A Fuzzy Front End Model for Concurrent Specification in New Product Development

By

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A thesis submitted for the degree of Doctor of Philosophy

October 2018

Originality Declaration

Except where otherwise stated, this thesis is the result of my own research. This research was conducted in the design engineering group at Imperial College London between October 2014 and December 2017. I certify that the thesis has not been submitted, either in whole or in parts, as consideration for any other degree or qualification at this or any other institute of learning.

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October 2018

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Abstract

This research reports on the development of a new model for an early design stage in new product development (NPD) programmes called the Fuzzy Front End (FFE). The new FFE model aims at overcoming two kinds of limitations identified in previous FFE models. The first limitation concerns current trends in FFE model improvement including the need for a data-driven model, and to address agile development, incremental and radical NPDs, balanced explicitness and responsiveness characteristics, and balanced procedural and performative structures. The second limitation concerns deficiencies in the performance structure and operating mechanism regarding contextual performance and concurrent collaboration. This means that performances in the FFE do not systematically link with each other, either in a single functional domain or multidimensionally across diverse functional domains, but instead exist independently.

A pragmatic-prescriptive model has been functionally embodied by analysing real-world FFE scenarios using inductive reasoning. The model is data-driven with a performative structure wherein parameters can interlock for contextual performance and concurrent collaboration throughout the entire FFE process. With this interlocking structure, once an initial parameter is produced, all remaining parameters considered from both perspectives can be obtained successively. This model allows performers to explicitly understand the purpose and roles of parameters and their relationships from both perspectives when processing parameters. The model thus leads to more agile FFE execution by reducing the iterative work needed to correct defective parameters which have not been handled with contextual performance and concurrent collaboration in mind but instead exist independently.

A theoretical-descriptive model, produced by validating the developed pragmatic-prescriptive model, using deductive reasoning, consists of mathematical formulas, providing the underlying concept of an overall FFE as well as that of its parts.

Consequently, the pragmatic-prescriptive model can serve as functional performance guidance, while the theoretical-descriptive model can serve as conceptual performance guidance when employing the pragmatic-prescriptive model.

Table of Contents

List of Figures

List of Tables

Acknowledgements

It would not have been feasible to achieve this PhD thesis without the support and aid from my supervisors, family and friends. It is only possible to mention some of them here.

I would like to appreciate my principal supervisor Professor Peter Childs, the head of the Dyson School of Design Engineering, for his ardent support and encouragement from start to finish. He has offered me very helpful guidance, useful advice, essential resources, opportunities to participate in research projects, discretion in studies, as well as aided me in creating an academic career path. I would also like to thank my secondary supervisor Dr Marco Aurisicchio.

I want to express my sincere thanks to my colleagues in the Dyson School of Design Engineering at Imperial College London. A special thanks to Ji, Feng, Tanawan, Fadzli, Anouk, Liuqing, Ravi, Cristobal and Inty who have all contributed to my PhD research. It has been a great pleasure to work with you for the past four years.

I would like to my deepest gratitude to my parents Samsoo Park and Soonduk Lee for their emotional and financial support. Thank you for supporting me with the strength, motivation and encouragement to complete this PhD research.

None of this would be possible without my loving and caring wife Hara Jung who always encourage and inspire me when I feel discouraged. I have enjoyed every moment we spent together. I am really grateful you are by my side accompanying me along this special journey.

Chapter 1. Introduction

This chapter provides an outline of this dissertation: the background, topic, and the underlying motivations. The project's aims, objectives, and its research questions are laid out. The investigation's scope, in terms of its specific study domains, the potential challenges, and prospected contributions, is also described.

1.1 Innovation Process

The Ford-inspired approach to the mass production of standardised products has been at the foundation of the manufacturing industry for the last century (Batchelor, 1994; Haslarn, 1987; Hounshell, 1985; Murray, 1988; Williams et al., 1992). Countless corporations in the manufacturing sector have gone through a cycle of birth, growth, maturity, decline and demise in line with this approach (Adizes, 1990; Yan, 2006). At the centre of these rises and falls, innovation has led to the creation of new products, tied to which were the fortunes of the companies who produced them (Foster & Kaplan, 2011; Gundling, 2000). Only a minority of these products survived, and many disappeared completely (Cooper, 1990; Evanschitzky et al., 2012; Frattini et al., 2013). In the 21st century, the global economy relies more on the ability of enterprises in developing and delivering new products (Durmuşoğlu & Barczak, 2011), which enter such new products entering the market on a daily basis (Barczak & Kahn, 2012; Goodwin et al., 2014; Su & Rao, 2011).

As many companies have grown up and matured by launching new products, they have devoted efforts to creating something new for their target market (Tidd & Bodley, 2002; Tidd et al., 2005). True success is rarely a 'one-hit wonder' but instead the continued production of ever superior products, often for a decade or more (Henderson & Clark, 1990; Tidd et al., 2005). Many companies consider the establishment of an innovation process for New Product Development (NPD) as a vital activity that underpins continual success (Henderson & Clark, 1990; Tidd et al., 2005).[1] The innovation process for NPD serves as a foundational systematic platform which produces innovative products iteratively (Cooper, 2008, 2014; Cooper & Edgett, 2008). In this context, innovative products[2] are defined as superior products (successful products) with positive market responses and less room for improvement. According to Prahalad (1990), the role of the innovation process for NPDs can be described by using the metaphor of the biological structures in a tree. The process itself is analogous to the tree's root system. The growth of leaves and flowers, supplied by nutrients from the roots funnelled through the trunk and branches, equates to the new products generated. Consequently, improvements in the innovation process in the manufacturing industry can lead to a more consistent production of innovative products (and thus outcomes).

In the pursuit of innovation process improvement, the following two considerations should be kept in mind.

Firstly, the innovation process should be recognised as a control platform for handling NPD-related parameters generated by research and analysis activities in order to achieve superior products (McCarthy et al., 2006; Scott-Kemmis & Bell, 2010). In this context, management of the parameters can be regarded as the processing of the parameters *intensively* in a single functional domain with in-depth expertise (Prasad, 2000; Ziv Av & Reich, 2005) as well as *multidimensionally* through collaboration with diverse functional

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[1] In this thesis, the definitions of 'Innovation Process', 'NPD Process', and Design Process' are as follows:

- Innovation Process: a process for innovation within an organisation itself, covering its activities and the products produced through such activities
- NPD Process: With respect to innovation processes, a process whose primary goal is for new product development
- Design Process: With respect to NPD processes, a process whose main purpose is for design activities

In this context, an innovation process in NPD is defined as a process for a manufacturing organisation to produce innovative new products.

[2] The meaning of 'Innovative Products' can vary since the context of the term, 'Innovative Products', shifts quickly. According to Cropley & Kaufman (2018) and Han et al. (2017), the term indicates products that are more novel or creative than other products in the same class. It also represents outstanding products from a functional or aesthetic perspective. However, in this thesis, when defining the meaning of 'Innovative Products', the view commonly accepted by many experts such as Crawford & Di Benedetto (2008), Cooper (2001, 2008, 2014), Cooper & Edgett (2008), Tidd & Bodley (2002) and Tidd et al. (2005) is used. Therefore, 'Innovative Products' in this context means superior products with much more positive market responses and much less room for improvement than any other products (by competitors). Based on the market response and consumer satisfaction with the current version of the target product, if there are few points for improvement identified (and thus low demand to develop an improved version), we can regard the current product as having less room for improvement.

domains (Melin & Einarsson, 2014; Swink & Song, 2007; Yoon & Jetter, 2015). Thus, considering how the parameters might be processed to effect the development of great products can be directly linked to the improvement of the innovation process.

Secondly, current and future trends should also be reflected in any attempt to improve the innovation process, as these trends will affect the overall attributes of the process. This reflection can have effects on how conducting NPDs with the innovation process by efficiently responding to essential considerations issued from industrial circumstances of today and the future (Childs & Pennington, 2016; Pennington, 2010). Keeping abreast of trends can support the continued development of superior products that not only remain 'current' (i.e. not out of date) but are in keeping with industrial circumstances. In many recent conferences and annual reports[3], current and future trends, e.g. a data-driven design activity, agile NPD, etc., as well as problems to be tackled, e.g. incremental and radical NPDs, have been highlighted for the next generation of innovation processes. Thus, considering current and future trends for developing the innovative process can help continue to develop superior products today and in the future.

Consequently, contemplating the processing of the parameters and reflections of current and future trends is considered critical for innovation process improvement. This can lead to reshaping a study on this already saturated research area.

The improvement of the innovation process has been recognised in both academic and industrial research circles for over forty years (Cross, 1994; Gorb, 1994; Mozota, 2003; Oakley, 1990; Tzortzopoulo et al., 2006). The innovation process is also often mentioned in editorial research materials describing the expert consensus on what the notable past, current, and potential future study issues are (Kahn et al., 2003). Given such an interest, studies on the innovation process are becoming more specific (Gurtner et al., 2016).

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[3] Conferences and Annual Report Lists

- Conferences which have stressed current and future trends for innovation process improvement include: 2017 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), 2017 International Conference on Engineering Design (ICED), 2015 21st International Conference on Automation and Computing (ICAC), and 2015 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD).
- Annual reports which have emphasised current and future trends for innovation process improvement include: Barnes (2016), Bindel (2016), Delooze (2015), Ford (2015), Goodman (2015), Johansson (2015), and Norbury (2015).

In the following sections, the most important and vulnerable part of the innovation process which is taken account to as the research target in this thesis, and reasons and characteristics of that part causing its significance and weaknesses are described first. Then, the limitations of the current study on that part which leads to the weaknesses are described in the two contexts of handling NPD-related parameters, and the current and future trends affecting an overall attribute of that part.

1.2 Fuzzy Front End

1.2.1 The definition of FFE

Generally speaking, the innovation process consists of three sub-phases (see *Figure 1.1*): a Fuzzy Front End (FFE), actual New Product Development (NPD), and commercialisation. Many experts, including Carbone and Tippett (2014), Koen et al. (2002, 2004), and Stevens & Burley (2003), have reached an agreement on how these three sub-phases should be divided, based on their different natures, goals, attributes, features, and functions.

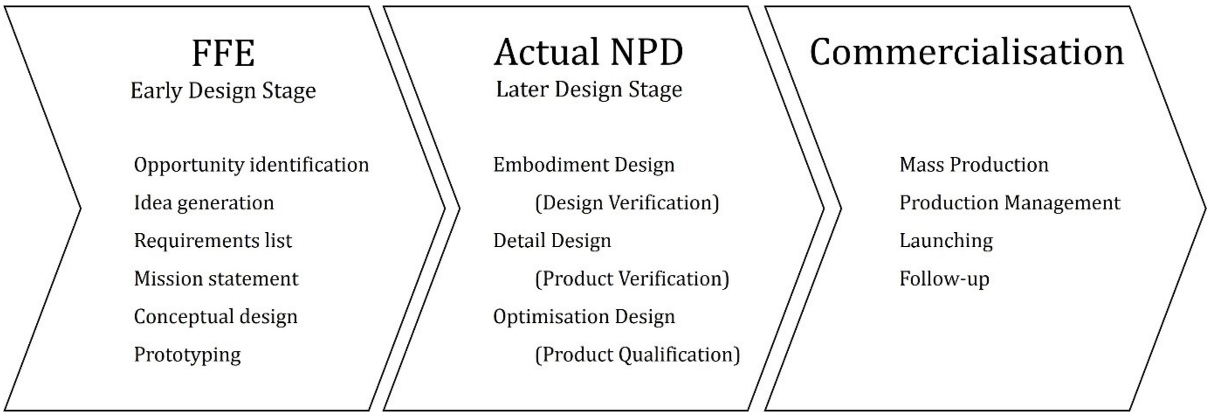

Figure 1.1. *Three components of the innovation process*

FFE, a term coined by Smith and Reinertsen (1991, 1998), describes an early design phase where an original idea is generated from the discovery of new opportunities, a potential product is defined and conceptualised, and a project to develop that product is drawn up and approved for further development in the more formal and well-structured actual NPD stage (Koen et al., 2001).

There is no standard terminology in academia nor is there one in industry for FFE (Dewulf, 2013), and authors use a variety of alternative synonyms and interchangeable neologisms to refer to what is essentially the same thing (Ester & Daniel, 2007; Hüsig & Kohn, 2003; Jacoby & Scheelen, 2012; Kosko, 1998; Kotler, 1998; Ozer 1999; Sandmeier et al., 2004;):

1) "Fuzzy Front End (FFE)" (Smith & Reinertsen, 1991)
2) "Front End" (Khurana & Rosenthal, 1998)
   "Front End of Innovation (FEI)" (Jacoby & Scheelen; 2012)

“Front-end practice / Front-end process” (Jetter, 2003)

“Frond-end (phase 1) Pre-Design” (Osteras et al., 2006)

3) “Pre-development activities” (Cooper, 1988)

“Pre-project phase” (Nobelius & Trygg, 2002)

“Pre-project activities” (Verganti, 1997)

“Advanced development” (Hipp & Kaelber, 2000)

4) “Pre-phase 0” (Khurana & Rosenthal 1997)

5) “Up-front activities” (Reid & Brentani, 2004; Kim & Wilemon, 2002)

6) “Early phase” (Herstatt & Verworn, 2001)

“Initiative phase” (Talke et al., 2006)

“Opening stages” (Nobelius & Trygg, 2002)

“Early stages of new product development” (Bacon et al., 1994)

7) “New Concept Development (NCD)” (Koen et al., 2001, 2002)

There are some who argue that the term “FFE” is inappropriate for use and should be renamed, with the term “Fuzzy” being removed entirely (Koen et al., 2001; Carbone & Tippett, 2014). “Fuzzy” suggests that ungoverned factors dominate the front-end, implying that this initial design segment cannot be managed permanently, which they contend is not true (Koen et al., 2001; Carbone & Tippett, 2014).

However, regardless of its name, there is general agreement about this rather loosely defined initial phase (Carbone and Tippett, 2014; Koen et al., 2002, 2004; Stevens & Burley, 2003). The FFE is a preparatory step comprising of all the required tasks that typically preceded the detailed execution of a design (Cooper, 1988; Khurana & Rosenthal, 1997; Oliveira & Rozenfeld, 2010; Reinertsen, 1994).

1.2.2 The importance of FFE

Many studies have emphasised the importance of the FFE (Koen et al., 2001; Smith & Reinertsen, 1991; Verworn et al., 2008; Yoon & Jetter, 2015). In recent years, studies on the FFE have attracted the notice of academia, to such an extent that there is intensive consideration to investigating the front-end innovation process separately and independently from the wider, and more general innovation process (Gurtner, & Reinhardt, 2016; Kock et al., 2015; Markham, 2013; Verworn, 2009).

There are a number of reasons why the FFE is significant, highlighted in many studies including those by Eling et al. (2014), Evanschitzky et al. (2012), Jacoby (2012), and Womack et al. (2016). These reasons however can essentially be distilled into two main factors based on their common attributes and features: 1) because it is during the FFE where parameters are decided, and 2) affecting an overall attribute and outcomes of the entire innovation process.[4]

1) Parameter Process and Decision

Regarding decisions on parameters, the FFE is a fundamental stage during which more than 70% of the crucial parameters for new product developments are set up (Talke et al., 2006; Williams et al., 2007). In addition, higher quality parameters are becoming ever more critical in the initial design phase (Jetter, 2003; Koen et al., 2002; 2004; Wowak et al., 2016). This initial design phase therefore requires more intensive research and analysis such that it can obtain high-quality parameters[5] in a single functional domain (Akgün et al., 2002; Brentani & Reid, 2012). Simultaneously, effective collaboration between these research and analysis activities across a range of diverse functional domains is becoming increasingly necessary (Akgün et al., 2002; Brentani & Reid, 2012; Melin & Einarsson, 2014; Yoon & Jetter, 2015). In this context, high-quality parameters are defined as situations where there is little need for improvement on missing and

[4] These reasons for the importance of the FFE are aligned with the context of the two considerations of the innovation process improvement (see *pp. 2-3*).

[5] If there are few points for improvement/revision when the target product is being developed in the actual NPD phase, we can infer that the FFE parameters, being higher-quality, have been processed precisely in a single functional domain as well as multidimensionally in diverse functional domains.

misinterpreted information. When the obtained parameters do have room for compensation, this directly leads to an investment of time, deployment of personnel, and an adjustment to the budget (Khurana & Rosenthal, 1997; Reid & Brentani, 2004; Tennant & Roberts, 2003; Thanasopon et al., 2016; Verworn et al., 2008). Consequently, as the FFE requires a remarkable proportion and a robustly defined set of product specifications, this initial phase is the significant.

2) Leverage of the FFE on Overall Attributes of Innovation Process

The overall attributes and outcomes of the FFE affect the entirety of the innovation process that follows. Even though, as mentioned before (*p. 5*), the innovation process is divided into three components, there is a continuum between each of them (Koen et al., 2002). Hence, there are many cases wherein the FFE takes direction from the overall innovation process and vice versa (Cheng & Van de Ven, 1996; Gomes, 2003)[6]. The rational bases for the leverage the FFE exerts on the whole innovation process can be examined based on three key effects it has: 1) the quality and outcomes, 2) time commitment, and 3) cost commitment

Firstly, the quality and outcomes of the FFE – which are highly related to those of the parameters produced in the FFE – have a huge and direct influence on those of the subsequent phase where a detailed design is drawn up and iterative optimisation takes place (Kim & Wilemon, 2002; Verworn et al., 2008; Wagner, 2012; Williams et al., 2007). The more accurate the product specifications generated during the FFE are, the fewer the deviations in design choices during the actual NPD (Gupta & Wilemon, 1990; Khurana & Rosenthal, 1997; Verworn et al., 2008). It stands to reason that the FFE stage is critical in determining the final outcomes of NPD projects (Herstatt & Verworn, 2001; Jacoby & Scheelen, 2012; Reid & Brentani, 2004). Namely, whether a new product is successful or

[6] Of course, there is an argument that the FFE should take different directions from the entire process since the nature, goals, attributes, features, and functions of the FFE are different to those of the actual NPD and the commercialisation phase (McCarthy et al., 2006; Sandmeier et al., 2004; Sperry & Jetter, 2009). However, the predominant view on the relationship between the FFE and the entire process is based on the idea that the continuum between each of the phases should be recognised, so that the overall attributes, features, processes, and outcomes of the FFE should be aligned with those of the entire process (Cheng & Van de Ven, 1996; Gomes, 2003).

not is exclusively decided by the quality and outcomes of the FFE (Cooper, 1998; Thanasopon et al., 2016; Wagner, 2012; Wowak et al., 2016). Looking at the issue in reverse, most of the failures that occur during NPD are the result of issues that germinated during the FFE (Bullinger, 1990; Kim & Wilemon, 2002). If the understanding of product specifications is unsatisfactory in the initial stage, significant revisions should be made as the actual design phase unfolds (Khurana & Rosenthal, 1997; Konda et al., 1992). Any issues in terms of the product parameters and constraints during the FFE will degrade the progress of the later design phase, requiring significant action to correct (Verganti, 1997). Thus, the better the FFE is at generating accurate parameters, the higher the possibility of the whole innovation process producing successful products.

Secondly, more than half of the overall product development period is typically committed to the FFE (Gemünden, 2001; Reinertsen & Smith, 1991, 1994; Verworn et al., 2008), meaning that the FFE itself is a big part of whether or not the total development cycle increases in duration (Gupta & Wilemon, 1990). The shorter the product development period, the more rapid the foray of a firm and its product into the market (in a pioneering role) which may result in a competitive edge (Cooper, 1999; Ester & Daniel, 2007; Murphy & Kumar, 1997; Reid & Brentani, 2004; Verganti, 1997). Agile product development is also conducive to gaining earlier customer adoption by launching ahead of competitors, which may enable greater customer satisfaction (Achiche et al., 2013; McKeen, 1983). Additionally, the sooner the product development stage is implemented, the sooner a new iteration of the product is available, which means that varied products can be created and that a more extensive product line can be established (Womack et al., 1990; Bacon et al., 1994). In sum, the faster the implementation of the FFE, the more feasible it becomes to produce the final output of the target product rapidly, reaping the benefits mentioned above.

Thirdly, along with the time investment[7], a considerable proportion of a project's total cost, nearly two-thirds, is generally determined during the front end period (Herstatt & Verworn, 2001; Koen et al., 2002; Thanasopon et al., 2016). This has profound impacts on the settlement of the total investment cost (Bacon et al., 1994; Herstatt & Verworn, 2001). The determination of the overall cost is also directly linked to gross profit (Koen

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[7] Many experts, including Pervin et al. (2018), Raatikainen et al. (2008), and Roy (2008), contend that time is cost. In this regard, a time investment is naturally followed by a cost investment; cost commitments are inextricably linked to commitments of time.

et al., 2001; Reid & Brentani, 2004). Namely, time savings during product development can lead to corresponding reductions in investment cost, resulting in increased revenue (Page & Stovall, 1994; Smith & Reinertsen, 1991, 1999). Thus, the better the FFE is at cost savings, the more likely it becomes for the innovation process as a whole to reduce costs.

Consequently, the overall attributes and outcomes of the FFE, both in terms of determining parameters and time-and-cost savings, have a great impact on the course of the entire innovation process that follows. For this reason, the FFE is recognised as an important component in that this early design phase can benefit or harm the entire innovation process 'downstream' (Backman et al., 2007; Kim & Wilemon, 2002; Poskela & Martinsuo, 2009; Specht et al., 2002;). Once an innovative FFE process has been established, the most significant hurdle has been surmounted, making a better innovation process comparatively less difficult to achieve in terms of deciding parameters and an overall attribute (Foster & Kaplan, 2001; Talke et al., 2006).

To sum up, the FFE is significant in terms of the remarkable proportion of parameters which should be robustly defined during this initial phase and the leverage it has on attributes and outcomes of the entire process. If a considerable number of parameters are only loosely decided in the FFE, this will lead to a more difficult implementation of subsequent NPD stages, increasing the likelihood of producing a poor final outcome in an NPD project. Also, when expenditures of time and cost increase at a high rate in the FFE, the time and cost invested throughout the project increases by default, since more than half of the time and cost commitments are decided in this early design phase.

1.2.3 The Weakness of the FFE – Uncertainty and Ambiguity

Despite overwhelming evidence indicating the importance of the FFE, it is, ironically, the weakest part of the product innovation process, a fact recognised by both academia and industry (Cooper, 1988; Khurana & Rosenthal, 1997; Smith & Reinertsen, 1992; Williams et al., 2007). The cause for this weakness is twofold: 'uncertainty' and 'ambiguity' (known also as 'equivocality')[8] which pervade the FFE to a significant degree (Chang et al., 2007; Khurana & Rosenthal, 1998; Jetter, 2003). What this means is that the FFE has the most difficulty in processing and determining parameters during research and analysis activities, both in a single functional domain and in multiple functional domains where there is an extensive collaboration of activities. Moreover, these two characteristics undermine the FFE due to the difficulties in reflecting current and future trends in FFE improvement, which impede the *determination of an overall attribute* in this initial design phase. As a result, such characteristics have made the FFE the weakest part, *less structured and systematised,* and thus less able to produce promising outcomes which have the full backing of reliable parameters and an appropriate overall attribute (Herstatt et al., 2004; Kurkkio, 2011; Reid & de Brentani, 2004; Sandmeier et al., 2004).

Although those two characteristics, *uncertainty* and *ambiguity*, seem identical at first glance, there have been many theoretical contributions on the differences and discrepancies between them (Brun & Saetre, 2009; Daft & Lengel, 1983, 1986; March, 1994; Weick, 1995). Uncertainty is caused by a lack of information while ambiguity, known also as equivocality in the literature (Chang et al., 2007; Frishammar et al., 2011; Yoon & Jetter, 2015), comes from different subjective interpretations of the *same* information (Brun & Saetre, 2009; Chang et al., 2007; Yoon & Jetter, 2015).

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8 Along with uncertainty and ambiguity, of course, other reasons for the FFE to be the weakest part – which are complexity, chaos, flexibility and variability – have been defined in many studies (Dewulf, 2013; Khurana & Rosenthal, 1998; Koen et al., 2002; Oliveira & Rozenfeld, 2010). In addition, different uses of languages/terminologies used in various functional domains can also be one of the reasons for the FFE to be vulnerable. However, they argued that these reasons are originated from uncertainty and ambiguity: the reasons are inherent in the nature of uncertainty and ambiguity. For instance, due to ambiguity which arises from different interpretations on the same information, chaos or variability are incurred in deciphering the information. Therefore, this section concentrates on uncertainty and ambiguity among all the reasons mentioned above.

More details about these weaknesses are presented through the lens of the following two rationales.

1) Poor Parameter Process and Decision

Firstly, poor processing and inadequate decisions on parameters during the FFE can be influenced not only by an insufficient quantity of information – giving rise to uncertainty – but an unwitting lack of consistent interpretation on a piece or set of information, leading to ambiguity (Chang et al., 2007; Frishammar et al., 2011; Yoon & Jetter, 2015).

Uncertainty is generally caused by missing parameters in the research and analysis activities for the countless pieces of information generated in each functional domain such as markets, technology, and industrial environment (Jetter, 2003; Kim & Wilemon, 2002; Patterson & Lightman, 1993; Schroder & Jetter, 2003; Verworn, 2006). According to Chang et al. (2007) and Jetter (2003), market, technological, and environmental uncertainties generally involve difficulties in terms of articulating the enormous quantities of data that exist on current/prospective demands of target users/markets, on cutting-edge technologies, and the current/future economic, ecological, social, political, and legislative issues.

Ambiguity on the other hand occurs as a result of different interpretations in the activities in the various functional domains due to a lack of effective collaboration and communication within cross-functional teams (Cooper, 2001; Khurana & Rosenthal, 1998; Oliveira & Rozenfeld, 2010). Namely, ambiguity frequently occurs during conflicts over differing interpretations of data by analysts with diverse backgrounds, specialties and views (Gupta & Wilemon, 1990; Yoon & Jetter, 2015; Zhang & Doll, 2001). Disputes, between marketing and R&D (Gupta et al., 1986; Melin & Einarsson, 2014; Moenaert & Souder, 1990; Moenaert et al., 1995), between marketing and manufacturing (Song et al., 1997; Swink & Song, 2007), and between marketing and design (Bailetti & Litva, 1995; Beverland, 2005; Crawford, 2008; Luo et al., 2005; Veryzer, 2005), can occur owing to their differing points of view, fields of expertise, and core mission (Zhang et al., 2011). In addition, ambiguity arises from the fact that the initial design phase tends to handle qualitative, subjective, and approximate information of an experimental nature rather than quantitative, formal, and accurate data (Dewulf, 2013; Kim & Wilemon, 2002; Lukas & Menon, 2004 Williams & Kochhar, 2000; Williams et al., 2007). The probability of obtaining the qualitative narrative type of data is higher in that most FFE activities are mainly directed toward developing the blueprint of a design through the identification of demands (Kim & Wilemon, 2002; Wowak et al., 2016).[9] As a corollary, the data acquired in the FFE have a greater tendency to be subjective rather than objective, implying that said information is not fixed and precise but flexible and experimental (Montoya-Weiss & O'Driscoll, 2000; Murphy & Kumar, 1997; Poskela & Martinsuo, 2009).

Consequently, although the FFE is significant in the sense that more than half of parameters are processed and determined in this front-end, mentioned in the previous section (*pp. 7-8*), the two characteristics, *uncertainty* (related to an insufficient quantity of parameters) and *ambiguity* (related to inaccurate parameter interpretations), lead to hardships in the overall processing and deciding of parameters, which leads to the FFE being the weakest part of the NPD process.

2) Difficult Overall Attribute Decision

Secondly, uncertainty and ambiguity create difficulties for the FFE in determining what current and future trends are in terms of FFE process improvement and how they should be reflected in this initial design stage, a failing which hinders a determination of an overall attribute for the FFE (Chang et al., 2007; Frishammar et al., 2011; Salerno et al., 2015; Yoon & Jetter, 2015). For example, disputes, between the open-structure or closed-structure, action-led or data-led performance, and agile or profound FFE performance, can cause difficulties when trying to ascertain which FFE attribute is appropriate for handling uncertainty and ambiguity. Thus, uncertainty and ambiguity prevent the explicit deciding of an overall attribute which would govern the FFE's general direction.

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[9] Statistical market data or technical parameters for the requirements list may, of course, involve mostly quantitative data, but the rationale underpinning those data, described in narrative form, are now becoming more and more necessary for not only an in-depth understanding of what those data mean but also for efficient communication between implementers (Kim & Wilemon, 2002; Wowak et al., 2016; Jetter, 2003).

To conclude, uncertainty and ambiguity make the FFE the weakest component in the NPD process as it hinders the processing and determination of parameters and the reflection of current and future trends in process improvement. This makes it difficult to generalise findings and to even study the FFE as a whole in a rigorous and systematic fashion, leading to difficulty in attaining a coherent, uniform picture of the early design phase (Khurana & Rosenthal, 1997; Kim and Wilemon, 2002; Koen et al., 2001; Murphy & Kumar, 1997). As a result, uncertainty and ambiguity results in a lack of clearly defined structure and system of handling the FFE both in theory and in practice, contrary to the actual NPD process, which still remains the main rationale for the FFE as the most intractable phase of the entire innovation process (Herstatt & Verworn, 2001; Kim & Wilemon, 2002; Koen et al., 2001; Montoya-Weiss & O'Driscoll, 2000; Williams et al., 2007).

1.2.4 Increased Interest in FFE Studies

There has been an increase in the study of the FFE over the past few years (Backman et al., 2007; Jetter, 2003; Kock et al., 2015; Verworn, 2009), with the recognition that it is the *sine qua non* of successful NPD innovation (Sandmeier et al., 2004; Yoon et al., 2015) since this initial design stage is the most vulnerable in the whole course of the innovation process (Khurana & Rosenthal, 1998; Kim & Wilemon, 2010; Koen et al., 2004). The FFE has been understood in a generic sense since the late 1990s, and efforts to understand the subject in-depth began in earnest over the last decade (Backman et al., 2007; Björk & Magnusson, 2009; Kock et al., 2015; Markham, 2013; Seidel, 2007). For example, Bacon et al. (1994) and McGrath (1995) researched the FFE itself, providing comprehensive insights on FFE execution. Studies by Khurana and Rosenthal (1997), Moenaert et al. (1995) and Reinertsen (1999), recognised as three representative works into FFE performance (Brentani & Reid, 2004), investigated, respectively, strategies pertaining to the opportunity identification task, the importance of communication, and decision-making processes. Cooper and Kleinschmidt (1994) identified the FFE factors that are key for NPD success, while Bacon et al. (1994) and Wilson (1991) explored which capabilities are crucial for success. Also, Schulze and Hoegl (2008) conducted a study on which organisations operate an FFE.

