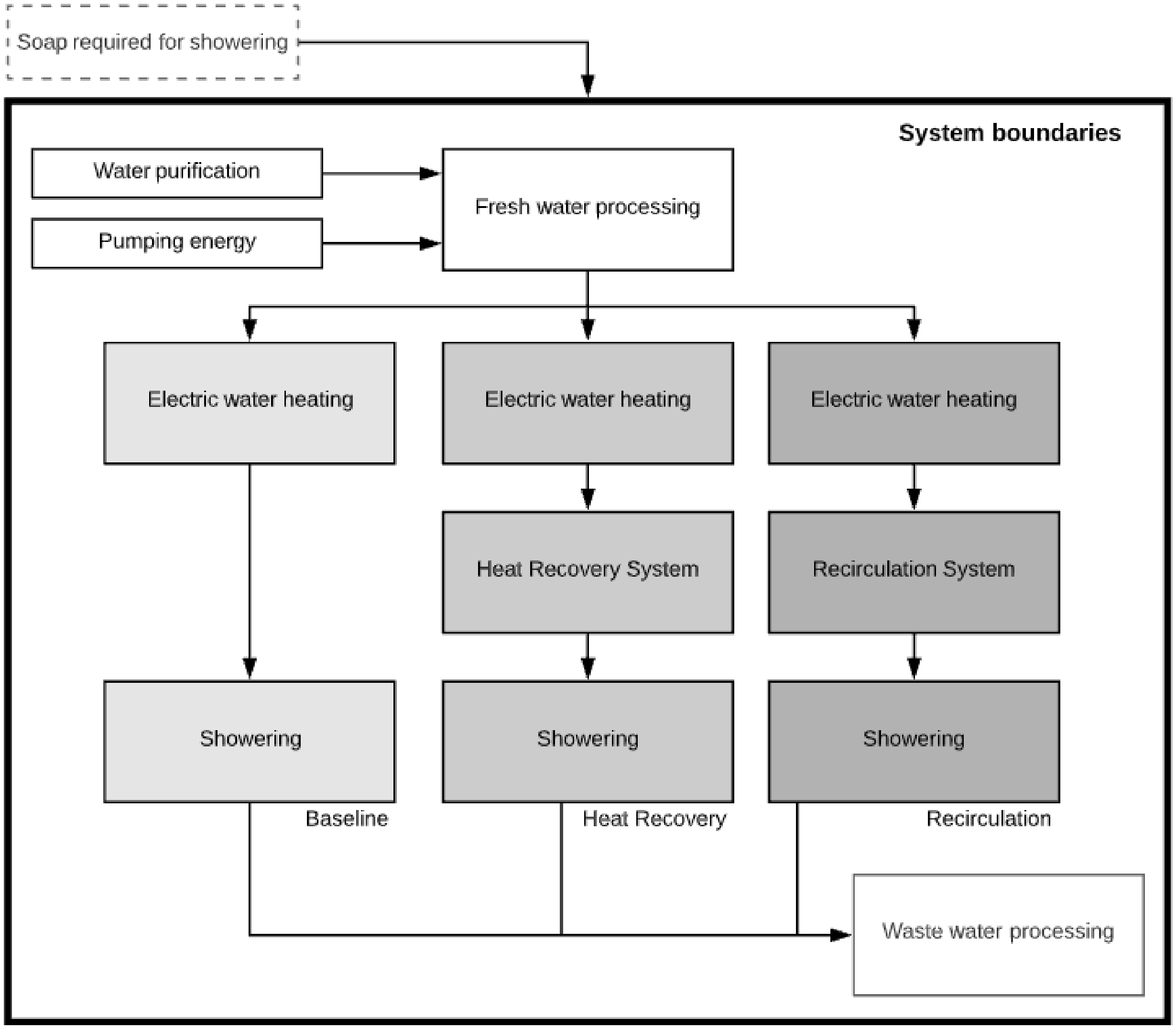


Figure 1 System boundaries

The system boundaries are illustrated in Figure 1. Environmental impacts associated with the manufacture and use of soap are assumed to remain the same across different scenarios. Energy and water required to treat and process fresh and wastewater are included as 'water processing' across all scenarios.

Gabi software was used to model the LCA and calculate the results. EF 1.8 was chosen as the impact assessment method as it includes relevant environmental impact categories. The selected environmental impact categories conform to the recommendations in the 'Product Category Rules for Building-Related Products and Services' (Institut Bauen und Umwelt e.V., 2014). The toxicity impact categories (human toxicity cancer, human toxicity non-cancer, and freshwater eco-toxicity) were omitted from the analysis due to lack of reliable data.

2.2 Inventory Analysis

Shower systems are defined as all the materials, components and products that are required to construct, maintain and deliver the function of showering for personal hygiene. The LCA compares the addition of two different types of recovery systems (as scenarios) with a baseline standard shower system. The manufacture of the parts for a standard shower system (shower pan, tiles, drain, shower head) is required for all scenarios and therefore adds nothing useful to the comparison. This data has, therefore, been omitted.

One type of recovery system is the heat recovery system. It is typical installed under a shower pan and is connected to the waste drain of a shower system. During showering, hot wastewater will enter the heat recovery product and some of the heat energy that would normally be lost to fresh cold-water mains through thermal conduction will be recovered. The data to model the heat recovery shower system was obtained from the case company R&D archives. The R&D team had completed numerous projects on heat recovery systems in the past where the final deliverable was a prototype system that was performance tested. The most recent report was used to quantify the materials and manufacturing process required to construct the system, and the energy savings associated with this system. The report details the exact quantities of copper used in the design. The construction consists of two copper plates that have been pressed with a custom die, and then welded together to create a freshwater cavity. This cavity is then placed at the base of the shower where hot wastewater will run over the copper allowing heat recovery to occur.

Several trials were presented in the report. These were all conducted in a R&D laboratory where the shower was simulated (i.e. there was no human occupant), therefore, other activities that may impact the results (i.e. washing with soap) are not represented in the report. In the simulated shower, the hot water passes over the copper cavity and a measuring device intermittently recorded both the hot- and cold-water temperature, hot- and cold-water flowrate and the duration of the shower.

The second type of recovery system is a recirculation system constructed with two major sub-systems and many additional interrelated components. The major sub-systems are the filter and water pump. The primary material in the construction of the filter is polycarbonate and it is surrounded by a PVC housing. These are connected to a separate water tank that provides a buffer between the water being recovered from the drain and the water being delivered to the occupant. While showering, when a sensor detects the wastewater is clean enough to be recirculated it sends this wastewater to the buffer water tank. If it is detected as too dirty, it is sent down the drain. All electronic switches, sensors and motors are managed by a microcontroller. Chemicals for cleaning of the recirculation system are included and it is assumed that an equal amount of biosolids are accumulated on the filter regardless of how much water or heat is consumed for an individual shower. The filtration system runs in a crossflow configuration, discarding 0.5 L/min to waste during the showering process. Based on the user maintenance manual of the filter and type of biosolids being filtered, it is assumed that a cleaning process (CIP) must run once per month to remove the biosolids. According to the user maintenance manual, the CIP tank must be large enough to fill and cycle 10 litres of 40°C water. The cleaning cycle must run for 45 minutes and repeat 3 times. Based on assumed heat losses and crossflow configuration losses, the total energy required for each cleaning cycle is 28.9 MJ. Pipes that are connected between the recirculation system and shower system have been excluded from the model based on lack of data.

The study assumes that both the Heat Recovery and Recirculation systems have a life of 10 years.

2.3 Conditions of use and calculation for energy recovery

Five different sets of results were calculated in the LCA to represent the base shower scenario plus various use profiles for the heat recovery and water recirculation systems (Table 1).

Table 1 Performance with energy and water used for each scenario

Performance Scenario	Heat Recovery	Water Recirculation
Standard (Baseline) 5.25MJ 50L Water		
Energy Best	45.0% 2.89 MJ used per shower	50.9% 2.58 MJ used per shower
Energy Worst	35.0% 3.41 MJ used per shower	18.2% 4.29 MJ used per shower
Water Best		22.0% 39 L used per shower
Water Worst		45.7% 27.15 L used per shower

Applying the results from a prior shower study Horrell et al. (2020), all scenarios are modelled on a shower that lasts 5 minutes with a flowrate of 10L per minute at a temperature of 40°C. For ease of reporting the study assumes that ambient water temperature remains at 18°C. The calculation for energy use for all scenarios uses the formula for energy required to heat a mass of water:

$$q = cm\,\Delta$$

Equation 1 Energy use to heat a mass of water
(c=specific heat capacity of water, m=mass)

Using equation x, the energy required for heating water for the standard shower is 5.25 MJ per use.

For the Heat Recovery scenarios, a best and worst profile was determined based on the R&D report mentioned in section 2.2. The recirculation system scenarios are based on user behaviour modelling and performance testing of a recirculation system under experimental trials (see M. Horrell, Tunnicliffe, and McLaren (2020).

2.4 Data summary

Data Record (Baseline)	Quantity	Source	Comments
Water Use			
Fresh water per shower	50 Litres	Gabi dataset	Fresh water, regionalised (country specific) Wastewater (assumes to sea water)
Water loss from leakage per shower	1.49 Litres	NZ Water Loss Guidelines (Lambert, 2010)	
Evaporation from water reservoir	5.37	Gabi dataset	NZ energy grid mix
Energy Use			
Energy per shower	5.25 MJ	Gabi dataset	NZ energy grid mix
1 Unit Heat Recovery System			
Copper Pipe	4.76 kg	Company Documentation	
Brass Pipe	0.45 kg	Company Documentation	
Methacrylic resin cover plate	1.20 kg	Assumed	
Ultra-filtration System (1 Unit Filter and Casing)			
Polycarbonate	8.82 kg	(Al-Sarkal & Arafat, 2013)	
PC Injection Moulding Electricity	34.6 MJ	(Elduque, Elduque, Clavería, & Javierre, 2018)	NZ energy grid mix
PVC Housing	0.72 kg	(Al-Sarkal & Arafat, 2013)	Aggregated with injection moulding electricity
Thermoplastic polyurethane adhesive	0.15 kg	(Al-Sarkal & Arafat, 2013)	
Ultra-filtration System (1 Unit Motor) Grundfos Scala 2 Water Booster Pump Datasheet			
Recirculating pump	10 kg	Gabi dataset	DE
Energy (10 Years Operation)	630 MJ	At 50% Max HP	NZ energy grid mix
Ultra-Filtration (Use per Clean In Place)			
Citric Acid (Substituted Hydrochloric acid)	0.50 g	Gabi dataset	Assumptions made based on Liqui-Flux® W-Series Operation Manual at 5% solution where CIP container is 10 L
Caustic soda	0.50 g	Gabi dataset	DE
Energy consumed to maintain 40ºC	28.19 MJ	Gabi dataset	NZ energy grid mix

4. Results

The results have been divided into two parts. The first part (section 4.1) identifies relevant environmental impact categories and details the impacts across the life cycle for each scenario in New Zealand. The second part of the assessment (section 4.2) models how the results differ between countries, comparing the New Zealand model with Australia, UK and China (as these are the main markets for the case company's products).

4.1 LCA Results for New Zealand

Figure 2 shows the normalised LCA results for all the scenarios. According to this analysis, water scarcity, climate change, resource use (energy) and/or resource use (minerals and materials) are ranked as being in the top four most significant impact categories for one or more of the scenarios. These are discussed in detail in sections 4.1.1 to 4.1.4.

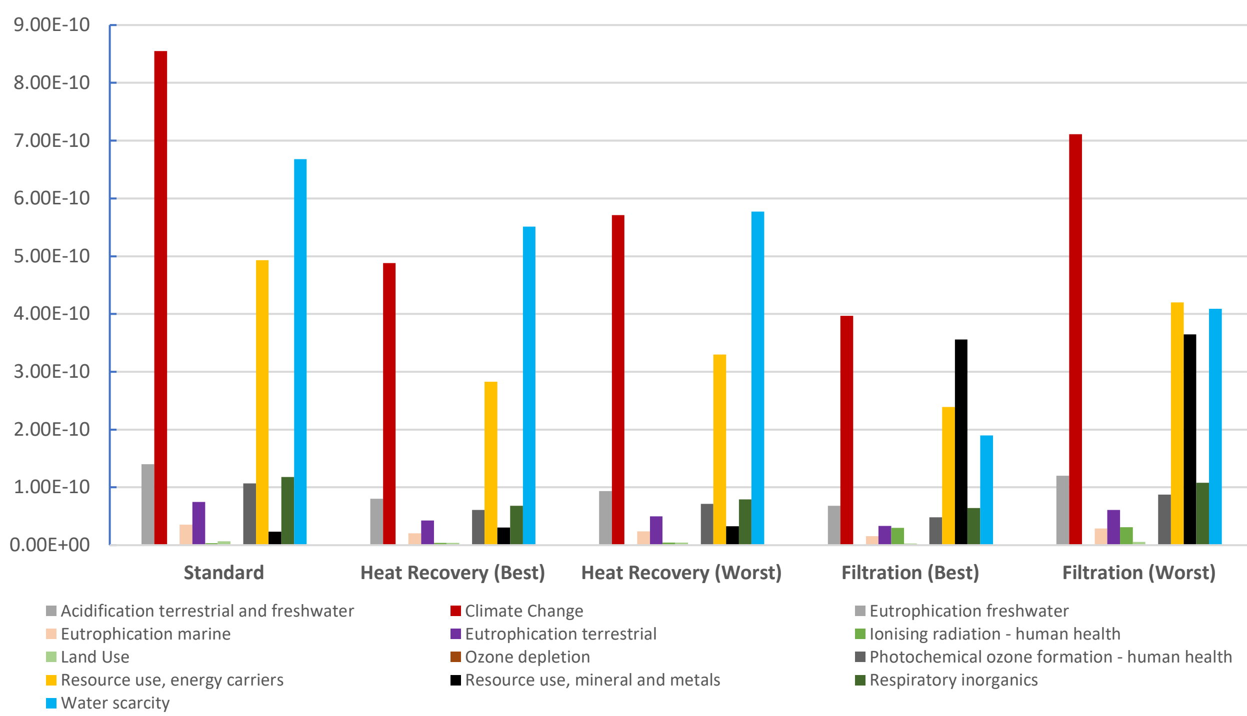


Figure 2 All Scenarios applied in New Zealand - EF 1.8 Normalised (Global Equivalents)

4.1.1 Non-renewable energy use

Figure 3 shows energy consumption of the different showering systems. Energy required to heat shower water is the major contributor to this impact category across all scenarios. In the **standard** shower scenario, the showering stage contributes 93% of energy use, and water filtration at plant contributes 7% of energy use.

The energy required to manufacture and process the additional components required for the **heat recovery** (best) and **recirculation system** (best) account for approximately 2% and 5% of energy use respectively over the life of the product.

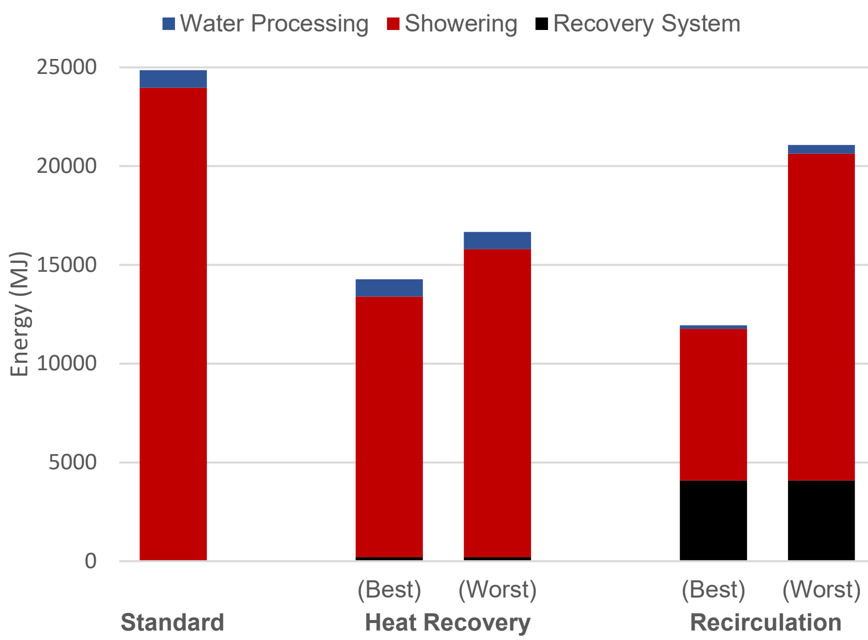


Figure 3 Non-renewable energy use (MJ)

Compared with a **standard** shower, 40% less energy is required for **heat recovery** (Best) and 31% less energy for **heat recovery** (Worst). 53% less energy is required for **recirculation** (Best) and 17% for **recirculation** (Worst). An additional energy (4000 MJ) is required for both the recirculation scenarios due to the heating of water for filter maintenance. For the **standard** shower scenario, the non-renewable energy carriers are mostly natural gas (72%) and hard coal (25%). All other scenarios show a similar distribution.

4.1.2 Climate change

Carbon emissions have a very similar distribution to energy-carriers (Figure 4) with all scenarios producing fewer carbon emissions than a standard shower. A **standard** shower produces approximately 2000kg of CO_2 over its lifetime (equivalent to driving a diesel car for 12,000 km). The **recirculation** (Best case) produces 54% less CO_2 emissions than the standard scenario. The amount of CO_2 produced reflects fossil-fuel use in energy generation described in section 4.2. Methane contributes approximately 6% of CO_2 emissions across all scenarios.

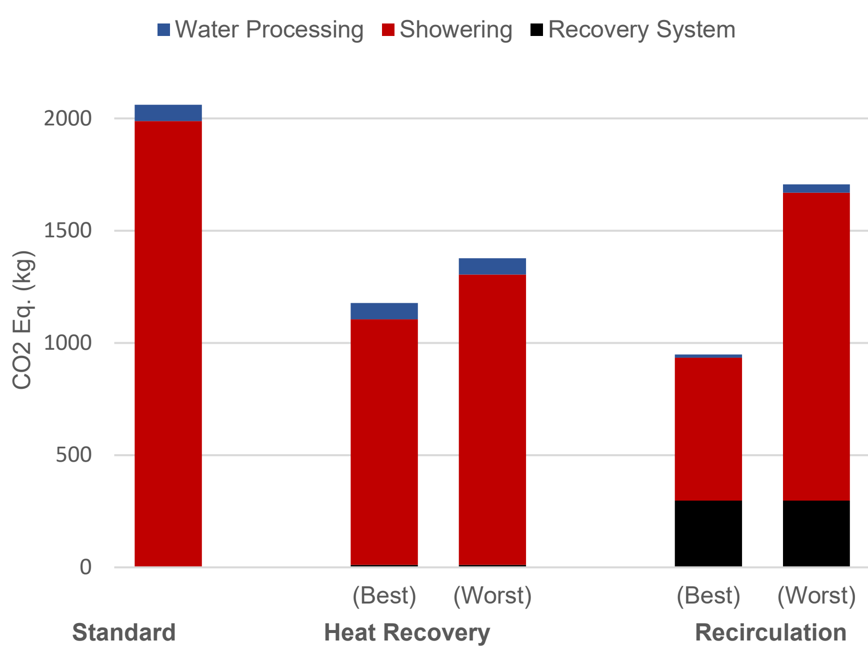


Figure 4 Climate change

4.1.3 Resource use (Metals and minerals)

Figure 5 shows the **recirculation** scenarios contribute significantly more to mineral and metal use (18g Sb eq.) compared with heat recovery (1.5g Sb eq.) and the standard scenario (0.1g Sb eq.) This is largely due to the additional mechanical and electronic parts required for the recirculation system (such as the recirculating pump). The pump contributes to 95% of the mineral and metal resource use, which is 33% Copper and 42% Gold. The dominant **heat recovery** contribution is from the copper metal required for the heat transfer system (approximately 75% copper).

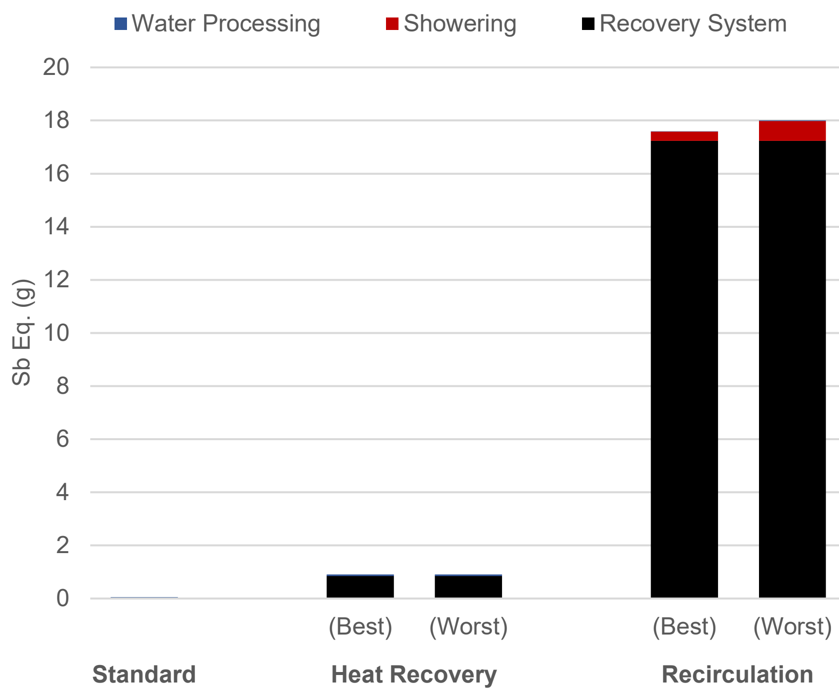


Figure 5 Resource use, mineral and metals

4.1.4 Water scarcity

Water scarcity has a similar distribution to non-renewable energy use and climate change. This is due to the energy required to heat shower water. In the **standard** scenario showering stage, the water use from showering contributes 60% to water scarcity, while electricity to heat the water accounts for 40%. This is because for every megajoule of energy generated in NZ approximately 5.37 litres of water are lost from evapotranspiration. This also explains why both the **heat recovery** system scenarios perform slightly better (18% less water for Best and 14% less water for Worst) since the application of the system provides some savings on energy while showering, even though it provides no savings on water use. The recirculation system saves on both energy and water providing the most savings in water scarcity (71% and 39% for best and worst case respectively).

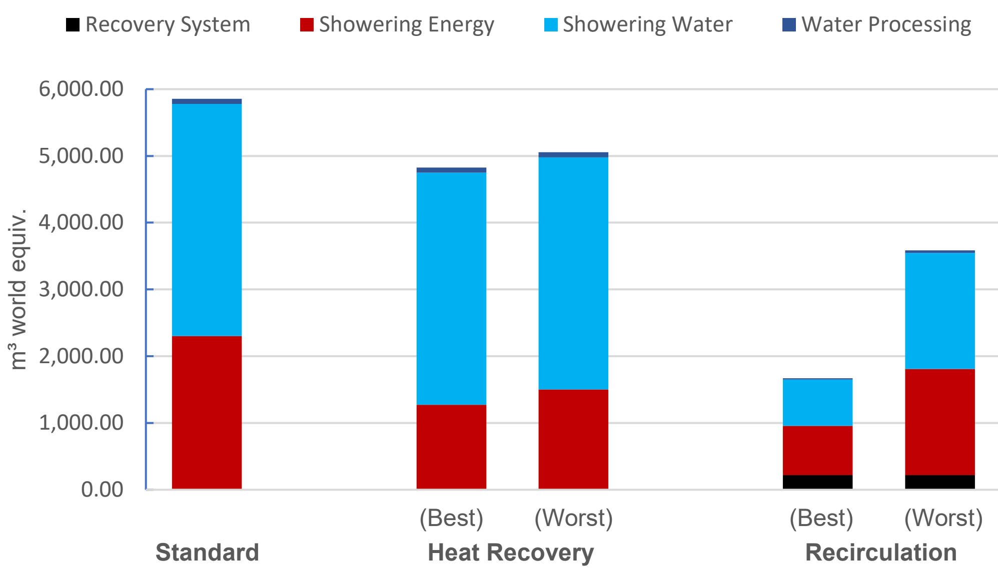


Figure 6 Water scarcity

4.2 Sensitivity Analysis of Countries

Two environmental impact categories were selected for further study in the sensitivity analysis. Water scarcity has been included as countries have different **water scarcity** characterisation factors. The inclusion of **non-renewable energy use** is also necessary because, based on the country the system is operated in, the electricity grid mix will ultimately determine the total non-renewable energy use.

Figure 7 and Figure 8 are country comparison of all scenarios for non-renewable energy use and water scarcity respectively.

Regarding non-renewable energy use, (Figure 7) New Zealand uses much less non-renewable energy compared to other countries across all scenarios. This is largely due to the scale of New Zealand's renewable electricity generation. As discussed in section 4.1.2, non-renewable energy use reflected the distribution of carbon emissions across all scenarios where an NZ **standard** shower scenario produced approximately 2000kg of CO_2. In China a **standard** shower produces approximately 11,000kg of CO_2 over the life of the system (10 years).

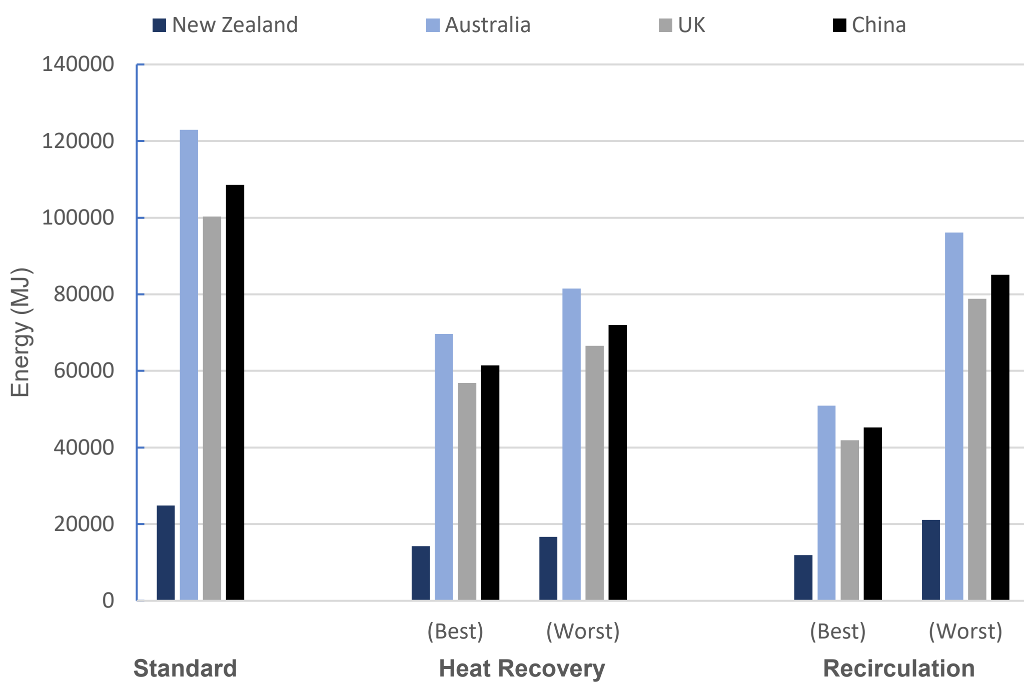


Figure 7 Non-renewable energy use by country

With respect to water scarcity (Figure 8), the impact of showering in China compared with New Zealand is considerably worse (300%). All scenarios for China are dominated by the water use from the shower (over 90%) while water used in energy generation contributed to less than 10%. This distribution was similar for Australia (approximately 80% for shower water use and 20% for water losses from energy generation). The UK had a similar distribution to the results reported for New Zealand (section 4.1.4) of 55% shower water use and 46% water loss from energy generation.

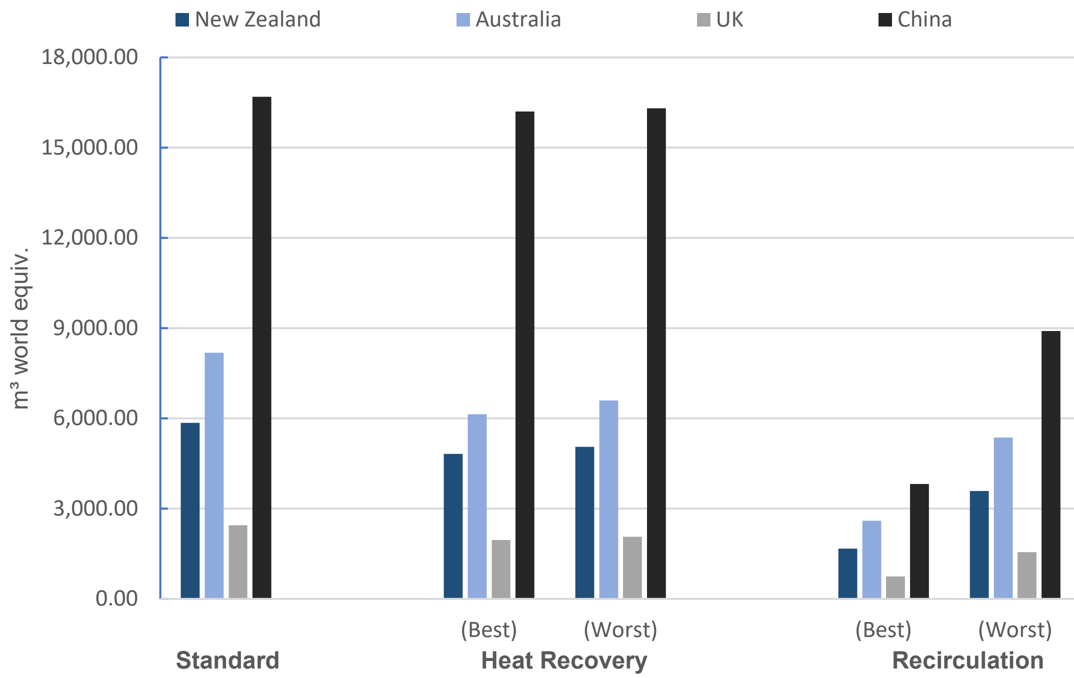


Figure 8 Water scarcity by country

5. Discussion

The purpose of this study was to address two main challenges faced by NPD and eco-design practitioners during the application of LCA in the early stages of the design process for active product systems. The first was to determine if LCA (which is commonly applied in the later stages of NPD) could be used as a decision support tool in the early design stages of active product systems. The second challenge focused on improving validity of the use phase modelling by including user behaviour data to provide further insights to NPD decision makers. These are discussed in detail in the following sections.

5.1 Decision support in the early stages of product development

When developing an eco-product system where the use phase dominates the life cycle based impacts, a designer or engineer needs to know where to focus their development efforts and ultimately how to improve the product system so there is a net environmental improvement when compared with the alternatives. In the case of a shower system, both water and energy are consumed, and there are different approaches to addressing both (i.e. Heat Recovery or Recirculation). When the different scenarios were modelled, the normalised results showed the four most significant environmental impact categories for these scenarios were non-renewable energy use, climate change, resource use, mineral and metals and water scarcity.

For these four categories the LCA results showed that the additional components (i.e. electronics, mechanical parts) over the life of both the heat recovery and recirculation system contribute little to the carbon emissions, energy use and water scarcity. However, the recirculation scenarios did have a more notable impact on mineral and metal use due to the manufacture of the pump. In addition, while the filter in the recirculation scenario had little impact on all impact categories, the filter cleaning process made a significant contribution across all the scenarios (between 25% and 35%) due to the energy required to heat water during maintenance of the filter.

This information could be used to assist designers and engineers in the early stages of development. Different pumps could be substituted to improve upon the impact associated with mineral and metal use. With regards to the cleaning process, some filter technologies may be better suited to this application than others. Filters that require less frequent cleaning – even if they have a larger impact at other stages of their life cycle (such as manufacturing) – may be preferred. In addition, engineers could also investigate how to improve the filter cleaning process by developing ways to clean it with cold water, and/or simply choosing to replace the filter entirely rather than maintain it.

The sensitivity analysis (section 4.2) provides additional insights that could be used to assist designers and engineers to select what type of system to develop. For example, the heat recovery system scenarios demonstrated that more than 40% of non-renewable energy could be saved by implementing that system in the UK, Australia and China. However, when comparing the water scarcity results for the different countries, the water recirculation scenarios for the UK show a relatively low improvement compared with the baseline but the improvements are greater for Australia and China. The implication is that a heat recovery system could be a better option for the UK, while in other countries, such as China and Australia, it may be better to design and implement recirculation systems. This allows manufacturers to select and design eco-systems for their markets that would give them the most environmental gains across the most relevant environmental impact categories.

This demonstrates that LCA can be used as an objective decision support tool in the early stages of development of active product systems such as showers.

5.2 Human behaviour modelling in LCA

The difference between the best and worse scenarios varied across the different impact categories. This was particularly evident in the recirculation scenario: the Recirculation (Best) scenario reduced carbon emissions by 54% compared to the standard shower, while the Recirculation (Worst) scenario only reduced carbon emissions by 17% compared to the standard (Figure 4). Since this performance data is based on user interaction with the system, this implies that users and their behaviours will influence the LCA results. These results also suggest that Heat Recovery systems may be a preferred alternative system over Recirculation systems in certain situations as both Heat Recovery scenarios outperformed the Recirculation (Worst) scenario. The implication for designers and engineers is to include data for a range of user behaviours when performing an LCA.

6 Conclusions

This study has demonstrated the feasibility, and relevance, of including LCA in the early design stages when prototyping active product systems such as shower recirculation systems. It can help inform priorities in the design process, and the insights gained can be critical to improving the environmental performance of the system.

The study has also shown the importance of incorporating user behaviour in LCA modelling. Product users in different countries may have different showering behaviours that could be generalisable (e.g. spending longer washing than not washing). This would impact the environmental performance of recirculation systems in different countries. Therefore, data of users and their shower behaviours in different countries could be collected and used to further improve the scenario modelling and sensitivity analysis.

Acknowledgements

This research was funded and supported by Callaghan Innovation [grant number MTVN1503] and the Dick and Mary Early Scholarship in Technology.

References

Adeyeye, K., She, K., & Baïri, A. (2017). Design factors and functionality matching in sustainability products: A study of eco-showerheads. *Journal of Cleaner Production, 142*(Part 4), 4214-4229. doi: 10.1016/j.jclepro.2016.11.143

Al-Sarkal, T., & Arafat, H. A. (2013). Ultrafiltration versus sedimentation-based pretreatment in Fujairah-1 RO plant: Environmental impact study. *Desalination, 317*, 55-66. doi: 10.1016/j.desal.2013.02.019

Anderson, A. M. (2008). A framework for NPD management: doing the right things, doing them right, and measuring the results. *Trends in Food Science and Technology, 19*(11), 553-561. doi: 10.1016/j.tifs.2008.01.015

Bhamra, T., Lilley, D., & Tang, T. (2011). Design for Sustainable Behaviour: Using Products to Change Consumer Behaviour. *Design Journal, 14*(4), 427-445. doi: 10.2752/175630611X13091688930453

Boks, C., & Wever, R. (2007). *Design for Sustainability in the Fuzzy Front End*.

Cooper, R. G., & Edgett, S. J. (2010). Developing a product innovation and technology strategy for your business. *Research Technology Management, 53*(3), 33-40.

Daae, J., & Boks, C. (2015). Opportunities and challenges for addressing variations in the use phase with LCA and Design for Sustainable Behaviour. *International Journal of Sustainable Engineering, 8*(3), 148-162. doi: 10.1080/19397038.2015.1010630

Elduque, A., Elduque, D., Clavería, I., & Javierre, C. (2018). Influence of material and injection molding machine's selection on the electricity consumption and environmental impact of the injection molding process: An experimental approach. *International Journal of Precision Engineering and Manufacturing-Green Technology, 5*(1), 13-28. doi: 10.1007/s40684-018-0002-0

Fitzgerald, D. P., Herrmann, J. W., Sandborn, P. A., & Schmidt, L. C. (2005). *Environmental Objectives for New Product Development Decision-Making*. Department of Mechanical Engineering and Institute for Systems Research. University of Maryland, College Park, MD 20742, USA.

Hassi, L., & Wever, R. (2010). *Practices of a "green" front end of innovation; A gateway to environmental innovation*.

Horrell, Shekar, & McLaren. (2020). USE OF DESIGN OF EXPERIMENTS TO OPTIMISE THE ENVIRONMENTAL PERFORMANCE OF CONSUMER PRODUCTS: A CASE STUDY OF SHOWERS AND TAPWARE IN NEW ZEALAND. *Proceedings of the Design Society: DESIGN Conference, 1*, 1911-1920. doi: 10.1017/dsd.2020.269

Horrell, M., Tunnicliffe, M., & McLaren, S. (2020). *Development and performance testing of a system-based eco-shower*.

Institut Bauen und Umwelt e.V. (2011). Environmental Product Declaration as per ISO 14025 for hand showers Croma 100 and Crometta 85. Panoramastraße, Berlin.

Institut Bauen und Umwelt e.V. (2014). Product Category Rules for Building-Related Products and Services.

Jolliet, O., Saade-Sbeih, M., Shaked, S., Jolliet, A., & Crettaz, P. (2015). Inventory Analysis of Emissions and Extractions *Environmental Life Cycle Assessment* (pp. 57): CRC Press.

Lambert, A. (2010). Water Loss Guidelines. Auckland, New Zealand: Water New Zealand.

Silva, N. D. (2012). Life Cycle Assessment in Product Innovation *Life Cycle Assessment Handbook* (pp. 329-343): John Wiley & Sons, Inc.

Vezzoli, C. (2018). *Design for environmental sustainability : life cycle design of products* (Second edition ed.): Springer.

WRAP. (2010). Environmental assessment of consumer electronic products Oxford, UK: Waste and Resources Action Programme.