With this level of attention devoted to the different FFE topics, many relevant models (processes or frameworks)[10] have also been developed (Ester & Daniel, 2007). Zhai et al. (2012) roughly classified those models according to each feature as follows. Firstly, models which focused on managing the FFE's nature can be found in studies by Brun et al. (2009), Chenglong and Fanrang (2005), Gao and Song (2005), Kahn et al. (2003), and so on. In the case of theoretical models which define the relationship between FFE-related

[10] In this context, firstly, 'Process' is defined as a procedural structure to support NPD activities/practices. Next, 'Model' is described as a functional structure wherein NPD-related input and output parameters are produced. Lastly, 'Framework' is defined as the structural relationships underlying a system or concept rather than the procedural structure. However, the boundary between these definitions is becoming more and more blurred. The reason is that many models and frameworks developed in NPD sectors contain characteristics of the process that provides procedural NPD steps. Thus, in this study, when we define the terms 'Process', 'Model' and 'Framework', those are considered to correspond, respectively, to the functional, technical, and structural systems that support NPD activities/practices (Blessing & Chakrabarti, 2009). Moreover, 'Model' is used as the representative term in this thesis since the definition of the term tends to not only embrace that of all the three terms (a procedural structure and a structural relation) but also contains specifics (a functional structure in which input/output parameters are produced).

issues, e.g. between market and technology portfolio management in the initial stage, Chen & Gao (2005), Yu et al. (2006), and Zhang and Doll (2001) are representative contributors. Next, models centred on FFE qualitative information were produced by Khurana and Rosenthal (1998), Koen et al. (2001), Montoya-Weiss & O'Driscoll (2000) and Rosenthal and Capper (2006) while Langerak et al. (2004) developed a model for properly quantifying FFE data. Lastly, Verworn et al. (2008) were particularly committed to the development of the causal model.

However, few of these models really shed light on how the FFE truly deals with processing and the deciding of parameters. They also do not describe which overall attributes are appropriate for this early design phase, something which is related to the two main rationales which make the FFE the weakest as well as the important part of the NPD process. More seriously, prior to the contributions of Khurana and Rosenthal (1997, 1998), very few studies concentrated solely on this initial process (Hüsig & Kohn, 2003; Specht et al., 2002). Unfortunately, many research centres and corporations still put more weight on developing and improving the back-end process rather than the front-end, since they continue to be under the serious misapprehension that the later phases of innovation have the greatest impact on final outcomes (Kurkkio, 2011; Murphy & Kumar, 1996; Williams et al., 2007; Yoon et al., 2015).

In the next section, limitations in existing FFE models are specifically defined from the viewpoints of those two dimensions, the processing and deciding of parameters in the FFE. The overall attributes of this front-end in which reflect current and future trends of the process improvement are also discussed.

1.2.5. The Limitations in Existing FFE Studies – The Motivation of Research

The limitations in existing FFE models fall into two dimensions: 1) deficiencies in reflecting current and future trends in FFE improvement which decide the overall attributes of this front-end and 2) deficiencies in improving the FFE performance structure and its operating mechanism which affects the processing and deciding of parameters. More details are illustrated below.

1) First Dimension : Overall Attributes – Current and Future Trends of the FFE Improvement

The first dimension is regarding the overall attributes decided by reflecting the current and future trends in FFE improvement. The following five trends which requires to be incorporated into a new FFE model development were identified, considering key proposals issued in many recent conferences and annual reports including papers[11]:

1.1) Data-driven Type
1.2) Agile Development
1.3) Incremental and Radical NPDs
1.4) Explicitness and Responsiveness Characteristic
1.5) Procedural and Performative Structures

[11] Conferences and Annual Report (Papers) Lists

- Conferences include: 2017 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), 2017 International Conference on Engineering Design (ICED), 2015 21st International Conference on Automation and Computing (ICAC), and 2015 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD).
- Annual reports (papers) include: Barnes (2016), Bindel (2016), Delooze (2015), Ford (2015), Goodman (2015), Johansson (2015), and Norbury (2015).

1.1) Data-driven Type

The FFE which aims to collect and analyse NPD-related information and then transform that information into knowledge which can be incorporated into an existing NPD project (as well as iterated for later projects) (Khurana & Rosenthal, 1997, 1998; Jacoby & Scheelen, 2012) is called a 'data-driven' FFE. This FFE type operates with data processing at its centre, in contrast with action-led type which places principal activities and guidelines at the centre of its execution. Although it is highly expected that this FFE type can reduce uncertainty and ambiguity by generating higher quantities of data, at higher quality also, in practice, few such models have been properly optimised for the collection, analysis, and transformation activities (Akbar et al., 2013; Backman et al., 2007; Hüsig & Kohn, 2003; Pizarro et al., 2002; Wormald, 2011). In particular, a data-driven FFE model for dealing with the qualitative data that is typically generated in the FFE has not yet been developed.[12] Thus, an FFE model optimised to process qualitative NPD-related information and transform that information into usable knowledge is required today and in the future.

1.2) Agile Development

One of the chief trends highlighted today is accelerating the speed of progress in the front-end, as it is a rapid 'Product Development Cycle (PDC)' that positively contributes to not only time savings but cost savings (Cooper, 2014; Cooper & Sommer, 2018). However, the rarity of agile models which focus on the early design stage has been repeatedly acknowledged even though there have been many dedications to materialising agile types over many years in the later design stage (Achiche et al., 2013; Backman et al., 2007; Hannola et al., 2013; Sperry & Jetter, 2009). Therefore, a model that can accelerate the FFE is in strong demand.

[12] Matrix-type models such as 'Quality Function Deployment' (QFD) and 'Design Structure Matrix' (DSM) seem, at first glance, to be appropriate for handling qualitative data. However, those models display the status of data processing only with symbols such as O and X or have the numbers graded, instead of the actual processing of qualitative data.

1.3) Incremental and Radical NPDs[13]

A model appropriate for both incremental and radical NPDs has been constantly received attention from both academic and industrial circles (Carbone & Tippett, 2014; Koen 2004; Verworn et al., 2008). However, the FFE systems of today, studied in academia and by firms, are not still sufficiently compatible between "Additions-to-the-Existing-product-Line (AEL)" type and "New-To-the-Company (NTC)" type of products (Carbone & Tippett, 2014). NPDs of both types coexist in the majority of companies today, with each type thus requiring its own compatible FFE model (Backman et al. 2007). A large proportion of the current early design models aim at only one of the two attributes (Dewulf, 2013; Ehrenfeld, 2008). Even if models target both NPD styles, it has been nearly impossible in practice to cater to both aims simultaneously (McCarthy et al., 2006; Sperry & Jetter, 2009). Therefore, study of the development of the front-end model to enable compatibility for both NPD types is still needed.

1.4) Explicitness and Responsiveness Characteristics

It is desirable to have both the 'Explicitness' and 'Responsiveness' characteristics in a single FFE model (Achiche et al., 2013; Kock et al., 2015; Martinsuo & Poskela, 2011). A fixed model structure, known as the 'Explicitness' type, is better for determining product definitions and specifications, by virtue of its stable management (Achiche et al., 2013; Cooper, 2008; Donaldson, 2001; Kim & Wilemon, 2002; Poskela & Martinsuo, 2009). On the other hand, a variably transformable model, known as the 'Responsiveness' type, is more suitable for encouraging creativity and inventiveness (Sperry & Jetter, 2009; Kock et al., 2015; Martinsuo & Poskela, 2011). Each of these types have their advantages which should not be underestimated. However, very few FFE models have been devised which strike the correct balance between the robustly structured and the variably flexible and includes the merits of both (Kock et al., 2015; Martinsuo & Poskela,

[13] Incremental and Radical NPDs

- Incremental NPDs: partially new products, including "evolutionary design" and "variant design" (van Aken, 2005), are improved based on new needs or problems identified from previous versions (Garcia & Calantone, 2002; Khurana & Rosenthal, 1997).
- Radical NPDs: totally new products that have never been developed before (Garcia & Calantone, 2002; Khurana & Rosenthal, 1997).

2011). Most models lean heavily towards one type, either the explicitness type, e.g. a linear, sequential and stage-activity-based process, or the responsiveness type, flexible and circular in nature, e.g. a spiral, recursive and modular process. Thus, today and going forward, a model to enable compatibility between the explicitness and responsiveness characteristics is required for both stable management and to foster creativity in FFE execution.

1.5) Procedural and Performative Structures

Most of FFE models are theoretical-descriptive type[14] in nature rather than being a pragmatic-prescriptive type[14] that provides specific structural processes and methodologies in FFE implementations (for example in the form of step-by-step guides) (Bertels et al., 2011; Carbone & Tippett, 2014; Dahan & Hauser, 2002; Kock et al., 2015; Sandmeier et al., 2004; Zahay et al., 2004). This tendency is the natural result of the uncontrollable FFE characteristics, mentioned previously (*pp. 11-13*). The more difficult it is to systematically manage the nature of a certain matter, the more challenging it becomes to define structural procedures, operating mechanisms and specific methods. However, a number of studies contend that the development of innovation processes has been relatively balanced between the theoretical-descriptive and pragmatic-prescriptive styles (Atsrim et al., 2015; Finger & Dixon, 1989; Konda et al., 1992). Hence, in the case of FFE part extracted from the entire innovation process, comparatively many focusing on the pragmatic-prescriptive type have been identified, e.g. Pahl and Beitz's (1984, 2007) and Hubka and Eder's (1987, 1996). Nonetheless, the FFE

[14] In general, a theoretical-descriptive model is arranged around a correlation of related FFE issues, e.g. a casual model, while a pragmatic-prescriptive model offers details of procedural action steps with specific guidelines. In this regard, many experts of today, including Atsrim et al. (2015) and van Aken (2005), argue that as long as model developers have not explicitly defined what the model type is, it is difficult to not only define an explicit way to separate these two types but also to recognise what the exact model type is, based on the output of models and the model development processes/methodologies they use. In addition, the boundary between the two types is becoming blurred since models are evolving continuously, which means that although originally a certain model might be pragmatic-prescriptive, subsequent studies examining the relationship between procedural steps may find the model to have theoretical-descriptive features. Conversely, even though the nature of an original model is theoretical-descriptive, the concept of procedural features can be inherent in the physical form of the correlation of related FFE issues.
One of the easiest methods by which to separate these types can be obtained from van Aken (2005). He said that the theoretical-descriptive model is typically generated from explanatory research while the pragmatic-prescriptive model is produced from exploratory research. More understanding of the theoretical-descriptive and pragmatic-prescriptive model types can be found in the following studies by: Atsrim et al. (2015), Finger and Dixon (1989), Konda et al. (1992), and van Aken (2005).

component has also tended to be examined in less depth from the viewpoint of the pragmatic-prescriptive style since the FFE component as part of the innovation process did not come to the fore until the late 1990s when the term FFE was officially coined (Carbone & Tippett, 2014; Kock et al., 2015; Sandmeier et al., 2004).

Furthermore, and more importantly, of the different kinds of pragmatic-prescriptive FFE models, procedure-type models have dominated, wherein practitioners understand the anatomy of the phases and relevant sub-phases (Massey et al., 2002; Rice et al., 2001; Talke et al., 2006; van Aken, 2005). Meanwhile, performance-type models have received little development; these are where practitioners can use the model physically and functionally, producing parameters in the model itself (Massey et al., 2002; Rice et al. 2001; Talke et al., 2006; van Aken, 2005). Namely, FFE models that lay out 'What' should be produced are more prevalent than those define 'How' it should be done (Lukas & Menon, 2004; Williams & Kochhar, 2000; van Aken, 2005; Williams et al., 2007). Moreover, models in which the 'How' aspect is equipped with a physical and functional form are extremely rare. Consequently, this illustrates the need for an FFE model that better incorporates the performative characteristic into the procedural structure.

In summary, FFE model improvement demands reflection on the following five current and future trends in terms of determining the overall attributes of the model: 1) data-driven type, 2) agile development, 3) incremental and radical NPDs, 4) the explicitness and responsiveness characteristics, and 5) procedural and performative structures. With these improvement directions, it is expected that a new model can provide bright prospects to overcoming limitations in reflecting current and future trends with respect to overall attributes.

2) Second Dimension
: FFE Performance Structure and Operating Mechanism
– Parameter Process and Decision

The second limitation in FFE models lies in the FFE performance structure and its operating mechanism which are related to processing and determining NPD-related parameters. This defect is akin to the shortcomings in performative-type FFE models in general (mentioned in the previous section, *p. 20*), but here it refers to more specific aspects.

FFE performance and its operation proceed around the following four hierarchical units: 'Task', 'Activity', 'Performance Method' and 'Toolkit'. These units are also the basic components that make up the structure of the model (Birkhofer et al., 2002; McCarthy et al., 2006; Herstatt & Verworn, 2001; van Aken, 2005).

- **'Task'** is the broadest unit making up the FFE phase, and covers tasks of any kind, including opportunity identification tasks, idea generation tasks, conceptual design tasks, etc.
- **'Activity'** is subordinate to 'Task' in that its actions aim to accomplish that 'Task', e.g. a market and technology research activity for an opportunity identification task, or a workable prototyping activity in a prototyping task, and so on.
- **'Performance Method'** refers to narrative manual instructions describing how to conduct each 'Activity'.
- **'Toolkit'** refers to a physical and functional construct in which a 'Performance method' is structured. 'Toolkit' has an explicit form and frameset in which input and outputs related to NPD-related parameters, variables and constrains are produced. 'Toolkit' can help to increase effectiveness in executing 'Performance methods' from a functional standpoint.

The task and activity units are relevant to FFE operations concerning 'What', while the performance method and toolkit units are associated with FFE operations concerning 'How'. In particular, the toolkit units are more related to the specific performance structure and its operating mechanism, directly linked to the embodiment of the performative model in which a physical and functional form directly generates NPD-related parameters.

Of the four units, many authors, including van Boeijen et al. (2014), Koen et al. (2002), Kumar (2012), Montagna (2011), have expended great effort to study the toolkit units. Some studies, including Achiche et al. (2013) and Ester and Daniel (2007), have been devoted to investigating the frequency, preferences and suitability of using each toolkit predominantly used in the initial design stage.

However, most of the toolkits and their implementation techniques that have been devised so far have a number of specific, critical flaws from the viewpoint of processing and determining NPD-related parameters. These flaws are about more than just developing and providing effective toolkits for the 'How' aspect and indeed concern FFE tasks and activities related to the 'What' aspect. The flaws are closely related to not only how toolkits and their operating mechanisms are structured functionally but also how they are to be incorporated into the procedural structure of the FFE. This functional and structural deficiencies of existing toolkits in considerable uncertainty and ambiguity, triggered by insufficient and inaccurate methods of gathering and interpreting NPD-related information which leads to a poor parameter process and decision, itself leading to markedly decreased effectiveness of FFE performance. These functional and structural deficiencies in toolkits (in terms of the processing and determining of parameters), present in two forms:

2.1) Contextual Performance
2.2) Concurrent Collaboration

2.1) Contextual Performance

Jetter (2003) argues that FFE toolkits should be provided from a holistic system-oriented perspective and that NPD-related information transferred between toolkits should contain context. This stresses the necessity of developing toolkits from a contextual performance perspective. Notwithstanding that, few toolkits have been devised with contextual performance in mind. It means those toolkits do not interlock with each other but instead have a tendency to be separated and exist independently for a given purpose and role. Since most of these toolkits have been developed independently for particular activities and tasks, they are not systematically connected, and thus parameters produced from one toolkit do not flow into the next. Namely, output parameters produced from previous toolkits are not linked with the input parameters that enter into subsequent toolkits. These functional and structural faults in toolkits can cause knock-on effects further down the line, as follows:

- During the use of a given toolkit for a certain activity or task, a performer can have difficulty in understanding the role and purpose of a given toolkit, with considering the purpose and roles of other toolkits for activities or tasks; the independent nature of each toolkit means that he cannot look to other toolkits used in the same activity or task to infer information about his current toolkit.
- After using the given toolkit for a certain activity or task, the performer can be faced with difficulty in apprehending the purpose, role, and meaning of a parameter produced from the given toolkit, even when considering the purpose, roles, and meanings of parameters of other toolkits.
- The performer can have trouble in comprehending the relationship between the parameters of each toolkit in terms of how to connect these outcomes with each other. More specifically, the performer cannot understand how parameters produced from the previous toolkit flow into parameters for the next toolkit. They cannot grasp how output parameters obtained in the previous toolkit become input parameters for the subsequent toolkit.
- As a result, after using a given toolkit, the performer can be confronted with difficulty in grasping which toolkit can be utilised next, from the toolkits available. The performer cannot understand what the next toolkit can be initiated, with considering output parameters produced from the previous toolkit. In short, the output parameters of previous toolkits do not in themselves tell users what the next toolkit should be or what toolkit they should flow into.
- Consequently, the performer only understands the constituent parts of the system – the separate toolkits themselves, and even then, only the ones that they themselves use – and not the system as a whole.

To conclude, the functional and structural deficiencies of toolkits from the contextual performance perspective means that the purpose, roles, and parameters of each toolkit cannot be inferred from those of other toolkits. The purpose, roles, and parameters of each toolkit have a high possibility of existing independently without an interrelationship between each of them. This out-of-order configuration of toolkits leads to a high degree of uncertainty incurred by gathering an insufficient quantity of parameters as a result of missing essential required toolkits. This also gives rise to a high degree of ambiguity as a result of a poor understanding of the purpose, roles, and parameters of each toolkit. The more deviations there are in the backgrounds and specialities of the performers, the greater the magnitude of the negative effects mentioned in the points above.

2.2) Concurrent Collaboration

Few toolkits have been developed for concurrent collaboration, a system which would simultaneously involve performers from diverse NPD-related functional domains such as engineering, design, marketing, and so on. Many studies, including those by Jetter (2003), Poskela & Martinsuo (2009), and Verworn (2009), have emphasised various types of collaborative work in the FFE phase, and these studies have noticed that most NPD collaborations require simultaneous work. However, most FFE models have not proposed even collaborative toolkits (Koen et al., 2001; 2002; 2004), to say nothing of the *concurrent* collaborative toolkits. Toolkits for concurrent, cross-functional work have not been functionally and structurally developed for incorporation into FFE models. This deficiency has resulted in the following adverse effects:

- When performers from different NPD-related functional fields such as engineering, design, and management employ different toolkits from the viewpoint of their own fields of expertise, they may have difficulty in understanding the purpose and roles of other toolkits used by other performers.
- After coming from different sectors and using different toolkits specifically for their field of expertise, they can be faced with difficulty in apprehending the purpose, roles, and meanings of parameters produced in their toolkits,

with considering those of parameters obtained in other toolkits conducted by other performers.

- They can have trouble in comprehending the relationship between the purpose, roles, and parameters of toolkits used by different performers with different backgrounds and areas of expertise.
- As a result, they may not be able to grasp how parameters produced by their toolkits affect or are influenced by other parameters obtained from other toolkits used by other performers. They cannot understand how output parameters produced by their toolkits become input parameters for other toolkits used by other performers. The difficulty essentially arises when multiple, disparate toolkits are used together.

Consequently, the functional and structural deficiency of toolkits from the concurrent collaboration perspective means that the purpose, roles, and parameters of each toolkit used by different performers coming from diverse functional fields cannot be inferred between each of them. It is quite possible that outcomes obtained from each toolkit exist independently without an interrelationship between outcomes produced from different functional domains. This results in incomplete parameters wherein NPD-related information researched and analysed from the different functional domains cannot be integrated, creating an insufficient quantity of parameters, which increases uncertainty. This also leads to incorrect interpretation and processing of parameters gathered from diverse functional domains, and thus a high degree of ambiguity. The less adequate 'T', 'TT', and even 'TTT' type performers are in NPD organisations, the greater the negative effects referred indicated above.

In conclusion, considering the limitations of existing FFE models explored in this section, it is apparent that a study on new FFE model development is required in the following two dimensions:

1) **The first dimension:**

   Reflect the following five current and future trends in FFE improvement, which will determine the overall attributes of the front-end:

1.1) Data-driven type

1.2) Agile development

1.3) Incremental and radical NPDs

1.4) Explicitness and responsiveness characteristics

1.5) Procedural and performative structures

2) The second dimension:

Improve the performance structure and its operating mechanism, which affects the processing and deciding of parameters through the following two approaches:

2.1) Develop toolkits which consider contextual performance.

2.2) Develop toolkits which consider concurrent collaboration.

1.3 Thesis Overview

The two dimensions of limitations found in existing FFE models – 1) deficiencies in reflecting current and future trends and 2) deficiencies in FFE performance structures and operating mechanisms – constitute the research directions this study intends to pursue to develop a new FFE model. This section establishes, first of all, a research aim, objectives, and questions. Then, the scope of this research and the expected challenges are specified. Next, contributions of the new FFE model which improves upon these identified deficiencies prospect. Lastly, an overall research structure is laid out.

1.3.1 Research Aim, Objectives, and Questions

1) Aim

This section defines a research aim of this research. Considering the two dimensions of limitations identified in the previous section (*pp. 17-27*), the aim is as follows:

To develop a new FFE model for new product development that corrects for the following two dimensions of limitations identified in existing FFE models.

1) The first dimension relates to incorporating current and future trends in FFE improvement which will determine the overall attributes of the front-end
    - 1.1) Data-driven type
    - 1.2) Agile development
    - 1.3) Incremental and radical NPDs
    - 1.4) Explicitness and responsiveness characteristics
    - 1.5) Procedural and performative structures
2) The second dimension relates to developing toolkits for contextual performance and concurrent collaboration to improve the FFE performance structure and its operating mechanism, which affects the processing and deciding of parameters.

2) Objectives

This section establishes a total of five research objectives, specific implementation goals for the aims defined above (*p. 28*). These research objectives are briefly divided into two categories: FFE model *development* and FFE model *validation*. The former includes initial three objectives while the latter covers the remaining two. The research objectives are aligned with five relevant investigations which will be specifically conducted throughout the course of this research project. Thereafter, outcomes expected from conducting those studies are also illustrated.

FFE Model Development

2.1) Objective 1 (Study 1.0)

To examine existing FFE models and related studies to understand the features of each model and the trends in FFE model development

- Expected outcome:

  Relevant knowledge-and-theories and cues-and-resources for establishing specific strategies to develop a new FFE model

2.2) Objective 2 (Study 2.1)

To research and analyse actual FFE practices in NPD industries to better understand real-world FFE scenarios

- Expected outcome:

  A representative FFE scenario in NPD industries

2.3) Objective 3 (Study 2.2)

To develop a new FFE model based on the outcomes of 'Study 1.0' and 'Study 2.1' listed above

- Expected outcome:

  A pragmatic-prescriptive FFE model

FFE Model Validation

2.4) Objective 4 (Study 3.1)

To validate the developed pragmatic-prescriptive FFE model in actual NPD fields in terms of correcting the identified limitations

- <u>Expected outcome:</u>

  Validation results on whether the pragmatic-prescriptive FFE model developed in 'Study 2.2' can address the identified limitations

2.5) Objective 5 (Study 3.2)

To generalise the pragmatic-prescriptive FFE model based on the outcomes of 'Study 3.1'

- <u>Expected outcome:</u>

  A theoretical-descriptive FFE model

Consequently, the research objectives target the producing of both a pragmatic-prescriptive and a theoretical-descriptive FFE model[15]. In 'Study 2.2', a pragmatic-prescriptive FFE model is devised from 'Study 2.1', based on FFE model strategies established in 'Study 1.0'. Then, a theoretical-descriptive FFE model is developed by generalising the pragmatic-prescriptive FFE model (Study 3.2), based on the validation results (Study 3.1).

3) Questions

Distilled from the research aims and objectives are the mission statements that this research shall bear in mind throughout the course of the study, written in the form of questions. The research questions are also divided into two directions: FFE model development and FFE model validation, in the same context as with the establishment of the research objectives.

3.1) Question 1 relates to FFE model development

What does a structural and functional pragmatic-prescriptive FFE model look like wherein development strategies are established based on the two dimensions of limitations found in existing FFE models?

[15] A more in-depth review of the pragmatic-prescriptive and theoretical-descriptive models can be found in *Footnote 14* (*p. 20*)

3.2) Question 2 relates to the model validation

How can we generalise the pragmatic-prescriptive FFE model based on the validation outcomes of the model to achieve a theoretical-descriptive FFE model: can we develop a mathematical theory as a form of theoretical-descriptive FFE model, based detections of a particular pattern which can be dealt with mathematically in the progress of generalisation?

To conclude, this section introduces the overall research direction, considering the research aim, objectives, and questions established above. This research aims at developing an FFE model for NPDs to address the shortcomings identified in existing FFE models, with the hope of generating the following two types of outcomes.

The first outcome is a pragmatic-prescriptive FFE model developed with knowledge-and-theories and cues-and-resources obtained from examining existing FFE models and an understanding of actual FFE practices.

Once the pragmatic-prescriptive FFE model is verified in actual NPD programmes, the second outcome, a theoretical-descriptive FFE model, as a generalised output of the pragmatic-prescriptive FFE model, is produced based on the results of the verification. When a particular pattern (which can be handled mathematically in the pragmatic-prescriptive FFE model's generalisation) is observed, the theoretical-descriptive FFE model can take a form of a mathematical theory.

1.3.2. The Expected Contributions

This section illustrates research contributions that are expected from the two types of research outcomes mentioned above.

1) Pragmatic-Prescriptive FFE Model

1.1) Overall Attributes

Once a pragmatic-prescriptive FFE model in which current and future trends of FFE model improvement are reflected is developed successfully, users including scholars and practitioners can operate the FFE by effectively responding to essential considerations stemming from the industrial circumstances of today and the future.

1.2) Performance Structure and Operating Mechanism for Contextual Performance

Once a pragmatic-prescriptive FFE model wherein toolkits for contextual performance is developed:

- The users can clearly understand the purpose, roles, and meanings of toolkits and outcomes and their relationships, accurately processing and deciding all of the required parameters in each functional domain, which reduces uncertainty and ambiguity.
- The users can comprehend the execution of toolkits from the viewpoint of the system as a whole and not the constituent parts of the system which they operate.
- As a result, a pragmatic-prescriptive FFE model can help to produce parameters more abundantly and precisely by reducing the effects of deviation in terms of the backgrounds and specialities of the users.

1.3) Performance Structure and Operating Mechanism for Concurrent Collaboration

Once a pragmatic-prescriptive FFE model in which toolkits devised with concurrent collaboration in mind is developed:

- The users can multidimensionally apprehend the purpose, roles, and meanings of toolkits and outcomes and their relationships, collaboratively processing and determining parameters in diverse functional domains, which decrease uncertainty and ambiguity.
- The users can understand the implementation of toolkits from the viewpoint of the complete system and not just its components.
- As a consequence, a pragmatic-prescriptive FFE model can support the production of more abundant and accurate parameters, with the same effect as employing 'T', 'TT', and even 'TTT' type experts.

As a result, the pragmatic-prescriptive FFE model can be utilised as practical-functional performance guidance of NPDs in the FFE.

2) Theoretical-Descriptive FFE Model

2.1) Once a theoretical-descriptive FFE model is produced by generalising the pragmatic-prescriptive FFE model (based on strong validation results of the pragmatic-prescriptive FFE model), users covering scholars and practitioners can theoretically understand the underlying concept of the FFE in NPDs.

2.2) As a result, the users can better comprehend the fundamental purpose, roles, and meanings of the FFE in NPDs when using a pragmatic-prescriptive FFE model.

Consequently, a theoretical-descriptive FFE model can serve as theoretical-conceptual performance guidance by using the pragmatic-prescriptive FFE model as practical-functional performance guidance of the FFE in NPDs.

1.3.3 Research Scope and Challenges

1) Scope

This section clarifies the research scope from two perspectives: 1) NPD domain and 2) company type.

In the former side, this research limited solely to the consumer product sector among various NPD domains. It does not involve intangible developments such the service design, branding or the social innovation aspect, but it does concentrate on tangible artefacts such as consumer products, electronics, medical devices, furniture, vehicles and so on. The NPD domain excludes pharmaceuticals, apparel, microchips, and software. The attributes, characteristics, and features of these product types are different to those of products covered by this research, meaning that their development courses and models are naturally different. Therefore, this research to develop an FFE model focusing on consumer products, excludes other product fields.

Concerning the latter perspective, this research targets NPDs in large corporations and small and medium-sized enterprises (SMEs), but excludes start-ups which have just started to find new business and markets. Large corporations develop a variety of product types, each with varied product lines. The SMEs investigated here are design specialty firms and NPD consultancies that engage in practical design activities throughout the FFE.

There are differences and similarities in the way large corporations and SMEs operate NPDs, according to the European Commission (Berisha & Shiroka-Pula, 2015) and the UK Commission (Ward & Rhodes, 2014). Large corporations operate NPDs using organised systems with significant numbers of personnel (more than 250 employees). SMEs have a comparatively flexible working and communication system to develop products with a relatively small number of employees (typically around 50 to 250). Furthermore, large corporations traditionally hire specialists, i.e. specialised in a single area; while SMEs hired generalists i.e. specialised in multidimensional areas. However, let us make one point here: today companies hire both types of employees, regardless of company's size, to foster effective communication in work environments. They are able to operate an effective NPD model and system, to respond any industrial circumstances. Namely, except for a company's size in terms of the number of employees and the size of its projects, both large corporations and SMEs require a similar NPD model, system, and working environment.

Thus, this research aims at consolidated FFE model development and application regardless of the two different company types, excluding varied mode developments and their applications of the FFE model according to different attributes and features between the two types.

2) Challenges

There are three challenges expected in conducting this research.

First of all, there are seven considerations for development of the new pragmatic-prescriptive FFE model. This may seem excessive for a single study. The simple application of those seven considerations to a single model might be very complicated, generating a very complex structure and operating system. It is quite possible that such a complex system runs counter to the FFE model of facilitating efficient and pragmatic performance. Therefore, grasping and understanding the correlations between these considerations is required in 'Study 1.0', to allow for the clear application of a single consideration and to see how it will affect the other six.

The next challenge is not only to increase the number of participants in the case studies (Study 2.1) and field tests (Study 3.1) but also to select and contact those who have relevant expertise. The greater the number of experts and the higher their degree of professionality, the better the model will be.

The final challenge to overcome in this research is how to generalise the pragmatic-prescriptive FFE model into a theoretical-descriptive FFE model, in the form of a mathematical theory. The significant issue here is whether we can indeed obtain strong validation results and ascertain a particular pattern that can be treated mathematically in the generalisation progress.

To conclude, in order to achieve reliable outcomes with the pragmatic-prescriptive and theoretical-descriptive FFE models that can ultimately contribute to both academia and industry, the three challenges mentioned above should be kept in mind during the course of this research.

1.3.4 Overall Research Structure

An overall research structure was adopted from Blessing and Chakrabarti's (2009) Design Research Methodology (DRM), shown in *Figure 1.2*.