Appendix D

PRODUCT SYSTEM LEVEL

7. Optimization of end-of-life system
Reuse of product
Remanufacturing/refurbishing
Recycling of materials
Safer incineration

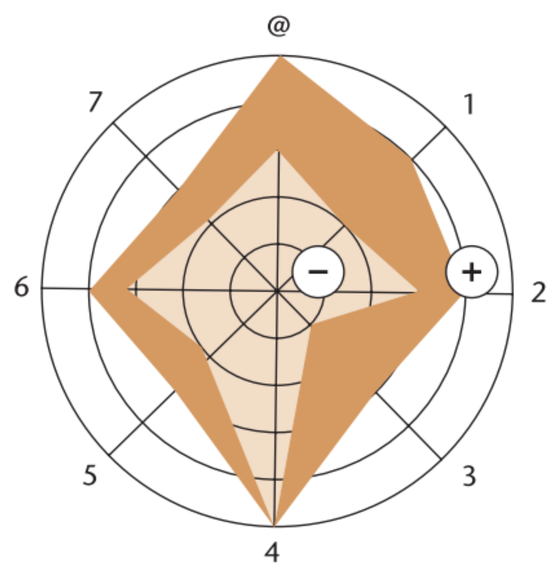
6. Optimization of initial lifetime
Reliability and durability
Easier maintenance and repair
Modular product structure
Classic design
Strong product-user relation

5. Reduction of impact during user
Lower energy consumption
Cleaner energy source
Fewer consumables needed
Cleaner consumables
No waste of energy/consumables

PRODUCT STRUCTURE LEVEL

4. Optimization of distribution system
Less/cleaner/reusable packaging
Energy-efficient transport mode
Energy-efficient logistics

@ New Concept Development*
Dematerialization
Shared use of the product
Integration of functions
Functional optimization
of product (components)



PRODUCT COMPONENT LEVEL

1. Selection of low-impact materials
Cleaner materials
Renewable materials
Lower energy content materials
Recycled materials
Recyclable materials

2. Reduction of materials usage
Reduction in weight
Reduction in (transport) volume

3. Optimization of production techniques
Alternative production techniques
Fewer production steps
Lower/cleaner energy consumption
Less production waste
Fewer/cleaner production consumables

Priorities for the new product

Existing product

Appendix E

Appendix E

CASE STUDY PROTOCOL

The purpose of this document is to provide a standardised agenda for conducting the research. It contains all the rules and procedures that the researcher will follow when conducting the case study.

Overview of the case study

1. **MISSION AND GOALS**

    a. The case study is sponsored by a shower and tapware manufacturer. The industry aim is to apply tools, methods, products strategies to improve their products from an environmental perspective. The objectives are to

        i. Gain Insight into customer interaction
        ii. Strengthened Environmental Concepts
        iii. Benchmark (pilot study) existing products
        iv. Improve R&D Knowledge on environmental tools and techniques
        v. Create a new commercial 'green' product

    b. The research aim is investigate eco-design related tools and techniques that the company performs throughout the case study, and how those can be best integrated into their NPD operations.

        i. Identification of strengths and weaknesses of project across elements of doing npd right (Org Structure, NPD Process, Tools)
        ii. Identify a process (such as an NPD model) that can facilitate eco-design integration into NPD operational activities

2. QUESTIONS & PROPOSITIONS

Status Quo

a) How does the organisation perform New Product Development and where are the opportunities for eco-design integration at an operational level? (survey, interviews)

b) What are the current eco-initiatives if any?

Applicability

c) What eco-design principles, methods or tools can help identify and mitigate the environmental impacts associated with the use phase of shower and tapware products?

   a. What works and what doesn't?

   b. What product and user characteristics limits or enhances their application?

Implementation

d) Of the appropriate principles, methods and tools how can they be best operationalised into the product development practices of a shower and tapware manufacturer?

   a. What product development best practices are related to successful application of the relevant eco-design principles, methods and tools?

Shower and Tapware eco-design integration model

e) Based on the findings can an eco-design model be created and generalisable for producers of shower and tapware products?

Transferability

f) Can this model be generalised for producers of active consumer products?

PROPOSITIONS

a) Principles, methods and tools related to the eco-design body of knowledge does not adequately address products with an active use phase such as those within the shower and tapware industry
b) There is a narrow consideration for the environmental impacts associated with the use phase of showers and tapware industry
c) The behavioural aspects of users of showers and tapware have an environmental impact, yet this is not reflected in current eco-design or NPD practice.
d) Eco-design initiatives can progress through levels or categories impacting the environmental performance of the product at varying parts of its life cycle

Data collection procedures

1. Fieldworld contacts
    a. R&D Manager
    b. HR Manager
    c. Head of Innovaiton

2. Data collection plan

    a. Access to key interviewees
        i. Attend company inductions (as employee)
        ii. R&D team makes new employees who are relevant to the study (such as within the innovation team) aware of the research and its importance.

iii. Attend regular work hours (9-5 Monday to Friday) at the organisation under study
iv. Attend and record stand-up meetings in the mornings
v. Attend R&D events / excursions

b. Resources

i. Access to company email, address book and calendar/scheduling
ii. Workspace is located within the innovation and R&D team

Appendix F

Appendix F

Best Practice Survey Results

Strategy & Portfolio Management

When it comes to New Product Development strategy this organisation has

ANSWER CHOICES		RESPONSES	
no NPD goals		0.00%	0
unclear NPD goals		37.50%	6
NPD goals which are clearly aligned with organisation mission and strategic plan		12.50%	2
NPD goals defined by a mission statement, and opportunities that were identified through analysis of strategic arenas		6.25%	1
The NPD goals are clear in my silo, I am not sure about other silos		31.25%	5
Other (please specify)	Responses	12.50%	2
TOTAL			16

What BEST describes how our New Product Development planning is driven

ANSWER CHOICES	RESPONSES	
market changes and new technologies and we respond to these in real time	6.25%	1
focused on short term with a more tactical view of NPD projects and their selection	50.00%	8
our strategic plan which helps us identify opportunities and define the most appropriate NPD projects	31.25%	5
our mission statement and goals that define what projects to undertake	12.50%	2
TOTAL		16

Please rank the priority in which you believe NPD projects are currently selected and driven by

	1	2	3	4	5	TOTAL	SCORE
what best fits our mission statement or goals	6.25% 1	25.00% 4	37.50% 6	12.50% 2	18.75% 3	16	2.88
available funding	18.75% 3	18.75% 3	31.25% 5	12.50% 2	18.75% 3	16	3.06
market studies	25.00% 4	25.00% 4	18.75% 3	31.25% 5	0.00% 0	16	3.44
higher management pet projects	31.25% 5	18.75% 3	12.50% 2	6.25% 1	31.25% 5	16	3.13
outcomes from strategic analysis (such as balancing the portfolio of project types)	18.75% 3	12.50% 2	0.00% 0	37.50% 6	31.25% 5	16	2.50

When it comes to New Product Development project prioritisation it

ANSWER CHOICES		RESPONSES	
never happens		0.00%	0
occurs only during the annual budget process		6.25%	1
is ongoing and formalised in its own systematic process		18.75%	3
is flexible to allow for resources to be re-allocated to new opportunities (ad-hoc)		56.25%	9
Other (please specify)	Responses	18.75%	3
TOTAL			16

New Product Development projects can often be grouped into types (Disruptive, Incremental, Progressive, Tactical): my organisation

ANSWER CHOICES		RESPONSES	
is not concerned with the types we develop		12.50%	2
tries to have a variety with little to no regard for mix appropriateness		12.50%	2
has a mix but this is due to trade-offs or decisions from strategic business units		43.75%	7
has keen consideration for balancing the number of project types and available resources		25.00%	4
Other (please specify)	Responses	6.25%	1
TOTAL			16

When it comes to pet projects

ANSWER CHOICES		RESPONSES	
they are prevalent		6.25%	1
they are prevalent but only in my department		0.00%	0
there are some throughout the business but we try to minimise them		56.25%	9
we only develop those approved by management even if they don't necessarily align with the NPD goals or mission statement		18.75%	3
only those that align with NPD goals and the mission statement are developed		18.75%	3
Other (please specify)	Responses	0.00%	0
TOTAL			16

Ideas and concepts that could evolve to a new project

ANSWER CHOICES		RESPONSES	
are independently reviewed		25.00%	4
are reviewed by different business units		18.75%	3
are reviewed and stored in an idea bank		12.50%	2
are not part of our formalised project prioritisation		18.75%	3
Other (please specify)	Responses	25.00%	4
TOTAL			16

Please complete the follow matrix to best represent what you believe the current New Product Development project portfolio looks like (resource=personnel & time)

Percentage number of projects

	0%	25%	50%	75%	100%	TOTAL
Disruptive Projects: Unmet consumer need, new technology	37.50% 6	56.25% 9	6.25% 1	0.00% 0	0.00% 0	16
Progressive Projects: Addresses consumer need better than competition, requires significant technology development	6.25% 1	62.50% 10	31.25% 5	0.00% 0	0.00% 0	16
Continuous Projects: Range extension or upgrade. Technology available but some development required	6.25% 1	75.00% 12	12.50% 2	6.25% 1	0.00% 0	16
Tactical Projects: Range extension that satisfies trade or customer need. Technology available	0.00% 0	81.25% 13	18.75% 3	0.00% 0	0.00% 0	16

Percentage resource allocation

	0%	25%	50%	75%	100%	TOTAL
Disruptive Projects: Unmet consumer need, new technology	37.50% 6	50.00% 8	6.25% 1	6.25% 1	0.00% 0	16
Progressive Projects: Addresses consumer need better than competition, requires significant technology development	6.25% 1	50.00% 8	43.75% 7	0.00% 0	0.00% 0	16
Continuous Projects: Range extension or upgrade. Technology available but some development required	6.67% 1	86.67% 13	6.67% 1	0.00% 0	0.00% 0	15
Tactical Projects: Range extension that satisfies trade or customer need. Technology available	0.00% 0	87.50% 14	6.25% 1	6.25% 1	0.00% 0	16

Incremental sales

	0%	25%	50%	75%	100%	TOTAL
Disruptive Projects: Unmet consumer need, new technology	40.00% 6	46.67% 7	13.33% 2	0.00% 0	0.00% 0	15
Progressive Projects: Addresses consumer need better than competition, requires significant technology development	12.50% 2	50.00% 8	25.00% 4	12.50% 2	0.00% 0	16
Continuous Projects: Range extension or upgrade. Technology available but some development required	12.50% 2	81.25% 13	6.25% 1	0.00% 0	0.00% 0	16
Tactical Projects: Range extension that satisfies trade or customer need. Technology available	12.50% 2	56.25% 9	31.25% 5	0.00% 0	0.00% 0	16

People and Process

What best describes the New Product Development team structure

ANSWER CHOICES	RESPONSES	
We have individuals that perform New Product Development	6.67%	1
We have development silos	6.67%	1
We have cross functional teams which underlie the NPD process	33.33%	5
We have department liaisons but our NPD teams are still multi-functional	13.33%	2
We do not have defined NPD teams but instead hold cross functional meetings to bring in relevant people	40.00%	6
TOTAL		15

The leadership within NPD can be best described as having

ANSWER CHOICES		RESPONSES	
a lack of leadership		13.33%	2
a champion that takes ownership of a project and is a mainstay for project success		40.00%	6
a clearly identifiable project leader for all NPD projects		13.33%	2
a clearly identifiable project leader but only for the projects I am involved with		20.00%	3
Other (please specify)	Responses	13.33%	2
TOTAL			15

Select the aspects you believe apply to you when it comes to the organisations team structure and personnel (select only those that are relevant to you)

ANSWER CHOICES	RESPONSES	
I take on too many projects	21.43%	3
I will often be drawn away from focusing on existing NPD projects to work on non-NPD related work	42.86%	6
As a manager I sometimes handle projects myself rather than have this go through the NPD team(s) (only tick if you are a manager)	14.29%	2
I have ongoing training that improves my ability within NPD	14.29%	2
None of these (perhaps due to limited involvement with NPD related work)	35.71%	5
Total Respondents: 14		

The organisation encourages internal entrepreneurship

ANSWER CHOICES	RESPONSES	
Strongly Agree	0.00%	0
Agree	66.67%	10
Somewhat agree	13.33%	2
Somewhat disagree	13.33%	2
Disagree	6.67%	1
Strongly Disagree	0.00%	0
TOTAL		15

The culture and climate promotes good communication between individuals, teams and divisions

ANSWER CHOICES	RESPONSES	
Strongly Agree	0.00%	0
Agree	33.33%	5
Somewhat agree	60.00%	9
Somewhat disagree	6.67%	1
Disagree	0.00%	0
Strongly Disagree	0.00%	0
TOTAL		15

I have a strong awareness of current NPD practice (such as projects in the pipeline, my part or contribution in a project and the projects wider context)

ANSWER CHOICES	RESPONSES	
Strongly Agree	26.67%	4
Agree	13.33%	2
Somewhat agree	40.00%	6
Somewhat disagree	6.67%	1
Disagree	13.33%	2
Strongly Disagree	0.00%	0
TOTAL		15

What best defines your NPD process

ANSWER CHOICES	RESPONSES	
We have no NPD process	0.00%	0
Informal, decentralised NPD process exists where different groups use their own tailored process	60.00%	9
A common NPD process cuts across organisational groups	33.33%	5
One formal stage-gate type process is employed for the entire organisation	6.67%	1
One formal stage-gate type process is employed for the entire organisation and this is coupled with agile and flexible rapid processes such as PDCA cycles "Plan, Do, Check, Act" or "Sprints"	0.00%	0
TOTAL		15

How much do you agree with the following statement "I am involved and engaged with the New Product Development Process"

ANSWER CHOICES	RESPONSES	
Strongly Agree	26.67%	4
Agree	26.67%	4
Somewhat agree	26.67%	4
Somewhat disagree	6.67%	1
Disagree	13.33%	2
Strongly Disagree	0.00%	0
TOTAL		15

How much do you or your team adhere to the documented NPD process

ANSWER CHOICES		RESPONSES	
Not at all and instead there is simply a flurry of NPD activity without any discipline surrounding the management of NPD development activities		0.00%	0
The process is often not adhered and can be readily circumvented by anyone		26.67%	4
It is mostly followed however time critical projects may skip stages of process		66.67%	10
Personnel are very disciplined in using the process to develop all new offerings		0.00%	0
Other (please specify)	Responses	6.67%	1
TOTAL			15

How well is the NPD process documented?

ANSWER CHOICES	RESPONSES	
There is no documentation on the process	6.67%	1
There is limited documentation on the process	13.33%	2
Good documentation is there, however it is not well exposed	66.67%	10
The NPD process is quite visible and well-documented	13.33%	2
TOTAL		15

When evaluating the performance and progress of a project

ANSWER CHOICES	RESPONSES	
there is no criteria defined for any kind of assessment	0.00%	0
a few standard criteria are used for evaluation of NPD project activity through the process or at stages/gates	46.67%	7
the criteria is based primarily on deadlines to achieve certain milestones	46.67%	7
there is Go/No-Go criteria (such as design specifications) which are clear and predefined for each review gate (tough-gates)	6.67%	1
TOTAL		15

What activities are performed at the front end of the product development process

ANSWER CHOICES		RESPONSES	
Development iterations that provide fast feedback		46.67%	7
We tap external ideas by bringing in third party companies, engineers, designers or entrepreneurs		6.67%	1
We hold formal or informal idea generation sessions		60.00%	9
We use TRIZ/TIPS or other idea generation methods and tools		0.00%	0
Other (please specify)	Responses	20.00%	3
Total Respondents: 15			

If the front end of a generic stage-gate includes 'Idea Generation', 'Scoping' and 'Building a Business Case' and the rest of development is everything else to get a product to launch, how much time should be allocated to the front end?

ANSWER CHOICES		RESPONSES	
At least 90% on front-end activities		0.00%	0
Around 75% on front-end activities		26.67%	4
No more than 50% on front-end activities		33.33%	5
Less than 25% on front-end activities		40.00%	6
Other (please specify)	Responses	0.00%	0
TOTAL			15

Please rank what you believe is the most important to least important aspects of new product success

	1	2	3	4	5	TOTAL	SCORE
A unique and superior product	26.67% 4	46.67% 7	13.33% 2	6.67% 1	6.67% 1	15	3.80
Building in the voice of the customer	60.00% 9	13.33% 2	20.00% 3	0.00% 0	6.67% 1	15	4.20
A global orientated product	0.00% 0	20.00% 3	26.67% 4	20.00% 3	33.33% 5	15	2.33
A well-conceived and properly executed launch	6.67% 1	20.00% 3	20.00% 3	40.00% 6	13.33% 2	15	2.67
Speed to market	6.67% 1	0.00% 0	20.00% 3	33.33% 5	40.00% 6	15	2.00

Using the following generic criteria please rank what you believe is the most important to evaluate new products

	1	2	3	4	5	6	7	TOTAL	SCORE
Ease of manufacture	0.00% 0	6.67% 1	6.67% 1	26.67% 4	26.67% 4	20.00% 3	13.33% 2	15	3.13
Long-life and Maintainability	0.00% 0	6.67% 1	0.00% 0	0.00% 0	13.33% 2	33.33% 5	46.67% 7	15	1.93
Aesthetics	7.14% 1	14.29% 2	64.29% 9	7.14% 1	0.00% 0	7.14% 1	0.00% 0	14	5.00
Functionality	66.67% 10	6.67% 1	6.67% 1	13.33% 2	6.67% 1	0.00% 0	0.00% 0	15	6.13
Environmentally friendly	0.00% 0	6.67% 1	6.67% 1	13.33% 2	13.33% 2	33.33% 5	26.67% 4	15	2.60
Cost	13.33% 2	20.00% 3	6.67% 1	13.33% 2	33.33% 5	0.00% 0	13.33% 2	15	4.13
Quality	13.33% 2	40.00% 6	13.33% 2	26.67% 4	6.67% 1	0.00% 0	0.00% 0	15	5.27

When starting a new product development project we always

ANSWER CHOICES	RESPONSES	
use project charters (or similar) to define a project scope	46.67%	7
can always describe the value proposition of a new project	33.33%	5
can describe the product features and requirement for new projects	53.33%	8
try to solve problems for customers that are not addressed elsewhere by our competitors	20.00%	3
create early product briefs which include descriptions that define superior and differentiated products	26.67%	4
create early product briefs include descriptions that define greater quality over competitors existing products	13.33%	2
Total Respondents: 15		

For this organisation how does the technology teams projects differ from NPD projects (select those you agree with)

ANSWER CHOICES	RESPONSES	
Funding should be budgeted for NPD, technology team should be variable	28.57%	4
Commercialisation dates are known for NPD projects, technology team is unpredictable	78.57%	11
It is usually not possible to determine possible revenue from a technology team based project	57.14%	8
Technology team work is undisciplined and chaotic and not necessarily goal orientated	21.43%	3
The measure of progress for a technology project is strengthened concepts	28.57%	4
Technology team projects should lead into NPD projects	71.43%	10
I do not have enough involvement with the technology team to answer	14.29%	2
Total Respondents: 14		

What role(s) do you think the technology team has within NPD (select those you believe apply)

ANSWER CHOICES	RESPONSES	
The technology team is part of the fuzzy front end of NPD	66.67%	10
The development of disruptive or progressive technology developments that can be commercialised	73.33%	11
Testing and validating OEM	40.00%	6
Ensuring compliance for new products or concepts	60.00%	9
Exploring and developing new technologies to be integrated into new or existing products	93.33%	14
Perform experiments to benchmark new products or competitors offerings	53.33%	8
I do not have enough involvement with the technology team to answer	0.00%	0
Total Respondents: 15		

Market Research and Metrics

How do you believe market research is performed

ANSWER CHOICES		RESPONSES	
No market research is performed; if any, market research is predominantly anecdotal evidence		0.00%	0
Market research is reactive in nature (ie initiated once a project has started)		35.71%	5
A formal market research function exists in the organization		50.00%	7
Market studies are ongoing		14.29%	2
Other (please specify)	Responses	0.00%	0
TOTAL			14

What types of market research activities occur that impact your NPD efforts

ANSWER CHOICES	RESPONSES	
Pilot testing	35.71%	5
Macro-environmental research using subject matter experts	7.14%	1
Focus groups	92.86%	13
Surveys	57.14%	8
Big-data analytics (ie Google analytics)	7.14%	1
Usability Research	42.86%	6
Mega-trends	42.86%	6
Total Respondents: 14		

How would you best describe how market research is currently built into the NPD process for YOUR team or silo

ANSWER CHOICES		RESPONSES	
We use the Voice of the Customer to guide our design and development efforts - but this informal, qualitative or a fuzzy approach.		50.00%	7
We have a formalised method (scorecards/check lists) for evaluating the "Voice of the Customer" and use this to make tradeoffs between what is possible and what is desirable		28.57%	4
We work on the philosophy that customers do not know what they want until you show it to them		21.43%	3
Other (please specify)	Responses	0.00%	0
TOTAL			14

What best represents the metrics which are used to evaluate NPD projects

ANSWER CHOICES		RESPONSES	
No standard criteria for evaluating projects		21.43%	3
There are some general guiding principles for evaluating projects		35.71%	5
Scoring models / checklists are used		7.14%	1
There is a standard set of criteria for individually evaluating NPD projects		7.14%	1
I don't know		28.57%	4
Other (please specify)	Responses	0.00%	0
TOTAL			14

What best represents metrics used for continuous improvement of NPD efforts

ANSWER CHOICES		RESPONSES	
No standard criteria for evaluating the overall NPD effort		28.57%	4
Revenue is the predominant metric for NPD project success		35.71%	5
Formal business analysis is undertaken		0.00%	0
There is standard set of criteria for evaluating the overall NPD effort		7.14%	1
I don't know		28.57%	4
Other (please specify)	Responses	0.00%	0
TOTAL			14

Who reviews NPD projects or the NPD process

ANSWER CHOICES		RESPONSES	
No one		0.00%	0
One person does all evaluations		0.00%	0
Business plans must be approved by Directors, VP's and/or Board of Directors must approve really new ideas/projects and/or big projects		21.43%	3
Multiple reviews and reviewers are used to evaluate NPD projects and NPD progress		64.29%	9
Other (please specify)	Responses	14.29%	2
TOTAL			14

How often do projects make it through NPD evaluations (projects that have already been formalised and resources/development time spent on them)

ANSWER CHOICES	RESPONSES	
Projects are never killed	0.00%	0
Some projects may be killed/dropped	71.43%	10
Projects can and are stopped/killed at any time and we have a formal group that undertakes this evaluation	28.57%	4
TOTAL		14

Sustainability

Using the following table, please indicate what you believe are the barriers that prevent you developing 'eco-products'

	AGREE	SOMEWHAT DISAGREE	TOTAL	WEIGHTED AVERAGE
our market does not respond to environmental aspects, they have other priorities that our development aligns with	66.67% 8	33.33% 4	12	1.33
we do not have the capital to market Life Cycle based design aspects to our customers, therefore we do not make this a priority in design and development	53.85% 7	46.15% 6	13	1.46
there is a lack of top management support for environmental consideration	23.08% 3	76.92% 10	13	1.77
I do not know what the tools, methods and techniques I can use in development to improve the environmental performance of products I am working on	57.14% 8	42.86% 6	14	1.43
we lack a formalised plan or metrics for evaluating the environmental performance of products	85.71% 12	14.29% 2	14	1.14
Eco-design aspects are not my responsibility, those decisions are made by others in the NPD team	38.46% 5	61.54% 8	13	1.62
I have no control over developing eco-products, the products are manufactured in China and that's where the major environmental impacts will likely occur	50.00% 7	50.00% 7	14	1.50
Developing eco-products might negatively impact our sales - we think its too risky and/or outside our comfort zone	42.86% 6	57.14% 8	14	1.57

Rank from (best to worst) what you believe to be the most appropriate method for evaluating the environmental performance of a shower or tapware product.

	1	2	3	4	5	6	7	TOTAL	SCORE
Energy (ie. the energy required to heat water for a shower)	15.38% 2	38.46% 5	15.38% 2	15.38% 2	15.38% 2	0.00% 0	0.00% 0	13	5.23
Internal Manufacturing Processes and Practices	7.69% 1	7.69% 1	15.38% 2	15.38% 2	38.46% 5	0.00% 0	15.38% 2	13	3.69
Flow rate	23.08% 3	15.38% 2	30.77% 4	15.38% 2	7.69% 1	7.69% 1	0.00% 0	13	5.08
The results of a full Life Cycle Assessment (From raw material extraction to end-of-life)	38.46% 5	7.69% 1	7.69% 1	7.69% 1	23.08% 3	7.69% 1	7.69% 1	13	4.77
Average Freight Distance	0.00% 0	7.69% 1	0.00% 0	7.69% 1	7.69% 1	23.08% 3	53.85% 7	13	2.00
Material Weight, Type or Volume	7.69% 1	7.69% 1	23.08% 3	15.38% 2	7.69% 1	30.77% 4	7.69% 1	13	3.69
The results of a Life Cycle Assessment but only Cradle to Gate (excludes the parts of the life cycle we assume happen when it ships from the factory i.e Use and Disposal)	7.69% 1	15.38% 2	7.69% 1	23.08% 3	0.00% 0	30.77% 4	15.38% 2	13	3.54

Please indicate how much percentage you believe each team has on the environmental performance of a shower or tapware product (sum does not have to equal 100%)

	0%	25%	50%	75%	100%	TOTAL	WEIGHTED AVERAGE
the industrial design team	14.29% 2	50.00% 7	28.57% 4	7.14% 1	0.00% 0	14	2.29
the product development team	0.00% 0	28.57% 4	35.71% 5	21.43% 3	14.29% 2	14	3.21
the technology team	0.00% 0	28.57% 4	35.71% 5	28.57% 4	7.14% 1	14	3.14
the marketing team	21.43% 3	42.86% 6	21.43% 3	14.29% 2	0.00% 0	14	2.29
the production team	28.57% 4	28.57% 4	21.43% 3	21.43% 3	0.00% 0	14	2.36
the supply chain team	14.29% 2	50.00% 7	28.57% 4	7.14% 1	0.00% 0	14	2.29

There are different levels of eco-design, please rate what you believe are most appropriate for this organisation

	(5) MOST APPROPRIATE	(1) LEAST APPROPRIATE	TOTAL	WEIGHTED AVERAGE
Level 1: Improvement Level - We should develop products (business as usual) and optimise their environmental performance during or after the NPD process.	57.14% 8	42.86% 6	14	1.43
Level 2: Redesign level - We should create new eco-products that have environmental performance at the forefront which are marketed and sold as a better alternative to existing products	92.86% 13	7.14% 1	14	1.07
Level 3: System Level - We should concern ourselves with the incoming water, heating and waste systems and develop a product or system which attempts to minimise water and energy across the system	42.86% 6	57.14% 8	14	1.57
Level 4: Business Model Level: We should create a new business model where we might recover end of life products and reuse them in manufacturing or offer our products as a service (take full ownership of the life of the product)	50.00% 7	50.00% 7	14	1.50

If your organisation markets itself as promoting sustainability, what internal actions do you believe best represents this

ANSWER CHOICES		RESPONSES	
My organisation does not promote sustainability or market itself to develop eco-products		0.00%	0
We always try to make products that have a minimum environmental impact by making responsible choices in the design and development process		28.57%	4
My organisation promotes sustainability but I do not see evidence in our products or NPD process		21.43%	3
Our products may not be environmentally friendly but our other processes are (manufacturing, internal recycling, green supply chain)		7.14%	1
We do a little but it is a bit ad-hoc and lacks direction		42.86%	6
Other (please specify)	Responses	0.00%	0
TOTAL			14

Does your organisation genuinely deliver products, aims or policies which are environmentally friendly ?

ANSWER CHOICES		RESPONSES	
Yes, my organisation backs up its claims and I see this diffused throughout the organisation		28.57%	4
Higher management may have this perception but at my level nothing actually happens		7.14%	1
We do the minimum to meet our obligations with respect to industry regulation on environmental policy		28.57%	4
Other (please specify)	Responses	35.71%	5
TOTAL			14

Appendix G

Appendix G

Strategy

1. Does <NAME REDACTED> **have a formalized strategy that reflects the goals and objectives of the organization?**

<NAME REDACTED> discusses the formalized strategy which has been agreed primarily between David and the board. The group wide marketing plan is the representation of the functional implementation of the strategy. More recently it has allowed them to align the different functional teams so they are guided by the business strategy. Their strategy has adapted to place a greater emphasis on the voice of the customer (VoC). <NAME REDACTED> believes that while they are improving year by year there is still room for improvement in the context of aligning teams and integrating the strategy into the functional aspects of the business.

Yea we do. We have a formalized strategy that sits at a pretty high level, agreed between David and the board primarily. And then we have cascaded that down into a functional marketing strategy which forms the basis of our group wide marketing plan. And we've taken the leave from that overarching marketing strategy to build out pillars and kpi's off that. Um I think we've, for the first time this year, we've also built in a disciple across all of the functional teams who are all working off a common strategy template and are all feeding off some, maybe not all, of the overarching business goals. They don't necessarily all apply in equal value to all disciplines. In addition to that we have also taken the liberty if you like to place a much greater emphasis on customer first as a mentality to our plan which was not in the over arching business strategy but it has been something that has evolved to gain strong support from David over time. I think we've been on a journey with <NAME REDACTED> and making that progressively stronger year by year. There is still a lot of room for improvement, to be more integrated, built to be more cohesively amongst the teams from the ground up. But yea, we do have a strategy and we are following it, and we are going into next year at a pretty aligned space in terms of focus areas.

2. Does(would) environmental consideration be apart of this? And if so, how would it be reflected?

<NAME REDACTED> spoke about two primary areas that environmental consideration is reflected in their strategy. The first revolves around a future proofed ethical business model. This considers the implementation of circular economy principles with two main objectives. The first objective is to retain customers and the second to retain the value add of components, parts or product through recovery and reuse. They have set a goal for changing some of their product to an alternative reusable/refurbished material by a certain date to enable this. The driver comes from managing risk of raw materials supply and to reduce the environmental impact – since this would eliminate the use of some materials thought to be an environmental hotspot. The second primary area involves closely looking at packaging and looking a number of different ways to reduce or remove plastic and the total quantity of packaging used from supplier to consumer product. This was initially driven by a project that works to standardize packaging and was later seen as an opportunity to take a step-change in improving the environmental footprint within the scope/objectives of the packaging project.

Yea it absolutely is. So if you look at our high level business plan, one of the four key focus areas talks about future proof ethical business model and that has tangible goals within that around environmental consideration. We've built that into our marketing plan in a number of different areas. One is around some key servitisations and model changes that we are looking to roll out. So one of those is a, preparing for a circular economy business model into the future. Designing our products to be modular, to be reskinned, and repurposed. We have recently put forward, in fact we sent a note out to shareholders, around this principle of upgrade for life. So once you are <NAME REDACTED> customer in the future off the back of our Turoa launch you can send back your Turoa product to us at end of life and we will give you a discount off a future <NAME REDACTED> purchase. So I guess it's a two fold idea, one is maintaining a customer beyond the life of a product, and the other one is that desire to then be able to repurpose or reuse those stainless components. Equally we have set out a mandate around wanting to achieve, its still to be validated, in fact we've got a session tomorrow around this, around materials strategy for the future. SO we have put a statement in the ground which says that by 2030 that we want 50% of our tapware to be in stainless steel. There are some practical challenges around achieving that. The ambition for change in that material space is 1. Driven by our desire to balance our risk of raw materials supply and it is very much the other side of that coin is, and I would say it is very much equal weighting, is around our desire to reduce our environmental impact by eliminating the need for chroming in a large portion of our range. Now that story might evolve from being stainless only to incorporating other more progressive metals, it might be printed metals vs cast or machined, and we need to work through that and make sure we are not in a place where we make a move to cast stainless steel and we find that actually the way that you cast it is has you know other environmental implications you know that offset the benefit. So yea so those kind of the key focus areas at the moment. In addition to that we are also we are literally just kicking off an over arching packaging project now. Which is aimed at looking at our entire packaging eco system from, finished goods, to shipper, to palatization through to bill of materials that goes inside it, and even the way the inserts and structure and internals of packaging are developed. And we have set out some fairly ambitions goals around reducing packaging material by 30%, by striving to eliminate plastic from our packaging altogether, and from aiming to reduce our carbon footprint through less freight as well, by being more efficient through our palatteization – with a 20% improvement in carbon footprint that we are chasing there as well. So that project has the propensity to save us a huge amount of money and have a significant benefit from an environmental standpoint as well. We do historically have a lot of, our approach to developing products has been to develop something in isolation and then typically leave it and then move on to the next thing. We find that we do a review of the bill of materials, packaging structure, across a dozen different tapware ranges we find that they have different DOMS for no good reasons other than at a point in time sometime decided that we didn't need this insert or we didn't need tube spanner to go in this particularly pack but we've never kind of tackled it as a whole, by saying this is our approach to it, and reduce wastage and increase our efficiency across what we do.

How did you quantify, or validate, the importance of reducing packaging and eliminating plastic, where did that come from?

Its kind of been built up from multiple sources. If im to be honest, the initial motivation was about trying to achieve a consistent brand expression through packaging. Youll be familiar with the fact that we have in recent years with our premium launches we've moved to a full colour individual boxes per sku, which has, you know, probably enhanced our premium look of our packaging, and maybe the status of our brand on shelf, but its been slightly misguided in the sense, because of the cost and complexity of handling individual boxes per sku we've never actually managed to roll it out across that catalogue, because the time and cost to do that was prohibitive, and the reality of the sticker on box today its much cheaper and much more efficient and a lot less raw material that we are dealing with and a low less raw packaging inventory we have to hold, so that was the genesis of it was our current approach to packaging, is not working for us it can't be just be about what we do for the new, we have to fix what we have today, but with that desire in mind, we then looked at all of the inefficiency that exists across our network, that results in us having this schizophrenic approach to the way the brand turns up, so we have full colour boxes, for a wiapori basin mixer in Australia, but in New Zealand we have a brown box with sticker on box, and New Zealands approach to that would be, we'll we're trying to keep lean, but actually, the complexity of that is worse than if both were in full colour boxes so in the case theres actually more wastage. So that conversation lead to a huge opportunity for us to save money by reducing the complexity in what we do to align markets behind common approaches and then off the back of that we said well, if we are doing all of that work now, and we are stepping back and looking at everything how would we take it a step further and say could we find a way to eliminate plastic altogether, or could we find a way to make a step change environmentally. That's bigger than just aligning markets behind common packaging.

There have been a couple of examples highlighted, we supplied a local, not for profit, called litefoot. In Auckland who partner with clubs and other things around new Zealand to try and reduce their environmental impact and actually save money along the way. And reducing water is a key part of their focus, so we supplied them a whole lot of aerators, and we picked the wrong item code and sent them 50 aerators in individual plastic bags, even tho we actually had a bulk code set up, but it highlighted the issue to us that , you know, do those aertators need to be in individual bags, and if they do is there a way we can make them more than single use and avoid that kind of unnessassary impact.

3. ***Start by explaining Portfolio Management tools, what they are and how they are used.*** **Do you have a portfolio management system or tools that you utilize to help decide what products should have priority or how to distribute resources?**

We have an NPD prioritization tool which grew up through our Australian business and its something we have adopted through the group function and it basically has a series of metrics that define the relative importance of one project vs another and we use that to rank our projects and prioritize what we are going to do. In addition to that we have a product architecture matrix that we use to map our portfolio and to make consider choices around what products need to move or where gaps exist in our portfolio. We've recently made a change to it, to give it a bit more sophistication. We historically used a fairly simple good, better, best type [likert] scale, but we had a real issue with technology getting too much weighting in the hierarchy of premiumization within that scale so we're now working with a matrix which applys both a lens of design, classic contemporary designer, and then premiumization which is a combination of different factors from technology through to price point through to materials what ever else and that helps to define why something would sit in a particular quadrant.

How is environmental aspects reflected within this?

Id say today we're not, its not an active part of that consideration but it absolutely could be, so we haven't as yet defined, say our premium products would have more environmental benefits than our cheaper products or vice versa we haven't defined that something with positive environmental impact would get a higher weighting, would get a higher ranking than something else, we haven't done that yet. It has primarily been based on the classical measures, such as return on investment, size of opportunity, speed and complexity, innovation. Things like that.

4 What do you think of the culture at <NAME REDACTED>

with respect to environmental issues? Is there good awareness of what can or should be done?

I think it is confused. So I think that there is real pockets of heightened awareness and real interest and a frustration on the inability to pervade through to the culture and be really meaningful. And that exists from the top down. And someone like David is very passionate about this stuff and we undertake a number of initiatives every year that aim to take us in that direction but I don't think we are quiet fully aligned on the role that, say the environmental philosophy through the business plays in our ultimate success

4.1 If you were to ask different teams (GET vs GMT) what would they say?) Would there be alignment?

There wouldn't be total alignment, there would be strong points of view in some teams vs others I think. And I think even within teams you know, you've got individuals like SM who has high awareness of these things and very passionate about it, and well educated on these things and you've got Marketing who are evolving to think more and more that way but it's a journey. And you've got probably pockets of other teams that think more traditionally about, just, how much we sell and our perception of what the market wants, and I think we are slowly sharpening the pencil on that so we are bringing more of these things to the forefront of our thinking and our prioritization we are actively planning for a future change in the way we do business. One thing I forgot to mention which is a part of the packaging project is one of the aims we're going to try and build into that model is design packaging for secondary use as well so if we do need to take a product back in the future that maybe the box that it came in could house the old product getting back to us for example that is probably in its simplest for, so there is more and more conversation heading that way, its not fully joined up in terms of placing something say environment at the forefront of what we do.

Current Products - Process

5. Turoa is one of the most recent products that has been through the NPD process – how would you describe the process and how it helped get the product from idea to launch.

That's a good question. I think the process itself was fine, so I think the process that we follow in terms of our gating system and the subsequent requirements for each of those gates is not an issue for us, what becomes an issue is our ability to adhere to those milestones and when our timing slips we would often keep going even if we've slipped say a gating meeting because we cant afford to miss that, miss that launch date. I think with V we were, that project was a step into the unknown, we were dealing with new materials, and new suppliers, and I think when we look bvack I think we realise that there was a whole lot more risk in that project that we imageined up front so that created a lot of changes in the direction of the project where we spent several months with H on a tapware solution before we realized that we couldn't do it so then we had to change tack to a new supplier , we probably unestimated how complex working with machined stainless parts was even for a third party expert, so I think the biggest reflection on V is not so much the process but it's the squeeze of time and pressure and the, perhaps inability for us to actively manage the risk fast enough, and to change and be dynamic quickly enough, to recognize when that risk was too great, and to squash it before it became real.

6. At the beginning of this project, and other projects like it, do you define a project brief?

6.1 Can you give me a few examples of the important criteria that goes into the brief that you use as a primary reference throughout the project?