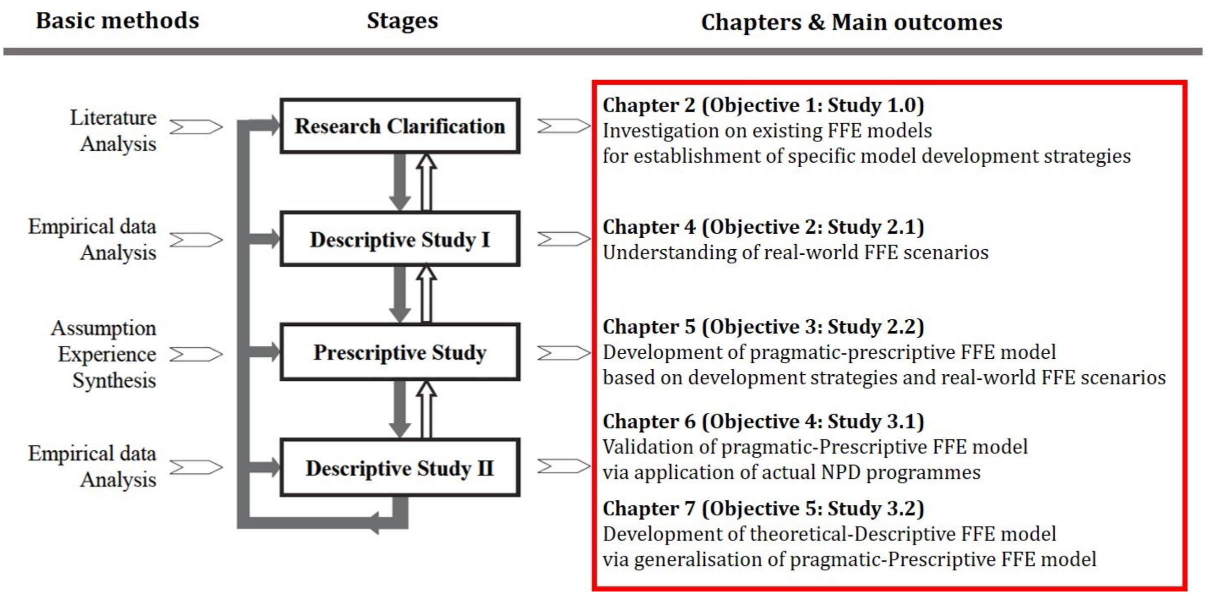

Figure 1.2. *Overall research structure 1 (own depiction, adapted from Blessing & Chakrabarti, 2009)*

The DRM is a research framework that has a proven track record of developing and validating all kinds of "Design Support Tools", in reference to models, processes, frameworks and detailed toolkits to support design activities. Many studies, including those by Aurisicchio (2006), Eng et al. (2017) and Sheldrick (2015), have borrowed the framework of the DRM to their overall research structure to develop a design support tool. The DRM framework is suitable for research which proceeds in the following sequence: 1) establishing specific research strategies by conducting a literature review, 2) developing a prescriptive model, and 3) generating a descriptive model by validating the prescriptive model. The basic stages of the DRM framework correspond to this present research's objectives and its sub-studies (Study 1.0 to Study 3.2).

The flow chart, shown in *Figure 1.3* below, provides a more detailed overview of the thesis, chapter by chapter.

Chapter One introduces the background behind FFE studies in the NPD domain, stating the core problems to be tackled. Seven key considerations for the development of new FFE model are established based on those problems, and the research aims, objectives and questions are laid out. The chapter also describes the prospected research contributions and the research scope and challenges, as well as the overall research structure.

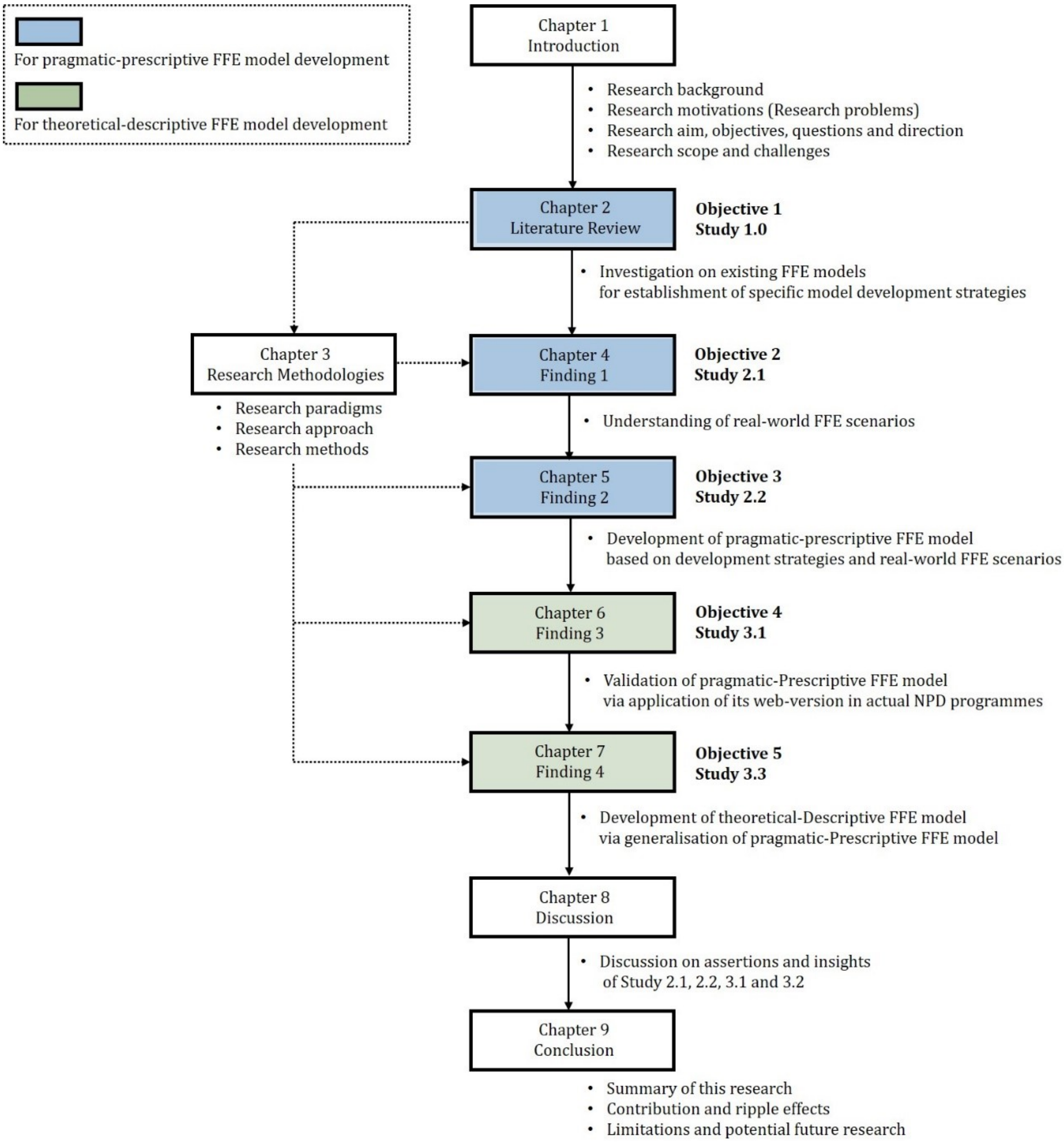

Figure 1.3. *Overall research structure 2*

Chapter Two (fulfilling **Objective 1**, as **Study 1.0**) reviews existing FFE studies. This intensive examination helps to narrow down potential research directions and allow specific strategies for a new pragmatic-prescriptive model development to be defined with relevant knowledge-and-theories.

Chapter Three presents the research methodologies framed in terms of research paradigms, research approaches, and specific methods which are appropriate for each stage of the research. The main role of this chapter is to introduce execution methods and their underlying research philosophies, for each objective and sub-study.

Chapter Four (fulfilling **Objective 2**, as **Study 2.1**) addresses the main findings obtained from the collection and analysis of data on actual FFE practices in NPD industries, to develop a view of the overall structure of the fuzzy front end, as well as their sub-structures, components and operating mechanisms. These findings serve as cues-and-resources for the development of the pragmatic-prescriptive FFE model.

Chapter Five (fulfilling **Objective 3**, as **Study 2.2**) presents the progress and results of building the pragmatic-prescriptive FFE model, considering not only specific development strategies established from Chapter Two but also relevant knowledge-and-theories and cues-and-resources gained from Chapters Two and Four. The pragmatic-prescriptive model can be regarded as a hypothetical model for validation which is carried out in the next chapter.

Chapter Six (fulfilling **Objectives 4**, as **Study 3.1**) illustrates the validation process of the developed pragmatic-prescriptive FFE model and its outcomes. The validation is followed by the application of the pragmatic-prescriptive FFE model in actual NPD industries. To ensure a more realistic environment and experimental conditions, a web-version embodied from the pragmatic-prescriptive FFE model is utilised in the validation.

Chapter Seven (fulfilling Objectives 5, as **Study 3.2**) illustrates the generalisation process of the developed pragmatic-prescriptive FFE model. After the verification process mentioned in the chapter description above is completed, which will indicate whether the pragmatic-prescriptive model has validity, it is transformed into the theoretical-descriptive FFE model, in the form of a mathematical model.

Chapter Eight discusses key assertions and insights on key findings produced in Studies 2.1 to 3.2 which are conducted in Chapters Four to Seven. Discussions on the findings of each study – the understanding of real-world FFE scenarios, the developed pragmatic-prescriptive FFE model, the application of the pragmatic-prescriptive FFE model, and the generalised theoretical-descriptive FFE model – are outlined with highlights of the assertions and insights.

Chapter Nine presents a comprehensive summary of this research. Its contributions and their ripple effects are also illustrated in this chapter. This chapter also includes a discussion of the study's limitations and potential future research directions.

Chapter 2. Study 1.0

– Review of Previous FFE studies
: FFE Model Development Strategies

2.1 Chapter Introduction

This chapter describes the progress and key findings of Study 1.0, fulfilling Objective 1 (shown in *Figure 2.1*).

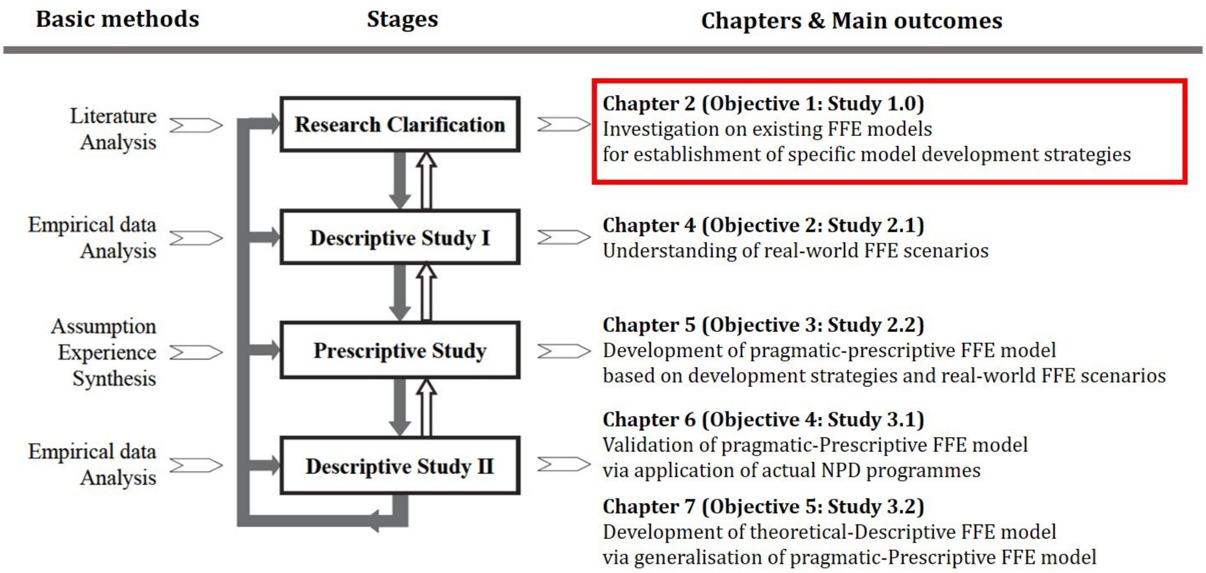

Figure 2.1. *Mini-map of study (own depiction, adapted from Blessing & Chakrabarti, 2009)*

This introduction begins by illustrating the research objective of the chapter, followed by the research method to achieve said objective, before concluding with a short summary.

1) Research Objective
2) Research Method
3) Research Summary

2.1.1 Research Objective

The purpose of Study 2.1 is to fulfil Objective 1: reviewing previous FFE studies to establish more effective strategies for the pragmatic-prescriptive FEE model development than the comparatively rough directions proposed in Chapter One (Introduction, *p. 28*).

In order to achieve this, van Aken's (2005) approach for developing a design process in the NPD domain was referenced and used to build the holistic structure of the literature review. According to his study, developing a design process means coming up with an 'optimum solution', the best platform for artefact designs, fitting the 'best requirements' derived from 'various ranges of solution concepts' which are themselves extracted from 'past to state-of-the-art processes'.

Based on his approach, 255 FFE studies were selected from both the academic and industrial bodies of literature, arranged in chronological order to identify 'past to state-of-the-art FFE models'. The 255 studies were analysed using specific appraisal criteria for the purpose of grasping 'various ranges of solution concepts'. Based on the results, specific strategies were clarified by narrowing the 'various ranges of solution concepts' down to 'best requirements', and finally the 'optimum solution'.

Via this approach, this section hopes to achieve the following sub-objectives:

1) To understand the attributes and features of each FFE study, by scrutinising each individual study with the established criteria
2) To understand the trends behind FFE studies and model developments, by classifying and analysing them in chronological order
3) To understand the FFE and gain in-depth knowledge-and-theories directly related to the FFE, by identifying how each study handles FFE issues and how the approach in each one satisfies the requirements for handling those issues
4) To understand other matters indirectly associated with the FFE and applicable knowledge-and-theories attained from those matters, and determining how this can be applied to this present study's own FFE model

In the following sections, the model selection process (the data collection method), and the establishment of the analysis criteria and methods are presented in detail.

2.1.2 Research Method

1) Data Collection Method
– Selection of the 255 FFE Studies

There have been around 600 NPD models developed since the 1970s, a figure which includes variations and related methods (Simms, 2012). It is not feasible nor necessary helpful to list and examine them all within the constraints of a single study, so it is essential to establish critical standards to choose the most generally accepted, relevant and suitable models for further analysis. In this study, a total of 255 FFE studies were gathered: some are widely adopted in various industries, e.g. telecoms (Nortel) (Montoya-Weiss & O'Driscoll, 2000), printing (Xerox) (Nobelius & Trygg, 2002), aircraft engines (GE, GM and Rolls-Royce) (Herstatt & Verworn, 2001), vehicles (Volvo) (Backman et al., 2007).

This section is further divided into two sub-sections, looking at: 1) the taxonomy of the subjects of FFE studies, and 2) process by which to gather FFE studies.

1.1) Taxonomy of the Subjects of the FFE Studies

A taxonomy of previous FFE studies was defined, based on Oliveira and Rozenfeld's (2010) suggestion. Although the purpose of the literature review is closely related to developing a prescriptive type of FFE model, many other types of models were collected regardless, e.g. the descriptive, prescriptive, etc., since they can provide useful cue-and-resources which can be applied to later development. The taxonomy is described below:

a) **Independent FFE model:** an analysis of models developed for the FFE only, e.g. Khurana & Rosenthal (1998), Kim & Wilemon (2002), Murphy & Kumar (1997), Verworn (2009), etc. Partial FFE models built solely for one or two front-end tasks were also included in this category. The six tasks – 'Opportunity identification-screening', 'Ideation', 'Mission statement', 'Requirement list', 'Conceptual design' and 'Prototyping' – were referenced from studies that define the range of the FFE phase, e.g. Jetter (2003), Koen et al. (2002) and Nobelius and Trygg (2002).

b) **Dependent FFE model:** FFE processes which are part of wider models covering the innovation process in general were also incorporated into this study, e.g. Cooper et al. (2002), Pahl & Beitz (2007), Salerno et al. (2015), among others. Mendes and Oliveira (2015) and Oliveira and Rozenfeld (2010) recommended including the general innovation process by targeting the first section. Most NPD processes have the FFE component at the head of the process (Oliveira & Rozenfeld, 2010; van Aken, 2005).

c) **Study of the FFE issue:** studies which do not provide any models but are related to FFE issues, e.g. its attributes, roles, functions, uncertainty control, 'Critical Success Factors (CSFs)', etc., were also included in this investigation. The reason for this is that one of the aims of '*Study 1.0*' is to develop in-depth knowledge-and-theories about the FFE which can be applied to model development.

d) **Study related to the FFE issue:** studies which do not directly target the FFE but are indirectly related to FFE issues and whose knowledge-and-theories may be relevant in the FFE model development were also included. For instance, knowledge, theories and applications in terms of 'information processing', 'knowledge accumulation', 'decision-making processing' and 'trend forecasting' can be applied to the development of either an overall FFE model or one of the tasks.

1.2) Process by which to gather FFE studies

Several studies which conducted surveys concerning different models were referenced to help design a protocol for the collection of models used in this investigation. The study by Mendes and Oliveira (2015) is the seminal work in this area, which carried out a "Systematic Literature Review", a method which has been in the spotlight in the social science and engineering domains in recent years (Cook et al., 1997; Reim et al., 2015). "Bibliometrics", a vital part of a systematic literature review, carries out statistical and quantitative interpretations of data (De Bellis, 2009; Okubo, 1997). One of the specific methods employed in bibliometrics is to concentrate on the most cited papers and authors as well as the most mentioned keywords in each article (Okubo, 1997; Ramos-

Rodríguez & Ruíz-Navarro, 2004). The books, journals and conference papers chosen for this examination were drawn from the 'Web of Science' database, one of the most prestigious interdisciplinary publication search engines (Carvalho et al., 2013; Mendes & Oliveira, 2015). The Web of Science is well-known for providing exhaustive and structured illustrations of indexed publications (Carvalho et al., 2013). Indeed, a large number of bibliometric studies have been performed using Web of Science (Mendes & Oliveira, 2015).

In establishing the protocol to select FFE studies, those studies mentioned above were primarily adopted, alongside others including Baumgartner & Pieters (2000, 2003), Biemans et al. (2007), Durisin et al. (2010), and Luchs & Swan (2011). The process by which models were chosen for inclusion is described below.

a) The most cited FFE models (e.g. Khurana & Rosenthal, 1998) and innovation processes (e.g. Cooper, 1983, 1990, 2001) were extracted from journals and conference papers, based on data from studies conducted by Luchs & Swan (2011), and Mendes & Oliveira (2015). [16]
b) Other models and studies which were referenced in those papers and found via the above step were also selected: Durisin et al. (2010) recommend considering both the given journals *and* journals that impact those journals.
c) The most cited models in well-known textbooks written by recognised experts in NPD areas (e.g. Ulich & Eppinger's 5th edition of *Product Design and Development*, published in 2012) were considered, based on recommendations by Biemans et al. (2007) and Durisin et al. (2010).
d) Other models and studies, which were adopted to develop those models identified in the above step, were chosen, based on the recommendation of Durisin et al. (2010).
e) The most representative models were brought in from studies reviewing the most archetypal and renowned models e.g. Adams (2015), Buijs (2003), Carbone and Tippett (2014), Eveleens (2010), Evbuomwan et al. (1996), Howard et al. (2008), Simms (2012), Sperry and Jetter (2009), van Aken (2005), Wynn & Clarkson (2005), and so on.

[16] In the study by Mendes & Oliveira (2015), Tables 5 and 6 provides "THE TWENTY MOST CITED PAPERS IN WEB OF SCIENCE" and "THE MOST CITED REFERENCES" respectively.

f) Other models and studies which were referenced in the papers examined in Step 5 were also selected.
g) In order to collect any remaining FFE model studies from the database that might be relevant, several keywords were chosen for each classification of model. Then, those keywords were used to build the character string search, which was employed on academic literature published between 1910 and 2018. The key words used were as follows:
    - For 'Independent FFE model': "Fuzzy Front End (FFE)", "Front End (FE)", "Front End of Innovation (FEI)", "Predevelopment", and "Early design".
    - For 'Dependent FFE model': "Innovation process", "New Product Development (NPD) process", and "Design process".
    - For 'FFE study' and 'Studies related to the FFE study': specific keywords were not defined because when analysing papers found using the strings for the above two categories ('Independent FFE model' and 'Dependent FFE model'), knowledge-and-theories related to 'FFE study' and 'Study related to the FFE study'was gained from other papers which the original papers recommend referencing. Therefore, we were able to search and examine other papers without the need for those particular search strings.
h) The other models and studies referenced in those materials investigated in the above step were targeted. For instance, Hale's (1993) model was developed, referencing Pahl and Beitz's (1984, 2007) model. A study by O'Connor (1995) recommended referencing Pugh's (1991, 2009) and Taguchi's (1986) model.

When selecting FFE studies, the guiding principle was focusing on the latest version of a model that has continuously evolved over many years. For example, the FFE model developed by Verworn and Herstatt (2003) and Verworn (2009) was analysed, concentrating on the version from 2009. However, when the initial or earlier version of a model has a broader representation, the examination instead looked at the most representative version. For instance, in the case of the model devised by Cooper and Cooper et al. from 1988 to 2018, the analysis relied upon the 1988 version as the cornerstone of the whole range of models. Another remarkable note was whether those papers and textbooks were published by top influential academic journal organisations and by those related to the NPD sector (Baumgartner& Pieters, 2000, 2003; Biemans et al., 2007; Durisin et al., 2010).

In order to filter out less relevant studies, a screening progress was borrowed from Mendes and Oliveira (2015). This process began in the early stages, as soon as the first ten papers were verified. It involved five researchers comparing their decisions on the publications. Intense discussions were held five times to arrive at an agreement in our judgements, focusing on two points. The first examined whether the papers were suitable for inclusion. The second is a more in-depth analysis of why each paper was adopted or excluded. After a consensus was reached, seven papers out of those initial ten were adopted, the remaining three dropped. The above method was used to filter subsequent tranches of potential studies until an additional 248 papers were finally included, resulting in the 255 studies this paper ultimately uses. When studies had very little to do with this investigation (determined by a review of the study's title, keywords and abstract) or when they concentrated on very different areas despite having FFE as one of their keywords (focus missing), or when studies only tangentially related to the domains of this investigation (out of scope) [17], e.g. biomedical and heavy industry sectors, these studies were excluded from the list. However, when occasion demanded, studies from the construction, apparel, and software development areas were included. [18] Also, duplicated models were excluded at every step.

Figure 2.2 depicts the overall taxonomy and collection process. By way of thorough classification and systematic selection of usable studies, this research endeavoured not only to maximise scientific rigour, validity and reliability but also to minimise bias in the gathering and screening of FFE models. Furthermore, what can be inferred in this well-organised eight- step process can be classified into two sections, connoting different development directions of new FFE models.

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[17] The range of research has already been defined in Chapter One (Introdution, *pp. 34–35*).

[18] The structure, composition, features and operational mechanisms of many different NPD processes have been applied to 1) construction, e.g. Halpin and Senior (2010), Kagioglou et al. (2000; 2003), Sanvido and Khayyal (1990), etc., 2) apparel design, e.g. Moretti and Junior (2017), and 3) software development, e.g. Aranda et al. (1993), Boeham (1988), etc.

The first part covers the most cited models found in Steps 1 and 3, and the most prominent models as determined by a majority of experts, identified in Step 5. The analysis of these models can offer basic insight into the development of a new model.

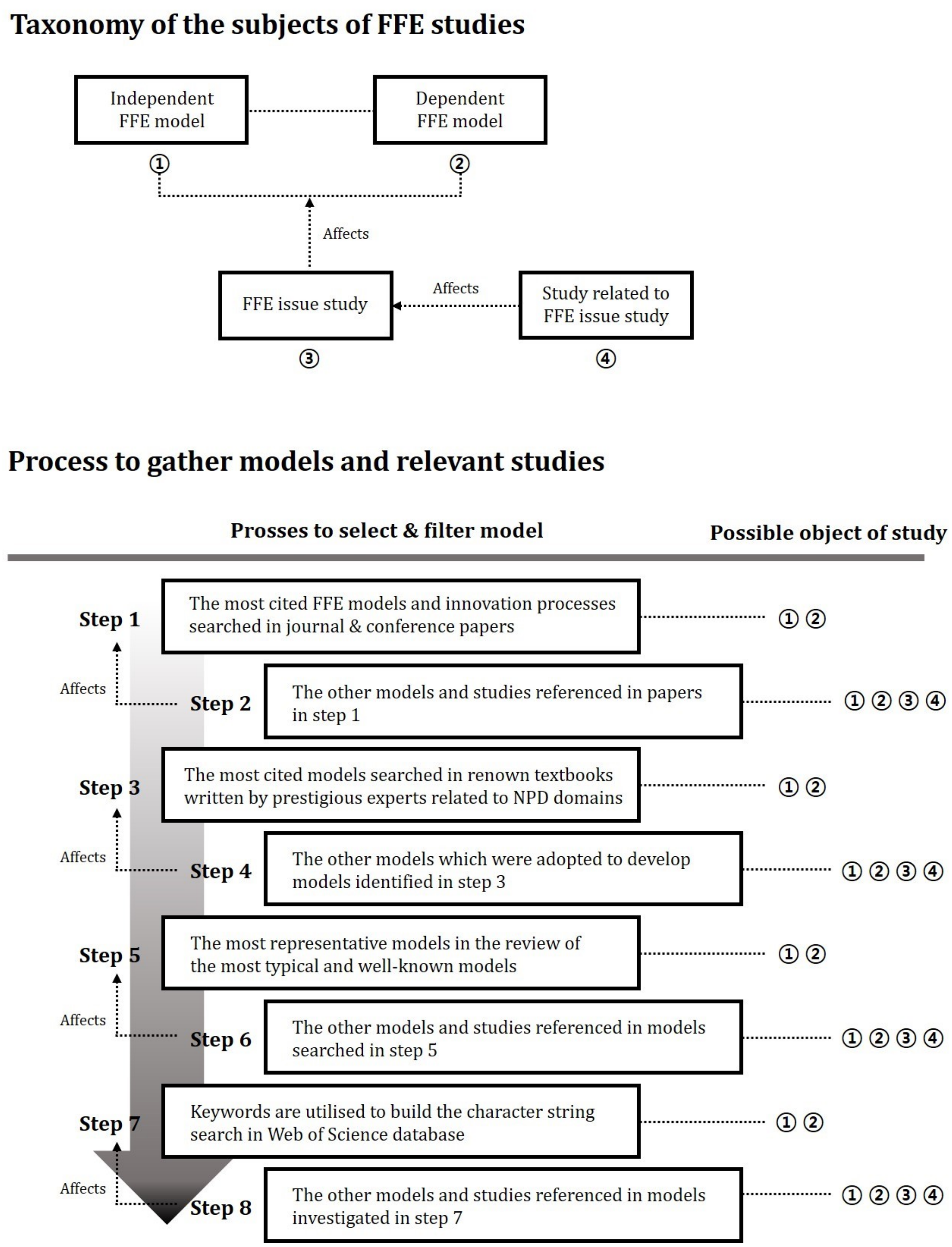


Figure 2.2. *Overall model selection protocol*

The second part includes the remaining models obtained during the second, fourth, sixth, and seventh steps. Most of these models were primarily collected from additional studies referenced in the original studies discovered in the first, third, and fifth steps. Through these steps, a significant number of models and studies were gathered to provide a more comprehensive view of existing FFE models and better inform the development of a new model. Even though the remaining models are weaker in their representativeness, each model has its own characteristics in the way it organises components, attributes, operations etc. Some of them have much more specific development objectives than the handling of traditional FFE problems. These steps are beneficial to prevent underestimation of parts which are easy to miss, which can affect the development of a more sophisticated model: most studies in the model review were focused on the most cited and representative models (this can lead to a clustering of outcomes with the majority of studies looking at the same models). As a result, they may have great value in analyses looking at exquisite, deep-rooted development. They may also be useful in the design of an entirely new model.

2) Data Analysis Method
– Investigation of the 255 FFE Studies

This section establishes the criteria by which to appraise the gathered FFE studies and builds the analysis methods that will be used.

2.1) Establishment of Appraisal Criteria

In order to investigate FFE studies more systematically to ensure a more accurate reflection of their results in the model development, it is vital to deliberate on how to build specific appraisal criteria.

As shown in *Table 2.1* (*p. 51*), a total of ten investigation criteria were derived, considering both model development directions as defined in Chapter 1 and basic model development considerations referenced from other studies. In order to create the most optimal demands for developing an ideal and pragmatic model in which the broadest and deepest range of development requirements are reflected (Williams et al., 2007), these appraisal criteria are specified in greater detail.

a) Appraisal Criterion 1
: The Taxonomy of FFE Studies

The first criterion is about the taxonomy of the FFE studies, borrowed from the model selection study (*p. 42*).

b) Appraisal Criteria 2 to 6
: Overall Attributes in FFE Models
– Current and Future Trends in FFE Model Improvement

Next, referencing the first insufficient dimensions in previous FFE models which were addressed in the introduction chapter (*p. 12*), the following five appraisal standards related to the overall attributes of the model were set: 1) [19] whether the model is oriented towards technology-push and market-pull (an integration/interaction of those two

[19] In the case of the second appraisal criterion, 'Model Direction', sub-criteria '2.1' to '2.7' were defined based on studies by Barbieri and Álvares (2016), Du Preez et al. (2006), Eveleens (2010), Hannola et al. (2016), Kotsemir and Meissner (2013), Rothwell (1994), Tidd (2006) and Trott (2005).

directions) and towards a network or data-driven type of model; referred to as 'Model type', 2) whether the model pursues agile or non-agile development; referred to as 'NPD speed', 3) whether the model aims at radical or incremental NPD; 'NPD attribute', 4) whether the form of the model is robustly fixed or variably flexible; 'Model characteristic', and 5) whether the model is a procedural or performative structure; 'Model structure'.

c) Appraisal Criteria 7 to 10

: FFE performance structure and operating mechanisms

– Parameter Process and Decision

The remaining appraisal criteria, Task', 'Activity', 'Performance method' and 'Toolkit' are units of the FFE performance structure, which were covered under the second dimension of deficiency in the review of previous models. These are also frequently referred to as the basic constituents making up the structure of the model, serving as core factors influencing the development of the pragmatic-prescriptive model. The structure consisting of 'Task', 'Activity', 'Performance method' and 'Toolkit' are depicted in *Figure 2.3*.