We absolutely do, we put a lot of rigor in to what we would call, the state it phase, so the initial conceptual idea is a one pager, that pretty much outlines the space that we want to operate in, we think its roughly in this segment, we think roughly the size of prize is here, but when it gets past that idea phase we put a lot of rigor into the state it componenet which deals with all the business aspects such as the size of prize, we get markets to input, their view on pricing and size of pricing information and we collate that together into a series of target sku's target cost information, id say its primarly focused on some of the more traditional business metrics, so I think if you take V as an example the idea for S I think was partly grounded in design, and party grounded in environmental benefit or perceived environmental benefit, and those two kinda came together as if you like a happy story, I think that if you went right the way back to state it I don't think we would have been really clear that one of the core objectives was that we need to be in stainless because this is a step change for us environmentally I think that story evolved, and our thinking through the course of the project and to be fair it has kind of become a catalyst for change almost by accident, whilst it was design led, I would say, pretty quickly into the project we identified the additional benefits that S could potentially bring and present an evolved story around what that meant and help that to define the ultimate position.

7. What is the evaluation criteria that is discussed at the gating meetings for these types of projects that allow for go/no-go decision support?

It does vary at the different gates, but it I do focus on the state it gate, we would evaluate basic financial metrics like, size of prize, volume, dollar reture, target costs and expected margin. Those would be your core financial measures. We could evaluate a level of complexity around the project, how many sku's, where would we make it, or source it, do we have resources in place to make it happen. So those are the kind of keys things, it then gets accessed against the other project ideas or ongoing projects we have to say, how do we squeeze it in. and if we other stuff on the go, in the way, is it more or less important and would be consider adjusting the timeline of other projects. Some of the softer metrics, non-financial metrics, like environmental benefit, packaging, what ever else those things are captured in the scoping documentation but they are probably as yet not a huge amount of rigor in those measures being applied in the gating process, I think they are talked about but tradionally what defines a prioritization here is still probably the classical business measures.

9. At the early stages of product development [Dream it stage] is environmental consideration part of the selection part of the concept selection process?

It is. It is captured in that initial document, because that is really a concept that is saying do we think that this is a good strategic fit, does the idea make sense, do we think that there is a gap in the market for something like this. So it absolutely does, so if you kinda went back to V right back from the start, really the core idea that drove the V was the shower experience through the V spray it wasn't an environmental story primarily, so if you went back to the dream it I don't think that you would find it there. However if we were developing a new S product now that would be a core part of our thinking of what we want to evolve to . so I think that I symptomatic of how the business has evolved during that project to be more conscious about those things. Faced with something that made you 20% less margin but was better for the environmental, im not quite sure we are there yet with having a balanced view of how we need to evolve our organization to see something like environmental benefit being a key part of our financial success. We talk about that at a high level, we know inherently that we need to evolve that way, its not quite tangible yet as we assess project by project how you would critique.

10. Turoa was designed for a lower flow but after consumer testing it was decided that a higher flow was preferable, was the environmental aspects included in any type of selection process for the flow restriction? (ie scoring charts or weighted matrix) Would this type of selection process be helpful? If not why?

I think from the very start there was a desire to get that flow rate as low as we could and that was driven from a desire to minimize our flow impact but also to recognize opportunity in pockets of the world now where regulations are defining that, so if you look at California where we have started selling some product into, that being said, what is at the heart of business and our brand is experience. If I was to say one thing that defines what we do, particularly in showering it is about experience. And for me that we've always got this balance, between we talk a good game at least in shower to say we are proud that we can deliver a good experience with lower flow rates. And that is one of the beauties of our technology through Sj and Aj we don't have to compromise to give you a crappy shower in order to reduce your flow rate. What we found V though, was admittedly it was only qualitative but we found, that when consumers were switching from the shower they currently use to V the experience was compromised, too far to a point where 70% of them said they wouldn't change . So regardless of how good it looks, and how much they like the variable spray , and how much water they could save that was not enough for them to compromise significantly enough for them on their experience or their belief that pressure was king. The move from 7.5 to 9 was based around the view that 7.5 we were compromising the experience too much. And one of things that is really interesting is that space is that environmental benefit through flow rate is only good if someone wants to use that shower right, there will be a cross section of the market for which low flow will be the number 1 thing, but actually for most people they would still want to have a reasonably good shower and if they could save a couple of litres per minute and still have a pretty good shower, then that tends to get traction. We have a lot of conversation with watercare with this issue where they have talked about their learnings in the past of trying to push out really low flow shower heads and even in other countries where they have been mandated and sent out through the post for free, people were just refusing to use them because the experience was so bad, and the learning that warecare came in, and even tho they have an even stronger objective than we do around that was that you have to find that sweet spot where you don't compromise the experience too much and turn people off actually using it. Because you are only going to realize benefit if people adopt it, not blindly thinking that the lowest possible is the best and so that's kind of guided our thinking where the heart of our brand is transforming everyday, is about that experience about that <NAME REDACTED> spray can give you, and the emotion that makes you feel, and the flow rate story today for us is an important supporting story but its not the number one driver. We would say today that experience is more important than low water use. But low water use is still important, its not as important as experience therefore if you are trading off you wouldn't compromise experience too far. If you were faced between a choice between one or the other, we would probably say experience rules . that might change for us over time, and that's the position we take today, and our desire is, can we do a bit of both , so were we get to with 9 l, yea it's a compromise of what we thought we could do with 7.5 but our view is that if we pushed it down to 7.5, we would actually sell a lot less showers because people would be underwhelmed by the experience, so that still became, at least in nz, the predominate selection criteria.

Future Products – Process

13. A shower system can be improved by recovering water or energy, or alternatively by changing the product system to incorporate circular economy principles that would take ownership of the use and disposal stages of the products life. Is <NAME REDACTED> **actively identifying or developing new technologies that could improve the environmental performance of new or existing products? Can you give an example?**

We do that in our R&D team. I think that there is a good culture around understanding that, particularly when we develop new sprays or when theres' new innovation that comes out from competitors. A good example of that is N we did a lot of evaluation work around N to understand there flow rate was low but their heat loss was significant there were other factors that .. ya know.. experience was rubbish. I think we do quite a lot of analysis to surround those things, but it tends to be focused around either when we're doing a big piece of innovation or somebody else is. In terms of ongoing standard benchmarking we could probably do a bit more in that space. To see how we compare on all of those measures

13.1 Do you monitor market trends that relate to eco-design and attempt to incorporate these into the NPD process? Would you consider products systems such as heat recovery or other step change products systems.

We are dabbling in third party developed tech, around water flow and that type of thing and we have got a project around smart water metres and if we could evolve nefa to be in that space. To behonest we are probably in the space where we …what I believe quite strongly is that in order to move forward in that environmental space you need to tag it to a tangible benefit for now. So I fyou talk about say the conversations that we might have had with watercare it might be, well you've got to show the home owner how they can save money, from using less water, because they get a little bit off their water bill but they actually save the energy that goes into heating it. And therefore if you can get that in front of a consumer and then you say you can use less water, that's good for the environment, you want to do that right? Most people would say yes, but if you say, well you could say you save 10 dollars a month, that's the hook that gets people to act. Doing good in isolation or how that makes me feel for me, that is typically not enough, to at least get the masses to convert or it takes a period of time before that social conformity becomes normal. And in my view its often driven by when that becomes a ticking point from something that I should do from something I feel peer pressured to do, so weather that be the antisugar craze where we've moved from being a small movement, from being I don't want someone to bust me eating a chocolate bar in my car, because I feel embarrassed about eating sugar and I think that's true of our game as well, that we need to find what the hook is beyond just doing good, that allows us to build a really compelling story around that so that we can recognize meaningful change, and achieve our business metrics at the same time. And its entirely possible through all of those things to do that, we know that using that using less water has multiple benefits, and if we can bundle those together into a compelling story and say by the way your shower experience is still amazing, what's not to like, but if you just say, you can use 2 l less per minutes, most people say that's nice but its not enough to convince them to change. For me that's how, we need to evolve our prioritization and thinking around some of those things if we talk about heat recovery, or use of water, how could we build a compelling story, beyond that, not just about doing good, or doing the right thing. Even tho that is a core motivation of what we do

Discussion Questions

Earlier in the month I presented an overview of where <NAME REDACTED> **might benchmark with respect to NPD best practices:**

Does your current practice limits your ability to engage in eco-design efforts and if so in what area?

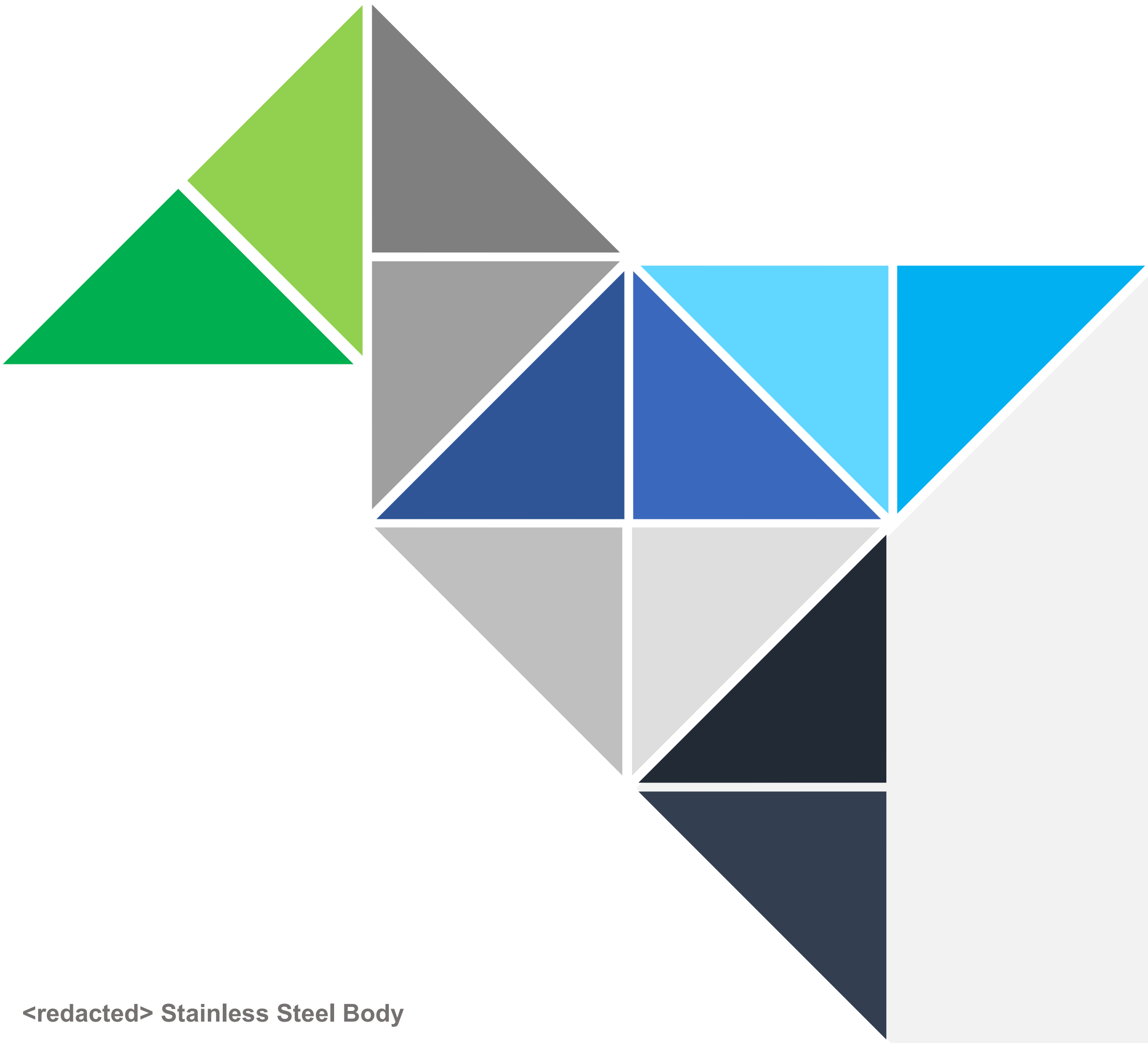
Some practitioners believe that additional eco-design practice should be integrated into the current formalized processes to promote sustainable product development.

Ie Identify the eco-design guidelines at the start of a project or integrating eco assessments (like an LCA) to provide additional information during product development.

Do you think these types of guidelines or tools would change how you develop products from idea to launch?

I think they would certainly help. It starts with us being really clear of hierarchy of importance of those measures vs others in our business. And as I said I think theres a heightened awareness of that and we are progressively changing, some of those measures through our process would absolutely help. The most important in those is defining what we want upfront. Because a lot of those decision feed into the financial metrics. The target costs. If we are to build in an certain environmental benefit, or an installation benefit, or some other over and above benefit , other than the normal product that is fresh and new, and you could probably factor in some additional cost, but you would trade off that benefit that gives us x amount of added value at the other end, so I think that's the part where it could be quite valuable for us, if we probably had a stronger lens upfront on what that could be and even have perhaps a more robust discussion upfront around how we could make it better without compromising cost or other metrics. So I think that there is definitely opportunity to bring more rigor to that space

Appendix H



<redacted> Stainless Steel Body

LIFE CYCLE ASSESSMENT AND COMPARISON

OVERVIEW

Produced by Mike Horrell

INTRODUCTION

This document is intended to provide an overview Life Cycle Assessment (LCA) of a stainless-steel pipe which are the dimensions used for the <redacted> body. The LCA provides detailed information relating to the environmental performance of this part of the product across different environmental impact categories.

The Life Cycle model includes extraction of raw materials, manufacturing of the part in China, transportation and distribution to and within NZ, and disposal to landfill. The Use phase is excluded (see notes).

Case scenarios are included allowing stainless-steel to be compared against alternative options for this part. These include;

Chrome Plated ABS Plastic

Chrome Plated Brass

304 – Stainless Steel (Currently used)

316 – Stainless Steel

304 – Stainless Steel Recovery, Refurbished and Resold [1]

RESULTS

ReCiPe 1.08 is the impact assessment method that has been applied in this LCA. Relevant environmental indicators have been reported in three categories (energy-, toxicity- and resource-related categories). **For most environmental indicators, Stainless 304 performs worse.**

To assist with interpretation of the results, a rating system (in the form of one star (least robust) to five stars (most robust)) has been provided for each environmental indicator based on how robust the environmental indicator is[2].

Each indicator is normalised to the Stainless 304 scenario - relative to Stainless 304 the scenarios with a lower percentage perform better while a higher percentage performs worse with respect to the enviormental impact.

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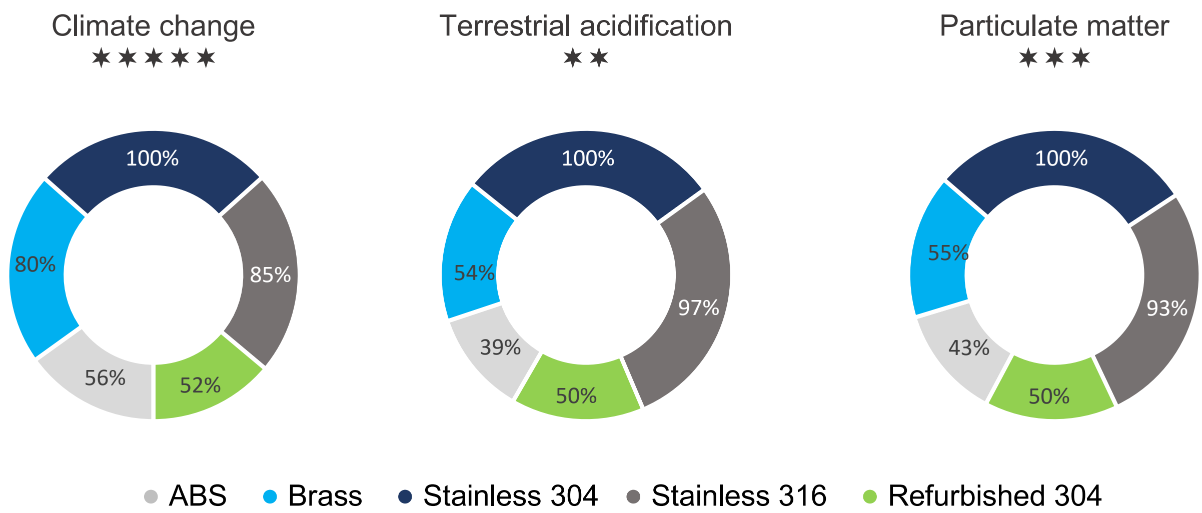
[1] A case where the stainless-steel product is returned to <redacted>, then machined and polished to restore the product to its original finish and then resold to a new customer, effectively extending its life through a Circular Economy approach

[2] Robustness factors are based on a 2018 European Commission report that provides a weighting method intended to help producers identify relevant impact categories (Sala, Cerutti, & Pant, 2018)

OVERVIEW OF ENVIRONMENTAL IMPACTS



Climate Change

Global warming potential is one of the most important environmental impact categories and remains consistent and robust across different LCA impact methods. Manufacturing of products is a human activity that contributes to global warming. Producers considering environmental aspects can take actions to minimize the impact their products have.

In this LCA the manufacturing phase is the major contributor for global warming across all cases (Figure 1). All material alternatives outperform the existing material used (stainless 304) for the <redacted> body with ABS plastic one of the best alternatives producing 43% less emissions than stainless 304. However, should the 304 stainless part be recovered, refurbished and resold it would perform better than all cases (48% improvement from the stainless 304 case).

Figure 1 Life Cycle Stages Contribution CO2

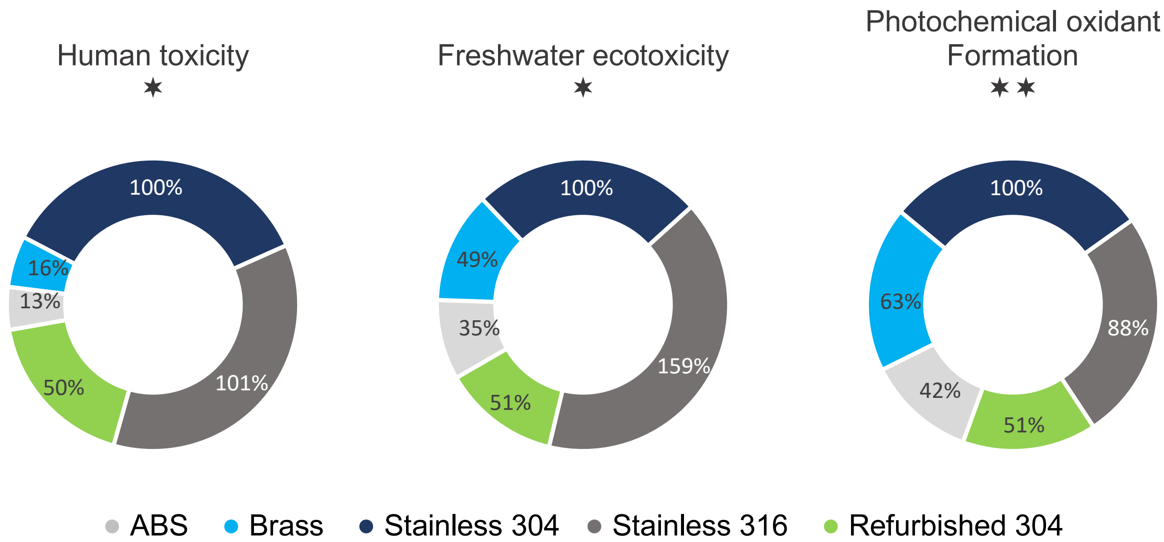
Acidification terrestrial and freshwater

This indicator represents an increase in acidity which leads to decrease in forests and biodiversity. Often this is caused by nitrogen and sulphur. Stainless 304 performs the worst in all cases primarily due to the manufacturing of the stainless steel 304 (75% nitrogen oxides, 14% Sulphur dioxide). The chrome plating process contributes to 63% of total emissions for the Brass case, and 87% for ABS.