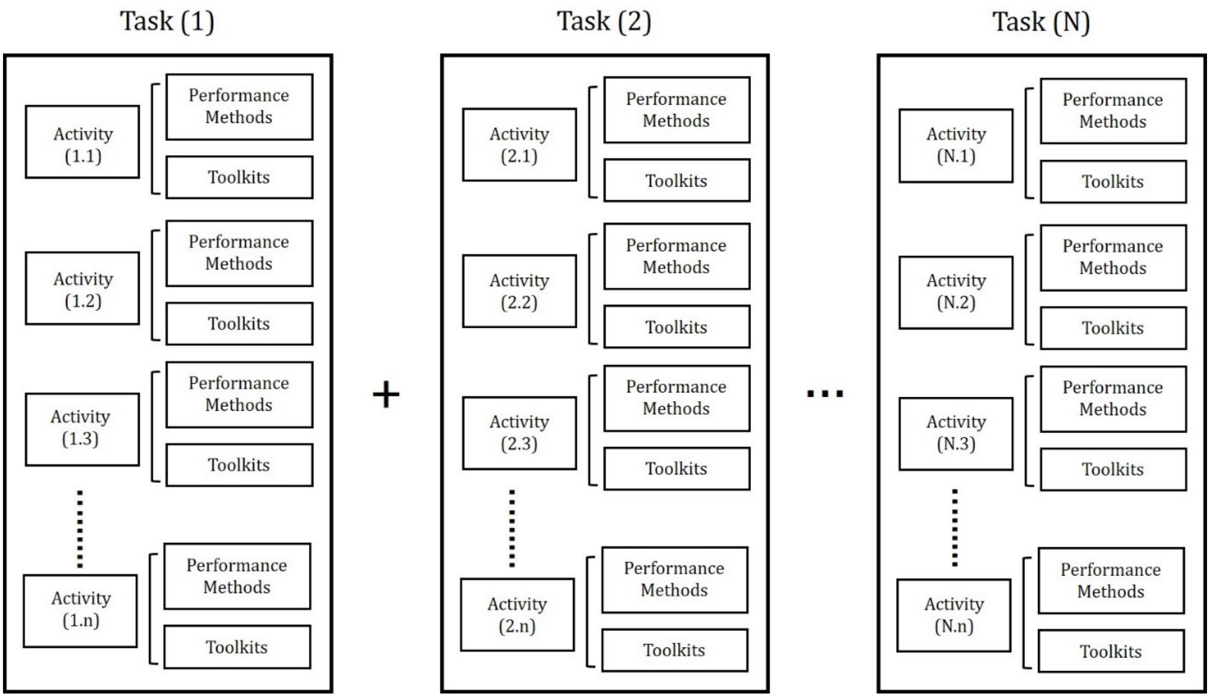


Figure 2.3. *Basic structure and components of the FFE*

Several studies have served as the foundation upon which to support the establishment of those four evaluation standards. According to Birkhofer et al. (2002) and McCarthy et al. (2006), most models consist of 'Task', 'Activity' and 'Performance Method' and 'Toolkit' in that order, from largest to smallest. Herstatt and Verworn (2001) argue that the model frame is first structured with 'Task' and 'Activity' units in a certain sequence with 'Performance method' and 'Toolkit' units applied to each of them. A study by van Aken (2005) finds that NPD model design is similar to the main "compositions (plots) of a play", "sub-acts of a play", and "scripts of a play". "Plots" are analogous to tasks, "sub-acts" correspond to activities, and "scripts" equate to performance methods and toolkits. In the NPD domain, it is the same as designing an action system for designers where a finite number of actions is defined with a division of main and sub-steps (corresponding to tasks and activities) in a certain order, and then their roles and techniques (corresponding to methods and toolkits) are designated in accordance with the aims of each action. Namely, the design process serves not only to form behaviours in designers, with the design task (main step) and activity (sub-step) unit carried out in a given order, but also to characterise their methods and toolkits (roles and techniques). Consequently, the design process is comprised of two strongly interlinked parts: 1) "Process-structure", forming the main and sub-steps of a design task and activity, and 2) "Role-structure" specifying each man and sub-step with performance methods and toolkits.

Table 2.1. *Appraisal criteria for 255 FFE studies*

#	Appraisal Criterion	Analysis Number	Description
1	Study taxonomy	1.1	Dependent FFE model 1) FFE models which depend on design processes or NPD processes as parent processes. 2) Items related to the FFE which are extracted from design processes/innovation processes/NPD processes.
		1.2	Independent FFE model 1) FFE models which exist independently. 2) Models which are explicitly for one or two FFE tasks or activities, e.g. idea generation model, product specification model, etc.
		1.3	FFE issue study 1) There is not a model in the given study. 2) Given studies are related to FFE issues, e.g. attributes, roles, functions, uncertainty control, CFS, etc.
		1.4	Study related to the FFE issue study : Given models/studies affect or apply to FFE tasks or activities, e.g. reasoning system, knowledge develop/diffusion system, adaptive system, innovation journey/diffusion system, quality & time control, risk management, etc.
2	Model direction[20]	2.1	Technology-push : Emphasis on R&D (and engineering & manufacturing)
		2.2	Market-pull : Emphasis on marketing (and management)
		2.3	Coupling model : Simple integration of R&D and marketing
		2.4	Interactive model

[20] In the case of the second appraisal criterion, 'Model Direction', sub-criteria '2.1' to '2.7' were defined based on studies by Barbieri and Álvares (2016), Du Preez et al. (2006), Eveleens (2010), Hannola et al. (2016), Kotsemir and Meissner (2013), Rothwell (1994), Tidd (2006) and Trott (2005).

			: Complex intertwined linkage of push and pull
		2.5	Network model : Interactive system, extensive networking and continuous innovation : Intertwined linkage of R&D, marketing and other fields such as industrial design, design management, etc.
		2.6	Data-driven model : Based on the network model, the key activity is to collect/analyse information and transform the information into knowledge which can be reflected in future NPD projects.
		2.7	The above directions cannot be identified in the given study.
3	NPD speed	O	Agile NPDs : The model pursues agile NPDs with particular structures or strategies.
		Δ	Agile NPDs The model attempts to pursue agile NPDs to some extent, although its particular structures or systems are not equipped to do so.
		X	Non-agile NPDs : The model does not pursue agile NPDs.
4	NPD attribute	4.1	Radical NPDs : The model is largely appropriate for Radical NPDs.
		4.2	Incremental NPDs : The model is largely appropriate for Incremental NPDs.
		4.3	Radical > Incremental NPDs : The model is moderately appropriate for radical NPDs, although it aims at both attributes.
		4.4	Radical < Incremental NPDs : The model is moderately appropriate for incremental NPDs, although it aims at both attributes.
		4.5	Radical = Incremental NPDs : The model is largely appropriate for both radical and incremental NPDs.
		4.6	The model cannot be verified as a radical and/or incremental NPD.
5	Model anatomy	5.1	Explicitness : The structure of the model pursues a robustly fixed structure.
		5.2	Responsiveness : The structure of the model pursues a variably flexible structure.
		5.3	Explicitness > Responsiveness : The structure of the model is more inclined to explicitness, although it aims at both structural characteristics.
		5.4	Explicitness < Responsiveness : The structure of the model is more inclined to responsiveness, although it aims at both structural characteristics.
		5.5	Explicitness = Responsiveness : The structure of the model is well-balanced between explicitness and responsiveness.
		5.6	The structure of the model cannot determined as to its focus between explicitness or responsiveness.
6	Model type	6.1	Procedure type : The model defines phases and relevant sub-phases.
		6.2	Performance type : The model has a physical and functional form where NPD-related input and output parameters are yielded.
		6.3	Procedure type > Performance type : The model is more inclined to the procedure type, although it aims at both types.
		6.4	Procedure type < Performance type : The model is more inclined to the performance type, although it aims at both types.
		6.5	Procedure type = Performance type : The model is a combination of both the procedure and performance types.
		6.6	Any other types : The type of model is a casual model or consists of pure mathematical or engineering formulas, etc.
7	Task[21]	The broadest units constructing the FFE phase	
		7.1	Opportunity identification and screening task (1) The following tasks can be regarded as corresponding to the opportunity identification task. : Problem/Need identification & screening (2), Preliminary uncertainty analysis of markets & technologies (3), Product-related information research from internal & external organisations (3), Feasibility studies of opportunities (4), Analyse (5)
		7.2	Idea generation and screening task (6) The following tasks can be regarded as corresponding to the idea generation task. : Ideation & idea competition (7), Feasibility studies of ideas (8), Synthesis & Evaluation (9), Hypothesis search &

[21] In the case of the seventh appraisal criterion, 'FFE Task', sub-criteria '7.1' to '7.2' were devised based on the widest range of FFE models referenced from studies including: Khurana and Rosenthal (1998), Koen et al. (2001, 2002, 2004), Kim and Wilemon (2002), Nobelius and Trygg (2002), Thomke and Fujimoto (2000), etc. The different terms for FFE tasks from '(1)' to '(28)' were adopted from several studies (Dewulf, 2013; Eling et al., 2014; Gurtner et al., 2016; Kurkkio, 2011; Poskela, 2009) which conducted a classification of FFE tasks.

				selection (10)
		7.3		Mission statement task (11) The following tasks can be regarded as corresponding to the mission statement task. : Strategic planning & formulation (12), Product planning (13), Task clarification (14), Outline of design proposal (15), Outline of specifications (16), Brief product features (17), Brief product definition (18)
		7.4		Requirements List task (19) The following tasks can be regarded as corresponding to the requirements list task. : Product specification (20), Priority lists (21), Specific product features (22), Specific product definition (23)
		7.5		Conceptual design task (24) The following tasks can be regarded as corresponding to the conceptual design task. : Conceptual product definition (25), product function and system structure definition (26), conceptual design principles (27)
		7.6		Prototyping task (28)
		7.7		The model does not define any FFE tasks.
8	Activity	The subordinate units under 'Task' to accomplish the purposes of 'Task' implementation, e.g. 'Trend research activity' in the opportunity identification task, 'Convergent-Divergent activity' in the idea generation task, 'Functional analysis activity' in the conceptual design task, etc.		
		O		The model defines FFE activities (n≥3) specifically for each FFE task (n= the number of activities).
		△		The model defines FFE activities (n≤2) briefly or defines them for some FFE tasks (n= the number of activities).
		X		The model does not define any FFE activities (n=0) for any FFE task (n= the number of activities).
9	Performance Method	The manual nstructions (with basic knowledge/relevant frameworks) describing how to conduct each FFE activity or task.		
		O		The model describes specific performance methods. : Performers can understand the provided performance methods without difficulty, using the given descriptions only.
		△		The model briefly describes provides performance methods. : Performers have difficulties understanding the provided performance methods with the given descriptions only.
		X		The model does not describe how to conduct each FFE activity.
10	Toolkit	A physical and functional form in which 'Performance method' is structured. It has an explicit form and frameset in which input and outputs related to product development parameters, variables and constrains are yielded. : The model and study provide toolkits from the following aspects.		
		1 Concreteness		How much detail is provided to structure and operate the toolkits?
			O	The provided toolkits are specific, so that performers can understand and use them step by step without difficulty.
			△1	Self-development type (the model developed its own toolkits.) : The provided toolkits are basic, so that performers have difficulties not only understanding the methods of implementation but also in using the toolkits, step by step.
			△2	Representative toolkit type (the model borrowed well-known toolkits) : Representative toolkits which are broadly used in academic and industries are presented with brief instructions or the names of toolkits only.
			X	Provided toolkits are not specific, so that performers cannot understand and use them step by step.
		2 Functionality		How much do the toolkits cover the various functional areas?
			O	Toolkits are devised for diverse functional areas (at least two areas), e.g. marketing, R & D, industrial design, etc.
			△	The provided toolkits target one functional area only.
			X	The provided toolkits do not target any functional areas, e.g. toolkits are aimed at managing FFE issues.
		3 Contextuality		How well do the toolkits interlock with each other from the contextual performance element?
			O	The toolkits are well devised from the contextual performance element. → The outputs of a previous toolkit are the same as the inputs of the following toolkit. → The outputs of a previous toolkit are directly related to the inputs of the following toolkit.
			△	Provided toolkits are partially devised from the contextual performance element. → The outputs of a previous toolkit are indirectly related to the inputs of the following toolkit. → The input of a following toolkit cannot be directly inferred, based on the output of the previous toolkit.
			X	The provided toolkits are not devised from the contextual performance element. : Each toolkit exists independently, or those are enumerated in a fragmented list.
		4 Cooperability		How are the toolkits structured and operated in the collaboration element?
			O	The toolkits are devised, widely used and are integrated with considerations for collaboration. : The inputs and outputs of toolkits can be physically and functionally yielded from the collaboration element.
			△	Toolkits are devised with limited considerations for collaboration. : The inputs and outputs of toolkits cannot be functionally and physically yielded from the collaboration element. : The inputs and outputs of toolkits can be yielded from one or two functional areas only.
			X	No toolkits are provided which consider collaboration. : The inputs and outputs of toolkits cannot be yielded from the collaboration element.
		X		The model does not provide any toolkits for any FFE activity.

*	N/A	The case where the model cannot be appraised using the above criteria.

It is worth discussing and providing additional explanations for the tenth investigation standard, 'Toolkit'. This criterion can serve in a core role to generate cues-and-resources for the development of a pragmatic-prescriptive FFE model. The criterion is further divided into four categories, based on an interpretation of the second dimension of shortcomings described in the first chapter, 'Chapter 1. Introduction' (*pp. 22-26*): 1) To what degree is the toolkit specific; known as 'Concreteness', 2) which functions are targeted by the toolkit; known as 'Functionality', 3) how was toolkit devised from the contextual performance aspect; 'Contextuality', and 4) how was the toolkit developed from the collaborative performance aspect; 'Cooperability'. In the case of 'Cooperability', even though concurrent collaboration is pursued in this research, toolkits were examined with only simple collaboration in mind, as it is rare for toolkits to be developed specifically for concurrent collaboration.

Specific descriptions of the first sub-criterion, 'Concreteness', were established based on a school of thought in the British design community; Broadbent's (1981) and Yoshikawa's (1989). They believe that 'Designing' can be taught using well-made guidance and educational instructions, and that the design process should be specific to such an extent that performers can fully appreciate not only which tasks and activities should be done but also how to conduct them, by providing certain techniques and toolkits. According to a study by William et al. (2007), the process for NPD performers should be abundantly concrete, with toolkits and a step-by-step action guide provided. The process should include a detailed layout of the procedures, performance techniques required for each procedure, and the operational mechanisms for each technique. Thus, the degree to which toolkits are specific was handled in this investigation.

The second and fourth sub-categories in the 'Toolkit' criterion, 'Functionality' and 'Cooperability', originated from the argument that the FFE should be conducted from the cross-functional working aspect (Castilho et al., 2015; Jetter, 2003; Mishra & Mishra, 2009; Troy et al., 2008; Verworn, 2009). The first issue here is how many functions toolkits cover, followed by how toolkits can be used together collaboratively.

The third sub-criterion, 'Contextuality', was developed based on studies by Archer (1984) and van Aken (2003). van Aken (2003) argues that the performance repertoires of performers are normally compiled by them over the years through formal education and learning on the job when they conduct a particular task and activity. Once they become familiar with a specific task and activity, they will follow their inherent knowledge gained from previous education and experience. Archer (1984) warned of the side-effects of reliance on individuals with different degrees of expertise who lack choice in the manner in which they can carry out tasks and activities. In particular, different degrees of competence stemming from a lack of prior education and experience can exacerbate the situation. Using such deviation due to differing degrees of expertise comes with considerably high risks which can result in oversights or mistakes. Even if all required tasks are carried out, there is still an unacceptable risk in terms that these tasks can be undertaken in incorrect manners. In this regard, toolkits should be created for the contextual performance to provide explicit directions and mechanisms. This means that outcomes of a certain performance should be connected to input sources for the subsequent performance, by means of toolkits developed from the contextual performance aspect, i.e. output parameters produced in the previous toolkit should flow into input parameters of the next toolkit. Otherwise[22], performers may be confused about what subsequent toolkits should be used once they are finished using the toolkit they are most familiar with. They can also have trouble understanding the relationships between the aims, roles, processes, and results of different toolkits. These situations can result critical problems wherein outcomes produced from each toolkit exist independently without consideration of outcomes generated by other toolkits. These independent results, when eventually combined in a given NPD project, is liable to create inefficiencies that may actually compound the more disparate sets of results there are. In this context, providing toolkits enumerated in a list fragment is not enough to perform tasks and activities effectively. Even though many specific types of toolkits are offered, if their design does not have contextual performance in mind, they will be inherently inadequate for FFE implementation, regardless of how effective they may otherwise be.

Thus, the toolkits provided in previous FFE studies should be thoroughly examined using the four sub-appraisal standards, to produce underlying cues-and-resources to develop toolkits for a new pragmatic-prescriptive FFE model.

The ten criteria for analysing the 255 FFE studies were robustly built based on model development directions to address shortcomings in the previous FFE models (*pp. 17-27*)

[22] A more detailed illustration of the side-effects caused by toolkits which are not developed from the contextual performance aspect has been presented in Chapter One (Introduction, *pp. 23-25*).

discussed in the introduction chapter and considerations of model development gained from various studies.

2.2) Data Analysis Method

a) Peer-review System

b) Historical Trend Analysis and Statistical Approach

This section discusses how to analyse the 255 FFE studies with the given ten-point appraisal criteria. The analysis method was adopted from other studies including, notably, a study by Mendes and Oliveira (2015) which used a peer-review system and historical trend analysis along with a statistical approach.

a) Peer-review system

In order to strengthen the internal validity of the analysis, a peer-review system was utilised. A consensus analysis method derived from the peer-review was applied to the examination of all models. Full details of the process are as follows.

In the first step, an examination was conducted on an initial batch of ten studies. Studies were drawn evenly from the four different categories of the FFE study taxonomy. A colour was assigned to each appraisal standard, to allow for more recognisable visual analysis. Text, figures or tables which related to any of the ten criteria were highlighted in different colours, and relevant comments were added for better understanding of each highlight.

In the second step, on those same ten studies, the same analysis method was performed by five colleagues chosen in advance: three experts were Ph.D. candidates who have more than seven years' experience in NPD sectors and thus possess in-depth knowledge on understanding what doing design and running a business involve, while the remaining two were selected from industry, chosen for their expertise.

Next, papers were compared to each other seeing which items matched and which did not. In sections where the five participants produced different analyses, the reasons for this disparity were discussed, and the relevant areas highlighted and annotated. Also, sections with identical interpretations were discussed in the same way. Through this process, any controversial parts, i.e. ambiguous cases where it is unclear which criteria apply, were excluded from the analysis to reduce bias.

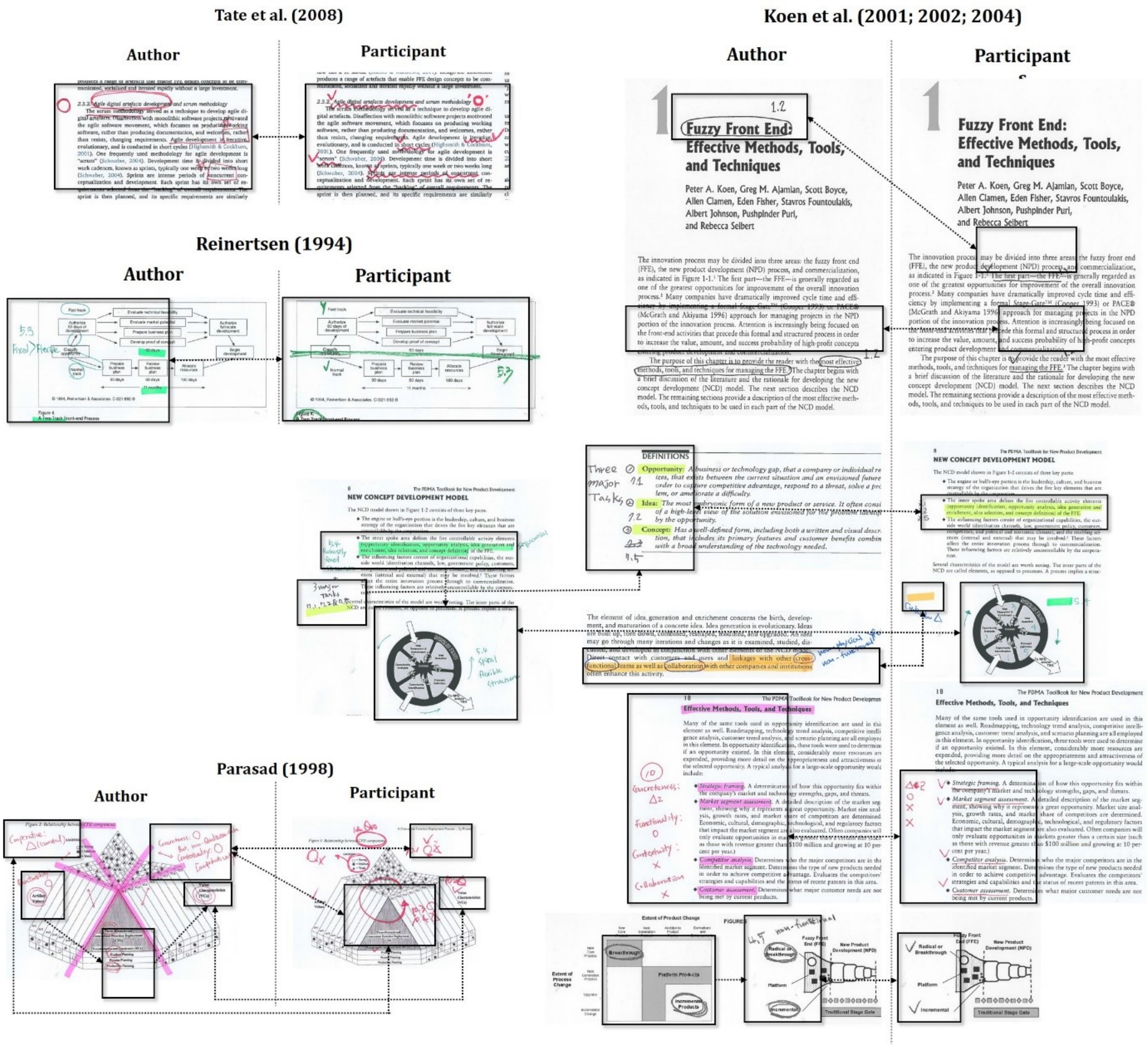


Figure 2.4. *Extracted example pages of papers in the process of reaching agreement*

Then, when the rate of matched items reached around 80 percent, the process of discussion and agreement continued. When agreement was reached on a particular matter, that analysis concluded, meaning that the process could move on to the next batch of studies. Figure 2.4 shows pages from four papers, Koen et al. (2001, 2002), Prasad (1998), Reinertsen (1994) and Tate et al. (2008), which show the process by which agreement was reached during the analysis. Using Koen et al. (2001, 2002) as an example, Table 2.2 presents a statistical interpretation of the 'Inter-rater agreement', known also as the 'Kappa test', which depicts the level of agreement between the analyses of each participant. In the table, the number of valid cases was thirteen which is the sum of the first to ninth appraisal criteria, with the tenth criterion consisting of four sub-criteria. Comparing analyses between the author and the four participants, the measures of agreement or the 'Kappa values', were greater than 0.81. In the case of the second participant, the matching rate was 100%. In the single case where the Kappa value was lower than the 0.80 threshold (0.748), this figure still rests comfortably within the range of 'Good' (0.61-0.80). In the remaining nine papers, data sets on the inter-rater agreement showed a similar trend. These statistics suggest a strong level of agreement between the various analyses and thus the conclusion that the analysis method used was reliable and could be applied to the remaining studies.

Table 2.2 *Inter-rater agreement, 'Kappa Test' between the analyses of the author and the participants*

#	Subject	N of Valid Cases	Kappa Values
1	Author to Participant 1	13	0.914
2	Author to Participant 2	13	1.000
3	Author to Participant 3	13	0.915
4	Author to Participant 4	13	0.748
5	Author to Participant 5	13	0.831

Kappa values and strength of agreements:

0.00-0.20: Poor, 0.21-0.40: Fair, 0.41-0.60: Moderate, 0.61-0.80: Good, 0.81-1.00: Very Good

b) Historical trend analysis and statistical approach

The next analysis was a two-pronged trend analysis: 1) a historical trend of particular characteristics revealed in the FFE studies and 2) their proportions. The historical analysis was aided by studies conducted by Conway and Steward (2009), Simms (2012) and Tidd et al. (2001). They substantiated the merit of conducting a historical analysis of the literature by looking at the historical tendencies in the way NPD processes have evolved. Pahl and Beitz (2007) also listed various design processes (shown in *Table 1.1* of their study), overviewing each in their study. From a statistical point of view, two-fold trend analysis is supported by the "Bibliometrics" approach, itself regarded as a "systematic [method of conducting a] literature review" (De Bellis, 2009; Okubo, 1997; Mendes & Oliveira, 2015), which was also utilised in collecting FFE studies. A statistical software package, SPSS Version 25.0, was used in these two analysis. The results of the trend analysis were depicted on a scatter plot graph, and the degree to which the characteristics affect the trend with respect to each appraisal criterion was depicted by a pie chart (Figures 2.5 to 2.16 shown in the following section).

For reference, studies on FFE issues and any related work were also faithfully arranged alongside the FFE models, in chronological order. Since these FFE studies greatly affected the development of those FFE models, it was judged that including those studies in both charts would be of help in describing the FFE model development trends.

3) Section Conclusion

This section has introduced the research methods used for the review of the 255 FFE studies.

Using established data collection methods (regarding the studies' selection protocol and the eight steps of the selection process), a significant number of FFE studies (n=255) were obtained to provide a more comprehensive and detailed view of existing FFE scholarship and better inform the development of a new pragmatic-prescriptive FFE model.

By means of strictly-built data analysis methods, details of knowledge-and-theories and cues-and-resources which can be practically reflected in the development of the new model were obtained to establish new FFE model development strategies. This analysis concerns the ten aforementioned criteria and involves two methods to examine the gathered studies: 1) a peer-review system and 2) a historical trend analysis.

Consequently, the 255 FFE studies were collected more methodically and were analysed more robustly, in order to build strategies for new pragmatic-prescriptive FFE model development.

2.1.3 Research Summary

This chapter reviews 255 FFE studies in order to establish specific strategies for pragmatic-prescriptive FFE model development, through the research methods introduced above.

This chapter is broadly divided into two parts and generates outcomes as follows:

- Findings: details of FFE model features and a comprehensive view of development trends are studied for each appraisal criterion.
- Discussion: Based on the findings, a total of nine strategies are established, and the possibility of executing those strategies using the chain-reaction effect is introduced.

In the following sections, full details of the findings and discussion on the 255 FFE study review are presented.

2.2 Findings

– FFE Model Features and Development Trends

In this section, the outcomes of the analysis of the 255 FFE studies are presented. These outcomes can be useful cues-and-resources in the pursuit of the pragmatic-prescriptive FFE model.

Table 2.3 shows a part of each FFE study analysed using the ten appraisal criteria, organised in chorological order of the study's publication: a complete table and list of these studies are presented in *Appendix 1* (*pp. 525-539*). Each field in the chart was marked with a number or symbol to designated whether said study met with the appraisal criterion in question.

In the case of *Figure 2.5* to *2.16*, the data in Table 2.3 have been converted into graphs depicting historical trends. The analysis for each appraisal criterion revealed relevant trends, documented using tracking values which change along the vertical axis. Below is a detailed description of the analysis for each appraisal criterion.

Table 2.3. *Table showing the examination of the 255 FFE models extracted from Appendix 1*

Model #	Appraisal Criteria												
	1 Study Taxo-nomy	2 Model Attribute	3 NPD Speed	4 NPD Attribute	5 Model Autonomy	6 Model Type	7 FFE Task	8 FFE Activity	9 Performance Method	10 Toolkit			
										1	2	3	4
2000s													
M110	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
M111	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
M112	1.2	2.1	○	4.2	5.3	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	X	X	X			
M113	1.2	2.5	X	4.6	5.1	6.4	7.1, 7.2, 7.3, 7.4, 7.5	○	△	○	○	△	X
M114	1.4	2.7	△	4.1	5.3	6.6	7.1, 7.2, 7.5	○	X	X			
M115	1.1	2.5	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	△	X			
M116	1.1	2.5	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	△	△2	○	X	X
M117	1.2	2.1	X	4.6	5.3	6.3	7.5	△	○	○	△	○	X
M118	1.2	2.4	X	4.5	5.1	6.3	7.1, 7.2, 7.4, 7.5	○	△	△2	○	△	X
M119	1.2	2.1	X	4.6	5.3	6.1	7.5	△	○	○	△	○	X
M120	1.4	N/A	N/A	N/A	5.3	6.1	N/A	N/A	X	X			
M121	1.2	2.7	○	4.6	5.1	6.1	7.5, 7.6	X	X	○ + △2	○	X	X
M122	1.2	2.7	○	4.6	5.3	6.1	7.5, 7.6	X	X	○	△	X	X
M123	1.2	2.3	X	4.1	5.1	6.1	7.1	△	X	X			
M124	1.2	2.5	○	4.5	5.4	6.1	7.1, 7.2, 7.3, 7.5	○	△	△2	○	X	X
M125	1.2	2.4	X	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	△	△	△2	○	X	X
M126	1.2	2.5	X	4.5	5.6	6.6	7.1, 7.3, 7.4, 7.5	△	X	X			
M127	1.2	2.7	X	4.6	5.1	6.2	7.4	○	△	○ + △2	○	△	X
M128	1.4	N/A	N/A	N/A	5.4	6.1	N/A	N/A	X	X			
M129	1.2	2.5	X	4.5	5.6	6.6	7.2	○	△	X			
M130	1.2	2.4	X	4.5	5.3	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	△	X	△2	△	X	X

1) Appraisal Standard 1 (*Figure 2.5*)

: Overall Attributes

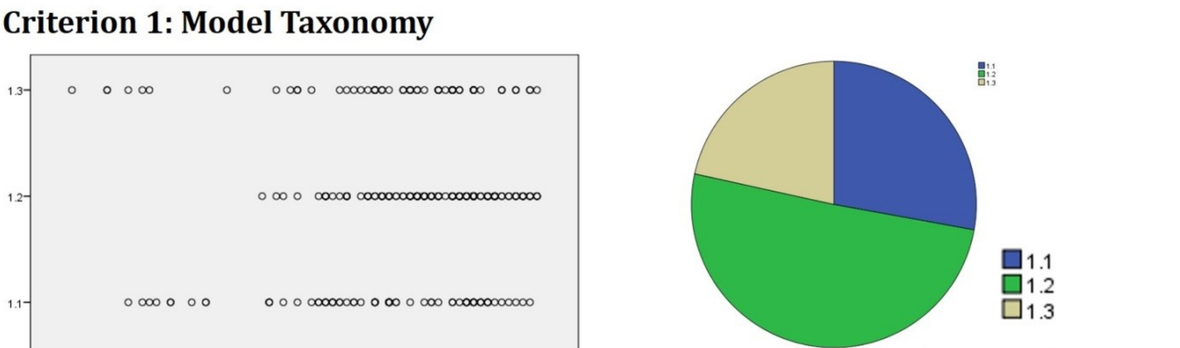
– Current and Future Trends in FFE Model Improvement

1.1) Appraisal Standard 1 (*Figure 2.5*)

: Study Taxonomy

Since the 1990s, when the initial term for the early design stage emerged, FFE models and related studies began in earnest, as shown in a study by Reinertsen (1994). Some of the representative models for intensive FFE study include M074 (Khurana and Rosenthal, 1997), M095 (Koen et al., 2001) and M124 (Kim & Wilemon, 2002).

With the increasing importance of the FFE, studies looking at only one or two FFE tasks (though in great detail) were conducted, e.g. 1) Opportunity recognition process: M054 (Rochford, 1991), M123 (Rice et al., 2001), etc.; 2) Ideation model: M106 (Goldenberg et al., 1999), M133 (Dahl & Moreau, 2002), M153 (Li et al., 2006), M239 (Gurtner et al., 2016), etc.; and 3) Product definition process: M075 (Bacon et al., 1994), M104 (Bhattacharya et al., 1998), M152 (Shino et al., 2002, 2006), M175 (Agouridas et al., 2008) M221 (Jacoby & Scheelen, 2012), etc.



		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.1	71	27.8	27.8	27.8
	1.2	129	50.6	50.6	78.4
	1.3	55	21.6	21.6	100.0
	Total	255	100.0	100.0	

Figure 2.5. *Historical trend and frequency analysis for appraisal criterion 1*

In addition, many studies were conducted to deal with issues generated in the FFE phase: 1) problem-solving: a study by Shpakovsky (2006) examines many types of models and methods for solving problems; 2) fuzziness management: M126 (Zhang & Doll, 2001), M134 (Kim & Wilemon, 2002, 2010), M168 (Chang et al., 2007), etc.; and 3) decision-making: M211 (Montagna, 2011), M150 (Ziv Av & Reich, 2005), etc.

Separately, innovation processes whose initial stages can be regarded as the FFE were developed and updated continually since the 1960s. There are also many studies providing typical examples of those processes such as those by Adams (2015), Buijs (2003), Carbone and Tippett, (2014), Eveleens (2010), Evbuomwan et al. (1996) Simms (2012), Sperry and Jetter (2009), Wynn & Clarkson (2005), etc.

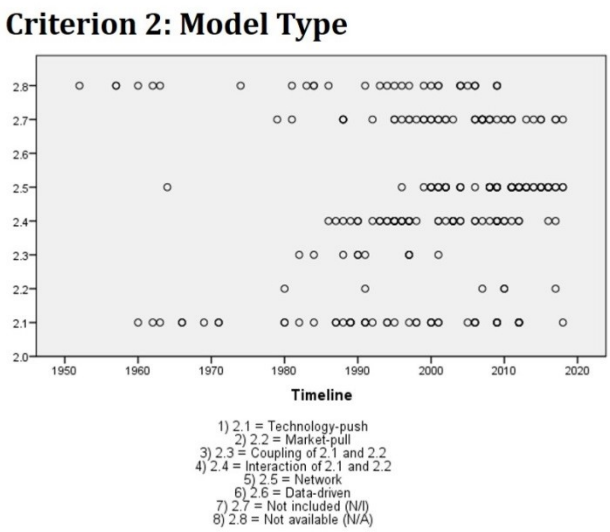
1.2) Appraisal Standard 2 (*Figure 2.6*) : Model Type

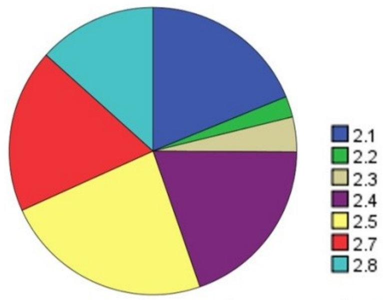
The technology-push and market-pull type, and their Integrating or interactive type models were found to be dominant, accounting for 44.7% of all models, compared to network type models which accounted for only 23.5%. Data-driven FFE models covering the entire range of the FFE have not devised yet.

Until the mid-1980s, most of the models under the technology-push type focused on developing elaborate machinery whose focus was on increasing the precision of technical processes and the quality of products, as well as reducing errors and risks during the manufacturing stages (Bruce & Bessant, 2002; Mozota, 2003; Press & Cooper, 2003, 2017).

Towards the late 1980s, many experts recognised that engineering-centric processes took too long and were thus unable to keep up with the pace of the market (Cooper, 1990, 2008; Griffin, 1997; Griffin & Hauser, 1993; Phillips et al., 1999). This led to a redesign of processes to improve the hit rate of released products and reduce the development cycle time and the invested resources by applying marketing and management principles and methodologies (Cooper, 1990, 2008; Griffin, 1997; Griffin & Hauser, 1993; Phillips et al., 1999). Namely, the process was rebuilt to include aspects from a market-pull type model, laid atop technology-push type processes. Until the early 2000s, these integrating or interactive type models were continuously iterated to strengthen advantages and remove weaknesses.

From the mid-2000s onwards, with its trend of "Open Innovation", network-type models began to be developed which emphasised communication between internal and external resources, involving many of the functional aspects engaged in NPD work. Also, an integration of two or three types of models to handle FFE issues was, notably, revealed in several studies, such as: 1) the integration of the "Business Evaluation Process" (BEP) and the "Technology Cycle Plan Process" (TCPP) in M165 (Backman et al., 2007), 2) "Integration of Technology Road-mapping and Portfolio Management" (ITP) in M199 (Oliveira & Rozenfeld, 2010), 3) the interaction between design and technology research, in M232 (Goto et al., 2014), and 4) the integration of product research and technology research with "Project Portfolio Management" (PPM) in M135 (Lawson & Finkelstein, 2002).





		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2.1	48	18.8	18.8	18.8
	2.2	6	2.4	2.4	21.2
	2.3	10	3.9	3.9	25.1
	2.4	50	19.6	19.6	44.7
	2.5	60	23.5	23.5	68.2
	2.7	47	18.4	18.4	86.7
	2.8	34	13.3	13.3	100.0
	Total	255	100.0	100.0	

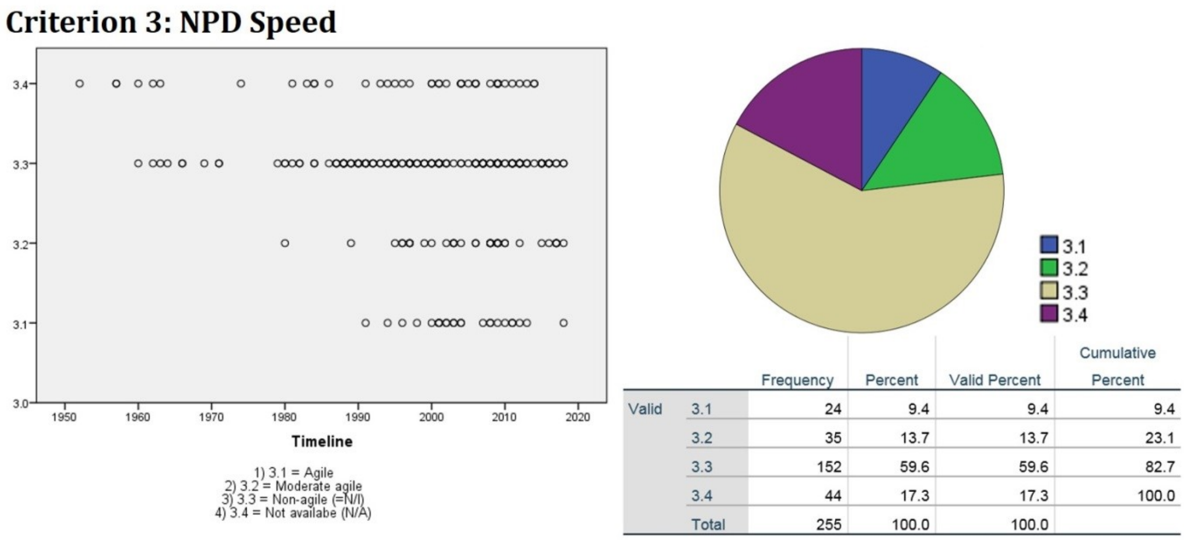
Figure 2.6. *Historical trend and frequency analysis for appraisal criterion 2*

With the emergence of "Industry 4.0", data-driven model types are in high demand. Model types that have evolved from network-based models are required not only for optimum collection and analysis of NPD-related information but also the efficient conversion of that information into usable knowledge which can be readily applied to NPD projects in the future. The cases which most closely match this data-driven type include M147, studied by Tidd et al. (2005) and M204 researched by Unger and Eppinger (2011). However, these two models also exposed the limitations of the data-driven type of model.

Although they suggested the need for this model type and the importance of the role it plays, the currently existing examples of such models did not seem to functionally apply data into their operations and thus were not truly data-driven.

1.3) Appraisal Standard 3 (*Figure 2.7*)
: NPD Speed

Of the 255 FFE studies examined, there were comparatively few studies on the 'Agile development', which comprised only 9.4% of the total. The concept of the agile NPD was generated in the early 2000s, and its reflection in models has actively continued to this day. In the majority of these models, tasks and activities are overlapped or carried out in parallel to realise rapid development. The main purpose of this mechanism is to reduce the wait for other tasks and activities to be completed. Another method to enable agile development is the installation of a rapid iterative cycle in the model. The representative model for this approach is shown in studies by Cooper (2014) and Cooper and Sommer (2018) in whose models the structure has evolved from the initial model, M036 (Cooper, 1983, 1998), addressing the fast-repetition cycle in the pursuit of agility.



		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3.1	24	9.4	9.4	9.4
	3.2	35	13.7	13.7	23.1
	3.3	152	59.6	59.6	82.7
	3.4	44	17.3	17.3	100.0
	Total	255	100.0	100.0	

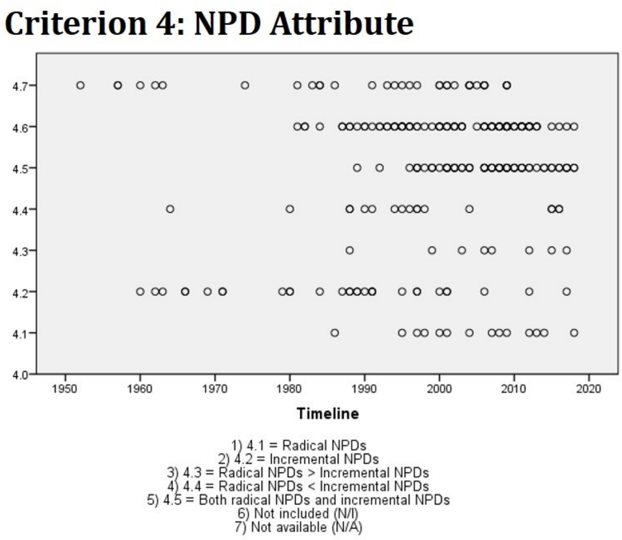
Figure 2.7. *Historical trend and frequency analysis for appraisal criterion 3*

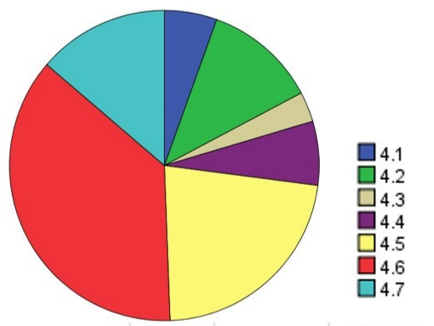
However, long before the concept of the agile NPD was generated, there were models which pursued rapid development. Models such as M055, M074 and M102 devised by Clark and Fujimoto (1991), Reinertsen (1994) and Thomke et al. (1998) respectively are examples of models which realised parallel and overlapping operations. Also, the "concurrent engineering mode", another agile NPD method were frequently mentioned in studies M034 (Andreasen & Hein, 1987), M073 (O'Connor, 1995) and M087 (Prasad, 1996, 1998, 2000).

1.4) Appraisal Standard 4 (*Figure 2.8*)
: NPD Attribute

There are a relatively large number of models and studies for solely incremental NPDs, and also many models more inclined towards incremental rather than radical development. The proportion of studies and models for radical NPDs are comparatively low at a total rate of just 5.5%.

Around the mid-1980s where the 'New-to-the-Company (NTC)' type, as well as the 'Additions-to-the-Existing-product-Line (AEL)' type, was required in markets, radical NPD appears to be gaining traction in the research community. A generation of new technologies and the inflow of user needs to new markets provoked academies and industries into researching radical NPD.





		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	4.1	14	5.5	5.5	5.5
	4.2	30	11.8	11.8	17.3
	4.3	8	3.1	3.1	20.4
	4.4	17	6.7	6.7	27.1
	4.5	57	22.4	22.4	49.4
	4.6	94	36.9	36.9	86.3
	4.7	35	13.7	13.7	100.0
	Total	255	100.0	100.0	

Figure 2.8. *Historical trend and frequency analysis for appraisal criterion 4*

'Radical Innovation' in NPD is shown in M114 (Sheremata, 2000), M145 (Sandmeier et al., 2004), M164 (Seidel, 2007), M220 (Brentani & Reid, 2004, 2012), M233 (Dell Era & Verganti, 2009), among others. Examples of models and studies targeting both incremental and radical NPDs are, as the ideal type, M134 (Kim & Wilemon, 2002), M139 (Bucher et al., 2003), M144 (Phaal et al., 2004), M147 (Tidd et al., 2005), M168 (Chang et al., 2007), M185 (Kutvonen & Torkkeli, 2009), and so on. However, as with the equipment in the agile system, it also tends to be that the division or integration of both development types was less physically and functionally established in the structures and operating mechanisms of these incremental-radical models.

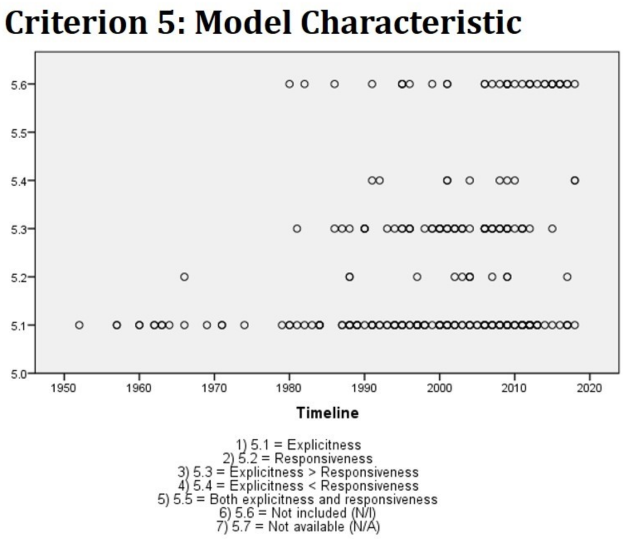
1.5) Appraisal Standard 5 (*Figure 2.9*)
: Model Characteristic

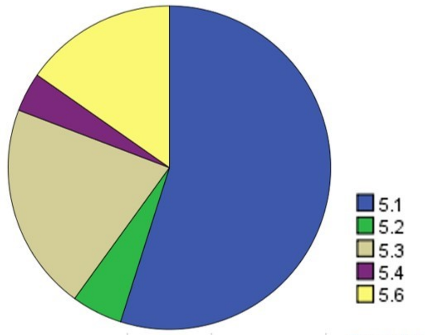
Models whose form is robustly fixed ("Explicitness") predominate in the analysis with a rate of 54.9%. Most of the models in this type belong to the linear type of phase-based model, which have been dominant in industry (Brun & Saetre, 2009; Carbone & Tippett, 2014; Castilho et al., 2015; Koen et al., 2002; Kurkkio, 2011; Stevens & Berley, 2003) as well as in the literature (Cooper & Kleinschmidt, 1994; Cooper, 2001; Cooper & Edgett, 2008; Simmis, 2012). Although there are many alternative terms to describe this type of model such as "Phased Development Process", "Structured Development Process", "Stage-gate", and "Phased Review Process", their fundamental tenets are similar (Zhang & Doll, 2001). The most recent representative processes for this phased-type were developed by Fairlie-Clarke & Muller (2003), Osteras et al. (2006), Luchs and Swan (2011) and Cooper (from 1988 to 2018).

In order to solve problems associated with those linear processes, e.g. lack of suitability for performing radical NPDs and generating creative outcomes, a more flexible model structure, a nonlinear type ("Responsiveness"), e.g. a recursive, chaotic, spiral and Complex Adaptive System (CAS) framework type[23] , started to be developed (McCarthy et al., 2006; Simms, 2012) from around the late 1990s. Examples of this type, whose

[23] The classification of types of the model structure was defined by Buijs (2003) and Sperry and Jetter (2009).

structure pursues responsiveness, can be found in M137 (Husing & Kohn, 2003), M144 (Phaal et al., 2004), M194 (Cascini et al., 2009) and so on.





		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	5.1	140	54.9	54.9	54.9
	5.2	13	5.1	5.1	60.0
	5.3	53	20.8	20.8	80.8
	5.4	10	3.9	3.9	84.7
	5.6	39	15.3	15.3	100.0
	Total	255	100.0	100.0	

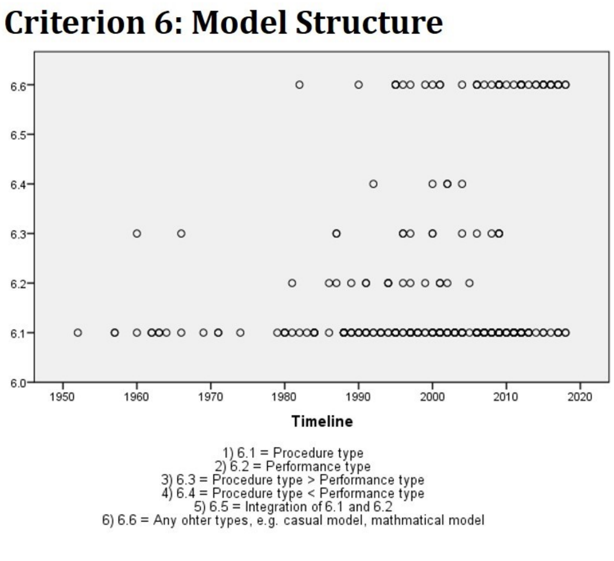
Figure 2.9. *Historical trend and frequency analysis for appraisal criterion 5*

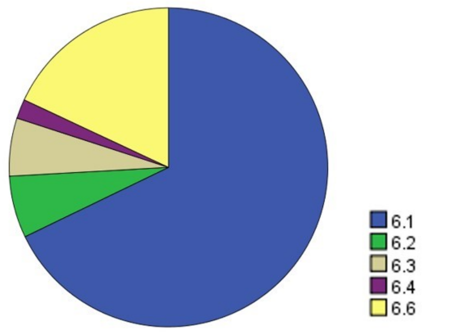
According to many studies, including Dershin's (2010), Rothwell's (1994) and a study by Tidd et al. (2005), structures of models have evolved to combine and intertwine various types previously mentioned, while the simple pure linear phase-structured type of process has been abandoned. The optimal form of this model is viewed to be a balance between "Explicitness" for more rational reasoning and to produce scientific outcomes and "Responsiveness" to allow unconstrained processes to generate creative results. The first type is a circular, funnel or spiral sub-structure (termed a "Recursive" structure) rooted in the main phased-frame, e.g. M173 (Michael, 2008), M174 (El-Sayed, 2008), M175 (Agouridas et al., 2008), M177 (Barczak et al., 2009), etc. Conversely, there is the type which forms a sequential sub-structure based on the recursive frame, e.g. M143 (Trott, 2008), M185 (Kutvonen & Torkkeli, 2009), M197 (Slack, 2010), etc. The last type is not the integration of the linear and nonlinear structures but a modular phased-structure in which the form can change flexibly. Representative cases are M130 (Nobelius & Trygg, 2002), M165 (Backman et al., 2007) and M241 (Salerno, 2015) in which modes of the process can be transformed according to the type of project. Based on these models which embody various types in the pursuit of both explicitness and responsiveness, basic principles on how to balance the two structural directions can be achieved along with relevant knowledge-and-theories.

1.6) Appraisal Standard 6 (*Figure 2.10*)
: Model Structure

Almost all of the models were of the procedure type. Compared against the number of performative-type models, the ratio was 10.68:1. The procedure type concentrates on the structural anatomy of the process and its components, considering 'what' tasks and activities should be carried out. On the other hand, the performative type, also known as the toolkit type, focuses on functional compositions and the operating mechanism in accordance with certain formalities, considering 'how' tasks and activities can be done.

So far, of the performance type models studied, none cover the entire range of the FFE phase. The existing performative models, accounting for 6.3%, focused on one or two tasks only. M059 (Cavallucci, 2001) and M106 (Goldenberg et al., 1999) are example models for the idea generation task. Performative models for the product specifications (and conceptual design) task include M073 (O'Connor, 1995), M127 (McKay et al., 2001), M150 (Ziv Av & Reich, 2005), etc. For product function and system structure in the product architecture aspect, M046 (Ito et al., 1989) and M071 (Shinno et al., 1994) are representative cases.





		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	6.1	173	67.8	67.8	67.8
	6.2	16	6.3	6.3	74.1
	6.3	15	5.9	5.9	80.0
	6.4	5	2.0	2.0	82.0
	6.6	46	18.0	18.0	100.0
	Total	255	100.0	100.0	

Figure 2.10. *Historical trend and frequency analysis for appraisal criterion 6*

Also, a model which effectively balances the performative and procedural styles has yet to be identified. A mixed type which comes close, wherein the performative aspects are actualised based on a procedural style (or vice versa) accounts for only 5.9% of the models examined. M033, conducted by Hubka and Eder (1987, 1996), is the most typical case for this mixed type. This model has a phased structure with each phase consisting of an input and output system which serves as a toolkit platform called a "Technical System (TS)". In the case of models M087 (Prasad, 1996) and M088 (Prasad, 2000), the version developed in 1996, M087, is much more related to the toolkit type, while its successor, M088, evolved from the 1996 version and has a procedural structure based on the performative style.

2) The Second Dimension

: FFE Performance Structure and Its Operating Mechanism – Parameter Process and Decision

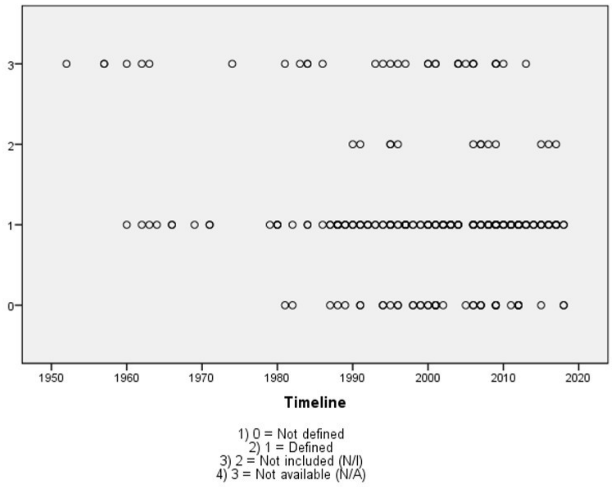
2.1) Appraisal Standard 7 (*Figure 2.11 to 13*) : Task

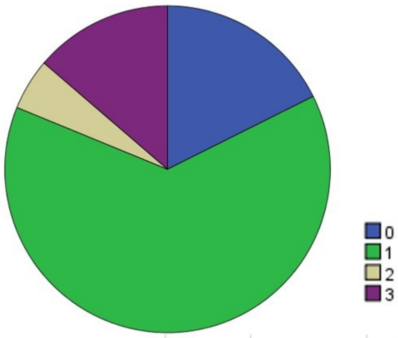
Husing and Kohn (2003) and Carbone and Tippett (2014) argue that definitions and descriptions of FFE tasks vary from expert to expert. Moreover, the boundary between FFE tasks is becoming increasingly obscure with more and more of those tasks now being intimately associated with each other (Alam, 2006; Khurana & Rosenthal, 1997; Yoon et al., 2015). Therefore, it is difficult to explicitly define what FFE tasks should be included or excluded when developing an FFE model. However, we can divide FFE tasks into several groups based on their role, it should be noted that there are numerous variant terms for these tasks. In Dewulf's (2013) research, many different terms for tasks defined by various authors (shown in Table 2 of his study) have been categorised into a smaller number of groups based on the function; similar tasks are grouped together.

As shown in *Figure 2.11* to *2.13*, except for models which cater specifically and exclusively to one or two FFE tasks, most of the models examined here were identical in that they catered to the same number and type of task. A total of 28 different terms were initially enumerated from the 255 FFE studies. These collected tasks were sorted again into six groups. These six taxonomic groups are also observed in various studies in the literature, such as Khurana and Rosenthal (1998), Koen et al. (2001, 2002), Kim and Wilemon (2002), Nobelius and Trygg (2002), Thomke and Fujimoto (2000), etc.

The chart indicates that opportunity identification and idea generation are key tasks, with 63.5% of all models focusing on these two tasks. Many authors, including Dornberge and Suvelza (2012), Gurtner and Reinhardt (2016) and Kock et al. (2015), also regard these two tasks as the core components of the FFE. Brentani and Reid (2004, 2012), Backman et al. (2007) and Wormald (2011) also argue that FFE models should be built based on the opportunity identification and idea generation tasks.

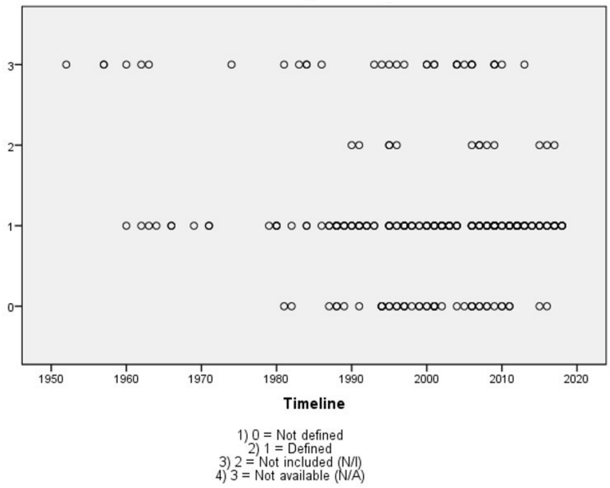
Criterion 7: Task 1 (Opportunity Identification-Screening)

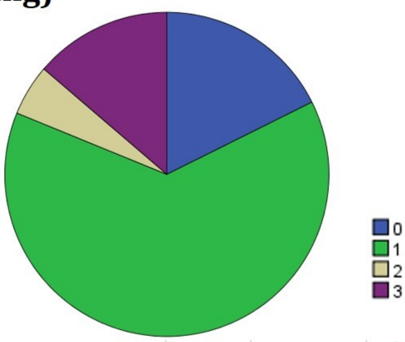




		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	45	17.6	17.6	17.6
	1	162	63.5	63.5	81.2
	2	13	5.1	5.1	86.3
	3	35	13.7	13.7	100.0
	Total	255	100.0	100.0	

Criterion 7: Task 2 (Idea Generation-Screening)



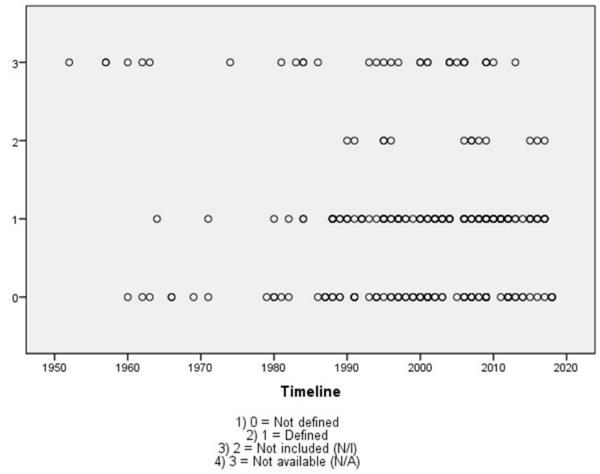


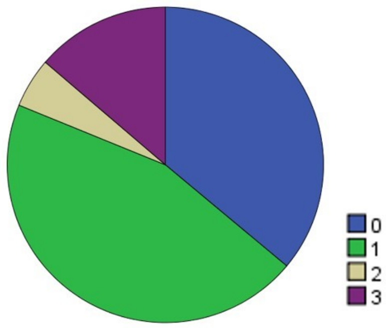
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	45	17.6	17.6	17.6
	1	162	63.5	63.5	81.2
	2	13	5.1	5.1	86.3
	3	35	13.7	13.7	100.0
	Total	255	100.0	100.0	

Figure 2.11. *Historical trend and frequency analysis for appraisal criterion 7 (Tasks 1 and 2)*

The requirements list task has also been stressed at the front-end stage for a very long time, since the primary purpose of the FFE is to identify product specifications such that they become the input parameters for the beginning of the actual NPD (Cooper, 1983; Carbone & Tippett, 2004; Jacoby & Scheelen, 2012; Williams et al. 2007).