Particulate matter

Particulate matter is often the result of burning fossil fuels which emit sulphate and nitrate aerosols. This particulate matter causes breathing difficulties. The case results are similar to the climate change indicator in that all cases perform better than stainless 304. The manufacturing phase contributes the most to particulate matter across all cases. For stainless 304, 62% is from inorganic emissions to air (17% nitrogen oxides, 45% sulphur dioxide) and 31% from particles to air (Dust PM10).

TOXICITY AND HEALTH INDICATORS



Human toxicity and freshwater ecotoxicity

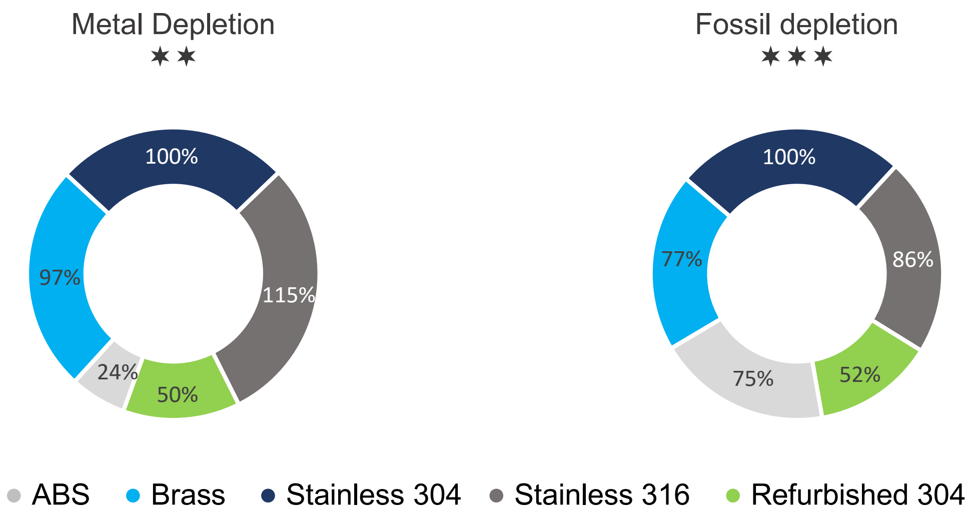
Human toxicity and ecotoxicity accounts for the environmental persistence and accumulation in the human food chain (exposure), and toxicity (effect) of a chemical. Stainless 304 performs worse against Brass and Plastic and is comparable to Stainless 316 for human toxicity. This is primarily due to emissions to air of Arsenic (+V) and Silver in the manufacturing phase.

With respect to Freshwater ecotoxicity, the manufacturing phase of stainless contributes 70% primarily due to emissions of Nickel to fresh water.

Photochemical oxidant formation

Photochemical 'smog' is formed in the atmosphere as a result of reactions between certain organic compounds such as hydrocarbons and nitrogen oxides and are often implicated in problems such as crop damage, human health issues, and acid precipitation. Stainless steel performs worse compared to all other scenarios.

METAL AND FOSSIL DEPLETION



Metal depletion and Fossil depletion

Metal and fossil depletion are arguable less relevant when assessing the environmental performance of the <redacted> body. Since the environmental impacts associated with extracting fossils fuels and metals are captured in other indicators, they are often viewed as economic rather than environmental indicators i.e. depletion of resources is largely an economic issue because incentives for recovery of resources after their first use are controlled by economic instruments.

For metal depletion, Brass and Stainless scenarios are comparable. For brass, this is due to the depletion of Copper in the manufacturing phase. For the stainless scenarios, the primarily contributor is due to the depletion of Chromium and Nickel.

With respect to Fossil depletion, the manufacturing phase contributes over 90% for all scenarios and is due to the extraction of non-renewable energy resources including Oil, Coal and Natural Gas.

Summary of scenarios and recommendations

A key consideration for improving the environmental performance of the <redacted> body should be the inclusion of a recovery, refurbish and repurpose program. Despite a high recycled content present in stainless steel 304 it does not perform better from an environmental perspective compared with the alternatives. Therefore an eco-strategy should be to include **Circular Economy** principles and **recover** the body from the customer at the disposal stage and **repurpose** to extend its life cycle. There is strong evidence that in doing so the environmental gains would outperform almost all material alternatives across most of the environmental impact categories.

Greening of the supply chain is also an important consideration. Production practices and energy types used in manufacturing has a significant impact on the environmental performance of products and therefore gains can be made by strategically selecting suppliers and distribution channels or moving some production in-house. As an example, when comparing chrome-plated ABS plastic produced in China with production in New Zealand, New Zealand shows over a 50% improvement in carbon emissions primarily due to a cleaner energy mix (Figure 2).

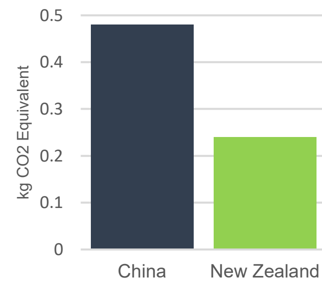


Figure 2 Comparison of Chrome Plated ABS Plastic

Additional Notes

Stainless Steel Recycling

Stainless-steel marketing reports that 90% of existing stainless is being recovered and used in new stainless steel products (Stainless, 2009). However, the reported average of recycled content in most stainless steel products is approximately 60% (Stainless Steel Information Centre, n.d). The stainless steel datasets used in this model obtained through LCA software (GaBi Professional) supports this and are based on European production for 304 and 316 of 54% and 65% recycled content respectively.

Use Phase

The use phase has been excluded from the model. Despite strong evidence that the use phase dominates the life cycle based environmental impacts of a tapware product, research on what influences change in environmental impacts during the use phase is still ongoing. Moreover, <redacted> cannot control how the end user chooses to shower even if it can influence this behavior. For example, implementing a flow restrictor may lead to environmental improvements at the use phase but this is not a certainty – as the user may instead choose to take longer showers. Therefore it is better practice to separate out the use phase, and not to trade off any assumed environmental improvements in the use phase against increased environmental impacts at other parts of the life cycle where the data are significantly more reliable. In addition, this LCA model is solely concerned with the environmental impacts of the external body of the product (excluding the internal engine) and therefore the use phase is out of scope.

References

Sala, S., Cerutti, A. K., & Pant, R. (2018). Development of a weighting approach for the Environmental Footprint. Publications Office of the European Union, Luxembourg: European Union.

Stainless Steel Information Centre. (n.d). Sustainable Stainless Steel. from http://www.ssina.com/sustainability/#rcont

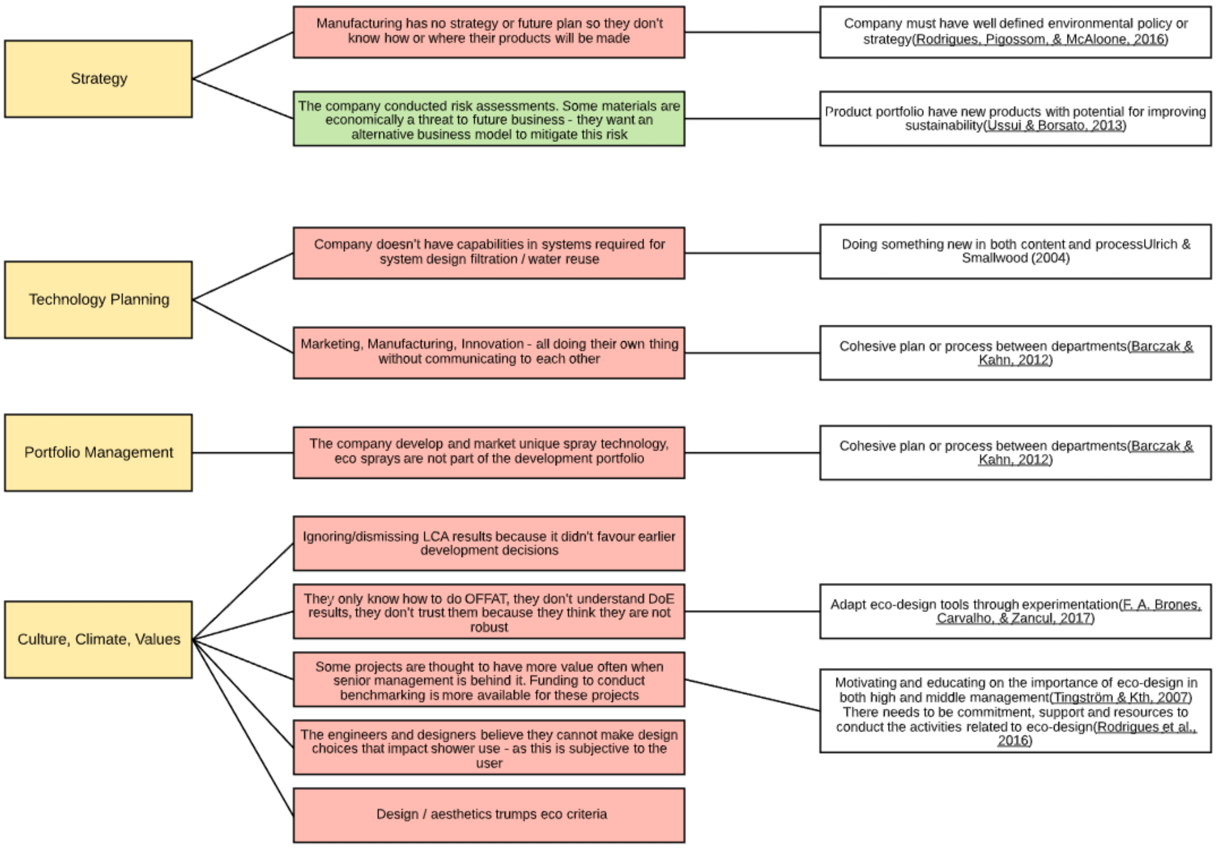
Stainless, W. (Producer). (2009). Recycled for lasting value. Retrieved from http://www.worldstainless.org

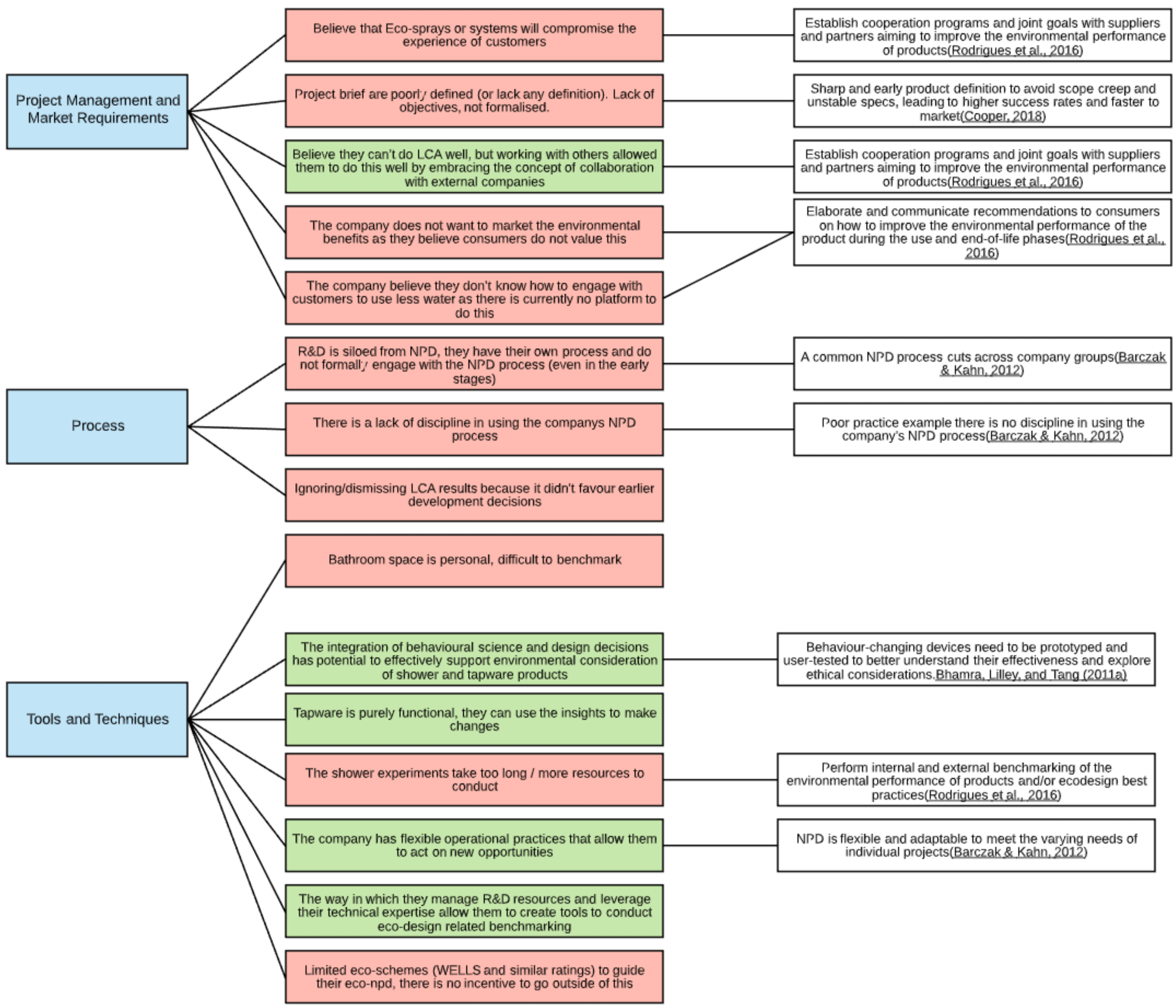
Appendix I

Appendix I

Barriers in RED

Enablers in GREEN




Project Management and Market Requirements
Believe that Eco-sprays or systems will compromise the experience of customers
Establish cooperation programs and joint goals with suppliers and partners aiming to improve the environmental performance of products(Rodrigues et al., 2016)
Project brief are poorly defined (or lack any definition). Lack of objectives, not formalised.
Sharp and early product definition to avoid scope creep and unstable specs, leading to higher success rates and faster to market(Cooper, 2018)
Believe they can't do LCA well, but working with others allowed them to do this well by embracing the concept of collaboration with external companies
Establish cooperation programs and joint goals with suppliers and partners aiming to improve the environmental performance of products(Rodrigues et al., 2016)
The company does not want to market the environmental benefits as they believe consumers do not value this
Elaborate and communicate recommendations to consumers on how to improve the environmental performance of the product during the use and end-of-life phases(Rodrigues et al., 2016)
The company believe they don't know how to engage with customers to use less water as there is currently no platform to do this
Process
R&D is siloed from NPD, they have their own process and do not formally engage with the NPD process (even in the early stages)
A common NPD process cuts across company groups(Barczak & Kahn, 2012)
There is a lack of discipline in using the companys NPD process
Poor practice example there is no discipline in using the company's NPD process(Barczak & Kahn, 2012)
Ignoring/dismissing LCA results because it didn't favour earlier development decisions
Tools and Techniques
Bathroom space is personal, difficult to benchmark
The integration of behavioural science and design decisions has potential to effectively support environmental consideration of shower and tapware products
Behaviour-changing devices need to be prototyped and user-tested to better understand their effectiveness and explore ethical considerations.Bhamra, Lilley, and Tang (2011a)
Tapware is purely functional, they can use the insights to make changes
The shower experiments take too long / more resources to conduct
Perform internal and external benchmarking of the environmental performance of products and/or ecodesign best practices(Rodrigues et al., 2016)
The company has flexible operational practices that allow them to act on new opportunities
NPD is flexible and adaptable to meet the varying needs of individual projects(Barczak & Kahn, 2012)
The way in which they manage R&D resources and leverage their technical expertise allow them to create tools to conduct eco-design related benchmarking
Limited eco-schemes (WELLS and similar ratings) to guide their eco-npd, there is no incentive to go outside of this

Appendix J

Analysis: Summarising Data Activity

"This summary will compress long statements into briefer statements in which the main sense of what has been said or observed is rephrased in a few words. Summarising, therefore, involves condensing the meaning of large amounts of text into fewer words." (Saunders, Lewis, & Thornhill, 2009)

All notes, transcripts, reports from data collection activities were combined into a single archive. The researcher then read through this archive noting or highlighting key points. To assist with this process the researcher used knowledge of best practice eco-design and NPD (from literature) to also identify any relationships the key points have with existing theory that may need to be further explored (in subsequent analytical activities).

List of key points identified in this process include;

Manufacturing has no strategy or future plan so we don't know how or where our products will be made
Company doesn't know anything about filtration / water reuse
The company develop and market unique spray technology, eco sprays are not part of the development portfolio
The company conducted risk assessments. Some materials are economically a threat to future business - they want an alternative business model to mitigate this risk
Marketing, Manufacturing, Innovation - all doing their own thing without communicating to each other
The engineers and designers believe they cannot make design choices that impact shower use - as this is subjective to the user
Lack of criteria in NPD process
Lack of environmental criteria in NPD process
Design / aesthetics trumps eco criteria
Ignoring/dismissing LCA results because it didn't favour earlier development decisions
They only know how to do OFFAT, they don't understand DoE results, they don't trust them cause they think they are not robust
They don't know how to conduct DoE or have the expertise to do it well
Some projects are through to have more value often when senior management is behind it. Funding to conduct benchmarking is more available for these projects
Project brief are poorly defined (or lack any definition). Lack of objectives, not formalised.
Believe they can't do LCA well, but working with others allowed them to do this well by embracing the concept of collaboration with external companies
The company does not want to market the environmental benefits as they believe consumers do not value this
The company is not good at doing LCA so internally they can't build it into the NPD process
The company believe they don't know how to engage with customers to use less water as there is currently no platform to do this
R&D is siloed from NPD, they have their own process and do not formally engage with the NPD process (even in the early stages)
There is a lack of discipline in using the companys NPD process
The shower experiments take too long / more resources to conduct
The company has flexible operational practices that allow them to act on new opportunities
The way in which they manage R&D resources and leverage their technical expertise allow them to create tools to conduct eco-design related benchmarking
The integration of behavioural science and design decisions has potential to effectively support environmental consideration of shower and tapware products
Bathroom space is personal, difficult to benchmark

Limited eco-schemes (WELLS and similar ratings) to guide their eco-npd, there is no incentive to go outside of this
Tapware is purely functional; they can use the insights to make changes
Believe that Eco-sprays or systems will compromise the experience of customers

Significance of these key points

It is also helpful to produce a summary that, in addition to providing a list of the key points it contains, also describes the purpose of the document and how it relates to your work and why it is significant. (Saunders et al., 2009)

Most of the key points can be used to compare with existing literature. From this it's possible to form some relationships that allow the researcher to make an initial assessment of some of the key points. This aids in determining if these points are enablers or barriers to eco-design integration into NPD. Therefore, the significance of this activity and the key points demonstrates a first step in conceptualising an appropriate framework (RQ1).