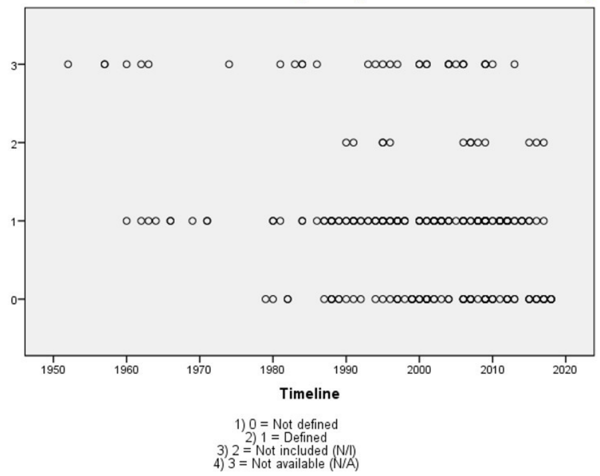
Criterion 7: Task 3 (Mission Statement)

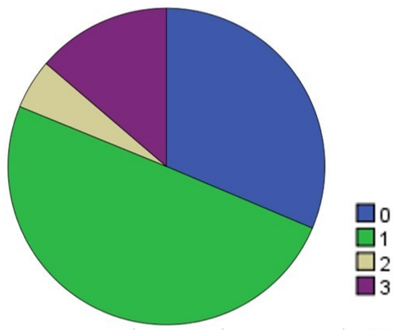




		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	92	36.1	36.1	36.1
	1	115	45.1	45.1	81.2
	2	13	5.1	5.1	86.3
	3	35	13.7	13.7	100.0
	Total	255	100.0	100.0	

Criterion 7: Task 4 (Requirements List)



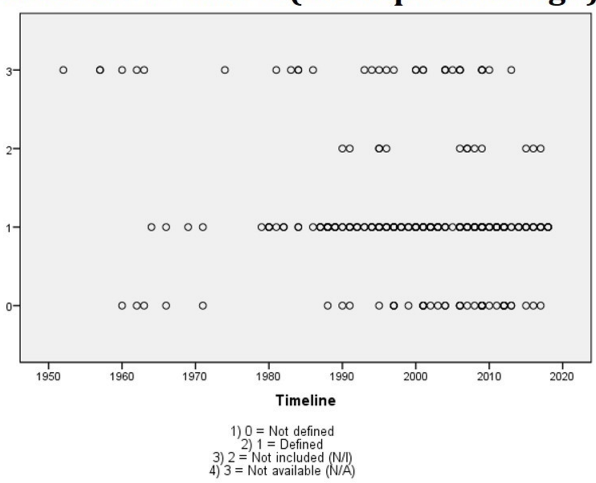


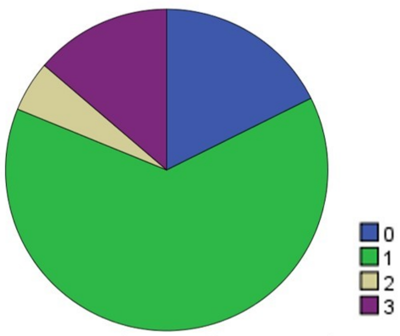
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	80	31.4	31.4	31.4
	1	127	49.8	49.8	81.2
	2	13	5.1	5.1	86.3
	3	35	13.7	13.7	100.0
	Total	255	100.0	100.0	

Figure 2.12. *Historical trend and frequency analysis for appraisal criterion 7 (Tasks 3 and 4)*

The most controversial issue among the six FFE tasks is whether the conceptual design and prototyping tasks should be included. In the case of the conceptual design task, in the 1970s it seemed to be included in the embodiment design or detail design stage. However, since the 1980s, it seemed that the conceptual design and embodiment design task had been explicitly separated, with an increase in the significance of the conceptual design task (Backman et al., 2007). Many authors, including Crawford (1984), Hüsig and Kohn (2003), Verganti (1997) and Zhang et al. (2009), highlighted that conceptual design should be included in the FFE in order to reduce iterative work (such as tinkering with design specifications) in the actual NPD phase. In the case of the developing prototypes, since the 1990s, with the trend of "Manufacture-able Design" (Verganti, 1997, 2009, 2011; Eveleens, 2010), also called "Design for Manufacturability (DFM)" (Barczak et al., 2009), most FFE models come with a prototyping task in addition to the conceptual design task. From that point on, many models and studies focusing solely on conceptual design and prototyping have also been generated, e.g. M109 (Ozer, 1999), M121 (Dahan & Mendelson, 2001), M122 (Loch et al., 2001) and so on. In this day and age, the prototyping task and the conceptual design task have become essential parts of the FFE. Christiansen and Gasparin (2017) have strongly stressed that the prototyping task should be conducted in the FFE stage, since a variety of modifications to designs can be generated based on the results of tested prototypes. 'Google Design Sprint' and 'IBM Design Thinking'[24] are processes which also emphasise the roles and functions of those two tasks.

Criterion 7: Task 5 (Conceptual Design)

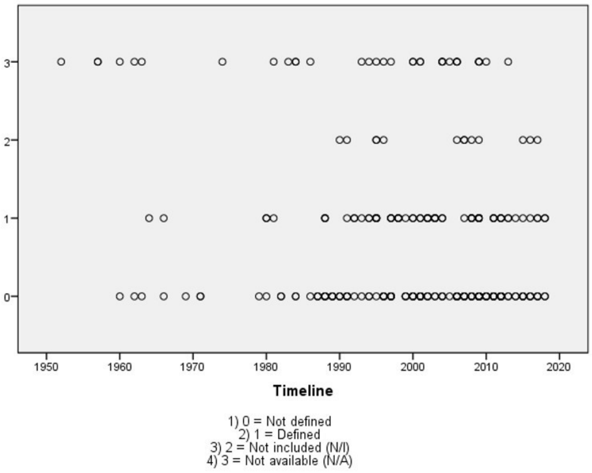


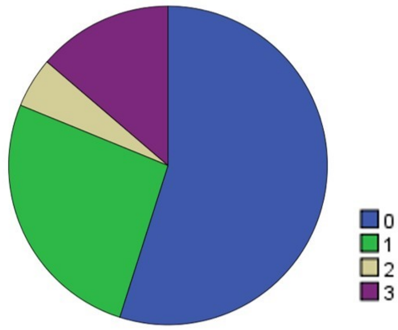


		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	45	17.6	17.6	17.6
	1	162	63.5	63.5	81.2
	2	13	5.1	5.1	86.3
	3	35	13.7	13.7	100.0
	Total	255	100.0	100.0	

24 Indeed, the 'IBM Design Thinking' process focuses more on consumer product development – as mentioned on their web-page – rather than software development.

Criterion 7: Task 6 (Prototyping)





		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	140	54.9	54.9	54.9
	1	67	26.3	26.3	81.2
	2	13	5.1	5.1	86.3
	3	35	13.7	13.7	100.0
	Total	255	100.0	100.0	

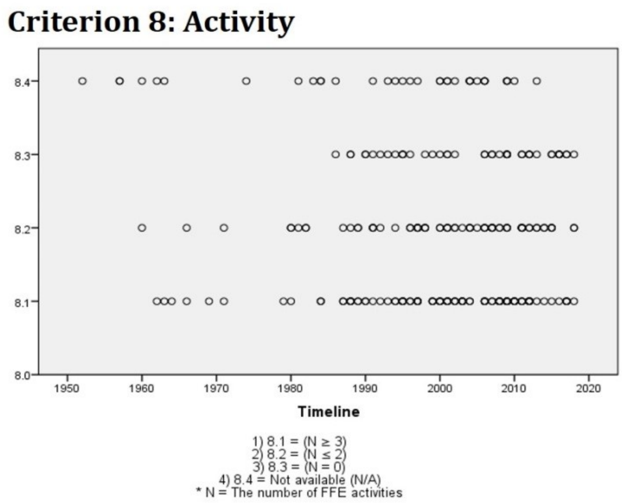
Figure 2.13. *Historical trend and frequency analysis for appraisal criterion 7 (Tasks 5 and 6)*

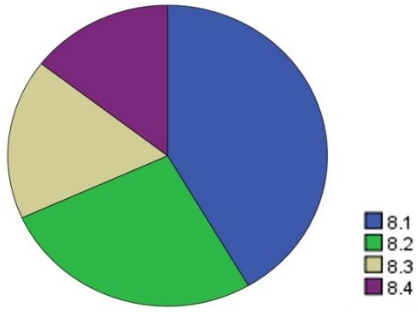
Along with those trends, whether the conceptual design and prototyping tasks were included in the FFE or the embodiment- or detail-design stage seems to have also depended on organisations' inherent NPD execution styles, application capability and maturity, scale of funding, etc. Indeed, this issue still remains controversial. However, as stated in research by Ester and Daniel (2007) and as shown in Figure 2.13, the trend is clear; these tasks are being incorporated into the FFE.

2.2) Appraisal Standard 8 (*Figure 2.14*) : Activity

Models which list more than two FFE activities for each task account for 41.6% of all models examined in this study. Models which moderately address FFE activities (listing only one or two activities per task) account for 26.7%. The majority of these models are of the pragmatic-prescriptive type; understandable observations due to the nature of this model type.

On the other hand, specific FFE activities are not defined explicitly in the theoretical-descriptive model type owing to its intrinsic nature.



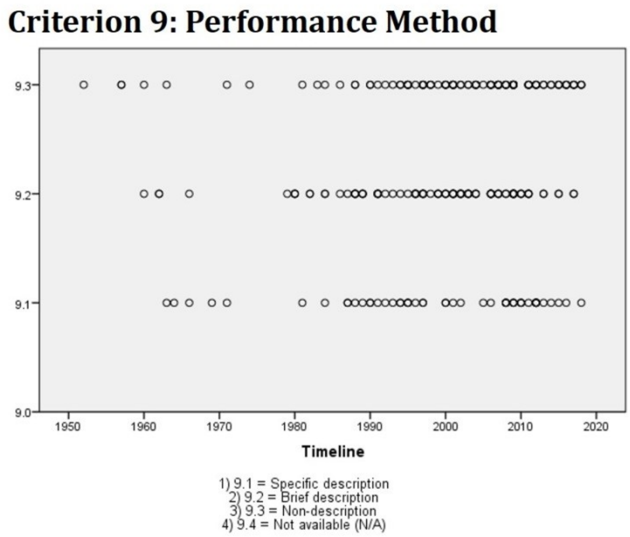


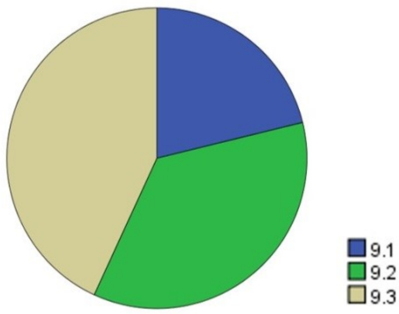
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	8.1	106	41.6	41.6	41.6
	8.2	68	26.7	26.7	68.2
	8.3	44	17.3	17.3	85.5
	8.4	37	14.5	14.5	100.0
	Total	255	100.0	100.0	

Figure 2.14. *Historical trend and frequency analysis for appraisal criterion 8*

2.3) Appraisal Standard 9 (*Figure 2.15*)
: Performance Method

The results here are similar to, and are to be reviewed in the same context as, the results of the previous criterion, number 8: FFE activity.





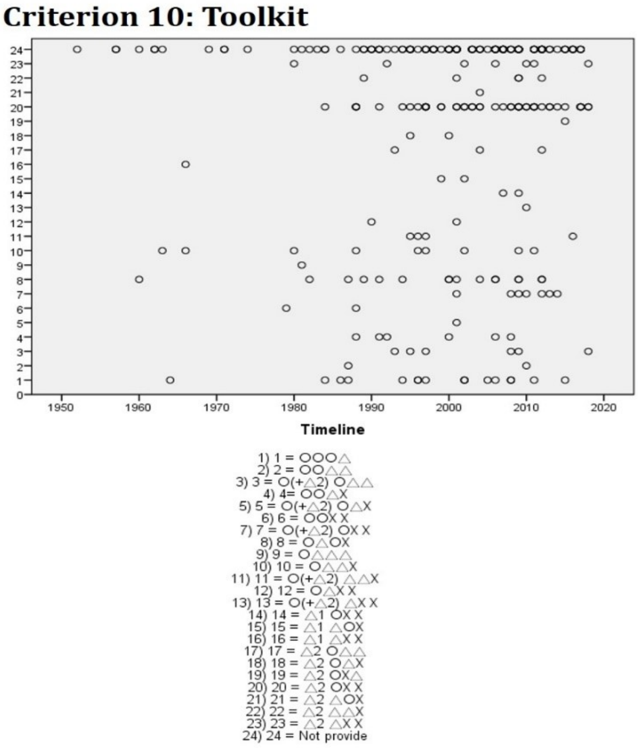
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	9.1	54	21.2	21.2	21.2
	9.2	91	35.7	35.7	56.9
	9.3	110	43.1	43.1	100.0
	Total	255	100.0	100.0	

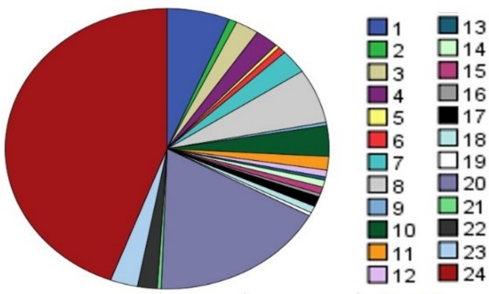
Figure 2.15. *Historical trend and frequency analysis for appraisal criterion 9*

The more theoretical and conceptual models whose purpose is not to provide step-by-step guidelines but mainly offer understanding of the relationships between FFE issues, accounted for 43.1% of the models; they contain a lower level of detail when illustrating performance methods for FFE activities. On the other hand, pragmatic-prescriptive models specifically describe performance methods and techniques step by step.

2.4) Appraisal Standard 10 (*Figure 2.16*) : Toolkit

There have been a few dedicated studies on toolkits for the FFE phase, however most studies are wider in scope and look at the structure of the FFE and relevant causal relationships. Koen et al. (2002) and Kim and Wilemon (2010) endeavoured to devise tools and methods after developing their models in 2001 and 2004 respectively. Barczak et al. (2009), Marion (2009) and Montagna (2011) also contributed to studies on tools, methods and techniques for design work. In the case of Achiche et al. (2013) and Ester and Daniel (2007), they figured out what toolkits were reasonable for each FFE task and how frequently each toolkit is typically provided, based on analysis of existing studies.





		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	16	6.3	6.3	6.3
	2	2	.8	.8	7.1
	3	6	2.4	2.4	9.4
	4	6	2.4	2.4	11.8
	5	1	.4	.4	12.2
	6	2	.8	.8	12.9
	7	7	2.7	2.7	15.7
	8	16	6.3	6.3	22.0
	9	1	.4	.4	22.4
	10	9	3.5	3.5	25.9
	11	4	1.6	1.6	27.5
	12	2	.8	.8	28.2
	13	1	.4	.4	28.6
	14	2	.8	.8	29.4
	15	2	.8	.8	30.2
	16	1	.4	.4	30.6
	17	3	1.2	1.2	31.8
	18	2	.8	.8	32.5
	19	1	.4	.4	32.9
	20	45	17.6	17.6	50.6
	21	1	.4	.4	51.0
	22	5	2.0	2.0	52.9
	23	7	2.7	2.7	55.7
	24	113	44.3	44.3	100.0
	Total	255	100.0	100.0	

Figure 2.16. *Historical trend and frequency analysis for appraisal criterion 10*

In this study, we attempted to understand the type, performance structure, and performance mechanism of the toolkits in the 255 FFE studies. In the case of FFE components that extend into the NPD process, the analysis was limited to the parts within the FFE. 23 distinct patterns were observed, the most remarkable of which, and the relevant models to which they apply, are described below. In these relevant models, the toolkits tend to be from prescriptive models rather than theoretical ones, to be expected given the nature of the model type.

2.4.1) Pattern 1 - Concreteness: ○, Functionality: ○, Contextuality: ○, Cooperability: △

Three types of toolkits which fit into this pattern was identified. These can be distinguished based on their structures and operating mechanisms.

The first type is a chart or matrix with morphological characteristics. The common version of this type is the 'Quality Function Deployment (QFD)' toolkit, which has merit in enabling showing detailed data and their relationships. This type also gives opportunities to involve diverse cross-functional works in a single matrix. The format has at least two edges (x- and y-axes), which intimates the possibility of two cooperating functions. For instance, M073 (O'Connor, 1995) and M150 (Ziv Av & Reich, 2005) equip a further strengthened the QFD type in which four different phased-QFD types are linked together in sequential steps. The 'Concurrent Function Deployment (CFD)' toolkit, having been transformed from the QFD toolkit with a change of dimensions, is shown in M087 (Prasad, 1996, 1998, 2000). The CFD is a three-dimensional matrix (x-, y- and z-axes), while the QFD is a two-dimensional matrix. Hence, more functions such as customer requirements and product planning can be managed in the CFD, whereas the QFD focuses more on technical parameters; the QFD also considers the market aspect to some extent. Other representative cases in this pattern include the connection of a modified 'Design Structure Matrix (DSM)'. The functional and physical features are similar to the transformed QFD in that the DSM also has an x- and y-axis and each value is marked in the intersection points of the x- and y-axes. Its structure is well-revealed in M152 by Shino et al. (2002, 2006), and comes with mathematical formulas and equations describing the elaborate controls present in the model.

The second type of toolkit featured in this pattern was partially adopted from a type of flowchart or break-down structure used in a number of tools including ‘Root Cause Analysis (RCA)’, ‘Decision Rationale editor (DRed)’, ‘Design Rationale Capture (DRC)’ and ‘Function Analysis Diagram (FAD)’. The chief characteristic of this type is that there is a cause and effect system as the basic framework, used to produce requirements and solutions by breaking down problems and undesirable statuses step by step. Since this type of toolkit is operated based on a cause and effect system, it is relatively easy for each value in the form to be connected to another. M133 (Alexandersdottir, 2015) and M213 (Kim & Kim, 2011) are appropriate examples.

Finally, the third type of toolkit is a combination of the above matrix form mixed with a break-down structure. The structure of model M085 (Christensen et al., 1996) involves a pure QFD and DSM matrix at each step of the break-down structure, to support more efficient management. In the case of M236 (Castilho et al., 2015), the QFD and the ‘Technology Road Map (TRM)’ is integrated into the phased-RCA structure. M176 (Birkhofer, 2008) is the model which best utilises modified QFD and FAD. Birkhofer developed an ‘Elementary Methods’ matrix tool based on eight categories of design variables extracted from the QFD. This new matrix format was incorporated into the transformed FAD system which in his study was called ‘Functional Genome’. This tool is helpful for establishing the relationship between requirements and constraints.

When viewed in terms of contextual performance and concurrent collaboration, these three types of toolkit tend to be better built than other toolkits. Despite this, they have their own shortcomings which lead to the following problems.

Firstly, values in matrices have trouble linking to each other and thus tend to exist independently. This suggests that contextual performance was not fully considered when developing these toolkits. For example, the target research and analysis elements presented on the *x*-, *y*-, and *z*-axes appear to be selected and arranged based on what the performers expect to find. Their expectations are likely to be based on previous education and experience. Meanwhile, the composition and arrangement of elements is key to how and which parameters are output. Therefore, these results are limited by the expectations of the performers. Consequently, the guaranteed inter-connectedness of parameters cannot be infinite.

Secondly, most of the output values have difficulty 'containing' qualitative data and instead feature numerical data or semantic symbols such as 'O' and 'X'. While these toolkits are useful for ascertaining the status of certain parameters, it is not sufficient to just provide descriptive evidential interpretations: the output values are mostly numerical" (i.e. quantitative).

Finally, the toolkits reveal a lack of structure and the required operating mechanisms to simultaneously conduct multiple functional activities. This implies that concurrent collaboration was hard to attain physically and was not functionally established into the structure of the toolkits.

2.4.2) Pattern 8 - Concreteness: ○, Functionality: △, Contextuality: ○, Cooperability: X

Toolkits which fit this pattern have components that are well connected for contextual performance. This result may be caused by the fact that the toolkits target only one or two tasks in the FFE from the viewpoint of a single functional area. It is relatively easy for this kind of toolkit to have a much simpler structure from the contextual performance aspect.

M153 (Li et al., 2006) is the representative for the idea generation task in that it is ideal for R&D. The toolkits suggested in their study are systematically organised in their structure, where the cause and effect system is well-reflected. They are executed based on the 'Thinking Process (TP)', whose major component is 'Theory of Constraints (TC)'. The aim of TP is to reduce the gap between the 'Current Reality Tree (CRT)', which states the present core problems (undesirable effects) in the similar form of an RCA, and the 'Conflict Resolution Diagram (CRD)', which addresses requirements and prerequisites for solving those core problems in the similar form of a 'Fish-bone Diagram (FBD)'.

Toolkits provided by the following studies were aimed at defining and designing the function and system structure of products from an R&D perspective. Ito and Shinno's (1982, 1989) studies – M023, M035 and M046 – can be examples. Toolkits were developed, modifying and integrating the structure and operation system of the

'Morphological Analysis (MA)' and the FAD. Other studies, including M007 (Marples, 1960), M070 and M071 (Shinno et al., 1991, 1994) and M117 (AI Hakim et al., 2000), developed toolkits whose rooted-structure was borrowed from the 'Logic Tree (LT)' or from RCA where the cause and effect system is well-reflected.

2.4.3) Pattern 10 - Concreteness: ○, Functionality: △, Contextuality: △, Cooperability: X

The main difference in this pattern compared to toolkits revealed in the previous pattern is that these toolkits cover the whole range of the front-end whereas previous toolkits target only one or two activities in a single task. This type of toolkit seemed to be partially devised from the contextual performance aspect, focusing more on a particular functional domain.

The most representative case for this pattern is shown in M026 (Paul & Beitz, 1984, 2007), M027 (Archer, 1964, 1968) and M033 (Hubka & Eder, 1987, 1996). In particular, the process developed by Hubka and Eder (1987, 1996) outfits engineering designers with a 'Theory of Technical Systems (TTS)' which can serve as an overall toolkit for each stage of their procedural model, on the basis of the theoretical concept of 'Design Science'. The TTS, as one of the first toolkits which made an effort to define a scientific design method, can serve as a channel for producing inputs and outputs for each phase. Outputs, as technical parameters, calculated through the TTS in each phase, can be the inputs of a following phase.

However, the inner system of the TTS and the connectivity between its sub-compositions need to be studied further, from the contextual performance aspect. M011 (Jones & Thornley, 1963; Jones, 1970) and M013 (Machett & Briggs, 1966; Gregory, 2013) can be similar cases to the model devised by Hubka and Eder (1987, 1996). Each phase is systematically structured, serving as the toolkit itself for the channel to generate inputs and outputs.

2.4.4) Pattern 20 - Concreteness: △2, Functionality: ○, Contextuality: X, Cooperability: X

Toolkits which fit into this pattern were the most frequently observed in the 255 studies. Studies providing this type of toolkit typically referenced prestigious representative toolkits without their own toolkit developments, focusing on the structure and management of models. Most of the studies had a tendency to offer formal names of tools in the form of a list. As many toolkits were obtained from different existing studies, there is an incidence of those tools existing separately without less interrelationship with each other, which also led to difficulties with collaborative work. However, there can be advantages in that a set of those tools cover more than two functional fields. Example models for this case are M036 (Cooper, 1998 to 2018), M37 (Murphy & Kumar, 1996), M188 (Marion, 2009), M226 (Dornberger et al., 2012), etc.

2.4.5) Six Patterns: 3, 5, 7, 11, 17 and 18
– Using Representative Toolkits
– Using Representative Toolkits alongside Self-development Toolkits

Toolkits or a set of toolkits fulfilling these six patterns seem to compensate for flaws identified in those which fit into the pattern above (Pattern 20). These patterns can be classified into two groups as follows.

The first classification is, chiefly, about linking representative toolkits from the contextual performance aspect. For instance, M079 (Roozenburg & Eekels, 1995) suggests a set of sequential representative toolkits which adhere to pattern 18, 'Concreteness: △2, Functionality: ○, Contextuality: △, Cooperability: X'. We observed some evidence showing that they endeavoured to organise quite methodically the well-known toolkits which possess superior capability. 'Technical Performance Specification (TPS)', QFD, FAD, 'Morphological Analysis (MA)' and 'Weighted Objectives (WO)' are sequentially linked in the form of a toolkit set. Each tool has a partial segment suggesting a possible linkage between tools, e.g. some of the parameters obtained from the TPS can be inputs for the QFD. In the case of M118 (Presley et al., 2000), which has the same toolkit set pattern, the set is formulated by a sequential connection between a two-phase QFD and IDEF0. In the first step, the customer requirements of the first phase of the QFD are linked to the design requirements of the second phase of the QFD. Next, methodological characteristics to realise those design requirements, as outcomes of the two-phase QFD, are defined. In the final step, each methodological characteristic is substituted into the IDEF0 to generate parameters related to constraints, mechanisms and resources. For pattern 17, 'Concreteness: △2, Functionality: ○, Contextuality: △, Cooperability: △', model M225 (Wang & Gan, 2012) can be referenced. A set consisting of representative toolkits is, to some extent, strengthened by the presence of collaboration. Even if the previously addressed toolkit sets included QFD in which at least two functional areas are engaged, these sets seem to be more reasonable for a single function, e.g. a technical parameter generation. The reason is that not all toolkits in the set involve multiple functional areas. Conversely, in the case of the toolkit set for the model developed by Wang and Gan (2012), each toolkit in the set is appropriate for use in various functional areas. Connecting each tool which involves two functional sectors implies the possibility of collaboration. The set of toolkits in this model consists of 'Voice of Customer (VOC)', 'Analytic Hierarchy Process (AHP)', the TRIZ and QFD. In the case of M048 (Cross, 1989), the toolkits and the connections between them are similar to those of M079 (Roozenburg & Eekels, 1995). In 'Objective Tree (OT)', TPS, QFD, FAD, MA, WO and 'Value Engineering (VA)' are connected in order: the link from TPS to WO is observed in M079 (Roozenburg & Eekels, 1995). However, parameters which involved the model's toolkit set have a tendency to gain technical-and-engineering attributes rather than embrace the aspects of various functional areas.

Even though all the above trials linking representative toolkits seem to be acceptable, these approaches tend to end up producing an effect where toolkits have a partial interrelationship from the contextual performance aspect. They also tend to not fully fulfil concurrent collaboration. The reason is that the representative toolkits were simply coupled for contextual performance and concurrent collaboration aspect, instead of developing those toolkits at the very start for these two aspects.

The second classification is about connecting the existing representative toolkits with self-development toolkits from the contextual performance aspect. This is a more advanced approach than the one mentioned above. The aim here is to make up for the deficiencies that arise from choosing and linking only representative toolkits. The first pattern that matches this classification is pattern 3, ʻConcreteness: ○+△2, Functionality: ○, Contextuality: △, Cooperability: △ʼ. Ulrich and Eppingerʹs (1995, 2011) model, M081, featuring a well-known NPD process, is included in this pattern. This model alongside Crawford and Di Benedutto's (2008) M172 and Dimancescu and Dwenger's (1996) M097 suggest more specific self-developed toolkits, e.g. 'Four Field Mapping (FFM)' 'Product Innovation Charter (PIC)', 'Joint Space Map (JSM)' and 'Awareness-Trial-Availability-Repeat (A-T-A-R)'. These toolkits are connected to most of the more well-known toolkits. In the case of M187 (Gausemeier et al., 2009), the tools they developed themselves operate in a network-based platform. In this platform, the representative toolkits from other studies are also deployed, and linked with self-developed toolkits.

Even if this attempt to connect their own developed toolkits with representative toolkits is more advanced than previous trials connecting only well-known toolkits, the same defects remain, since, from the outset, the toolkits are not devised with contextual performance and collaboration in mind, self-developed toolkits and representative toolkits still have a partial correlation. Besides, most of the toolkit sets do not sufficiently fulfil the physically and functionally embodiment for concurrent collaboration.

In the second classification, toolkits which accord with pattern 7, ʻConcreteness: ○+△2, Functionality: ○, Contextuality: X, Cooperability: Xʼ, are those that have frequently been observed in recent literature. The structures and formats of self-developed toolkits and representative toolkits are organised together in the form of a collection book. These collections also provide a precise instruction manual, grounded on the idea of pragmatic-prescriptive guideline development. In M200 (Lidwell et al., 2010; Hanington & Martin, 2012), toolkits for universal design principles are sorted in alphabetical order. M201 (Kumar, 2012) suggested 101 kinds of design toolkit, each complete with detailed user manuals. M202 (Clarkson et al., 2007, 2013) offers inclusive design methods and toolkits.

In the case of M203 (van Boeijen et al., 2014), the most popular in the collection books, specific design tools and user guidelines are appropriately arranged in a kind of 'Double-Diamond Design Process' structure. Although self-developed and representative toolkits in these collections are more concrete and sophisticated than others, if they are not developed and structured with contextual performance and concurrent collaboration in mind, it is likely that they will have the same limitations as mentioned above.

2.4.6) Section Conclusion
– A Summary of Toolkit Analysis

As noted in our review of these 23 patterns, model structures with self-developed toolkits received a great deal of attention in the 1960s and 1970s. It would appear that the development of these toolkits began in earnest alongside the development of pragmatic-prescriptive FFE models. From then until the late 1990s, attention on studies about model structures, operation methods, and the correlation between relevant issues were much more focused, generating both the theoretical-descriptive and the pragmatic-prescriptive process types. Those studies also tended to recommend referencing toolkits previously devised; there were very few cases of models developing their own toolkits. With the cross-functional work trend on the rise, there was a tendency to suggest many tools developed in various functional areas for use in new models. From the early 2000s when the potential to represent particular differences in structures and operating systems of models was beginning to decline, efforts to determine how to perform tasks and activities more efficiently seemed to resume. A movement towards providing more specific toolkits reached a peak in the late 2000s. Around this time, many studies on concrete toolkits and guidance were carried out, which resulted in various books and other educational materials for a massive set of toolkits, e.g. Human-Centred Design Toolkit (IDEO, 2003, 2009), Cambridge's Inclusive Design Toolkit (Clarkson et al., 2007, 2013), TU Delft's Design Guide (van Boeijen et al., 2014), and the Narrative Design Toolkit (2010). This might be caused by the emergence of a new dimension of practice.

3) Section Conclusion
– A summary of FFE model analysis

We have examined results from 255 FFE studies using ten appraisal criteria designed to aid the development of a new pragmatic-prescriptive FFE model. Many cues for the establishment of strategies for the model development have been identified. However, there some few aspects that should not be neglected when looking at these cues.

In the analysis chart, the fact that a high percentage of studies dealt with a certain aspect does not mean that studies on that aspect are no longer necessary. On the other hand, it cannot be asserted that research carried out on a particular aspect should be intensified in the future just because the proportion of studies dedicated to that aspect is low. To establish the strategy for developing a new model, we should consider development trends thus far and the demands of the modern age. For instance, though the development of the agile model has been relatively fervent over the past fifteen years with a steep growth trend, that does not mean that its importance is now starting to taper off. It stands to reason that studies on the development of models to accelerate the NPD cycle will be still needed, to create different structures and more innovative operating mechanisms in agile systems.

Next, not all of the studies fall neatly into the time periods in the trend chart. The interpretation must be that the chart depicts a comprehensive trend instead of scrutinising each model and the time division in detail. However, we should still keep in mind that the overall analysis of FFE studies as a function of time gives the advantage of not only boosting understanding of the comprehensive trend but also to provide a blueprint for new model development.

Lastly, it does not mean that there is nothing to be gained from models and their relevant studies, even if some aspects are not physically or functionally well established in those models. Even in this case, useful resources for a new pragmatic-prescriptive model development can be achieved.

Based on the detailed analysis by each evaluation criterion, specific FFE model development strategies for a pragmatic-prescriptive FFE model can be established. These strategies and relevant knowledge-and-theories are clarified in the next section.

2.3 Discussion

– Pragmatic-Prescriptive FFE Model Development Strategies

This section addresses the pragmatic-prescriptive FFE model development strategies established based on key findings of FFE studies' reviews, which were presented in the previous section.

There are a total of nine strategies derived from the key findings of the analysis of the FFE studies, with nine appraisal criteria, except for Appraisal Standard 1 (The Taxonomy of FFE Studies). The first appraisal criterion is directly related to the research aim to develop an FFE model, meaning that the strategy related to the first criterion is skipped.

1) The First Dimension:

: Overall Attributes

– Current and Future Trends in FFE Model Improvement

1.1) Strategy 1

: Data-driven Type

– by Information Processing and Knowledge Accumulation System

With the demands of the modern age, FFE models have been forced to move towards the data-driven type. Unfortunately, as shown in the analysis chart (*Figure 2.6*, *p.* 64), the development of data-oriented models fulfilling the entire FFE phase has thus far been imperceptible.