Key point	Relationship to literature	Barrier or enabler
Manufacturing has no strategy or future plan so they don't know how or where their products will be made	Company must have well defined environmental policy or strategy (Rodrigues, Pigossom, & McAloone, 2016)	Barrier
Company doesn't know anything about filtration / water reuse	Doing something new in both content and process Ulrich & Smallwood (2004)	Barrier
The company develop and market unique spray technology, eco sprays are not part of the development portfolio	Product portfolio have new products with potential for improving sustainability (Ussui & Borsato, 2013)	Barrier
The company conducted risk assessments. Some materials are economically a threat to future business - they want an alternative business model to mitigate this risk	Develop business, product and market strategies considering environmental trends (Rodrigues et al., 2016)	Enabler
Marketing, Manufacturing, Innovation - all doing their own thing without communicating to each other	Cohesive plan or process between departments (Barczak & Kahn, 2012)	Barrier
The engineers and designers believe they cannot make design choices that impact shower use - as this is subjective to the user	Take ownership of use stage (Rodrigues et al., 2016)	Barrier
Lack of criteria in NPD process	Subjective weighting / lack of robust evaluation at decision stage (Barczak & Kahn, 2012)	Barrier
Lack of environmental criteria in NPD process	Clearly define the environmental indicators and the methodology to be used during the gates (phase assessments) (Rodrigues et al., 2016)	Barrier
Design / aesthetics trumps eco criteria		Barrier
Ignoring/dismissing LCA results because it didn't favour earlier development decisions		

They only know how to do OFFAT, they don't understand DoE results, they don't trust them because they think they are not robust	Adapt eco-design tools through experimentation (Brones, Carvalho, & Zancul, 2017)	Barrier
They don't know how to conduct DoE or have the expertise to do it well		Barrier
Some projects are thought to have more value often when senior management is behind it. Funding to conduct benchmarking is more available for these projects	Motivating and educating on the importance of eco-design in both high and middle management (Tingström & Kth, 2007)	Enabler
Project brief are poorly defined (or lack any definition). Lack of objectives, not formalised.	Sharp and early product definition to avoid scope creep and unstable specs, leading to higher success rates and faster to market (Cooper, 2018)	Barrier
Believe they can't do LCA well, but working with others allowed them to do this well by embracing the concept of collaboration with external companies	Establish cooperation programs and joint goals with suppliers and partners aiming to improve the environmental performance of products (Rodrigues et al., 2016)	Enabler
The company does not want to market the environmental benefits as they believe consumers do not value this	Elaborate and communicate recommendations to consumers on how to improve the environmental performance of the product during the use and end-of-life phases (Rodrigues et al., 2016)	Barrier
The company is not good at doing LCA so internally they can't build it into the NPD process	LCA is systematised (Rodrigues et al., 2016)	Barrier
The company believe they don't know how to engage with customers to use less water as there is currently no platform to do this		Barrier
R&D is siloed from NPD, they have their own process and do not formally engage with the NPD process (even in the early stages)	A common NPD process cuts across company groups (Barczak & Kahn, 2012)	Barrier
There is a lack of discipline in using the companys NPD process	Poor practice example there is no discipline in using the company's NPD process (Barczak & Kahn, 2012)	Barrier
The shower experiments take too long / more resources to conduct	Perform internal and external benchmarking of the environmental performance of products and/or ecodesign best practices (Rodrigues et al., 2016)	Barrier
The company has flexible operational practices that allow them to act on new opportunities	NPD is flexible and adaptable to meet the varying needs of individual projects (Barczak & Kahn, 2012)	Enabler
The way in which they manage R&D resources and leverage their technical		Enabler

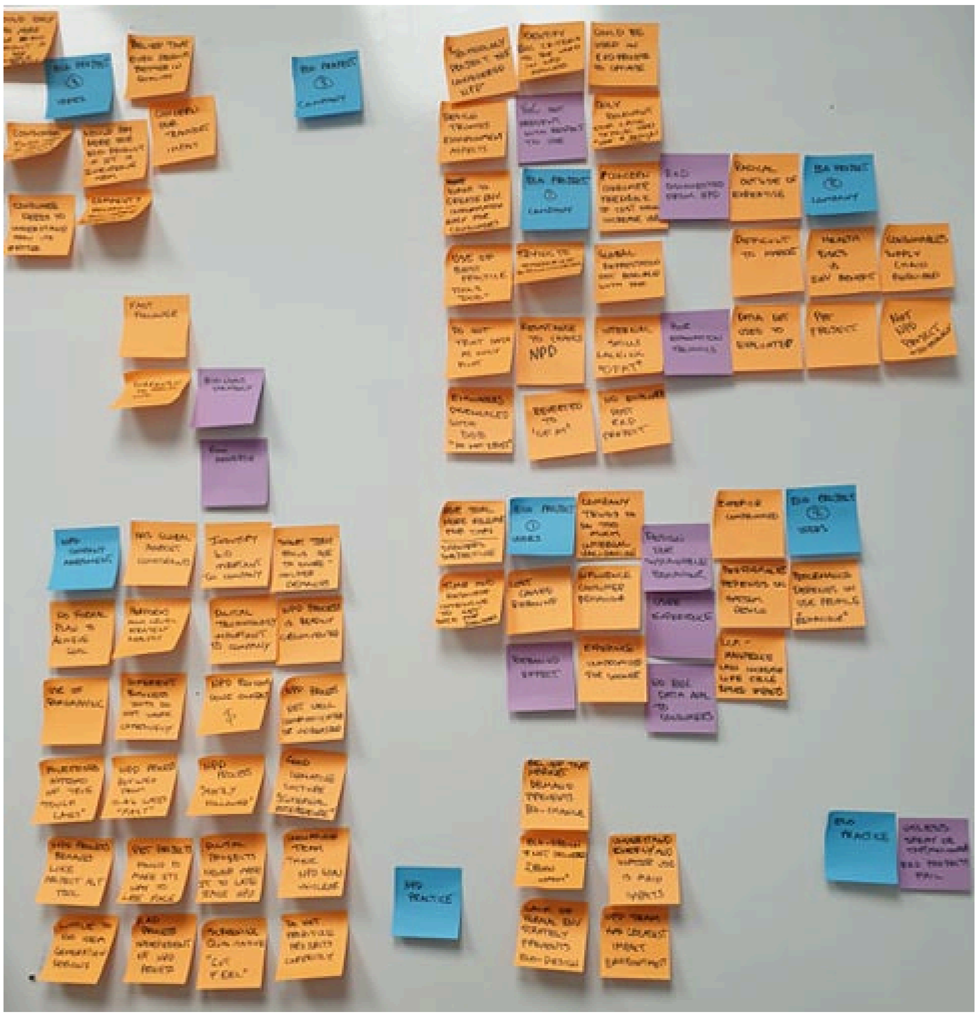
expertise allow them to create tools to conduct eco-design related benchmarking		
The integration of behavioural science and design decisions has potential to effectively support environmental consideration of shower and tapware products	Behaviour-changing devices need to be prototyped and user-tested to better understand their effectiveness and explore ethical considerations. Bhamra, Lilley, and Tang (2011)	Enabler
Bathroom space is personal, difficult to benchmark		Barrier
Limited eco-schemes (WELLS and similar ratings) to guide their eco-npd, there is no incentive to go outside of this		Barrier
Tapware is purely functional, they can use the insights to make changes		Enabler
Believe that Eco-sprays or systems will compromise the experience of customers		Barrier

Analysis: Categorising data

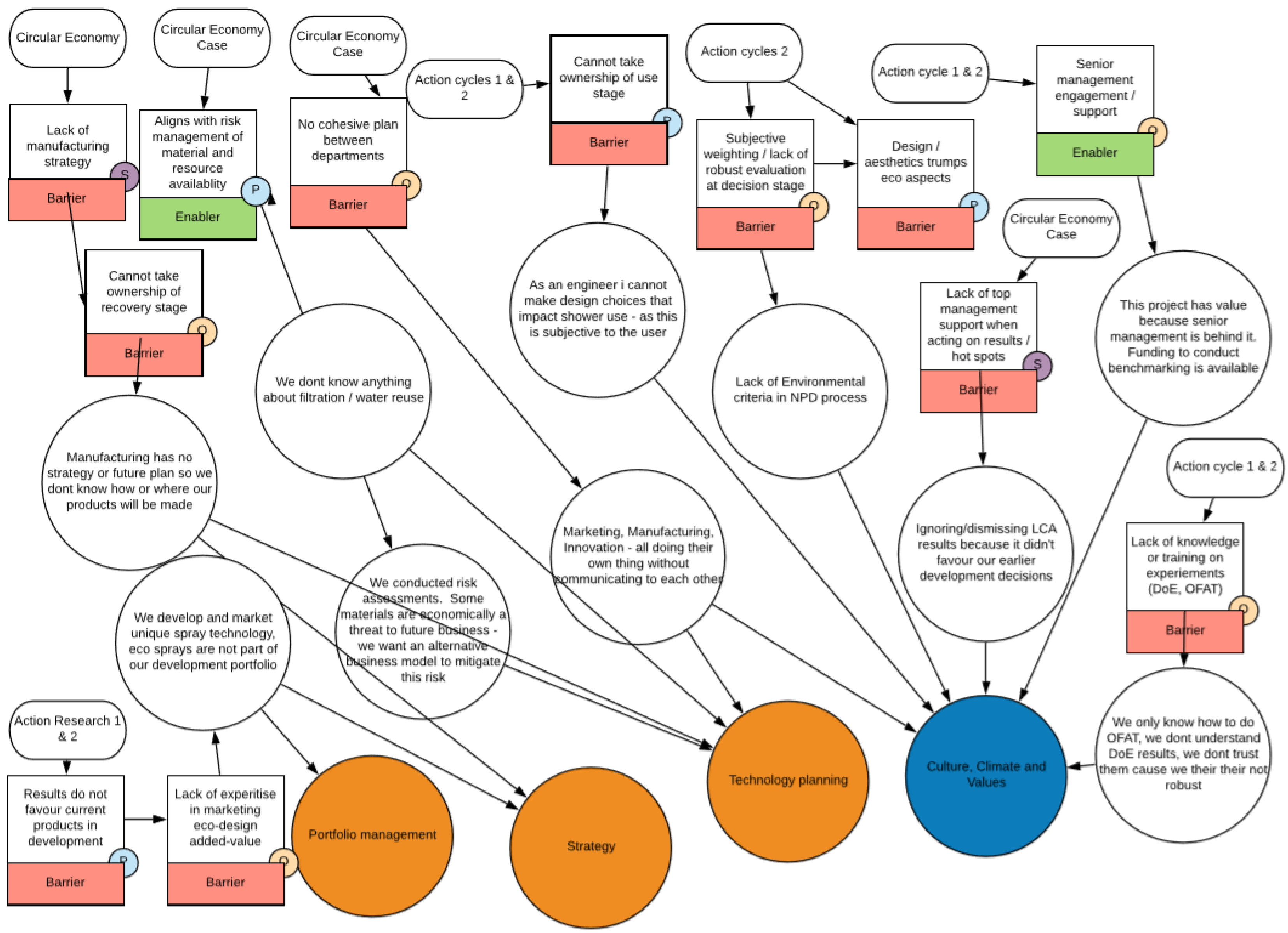
Categorising data involves two activities; developing categories and, subsequently attaching these categories to meaningful chunks of data. (Saunders et al., 2009)

At first the researcher attempted to order the key points (which represent chunks of data) into categories that reflect the elements on NPD. It was thought by doing this it would create a more meaningful connection to NPD theory.

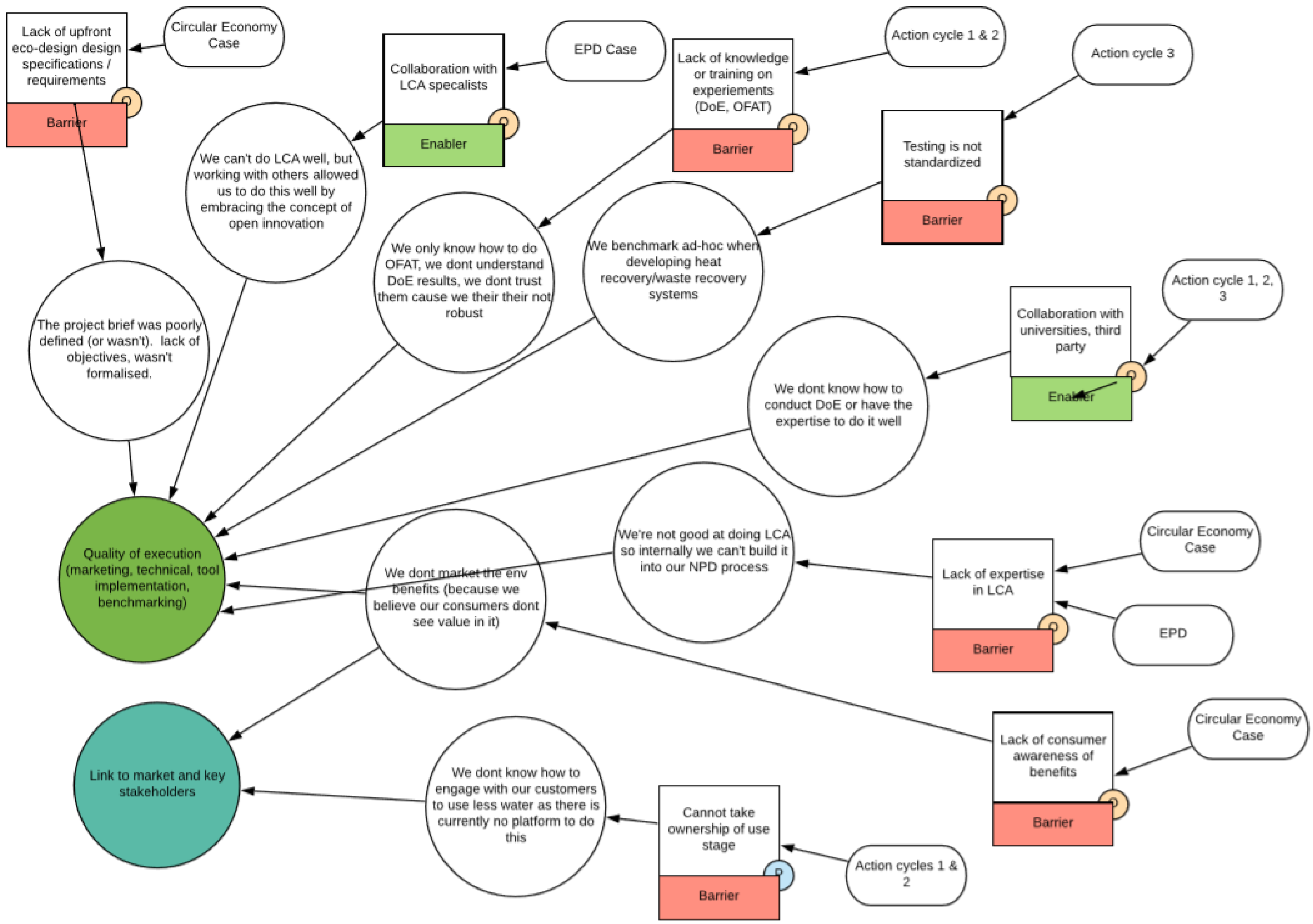
Affinity diagrams facilitated this process (example below).



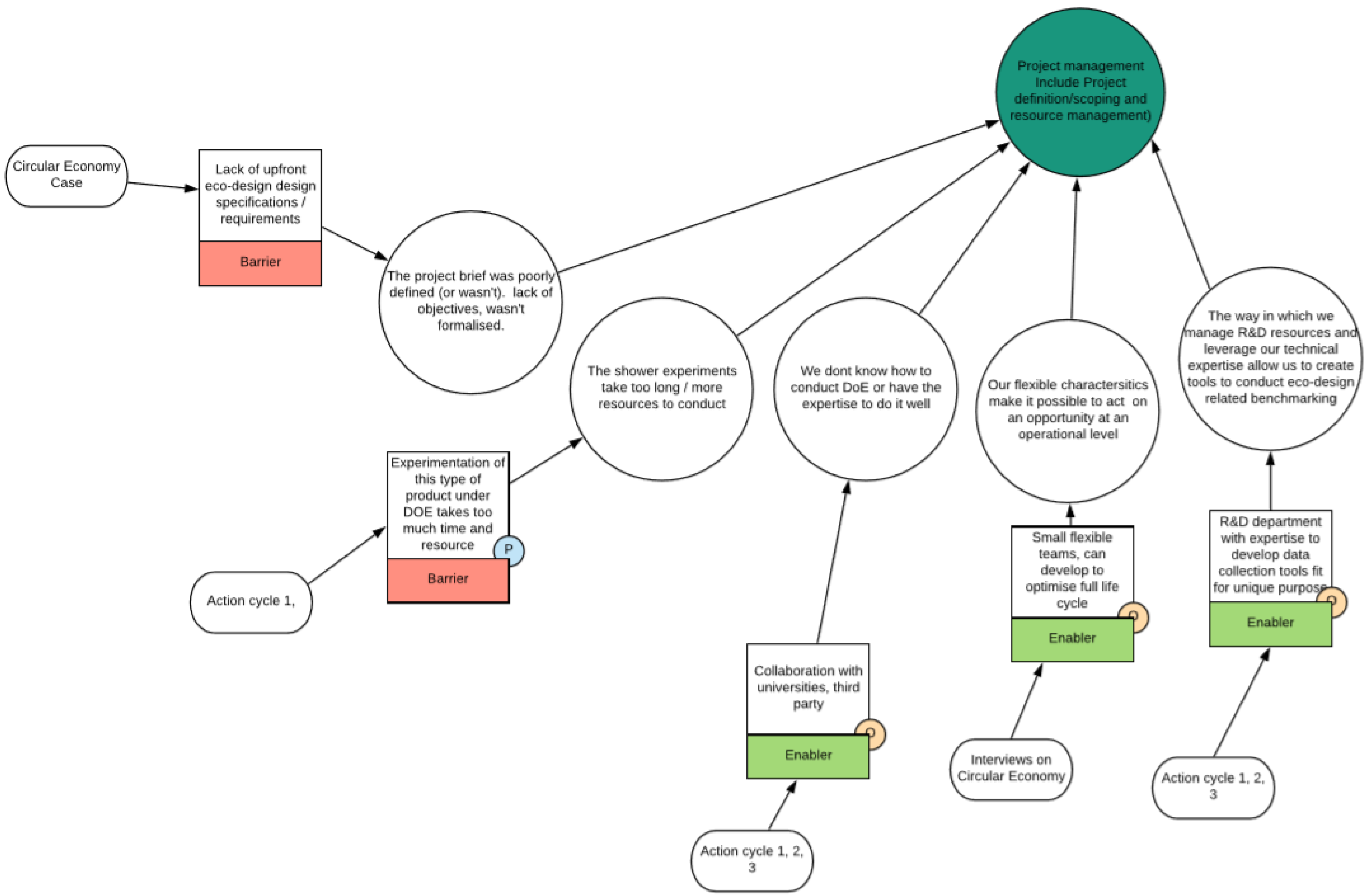
At the end of the categorisation (through a number of iterations) the final outcome was visualised in a bubble diagram (below diagram has been divided into 4 sections for readability).

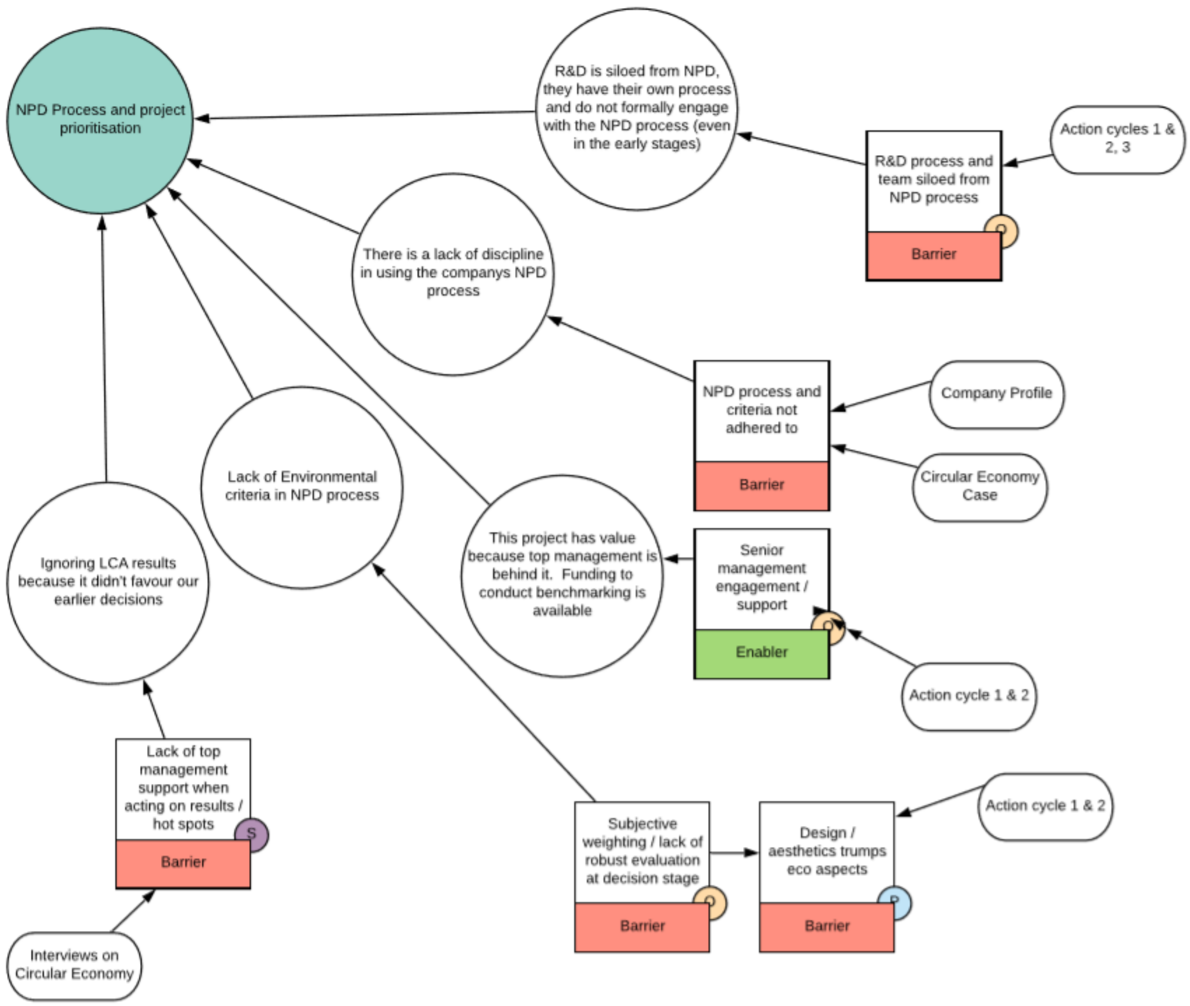


Circular Economy
Lack of manufacturing strategy
S
Barrier
Circular Economy Case
Aligns with risk management of material and resource availablity
P
Enabler
Circular Economy Case
No cohesive plan between departments
O
Barrier
Action cycles 1 & 2
Cannot take ownership of use stage
P
Barrier
Action cycles 2
Subjective weighting / lack of robust evaluation at decision stage
O
Barrier
Design / aesthetics trumps eco aspects
P
Barrier
Action cycle 1 & 2
Senior management engagement / support
O
Enabler
Cannot take ownership of recovery stage
O
Barrier
As an engineer i cannot make design choices that impact shower use - as this is subjective to the user
Circular Economy Case
Lack of top management support when acting on results / hot spots
S
Barrier
This project has value because senior management is behind it. Funding to conduct benchmarking is available
We dont know anything about filtration / water reuse
Lack of Environmental criteria in NPD process
Manufacturing has no strategy or future plan so we dont know how or where our products will be made
Marketing, Manufacturing, Innovation - all doing their own thing without communicating to each other
Ignoring/dismissing LCA results because it didn't favour our earlier development decisions
Action cycle 1 & 2
Lack of knowledge or training on experiements (DoE, OFAT)
O
Barrier
We develop and market unique spray technology, eco sprays are not part of our development portfolio
We conducted risk assessments. Some materials are economically a threat to future business - we want an alternative business model to mitigate this risk
Action Research 1 & 2
Results do not favour current products in development
P
Barrier
Lack of experitise in marketing eco-design added-value
O
Barrier
Portfolio management
Strategy
Technology planning
Culture, Climate and Values
We only know how to do OFAT, we dont understand DoE results, we dont trust them cause we their their not robust

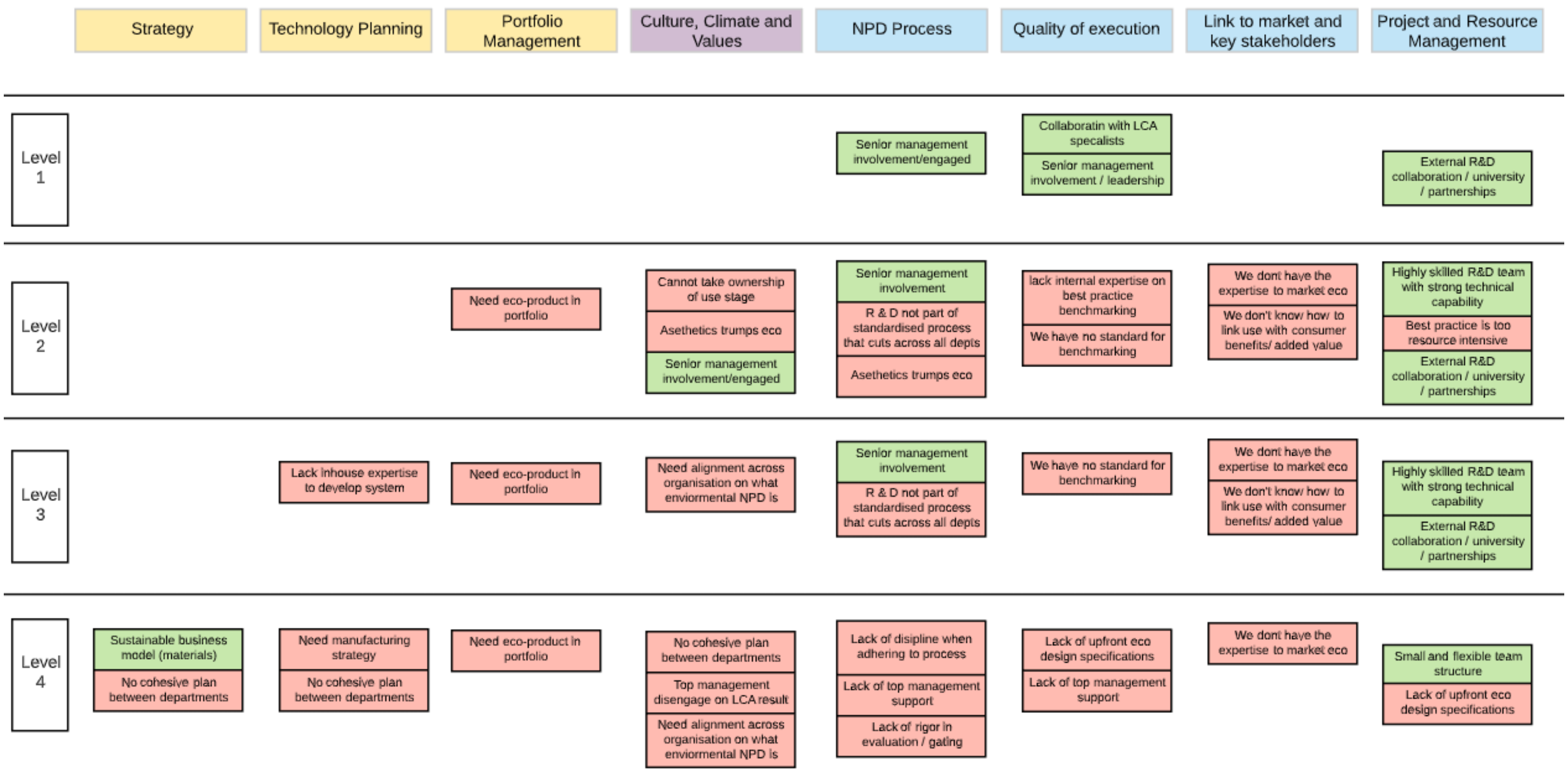


Lack of upfront eco-design design specifications / requirements
Barrier
Circular Economy Case
Collaboration with LCA specalists
Enabler
EPD Case
Lack of knowledge or training on experiements (DoE, OFAT)
Barrier
Action cycle 1 & 2
Action cycle 3
Testing is not standardized
Barrier
We can't do LCA well, but working with others allowed us to do this well by embracing the concept of open innovation
We only know how to do OFAT, we dont understand DoE results, we dont trust them cause we their their not robust
We benchmark ad-hoc when developing heat recovery/waste recovery systems
The project brief was poorly defined (or wasn't). lack of objectives, wasn't formalised.
Collaboration with universities, third party
Enabler
Action cycle 1, 2, 3
We dont know how to conduct DoE or have the expertise to do it well
Quality of execution (marketing, technical, tool implementation, benchmarking)
We're not good at doing LCA so internally we can't build it into our NPD process
We dont market the env benefits (because we believe our consumers dont see value in it)
Lack of expertise in LCA
Barrier
Circular Economy Case
EPD
Link to market and key stakeholders
We dont know how to engage with our customers to use less water as there is currently no platform to do this
Cannot take ownership of use stage
Barrier
Action cycles 1 & 2
Lack of consumer awareness of benefits
Barrier
Circular Economy Case


Project management Include Project definition/scoping and resource management)
Circular Economy Case
Lack of upfront eco-design design specifications / requirements
Barrier
The project brief was poorly defined (or wasn't). lack of objectives, wasn't formalised.
The shower experiments take too long / more resources to conduct
We dont know how to conduct DoE or have the expertise to do it well
Our flexible charactersitics make it possible to act on an opportunity at an operational level
The way in which we manage R&D resources and leverage our technical expertise allow us to create tools to conduct eco-design related benchmarking
Experimentation of this type of product under DOE takes too much time and resource
P
Barrier
Action cycle 1,
Collaboration with universities, third party
Enabler
Action cycle 1, 2, 3
Small flexible teams, can develop to optimise full life cycle
Enabler
Interviews on Circular Economy
R&D department with expertise to develop data collection tools fit for unique purpose
Enabler
Action cycle 1, 2, 3

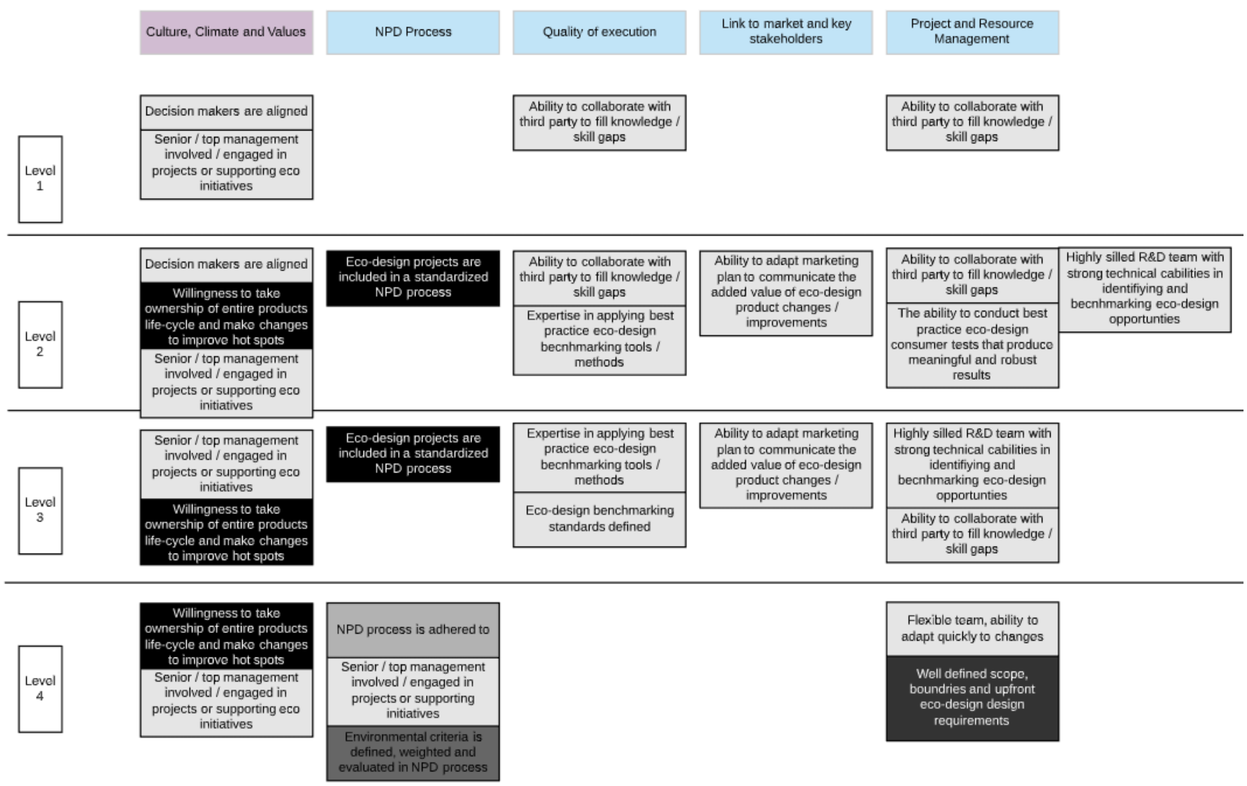


Based on existing eco-design literature which states that companies can perform eco-design at varying levels (The Classes of Eco-Design), the researcher also attempted to categorize the chunks of data with respect to this. This formed a matrix (NPD elements x Classes of Eco-Design) that allowed the key points to be further categorised.



Strategy
Technology Planning
Portfolio Management
Culture, Climate and Values
NPD Process
Quality of execution
Link to market and key stakeholders
Project and Resource Management
Level 1
Senior management involvement/engaged
Collaboratin with LCA specalists
Senior management involvement / leadership
External R&D collaboration / university / partnerships
Level 2
Need eco-product in portfolio
Cannot take ownership of use stage
Asethetics trumps eco
Senior management involvement/engaged
Senior management involvement
R & D not part of standardised process that cuts across all depts
Asethetics trumps eco
lack internal expertise on best practice benchmarking
We have no standard for benchmarking
We dont have the expertise to market eco
We don't know how to link use with consumer benefits/ added value
Highly skilled R&D team with strong technical capability
Best practice is too resource intensive
External R&D collaboration / university / partnerships
Level 3
Lack inhouse expertise to develop system
Need eco-product in portfolio
Need alignment across organisation on what enviormental NPD is
Senior management involvement
R & D not part of standardised process that cuts across all depts
We have no standard for benchmarking
We dont have the expertise to market eco
We don't know how to link use with consumer benefits/ added value
Highly skilled R&D team with strong technical capability
External R&D collaboration / university / partnerships
Level 4
Sustainable business model (materials)
No cohesive plan between departments
Need manufacturing strategy
No cohesive plan between departments
Need eco-product in portfolio
No cohesive plan between departments
Top management disengage on LCA result
Need alignment across organisation on what enviormental NPD is
Lack of disipline when adhering to process
Lack of top management support
Lack of rigor in evaluation / gating
Lack of upfront eco design specifications
Lack of top management support
We dont have the expertise to market eco
Small and flexible team structure
Lack of upfront eco design specifications

Lastly, the key points (and linked enablers and barriers) were rephrased to represent success factors for the integration of eco-design into NPD for a shower and tapware manufacturer. They were also given a darker colour that represented significance (i.e. a common theme that appears may have more of an impact at an operational level). The Culture category contained many of these significant practices. Based on the focus of the research being the operational practices (Section 3.1) it was decided any further analysis should focus on the operational elements while also exploring the significance of Culture and its impact on these operational elements.



The significance of this step is that it provides structure to the data that better represents the analytic framework of the research.

Analysis: Explanation Building

"Explanation building appears to be similar to grounded-theory (and analytic induction) however, unlike these, explanation building is designed to tests a theoretical proposition, albeit in an iterative manner" (Saunders et al., 2009)

Based on the categorisation, identification of success factors and link to current theory the researcher was able to form an initial analytical framework. The framework proposes that there are various practices that if operationalised would contribute to the successful integration of eco-design for a shower and tapware manufacturer. However, there is still a need to determine the adequacy of the framework.

Many of the practices appeared to be common across varying eco-design project types suggesting that perhaps the successful development in eco-project types (redesign / systems / platform) may be dependent on factors related more generally to NPD.

The culture of the organisation was never a direct focus of the research and yet it appears to have had an impact on the operational practices of eco-design integration. This poses new questions to the research and a need to identify patterns that could explain the relationship between culture and the operational practices and its relevance to the shower and tapware organisation.

Explanation building was then applied in an inductive approach (similar to analytic induction) to explore the adequacy of the framework.

Barczak, G., & Kahn, K. B. (2012). Identifying new product development best practice. *Business Horizons, 55*(3), 293-305. doi: 10.1016/j.bushor.2012.01.006

Bhamra, T., Lilley, D., & Tang, T. (2011). Design for Sustainable Behaviour: Using Products to Change Consumer Behaviour. *Design Journal, 14*(4), 427-445. doi: 10.2752/175630611X13091688930453

Brones, F. A., Carvalho, M. M. D., & Zancul, E. D. S. (2017). Reviews, action and learning on change management for ecodesign transition. *Journal of Cleaner Production, 142*, 8-22. doi: 10.1016/j.jclepro.2016.09.009

Cooper, R. G. (2018). The drivers of success in new-product development. *Industrial Marketing Management*. doi: https://doi.org/10.1016/j.indmarman.2018.07.005

Rodrigues, V. P., Pigossom, D., & McAloone, T. (2016). *Process-oriented performance indicators for measuring ecodesign management practices.* Paper presented at the Proceedings of International Design Conference, DESIGN.

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research methods for business students*: Harlow, England ; New York : FT/Prentice Hall, 2009

5th ed.

Tingström, J. A., & Kth, S. f. i. t. o. m. M. M. O. (2007). *Product development with a focus on integration of environmental aspects.* (Doctoral Thesis), KTH, Stockholm. Retrieved from http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edsswe&AN=edsswe.oai.DiVA.org.kth.4289&site=eds-live&scope=site Available from EBSCOhost edsswe database.

Ussui, P. R. S., & Borsato, M. (2013). *Sustainability Indicators for the Product Development Process in the Auto Parts Industry*. Paper presented at the ISPE International Conference on Concurrent Engineering.