Data-driven Type

In this research, the development of the data-driven type is highly related to that of the performative type, but development directions are different to some extent. The performative type concentrates on the structure wherein NPD-related parameters can be produced in the model itself. On the other hand, the data-driven type focuses on how to process the parameters in the structure. Hence, in this study, the embodiment of the data-driven type is also linked to that of toolkits wherein the parameters interlock from the contextual performance and concurrent collaboration aspect. If the parameters are just generated but not processed in the structure of the model, the model is only performative. However, if the model has the structure to process the parameters in a certain manner, e.g. input and output parameters interlock consecutively, the model can be regarded as the data-driven type. With advances in computer engineering technologies, the data-driven model of today, which evolved from machine learning and data mining methods, can learn to process data by itself. However, this research will focus on building a foundational platform wherein data can be processed in the performative structure from the contextual performance and concurrent collaboration perspective. An introduction and application of the machine learning and data mining method will be executed in the future research.

Information Processing

The data-driven type of FFE model requires a platform which operates based on 'Information Processing' (Carbone & Tippett, 2014; Jetter, 2003; Poskela & Martinsuo, 2009; Sandmeier et al., 2004; Zahay et al., 2004; Zhang & Doll, 2001) and 'Knowledge Accumulation' (Talke et al., 2006; Wenger, 1998).

Firstly, information processing (O'Connor & Rice, 2001; Dröge et al., 2008; Leenders, van Engelen & Kratzer, 2003) does not simply mean the collection of information but also a systematic and structured process for generating actionable findings based on both "Factual" and "Value" principles (Reid & de Brentani, 2004; Koen at al., 2002). The key is this structured process, to convert factual data into the usable information which can be applied to the NPD (Reid & de Brentani, 2004). Collection tends to be informal and tacit, and so a formalised process of collection is key to the data-driven type (Dewulf, 2013; Jacoby, 2012). 'Mere' collection and analysis are no longer sufficient; a systematic process or cycle of transforming data into actionable information is required.

Information processing has two aspects: 'Speed of Information Flow' (Kim & Wilemon, 2002) and 'Quality of Information Flow' (Millson et al., 1992). The former can significantly affect first-mover advantage and help a business achieve an edge over the competition (Kerin et al., 1992; Langerak & Hultink, 2005; Reinertsen, 1999; Robinson, 1988; Robinson & Fornell, 1985). In addition, Boulding and Christen (2003) argue for 'Three Moderators' which they say benefit the speed of information processing: rapid customer response, rapid market positioning, and rapid intellectual protection. The latter aspect, quality of information flow, is for product superiority, which means more superior NPDs can be realised by producing more accurate information and by reducing uncertainty and ambiguity (Glazer, 1991; Henard & Szymanski, 2001). There are two models which focus on the quality of information processing. Laswell's (1948) model, a typical information processing model, has a sequential structure consisting of 'Information Source', 'Encoding', 'Transmission Channel', 'Receiver, 'Decoding', 'Noise' and 'Feedback'. Rogers' model (1962, 2003, 2010) complemented Laswell's by adopting diffusion theory to improve Laswell's three components: 'Receiver', 'Decoding' and 'Noise'. A control system for both 'Receiver Variables' and 'Social System Variables' were integrated into the progress from 'Receiver' via 'Decoding' to 'Noise'.

Knowledge Accumulation

However, implementing a system of information processing, even if in pursuit of 'Speed' and 'Quality', is not sufficient to make a model a data-oriented model. There needs to be an equal focus on converting the processed information into usable knowledge assets. This conversion is sometimes known as the transition from 'Perception' to 'Cognition' (Brentanit & Reid, 2012; Bunge, 1962; Khun, 1962, 2012; Roos, 1996). Perception means to recognise, collect and interpret certain patterns in a given set of information while cognition is the ability to reconstruct that information and transform it into applicable formats for the organisation and its tasks. The data attained through cognition is counted as a knowledge asset, evolved from information processed through perception. There are many studies on knowledge accumulation. Akbar and Tzokas (2013) and Du Chatenier et al. (2009) reviewed various knowledge accumulation theories. According to their studies, knowledge accumulation is a kind of loop system which enables processed-information to be utilised sustainably (Armbrecht et al., 2001; Talke et al., 2006). The loop, as its name implies, operates as a cycle: 1) track past information, 2) discover current information, 3) envisage future-oriented information through a combination and transformation of past and current information, 4) conduct a feasibility study of new information, 5) build up knowledge and 6) go back to step one (Goodman & Lawless, 1994; Usher, 2013). Through repetition of the cycle, the process of accumulating knowledge is learned, with know-how and expertise on relevant sectors acquired by each NPD project (Armbrecht et al., 2001; Kim & Wilemon, 2002; Talke et al., 2006; Thomke & Fujimoto, 2000).

Information Processing and Knowledge Accumulation

By putting information processing and knowledge accumulation together, an ideal data-driven type of the model, serving as a knowledge-based platform, plays a role in dealing with relevant collected information through enhanced information processing capabilities for depth and breadth, after which the accumulated knowledge can be disseminated to appropriate projects in the future.

In particular, for the FFE phase, a model designed specifically for processing qualitative rather than quantitative data is required, as much of what is acquired during the FFE is non-countable (Dewulf, 2013; Kim & Wilemon, 2002; Lukas & Menon, 2004; Williams et al., 2007; Wowak et al., 2016). Since the FFE stage involves a significant degree of uncertainty and ambiguity (Jetter, 2003; Chang et al., 2007; Brun and Saetre, 2009; Kurkkio, 2011) and subjective and approximate information (Kim and Wilemon, 2002), it is likely that there is much information that cannot be quantified. Even if this were not true, quantitative data can often be meaningless without qualitative data to provide meaning and context.

In summary, the data-driven FFE model can be embodied by enhancing the information processing and knowledge accumulation capacity of a model which focuses on qualitative information.

1.2) Strategy 2

: Agile Development

– by Increasing the Quality of Information Flow

In order to realise a new, agile type of model, we need to devise a new method. Most of the previous models have achieved agility by implementing a rapid iteration system or enabling parallel-overlapping performances, as shown in the analysis outcome. Constant loop-backs and their iterations tend to be regarded as inherent to the FFE (Koen et al., 2002; Sperry & Jetter, 2009). This system is related to increasing the speed of information flow mentioned in the section above. However, there are side-effects in reducing the NPD cycle time by seeking agile repetition or otherwise shortening the time it takes. According to many studies, including by Achiche et al. (2013), McKeen (1983) and Wheelwright and Clark (1992), whenever 'Redo' and 'Redirect' activities occur in the NPD cycle, the overall project time and costs increase exponentially. In the case of the study by Love and Edwards (2013), various types of risks occurred as a result of continued repeats. Carbone and Tippett (2014) and Cooper (1997) argue that it is foolish to focus overly on shortening product development time to get products to market faster without properly performing research and analysis from the viewpoint of the range, details, and amount of information. Developing products based on poor quality product data incurs more risks than an extended development period in the FFE (Carbone & Tippett, 2014). If there is a concentration on compressing the development process to reduce development time, it is quite possible that that even essential activities may be curtailed, to the overall detriment of the project (Backman et al., 2007).

Therefore, it is important to consider how agile NPD can be effected from a quality of information flow point of view. Namely, what if the actual number of iterations can be conspicuously reduced through enhanced capabilities in the quality of information flow? What if the efficiency of acquiring relevant data by filtering irrelevant information can increase by setting up a high-performance database for information processing and knowledge accumulation? Rapid iterations no longer become as necessary if fewer iterations are ultimately required. Such a system can help bring about agility. Furthermore, this approach is anticipated to interact internally to reduce ambiguity, regarded as one of the most critical issues in the FFE (Brun & Saetre, 2009; Chang et al., 2007; Frishammar et al., 2011; Yoon & Jetter, 2015; Zhang & Doll, 2001) as it is strongly influenced by the quality of information.

Consequently, an FFE model enabling agile NPDs can be materialised by reinforcing the quality of information flow in the information processing system.

1.3) Strategy 3

: Incremental and Radical NPDs

– by Different Arrangements of FFE Activities in the Front or Back Parts

There are very few FFE models which are acceptable for both incremental and radical NPD (shown in the analysis, *Figure 2.8*, *p.66*). Many experts on the FFE, including Reinertsen (1994) and Smith and Reinertsen (1991), argue that a one-size-fits-all type is no longer capable in many NPD situations such as those with varied types of product lines (which are more related to incremental development), or those with newly added product families (which are much more relevant to radical development).

A suitable model for both NPD attributes can be structured by forming a distinction between 'early' or 'late' activities in the front-end (Backman et al., 2007). This type of discrimination in the FFE is called 'Contextualisation' and 'Conceptualisation'. Contextualisation is where the collection and analysis of information, which primarily occurs in the early parts of the FFE, are undertaken differently due to contextual differences between incremental and radical NPD. These contextual differences come from the intrinsic nature of the two NPD directions: incremental NPD tends to depend more on finding out the problems in previous products by further utilising internal (in-house) resources whereas radical NPD is more inclined to discovering new trends to develop new-to-the-world products through communication with external resources. The differences between these two tendencies are most apparent during the research and analysis portions of the FFE. On the other hand, structuring this variation in the late phase is referred to as 'Conceptualisation'. This aims to differentiate conceptual designs which are normally inserted into the initial actual NPD phase, divided into two groups respectively in accordance with the incremental and radical NPD.

We can obtain valuable cues from the approach above; different deployment of FFE activities and routes of information flow can result in different model structures. One possible method to actualise this cue can be a modularity approach. The approach enables at least two-channels for incremental and radical NPD to be established in the new model. M130 (Nobelius & Trygg, 2002) and M165 (Backman et al., 2007) are relevant here. Even though these two models have multiple routes in their structures which differ depending on the type of project being conducted (e.g. a business evaluation-driven or advanced engineering-driven), the approach to building diverse channels through modularisation can be applied to a new model which incorporates the two NPD attributes.

In conclusion, an FFE model for handling both incremental and radical NPDs can be realised through different arrangements of FFE activities in the front or back part of the FFE.

1.4) Strategy 4

: Explicitness and Responsiveness

– by Planned Flexibility

Many authors, including Gurtner et al. (2016), Khurana and Rosenthal (1998), Poskela and Martinsuo (2009) and Sandmeier et al. (2004), recommend developing an appropriate model which balances "Explicitness" (which typically presents in sequential formalised structures) and "Responsiveness" (which normally shows in non-sequential flexible structures), e.g. a recursive, chaotic, spiral and modular type. We can call this balanced structure the 'Planned flexibility', 'Twofold' or 'Ambidexterity' type (Andriopoulos & Lewis, 2009; Backman et al., 2007; Verganti, 1999).

Neither characteristics can be overlooked since both types each have their own advantages. The benefits of one structural type are the weaknesses of the other.

A fixed structure is beneficial for stable executions, as it decreases fuzziness and strengthens the systematic approach (Cooper, 1998; Cooper & Kleinschmidt, 1986; Griffin, 1997; Kim & Wilemon, 2002; Koen et al., 2001). The structure has benefits in that it is keenly aware of more explicit directions for not only individual implementation but also for coordinate synthesis in given implementations (Bonner et al., 2002; Tatikonda & Rosenthal, 2000).

On the other hand, a responsive structure which takes a critical stance on formal process control has merit for producing more creative outcomes by allowing for discretion on specific performance methods and their approaches (Amabile, 1998; Bonner et al., 2002; Ramaswami, 1996; Tatikonda & Rosenthal, 2000). A structure which can be flexibly changed be it in the centralisation or decentralisation types is of help for exploring alternative opportunities, ideas and concepts (Donaldson, 2001; Stringer, 2000).

These two types should thus be balanced in the FFE based on the advantages for a given objective. In balancing the two characteristics, Khurana and Rosenthal (1998), Lynn and Akgun (1998) and Rice et al. (2001) argue that explicitness is better for the overall structure rather than for sub-structures in the sense that flexible performance can be controlled through a formalised process by taking the benefits of both sides; referred to as 'Planned flexibility'. They further argue that in the opposite case, explicitness in the sub-structures, there are many circumstances in which the very advantages of explicitness diminish.

To conclude, the overall characteristic of the FFE model can be designed based on explicitness in the pursuit of stable operations (e.g. a phased and formalised process), or responsiveness which can support sub-structures in the pursuit of creative behaviour (e.g. a modular and spiral process).

1.5) Strategy 5

: Procedural and Performative Structure

– Procedural Structure with Performative Sub-structures

The procedural structure predominates in most of the pragmatic-prescriptive models so far, since theoretical-descriptive models aim to interpret correlations between FFE issues rather than prescribe performance procedures and methods. In order to increase the efficiency of what the pragmatic-prescriptive model pursues, models which balance the procedural and performative structure have occasionally been developed, as shown in *Figure 2.10* (*p. 69*). Some models have an overall procedural structure, with the sub-structures being of the performative type. On the other hand, there are some models whose overall structure is the performative type, but with procedural components.

In order to realise the planned flexibility characteristic defined in the section above, 'Strategy 5: Explicitness and Responsiveness', the procedural form, which tends to pursue to explicitness, can become the overall structure whose sub-structures can be of the performance type, which leaves room for flexibility. To be specific, 'Task' units can be arranged and structured in a procedural manner to pursue explicitness, while 'Activity' units (units which fall under 'Tasks') and 'Toolkit' units (support systems to perform those activities) can be structuralised in a performative manner to pursue responsiveness. The model of reference here is M033 by Hubka and Eder (1987, 1996), wherein each stage of the process-oriented sequential structure is the same as the toolkit itself, termed the "Technical System (TS)". Outputs from the previous stage become inputs of the next stage, using the TS toolkit.

Consequently, the FFE model can be built using a procedural structure with performative-type sub-structures if the aim is to establish a balance between the procedural and performative structures.

2) The Second Dimension

: FFE Performance Structure and Its Operating Mechanism
– Parameter Process and Decision

2.1) Strategy 6

: Six Main Tasks

The FFE phase is typically made up of six essential tasks. These tasks commonly referred to most of the FFE models include.

- Opportunity Identification-Screening
- Idea Generation-Screening
- Mission Statement
- Requirements List
- Conceptual Design
- Prototyping

Firstly, the task deemed to be most important is the opportunity identification-screening. Many experts, including Alam (2003) and Brentani and Reid (2012), have highlighted that the information and knowledge generated from this task is the most crucial input throughout the FFE. The primary aim of the task is information processing and knowledge generation from many functional areas (O'Connor & Rice, 2001; Tushman & Scanlan, 1981), so that a database can be built covering the experiences of product development (Lynn, 1995; O'Connor & Veryzer, 2001). Hence, opportunity identification-screening, which contributes to building the database to accumulate knowledge assets for the company, is one key task to realising a data-driven model. In many studies such as those by Khurana and Rosenthal (1997), Koen et al. (2001, 2002) and McGrath (1995), opportunity identification-screening is considered to mark the kick-off of the FFE, preceding the idea generation-screening task.

The second task, idea generation-screening, is also considered to be a crucial component of the FFE along with the opportunity identification-screening task. The main aim here is to develop ideas or solutions to realise discovered opportunities and evaluate their practicality (Montoya Weiss & O'Driscoll, 2000). If ideas and solutions to realise opportunities pass feasibility testing (Burt, 2009; Crossan et al., 1999; Macdonald & Williams, 1994), then these filtered ideas and solutions can be accumulated as new knowledge assets in the database (Brentani & Reid, 2012). Therefore, idea generation-screening is also regarded as an essential task which contributes to fostering the data-driven type of model.

The next tasks for the FFE are the mission statement and requirements list. Based on the discovered opportunities and ideas, the mission statement, as a brief product definition, is drawn up through the establishment of aims and objectives which support the overall actions of the project (Cooper, 1983; Carbone & Tippett, 2004; Jacoby & Scheelen, 2012; Williams et al. 2007). The requirements list aims to specify the product definition by building up detailed product specifications and priorities (Bacon et al., 1994; Cooper, 1998; Khurana & Rosenthal, 1997). The requirements list is a kind of a project protocol, acting as an aggregate of an overall course map for NPD implementation phase (Cooper, 1998).

The final FFE task has been regarded as important only since around the early 2000s: conceptual design and prototyping. The conceptual design task, in general, aims to visualise a function and system structure and to design an aesthetic and functional appearance of a new product (Khurana & Rosenthal, 1997, 1998). Design concepts are built by reflecting product specifications across all corners of the product (Crawford, 1984; Cooper, 1998). In the case of prototyping, its purpose is to test and verify those conceptual designs functionally and technically through operational or non-operational mock-ups (Bacon et al., 1994; Clark & Fujimoto, 1991). The more complex the products, the more prototyping and testing is needed (Bacon et al., 1994; Clark & Fujimoto, 1991). With the "Manufacture-able Design" design trend becoming popular (Eveleens, 2010; Verganti, 1997, 2009, 2011), referred to sometimes as "Design for Manufacturability (DFM)" (Barczak et al., 2009) in the conceptual design task, the evaluation of those conceptual designs through physical embodiment is becoming more essential (Veryzer, 2005; Zhang et al., 2011). The test of prototypes in the early design stage is of help to gain rapid customer feedback which can be applied to fast-improvements of the conceptual design (Bacon et al., 1994; Clark & Fujimoto, 1991).

2.2) Strategy 7

: Activities

In order to develop the pragmatic-prescriptive type, all core activities required in the FFE should be formally structured within the model. Next, it is better for FFE activities to involve many different functional areas to support concurrent collaboration.

2.3) Strategy 8 and 9

: Performance Method and Toolkit

– Contextual Performance and Concurrent Collaboration

Many authors, including Achiche et al. (2013), Dewulf (2013), Ester and Daniel (2007), Jetter (2003), have stressed in-depth study of FFE toolkits. Toolkits need to be specific enough to enable performers to conduct the given task and activity with the minimum possible difficulty in terms of performance directions and methods (Sandmeier et al., 2004). It is difficult for all performers participating in an NPD project to have a high degree of expertise in a particular domain (Dane & Pratt, 2007; Eling et al., 2014; Policastro, 1995). According to Archer (1969, 1984), Cross (1993) and van Aken (2005), detailed toolkits which indicate specific performance directions and mechanisms can reduce deviation in individual expertise and capabilities caused by their different education and levels of experience. It also helps enormously if toolkits can prevent performers from carrying out certain work in incorrect ways. Fortunately, many detailed toolkits for FFE performance have been devised so far. However, there are only a few toolkits developed from the contextual performance aspect. Nevertheless, they cover only one or two functions, e.g. devising the function and system structure or developing concepts. These tools also do not encompass the entire range of the FFE phase. Moreover, most of the previous toolkits were not devised with concurrent collaboration in mind. Although there are many tools which pursue collaboration, they are not physically and functionally equipped into the structure of toolkits. In this regard, development of a toolkit which can compensate for the above defects is required.

Firstly, toolkits should be developed from the contextual performance aspect. Bacon et al. (1994), Khurana and Rosenthal (1997), Rosenthal (1992) and Simms (2012) have also emphasised this kind of development direction to some degree in their studies. Toolkits should be systematically interlinked with each other, with consideration of the relationship between them. To be specific, outputs obtained from a previous tool should flow into the inputs of the following tool, to hinder the negative effects mentioned in the introduction chapter (*p. 23–25*). Therefore, in considering the contextual performance aspect, it can be a key consideration to understand both the overall and specific data flows between toolkits, i.e. where data come from and where it goes.

Secondly, toolkits developed from the contextual performance aspect should be realised from the concurrent collaboration aspect. The toolkits should be physically and functionally embodied for simultaneous collaboration. By detecting the points of contact between each toolkit and connecting them centrally, the structure for concurrent collaborative toolkits can be constructed. These points of contact can be detected by grasping which toolkits have the same purpose and what the inputs and outputs of each toolkit are. Concurrent collaborative toolkits can make up for deficiencies in organisations which have difficulties with “T-type”, “Double-T type” and “Triple-T type” “Multi knowledgeable” performers skilled in various NPD domains (Eling et al., 2014; Griffin et al., 2009; Kim & Wilemon, 2002; Iansiti, 1993; O’Connor & Rice, 2001; Park et al., 2009; Troy et al., 2001).

Thirdly, when toolkits are structured from above two aspects, they must consider whether they are appropriately formatted to process qualitative data over quantitative data. As mentioned before, FFE data tends to be qualitative data rather than quantitative (Jetter, 2003; Karsak, 2000). Hence, Achiche et al. (2013) and Lin and Chen (2004) argue that typical toolkits, which primarily use conventional quantitative techniques and mathematical and economic approaches, have limitations in their ability to manage data generated from the FFE phase. In this regard, the consideration of which format is more appropriate for handling values which are not numerical but textual and narrative in nature is needed to physicalise the form of the toolkits. Kim and Kim (2011) recommend the QFD and DSM types as the best formats for processing product-related information. However, many experts, e.g. Smith and Reinertsen (1991), noted that the format of the QFD and DSM type still has much room for the improvement since it has many limitations in its ability to manage qualitative data. A more acceptable format for handling qualitative data is thus needed.

Fourthly, when the structure of these toolkits is considered using the above three aspects, we should not overlook pursuit of both the explicitness and responsiveness characteristics. According to Cooper (1983) and van Aken (2005), toolkits should be detailed enough to provide useful instructive action guides for implementers. However, it should at the same time not provide too many rules and regulations which can hinder creative performance in those implementers (Cooper, 1983; van Aken, 2005). Toolkits should explicitly give directions to handle NPD-related parameters, and it is better to leave room for selecting optional methods or techniques when using the given toolkits. To realise this suggestion, the study on 'Rational analysis approach' and 'Use of intuition' conducted by Eling et al. (2014) can be utilised. The toolkit development strategies established in this study has considered both: 1) how to enable performers to conduct their FFE performance in more scientific and rational ways; and 2) how to increase their creative behaviour by using intuition. The former can be made possible by not only developing toolkits for contextual performance and concurrent collaboration but also physical and functional structuring of those toolkits into model's overall architecture. The latter can be feasible by leaving room for selecting options when executing those toolkits. For instance, a particular toolkit is robustly structured with a systematic process for idea generation, while detailed skills involved in ideation performance, e.g. brainstorming, six-hats, SCAMPER, etc., are left to the discretion of the performers concerned.

Lastly, we need to determine how to structuralise these toolkits into the FFE model. This relates to building a model of the procedural type with performative-type sub-structures (Strategy 5). Sub-structures can consist of those toolkits whose type can accelerate performance, while the overall structure (the fundamental architecture of the whole model) can have a phased form. This means that toolkits are not just 'Suggested With' the model, but those are 'Incorporated Into' the model itself, as integral components. Even if a toolkit is appropriately structured from the contextual performance and concurrent collaboration aspect, if they are not well-harmonised with the given model, those toolkits will be still lacking from the performance structure and its operating mechanism standpoint.

In the case of providing performance methods, a manual step-by-step instruction guide on how the toolkit is to be used can be resources for embodying toolkits. This does not so much require a specific structure for instructions and detailed methods to be integrated into the model, since it is expected that the format and structure of toolkits devised from the above four aspects can serve as intuitive guidance.

2.4 Chapter Conclusion

– Pragmatic-Prescriptive FFE Model Development Strategies

255 studies on the FFE have been examined. These were chosen via an eight-phase study selection process, using ten appraisal criteria. The main purpose of this review was to come up with new pragmatic-prescriptive FFE model development strategies by understanding the features of existing FFE models as well as, in general, to gain relevant knowledge-and-theories and to understand trends in FFE model development. Nine strategies divided into two dimensions and corresponding to the limitations of previous FFE models defined in Chapter One (Introduction, *pp. 17–27*) were built according to each appraisal criterion. *Table 2.4* shows a summary of these strategies.

Table 2.4 *Nine strategies for pragmatic-prescriptive FFE model development*

Dimension	#	Area	Strategy
The First Dimension: **Overall Attribute**	1	Model Type	A data-driven type can be created by augmenting information processing and knowledge accumulation.
	2	NPD Speed	An agile development can be realised by concentrating on quality of information processing capabilities.
	3	NPD Attribute	A model aims at balancing both incremental and radical NPDs can be developed through different arrangements of FFE activities in the front or back sections of the FFE.
	4	Model Characteristic	An overall characteristic can be designed based on explicitness in the pursuit of stable operations, e.g. phased and formalised process, while responsiveness can support the sub-structures in the pursuit of creative behaviour, e.g. a modular and spiral process. In addition, by leaving room for performers to select optional performance techniques (to foster creative behaviour) in each formalised performance structure (to control performance directions), the explicitness and responsiveness characteristics can be balanced.
	5	Model Structure	A model can be built with a procedural structure with performative-type sub-structures.
The Second Dimension:	6	Task	The six main FFE tasks are: an opportunity identification-screening, idea generation-screening, requirements list, mission-statement, conceptual design and prototyping.

FFE Performance Structure & Operating Mechanism	7	Activity	Essential FFE activities can involve diverse NPD-related functional domains.	
	8	Performance Method	Performance methods can serve as underlying resources for a physical and functional embodiment of toolkits.	
	9	Toolkit	9.1	Toolkits can be developed with consideration of the contextual performance and concurrent collaboration perspectives.
			9.2	Toolkits are more appropriated for dealing with qualitative (as opposed to quantitative) data.
			9.3	Toolkits using the above two considerations can be incorporated into the model structure.

It is noteworthy that such strategies do not exist independently but instead influence each other. This is beneficial for applying many variables and various aspects to new model development in a less complicated way. Namely, the strategies exert influence on the form of the cluster network (shown in *Figure 2.17*). We can expect a chain-reaction effect when embodying more than two strategies by executing a single strategy. Details are outlined below.

Firstly, the development of the data-driven FFE model can be related to an arrangement of the toolkits which considers contextual performance and concurrent collaboration in the performative structure. The arrangement wherein input and output parameters interlock with each other for contextual performance and concurrent collaboration can align with the mechanism of the data-driven model in which data is encoded and decoded in an information processing system. The parameters processed can also be in line with the information processing system in the data-driven model that pursues conversion of factual data into usable information.

Secondly, the data-driven type can help realise agile development by increasing efficiency in the quality of the data flow. Increased effectiveness in the quality of information flow can contribute significantly to reducing iterative works which are typically regarded as the inherent to the FFE phase.

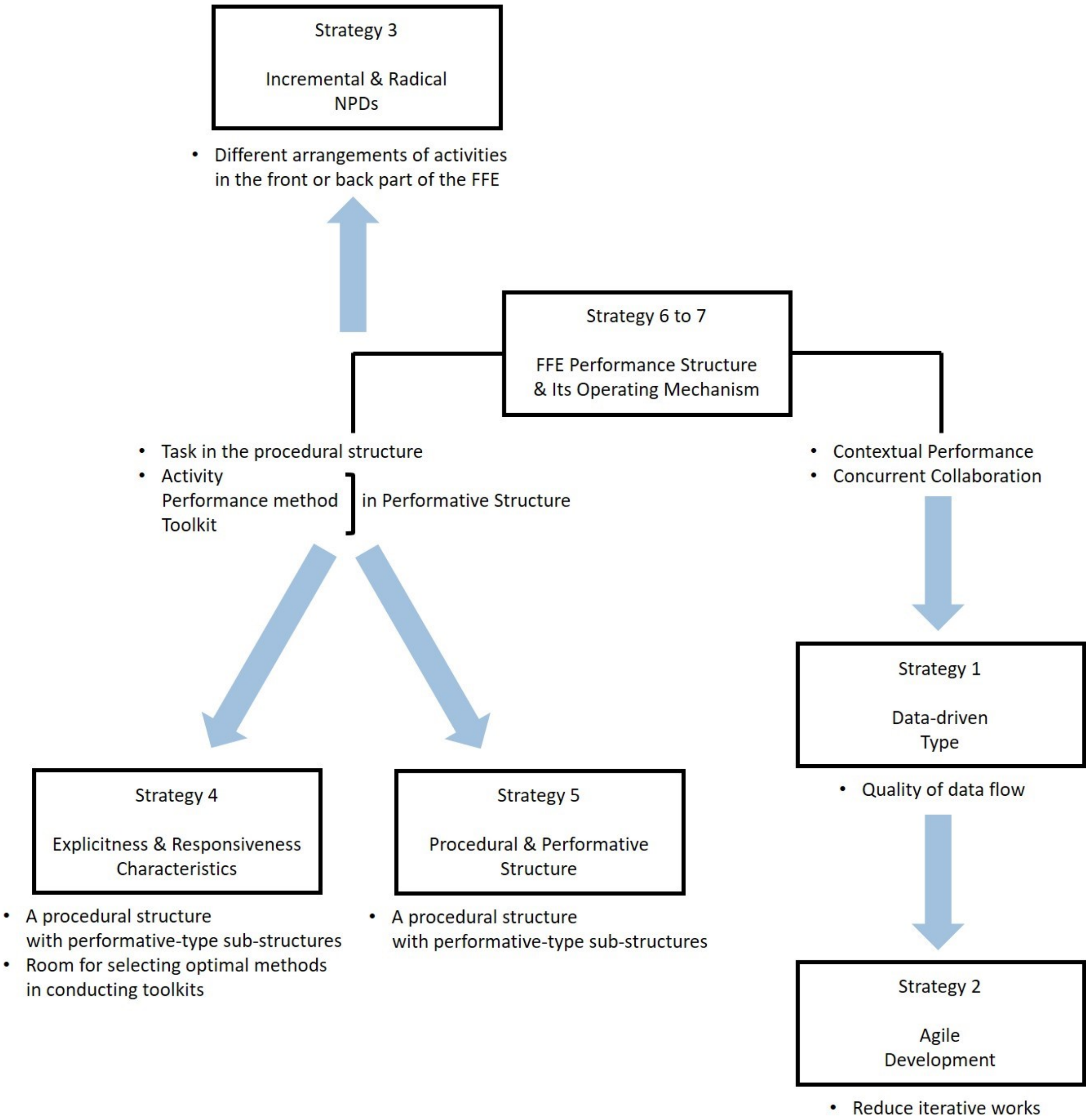


Figure 2.17. *Correlation of model development strategies*

Thirdly, hierarchical FFE units can have a strong interrelationship with model characteristics regarding the explicitness and responsiveness characteristics, as well as the division of the model structure into the procedural and performative types. The FFE units consist of 'Task', 'Activity', and 'Toolkit'. Tasks can be structured in a procedural manner to pursue explicitness, while activities (units which are subordinated to 'Tasks') and toolkits (support systems to perform those activities) can be structured in a performative manner to pursue responsiveness. Of these units, Toolkits arranged for contextual performance can provide a procedure for performing each toolkit, so that it can also contribute to building the procedural structure. Furthermore, the entire frame of each toolkit can be formalised to provide explicit performance directions and operating mechanisms from the viewpoint of the explicitness characteristic. On the other hand, responsiveness can be realised by providing discretion to select specific techniques when using each toolkit.

Lastly, the model type that targets both incremental and radical NPDs affects the placements of activities in the front or back part of the FFE phase.

We have defined the possibility of correlations between different model development strategies. Those correlations were not directly revealed in the analysis of the existing 255 FFE studies as factual correlations, but newly intended correlations established for application to the pragmatic-prescriptive FFE model.

Chapter 3. Research Methodology

3.1 Chapter Introduction

This chapter describes the research methodologies (shown in Figure 3.1) for both developing a pragmatic-prescriptive FFE model (which will be conducted Studies 2.1 and 2.2, fulfilling Objectives 2 and 3 respectively), and validating this in order to then generate a theoretical-descriptive model (which will be conducted in Studies 3.1 and 3.2, fulfilling Objectives 4 and 5 respectively).

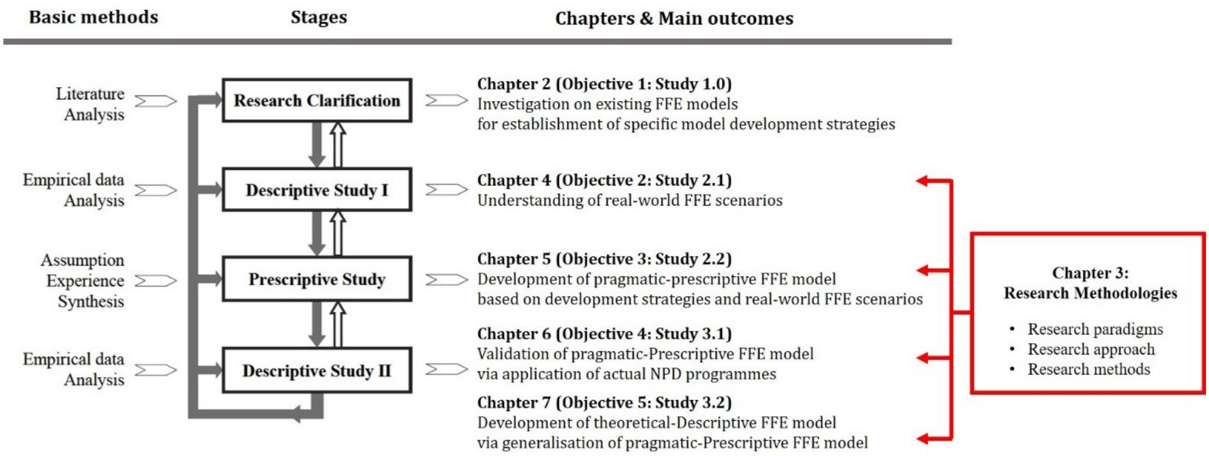


Figure 3.1. *Mini-map of study (own depiction, adapted from Blessing & Chakrabarti, 2009)*

Designing research methodologies involves an in-depth understanding of the 'Research Paradigms', 'Research Approaches' and 'Research Methods' which are appropriate for executing the objective (in this context, Objectives 2 to 5; Studies 2.1 to 3.2). It is important to consider the relationship between the research direction, the research paradigm (also known as 'Research Worldview' or 'Research Philosophy'), the research approach, and the research method (Best, 2011; Bryman, 2015; Collins, 2017; Creswell & Creswell, 2017; Gray, 2013; Punch, 2013; Saunders, 2011). Depending on the research direction, different research paradigms can be employed. Research paradigms are a philosophical classification of different ways of thinking[25] in terms of how humans can rationally and logically approach and solve problems and, contribute to or create knowledge. The worldviews play a crucial role in determining each research approach and method. A study that does not explicitly consider this interconnection may have flaws in that its premise could run counter to one of the underlying worldviews. It may result in the research going to different directions, and thus having difficulties in achieving research purposes.

In the following sections, an overview of the research paradigms, approaches and methods are first presented. Then, worldviews, approaches and methods suitable for 'Study 2.1', 'Study 2.2', 'Study 3.1' and 'Study 3.2' are discussed with their rationales. Additionally, in order to better outline the suitability of these methodologies, cases of inadequate and unsuitable methodologies are laid out.

[25] Guba (1990) defined this as "a basic set of belief[s] that guide[s] action".

3.2 Basic Understanding of Research Worldviews, Approaches and Methods

3.2.1 Research Worldview

Many experts, including Bryman (2015), Collins (2017), Gray (2013), Guba (1990) and Punch (2013), have classified research worldviews into several categories. Among them, the four most common are: 'Positivism', 'Constructivism'[26], 'Pragmatism', and 'Transformative'. While the latter – the transformative worldview – may be substituted for 'Realism' or 'Criticism', depending on the degree to which the author places significance on each research purpose and direction, the three former categories are commonly regarded as representative paradigms in building theories or models (Best, 2011; Creswell, 2013; Mackenzie & Knipe, 2006; Saunders, 2011). These three worldviews can be approached from the viewpoint of 'Ontology'; how a matter and its reality *exists*, and 'Epistemology'; how a matter and its reality are *perceived* (Creswell, 2013; Mertens, 2014). *Table 3.1,* generated from studies by Creswell (2003), Johnson and Onwuegbuzie (2004), Mertens (2014), Morgan (2007) and van Aken (2004), reviews the core concepts of these three philosophies.

[26] Stake (1995) argues that interpretivism is included under constructivism in the sense that a particular matter or phenomenon is reconstructed by individuals' different contextual interpretations, from a hermeneutic perspective.

Table 3.1. *Comprehensive review of positivism, constructivism and pragmatism*

Research Worldview	**Positivism**	**Constructivism /Interpretivism**	**Pragmatism**
Ontology: **Nature of reality or being**	. Realities exist as independent domains . Science is based on experiments and measurements . People as passive . Objective subject, not active object . Disavow the existence of Unexperimented entities . Perceptibility as a criterion for the existence from Humean's view of causality	. Realities exist in the form of contextual meanings and interpretations individually created . Science is based on phenomenological experiences and interpretations of them . People as active . Creative subject, not passive object . Deny the "natural attitude" of everyday life and become observers with intended consciousness . The taken-for-granted interpretive activity (*Lebenswelt*) from Heidegger and Schutz's view of phenomenology	. All-encompassing perspectives on realities . All-encompassing paradigms to find a workable solution; a middle ground between any longstanding philosophical dualisms about which agreement has not been historically forthcoming (sometimes including outright rejection)
Epistemology: **What constitutes acceptable knowledge**	. Objectivism Truth is a matter of the authenticity of an experiment and its factual results	. Subjectivism Truth is a matter of the authenticity of interpretation and its reconstruction	. Mixed perspectives Truth is a matter of the authenticity of approach to best answers to questions, focusing on problems, practices and relevance

- Own depiction, integrated from studies by Creswell (2003), Johnson and Onwuegbuzie (2004), Mertens (2014), Morgan (2007), Saunders (2011) and van Aken (2004)

From the viewpoint of ontology and epistemology, philosophical explanations of those worldviews tend to be abstract and difficult to understand, so some general examples are used here to illustrate them.

1) Positivism and Constructivism/Interpretivism

– Referenced from studies by

Best (2015), Creswell (2013), Mertens (2014), Saunders (2011) and van Aken (2014)

Positivism

The view of the positivists is that a matter and its reality are perceived objectively as an independent domain, which means that said matter has an objective meaning, and exists in and of itself. For instance, an apple is an apple, a fruit from the *Malus pumila* species of tree; this is true regardless of the time or place or how it is cultivated. Apples in the UK, US, South Korea, Japan or indeed any other country are all regarded as apples, provided they have been demonstrated to have the same characteristics which qualify them as apples (for example to exclude fruits which may resemble apples but in fact are not). As shown in this example, positivism is a grounded worldview used primarily to generalise a theory and model as a sort of 'law', through some means of verification, usually experimentation. However, this is not to say that this worldview is unsuitable for generating new theories or models. Rather, it is simply better suited to verifying ones that already exist, and as such, is mainly used in the natural sciences.

Constructivism/Interpretivism

On the other hand, the perspective of the constructivists (which includes interpretivists) is that a matter and its reality are constructed differently by different interpretations of individuals in different contexts. For example, to continue with the apple analogy, apples cultivated in different conditions (for example, different locations, under different temperatures and in different seasons) are all considered to be different apples, even if all of those apples do indeed belong to the *Malus pumila* species. Each apple is perceived and interpreted differently depending not just on the conditions but also depending on the perceivers and interpreters. This allows the matter to be reconstructed, creating new realities, e.g. a red apple cultivated in temperate latitudes or a green apple grown in colder regions. Constructivism is thus a philosophy that creates new theories and models and specifies them through contextual interpretations. However, this does not imply that the paradigm is not proper for validating new theories or models. A study by van Aken

(2004) recommends validating not only whether a generalised theory and model is applicable to subspecialised domains but also how they can be specified in each domain. Therefore, constructivism is more suited to building new theories and models and specifying them, and can also be utilised in validating generalised theories and models for a specific application. As such, constructivism is primarily utilised in the applied sciences.

2) Pragmatism

– Referenced from studies
by Johnson and Onwuegbuzie (2004), Morgan (2007) and Saunders (2011)

The pragmatists focus on devising effective methods (actions or practices) to solve problems or achieve objectives. Pragmatism is a problem-based, objective-oriented or practice-centred worldview. In the process of finding workable solutions, concepts from positivism and constructivism are sometimes included, dualistic philosophies which, historically, have disagreed. However, sometimes, pragmatism rejects these two worldviews entirely.

Whereas pragmatism has advantages in accomplishing goals effectively given its objective-oriented mindset, there are also a number of weaknesses. First of all, basic research tends to be neglected in favour of applied research since the latter can more promptly result in pragmatic outcomes. Second, pragmatism has a tendency to foster incremental innovation rather than more fundamental, radical and revolutionary innovation. Third, according to philosophers of the transformative worldview, the utility of solutions created by pragmatists are highly reliant upon individuals' abilities to view and gain insight into problems and objectives. Personal judgement on such utility can be ambiguous if there are no explicit appraisal criteria. Lastly, from a strict point of view, pragmatists tend to not much care about developing logical thinking, they want a solution (research method) to achieve goals (research outcomes), does not matter how they get there. For these reasons, many philosophers eschew this paradigm in certain domains even if it has worked comparatively well.

3) Positivism, Constructivism/Interpretivism and Pragmatism

Each research paradigm described above has strengths and weaknesses, the result of different rationales and approaches by which to solve problems and additionally, whether they contribute to or create theories and knowledge. Hence, each paradigm is in itself a criticism of the others. Positivists question whether theories built under constructivism can be accepted as universal knowledge. Conversely, if a certain theory has limits on its applicability in different contexts, constructivists raise objection as to whether such a theory can be indeed said to be universal knowledge. Meanwhile, pragmatists argue that the most rational way of thinking is to fundamentally perceive what the problem to be tackled is first and then concentrate on finding a solution. They argue that this is the most suitable way of producing an optimal theory. In response, positivists and constructivists believe that the pragmatists' method may be prone to logical error, especially if the method relies heavily on individual judgement. The result is a set of mutually exclusive theorems that undermine each other, and the 'logical' conclusion is that none of these are correct.

However, in research seeking to build a specific model or theory based on contextual interpretations with subjective perceptions on certain phenomena, constructivism is nevertheless regarded as an appropriate research paradigm. On the other hand, in research seeking to generate a conceptual model and theory based on factual results with objective perceptions, positivism is considered the most reasonable. Lastly, in research seeking to find a particular model or theory as the most rational method or solution to a given research problem, pragmatism may be most acceptable as a research worldview.

3.2.2 Research Approach

This section illustrates a fundamental understanding of reasonable research approaches for different research paradigms. *Table 3.2* outlines the relationship between the paradigms and approaches.

Table 3.2. *Research approaches for different worldviews*

Research Worldview	**Positivism**	**Constructivism /Interpretivism**	**Pragmatism**
Research Approach	. Deductive approach 1) Based on previous knowledge/theories, hypothetical and theoretical theories or models are established 2) Validate them 3) Generalise them	. Inductive approach 1) Understanding previous knowledge/theories 2) Collect and analyse real world phenomena or practices 3) Develop new theory or model	. Approach following research problem and question, focusing on practical solutions and outcomes
	. Mainly quantitative data - Large samples - Measurement - A range of data can be numerically analysed (statistical analysis)	. Mainly qualitative data - Small samples - In-depth investigation - A range of data can be hermeneutically interpreted (text analysis)	. Mix of quantitative & qualitative data
Feature	. More appropriate for robust theory building	. More appropriate for creative theory building	. Mixed features

- Own depiction, integrated from studies by Best (2015), Creswell (2003), Mackenzie & Knipe (2006), Mertens (2005) and Saunders (2011)

1) Deductive Approach mainly involving quantitative data

Inductive Approach mainly involving qualitative data

Mixed Approaches

– Referenced from studies by Creswell (2013), Johnson and Onwuegbuzie (2004), Mackenzie & Knipe (2006), Mertens (2014) and Saunders (2011)

Deductive Reasoning

Deductive reasoning is typically more appropriate for research under the positivist paradigm. Research using deductive reasoning generally progresses as follows:

1) Bsed on existing knowledge and theories in the literature, a hypothetical theory or model is built

2) The theory or model is verified iteratively, with many, quantifiable data points

3) If the outcomes of the validation are satisfactory, the theory or model can be generalised as law-like.

The generalisation of particular theories and models through validation with large quantities of numerical data closely matches with the underlying belief of positivism in which a matter and its reality are recognised objectively, such that said reality can be generalised with sufficient data.

Thus, in general, the deductive reasoning approach typically involves a large quantity of measurable information[27] and interpreting that information statistically to increase objectivity, which supports generalisation. Quantitative data is precise and objective, and thus is appropriate for robustly testing and/or demonstrating the particulars of a theory or model. Despite this robustness, quantitative data can sometimes be too abstract when

[27] This does not mean that deductive reasoning or the positivism paradigm cannot involve qualitative data. Under the positivist paradigm, there are many research cases in which text data is utilised. One of the representative positivists, Yin, recommends using a coding scheme development method for analysing qualitative data under the positivism worldview (Yin, 1981, 2011, 2013; Yazan, 2015). The method is suitable for developing conceptual models closer to the generalised model by identifying common patterns revealed in those narrative data based on predefined codes (Vaismoradi et al., 2013).

devoid of qualitative descriptions or of explanations as to what the data represent. This may create difficulties for application in certain situations.

Inductive Reasoning

On the other hand, inductive reasoning is more appropriate for studies employing the constructivism worldview. A study approached using inductive reasoning would commonly proceed with the following steps:

1) Obtaining existing knowledge and theories from the literature which are related to the research aims, objectives and questions
2) Understanding real-world phenomena by carrying out qualitative data collection considering not only the attained knowledge and theories but also the research aims, objectives and questions
3) Developing a new theory and model.

This process better fits the grounded thoughts of constructivism where a matter and its reality are specified and reconstructed through contextual interpretations, so that a new reality can be created.

Thus, in general, the inductive reasoning approach involves mainly qualitative information[28] in the form of text, analysed using hermeneutics, which aids in developing a new theory and model based on contextual constructions and reconstructions of particular matters. Qualitative data can thus be useful to describe complex phenomena which occur in specific contexts, by conducting cross-case comparisons and interpretations. However, the obtained data can be easily influenced by the researcher's bias, which can lower credibility. This may lead to difficulties in verifying theories and models and in generalising them.

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[28] This does not mean that inductive reasoning under the constructivist paradigm cannot involve quantitative data. According to Vaismoradi et al. (2013), studies using inductive reasoning sometimes involve quantifiable data. The content analysis method however, which takes notice of the number of content repeats, is widely used on gathered qualitative information (Graneheim & Lundman, 2004; Hsieh & Shannon, 2005).

*** Content analysis can also be utilised by deductive reasoning under the positivism paradigm. Indeed, this analysis is frequently used more under the positivism to generalise certain phenomena. However, this method is sometimes used under constructivism as well to understand the contextual frequency of certain phenomenon.

Mixed Methods

In the case of the mixed method approach, both quantitative and qualitative data are involved, either separately or intertwined together in a single study, based on the significance of the two data types and what those types pursue. Namely, this approach is generally used when the research aims to understand multiple phenomena simultaneously, something which requires both contextual interpretation and quantification. This approach draws on the strengths of each data type and attempts to dispense with their weaknesses, to practically produce optimal outcomes.

Therefore, it is well-matched with the underlying philosophy of the pragmatism worldview. As an example, consider a study to understand the use of sustainable materials in consumer products. To grasp which kinds of sustainable materials are used and how often, a statistical analysis on quantifiable data gathered from a survey may be ideal. In addition, for apprehending how those materials are used in different sorts of products and in which parts, contextual interpretation using qualitative data can be useful. This would need to be undertaken alongside consideration of what is meant by sustainable and what factors relating to sustainable are relevant.

2) Circular Relation of Inductive and Deductive Approach

– Referenced from studies by Agouridas et al. (2007, 2008)

Circular Relationship

Inductive reasoning (which mainly involves qualitative data under constructivism) and the deductive approach (which mainly involves qualitative data under positivism) have a circular relationship. This relationship is rooted in the need to capitalise on the strengths and compensate for the weaknesses of each approach.

As shown in *Figure 3.2* below, in the initial revolution of the circle from the inductive to the deductive approach (shown in the upper part), a specific new model or theory is developed first through contextual interpretations and reconstructions of phenomena, in inductive reasoning. Then, in the following deductive reasoning process, the specified new model and theory (which is a hypothetical model or theory being verified), is generalised. In this circle, the defects of any model or theory developed under inductive reasoning, which will give a study comparatively lower validity, can be reinforced through verification in the subsequent deductive approach.

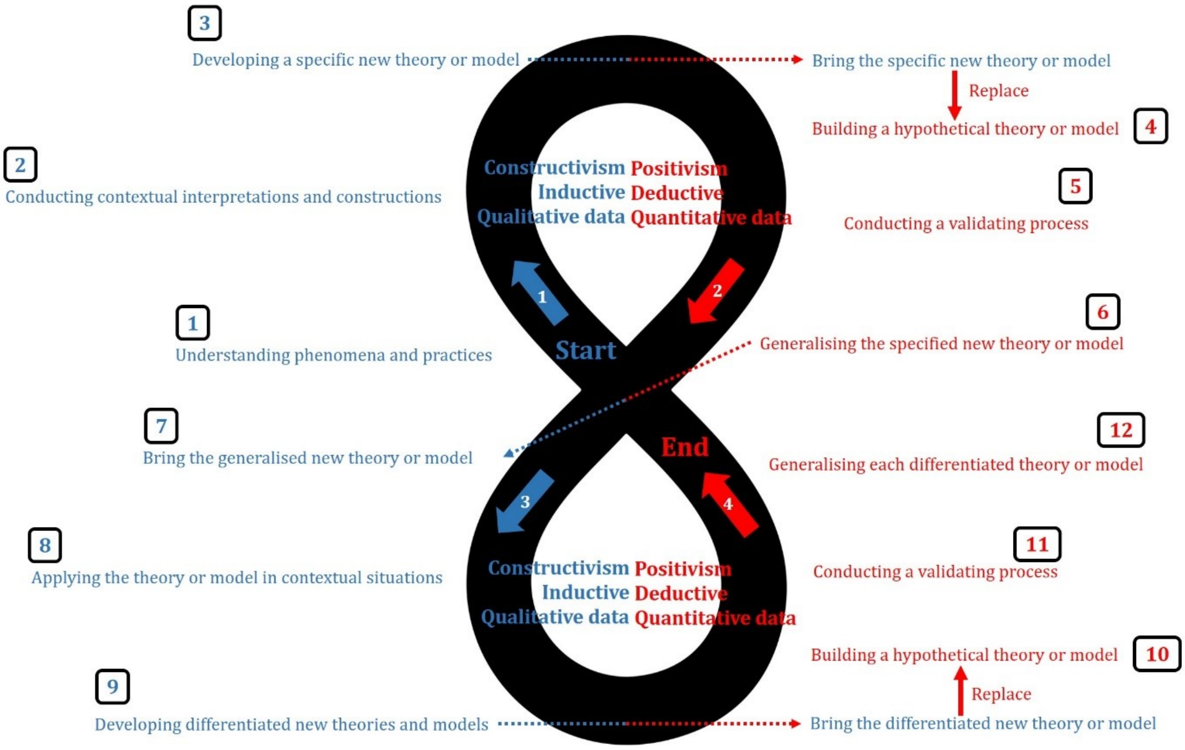


Figure 3.2. *The first circulatory relation of inductive and deductive reasoning*

In the following revolution of the circle from inductive back to deductive reasoning (shown in the bottom part of *Figure 3.2*), the previously generalised model or theory is differentiated into several specific models or theories by interpreting and reconstructing it for different contextual situations, in inductive reasoning. Then, with the following deductive reasoning process, each differentiated model or theory is validated to produce a generalised one. In this latter circle, the deficiencies regarding lower validity caused by the inductive reasoning process can be strengthened through the validation process in the subsequent deductive approach.

As shown in *Figure 3.3* below, in the first revolution of the circle from the deductive back to the inductive approach (shown in the upper part), a hypothetical model or theory is generalised first through the robust verification process in inductive reasoning. Then, the model or theory is differentiated by applying it to different contextual situations in the subsequent deductive process. In this circle, the limitations which the model or theory is generalised using the deductive reasoning offers the study which has a comparative inappropriateness in the application to contextual situations. This limitation can be reinforced using the following inductive reasoning process.

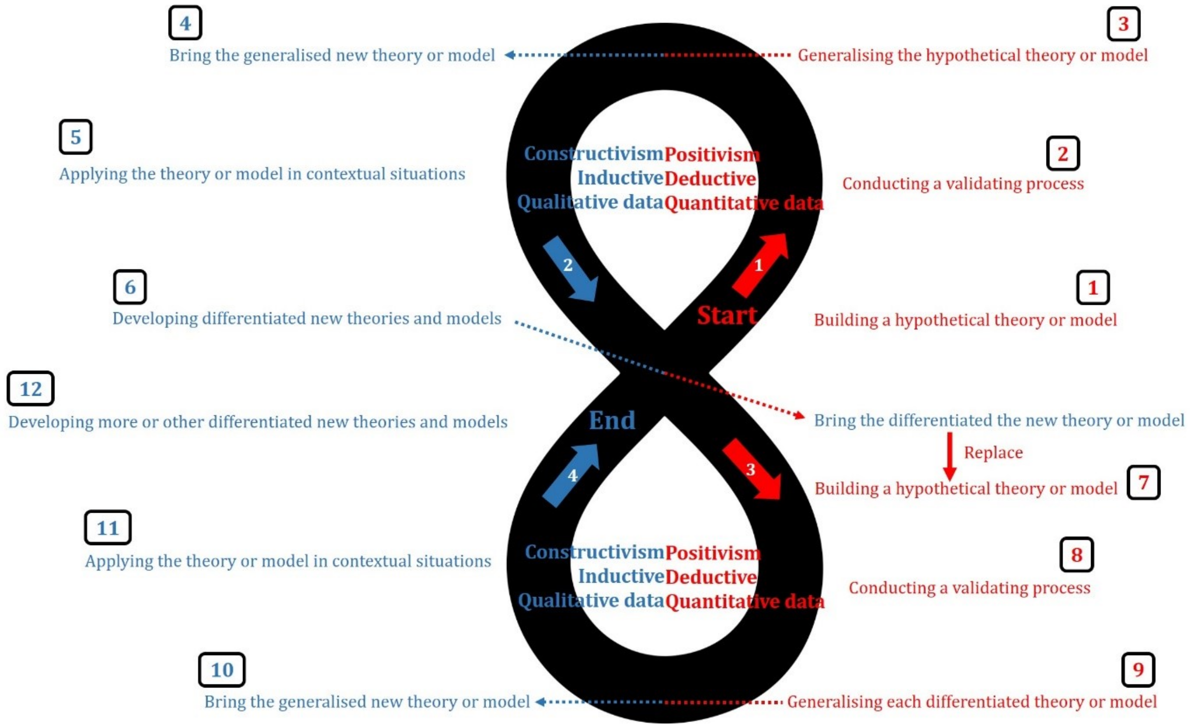


Figure 3.3. *The second circulatory relation of inductive and deductive reasoning*

In the latter revolution of the circle from the deductive to the inductive approach (shown in the bottom part of *Figure 3.3*), with the deductive approach, each differentiated model or theory is verified first, producing a generalised model or theory. Then, in the deductive process, each generalised model or theory is more or differently materialised by applying it to other contextual situations. In this latter circle, the shortcomings which the model or theory gained using deductive reasoning gives the study relatively low practicability in different situations. This low practicability can be improved using the following inductive reasoning process.

Consequently, as shown in the relationship between inductive and deductive reasoning, illustrated above, through the iterative process of circulation, studies can continue to be reinforced and optimised. Furthermore, this circular reasoning leads to the generation of all four types of core research outcomes recommended in academic investigations: 1) phenomena understanding, 2) new method development, 3) new applications, and 4) new theory generation.

Logical Fallacy

During this circular reasoning progress, researchers should be aware of the potential to fall into a logical fallacy in which an argument starts with what it is trying to end with (Dowden, 2003; Nolt et al., 1998; Walton, 2008).

For instance, in reasoning the location of Tanawan's house, suppose that an argument is that his house is to the right of Anouk's. If this is so, in reasoning the location of Anouk's house, what if the argument is that Anouk's house is to the left of Tanawan's? This is an example of the logical fallacy of circular reasoning. One of the methods to solve this logical error can be as follows: 1) The location of Tanawan's house is objectively identified in the deductive reasoning phase, e.g. 123 Main Street; and then 2) the contextual relationship of the location of Anouk's and Tanawan's houses determined in the inductive reasoning, e.g. Anouk's house is to the left of Tanawan's, and finally; 3) the specific location of Anouk's house can be inferred, e.g. 125 Main Street.

3.2.3 Research Method

Various research methods such as interviews, surveys, observations, and case studies are classified accordingly into each research paradigm and relevant approach (Best, 2011; Creswell, 2013; Mackenzie & Knipe, 2006). As shown in *Figure 3.4*, many experts, including Niglas (2001) and Saunders (2011), have devoted studies to this. The classification considers which research worldview and approach is more appropriate to both the nature and characteristics of each research method and their methods of execution. Broadly speaking, experiment-based methods mainly involving quantitative data are more adequate for positivism, while methods primarily involving qualitative data are more appropriate for constructivism.

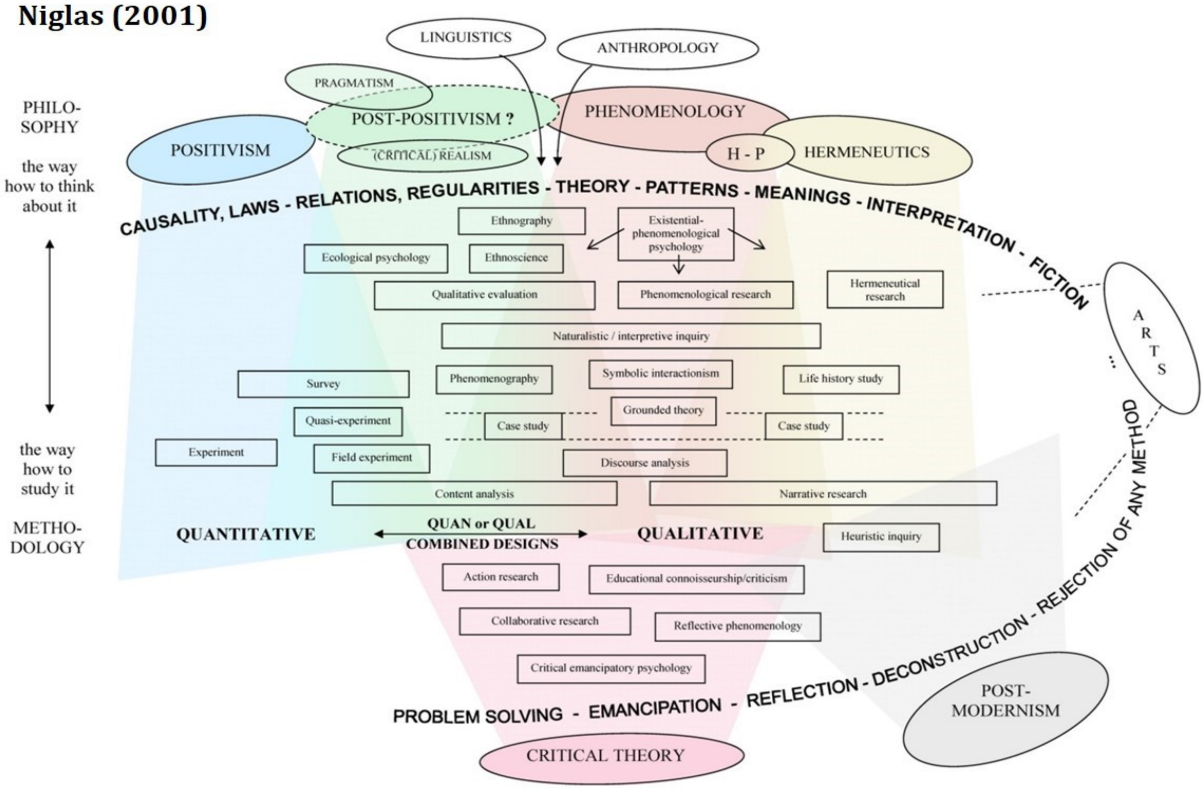
However, not all methods are explicitly divided in accordance with this standard. Although a questionnaire survey is not an experiment-based method, it is more closely matched with positivism in that the purpose of the method is to understand the general status of a particular matter or phenomenon and to generalise that understanding into a theory by analysing quantitative data.

Even within the same research method, worldviews can differ depending on the purpose and direction of the study at hand, and so methods of data collection and analysis can differ accordingly. This means that based on the nature and characteristics of each research method, if the method does not fit into a particular worldview, then the consequence, as well as the processes thereof, will diverge from what the research aimed to pursue originally.

For example, in the case study method, the collection of interview data and its analysis methods can be divided into three types according to the research paradigm (Baxter & Jack, 2008; Darke et al., 1998; Soy, 1996; Steenhuis & de Bruijn, 2006; Yazan, 2015), e.g. Yin's (Yin, 1981, 2011, 2013) under positivism, Stake's (Boblin et al., 2013; Stake, 1995, 2008, 2010, 2013) under constructivism, and Eisenhardt's (Eisenhardt, 1989; Eisenhardt & Graebner, 2007) in a point between Yin's and Stake's philosophies. Even though the aim of the study in this example is to build a specific theory by grasping a particular phenomenon using the interview method, if the phenomenon is analysed using Yin's positivist approach, the outcomes of the study will appear closer to a conceptual (or generalised) theory. In this case, it is more reasonable to use Stake's approach.

Thus, it is very important to employ suitable research methods for a given worldview and approach for best results.

Niglas (2001)



Saunders (2011)

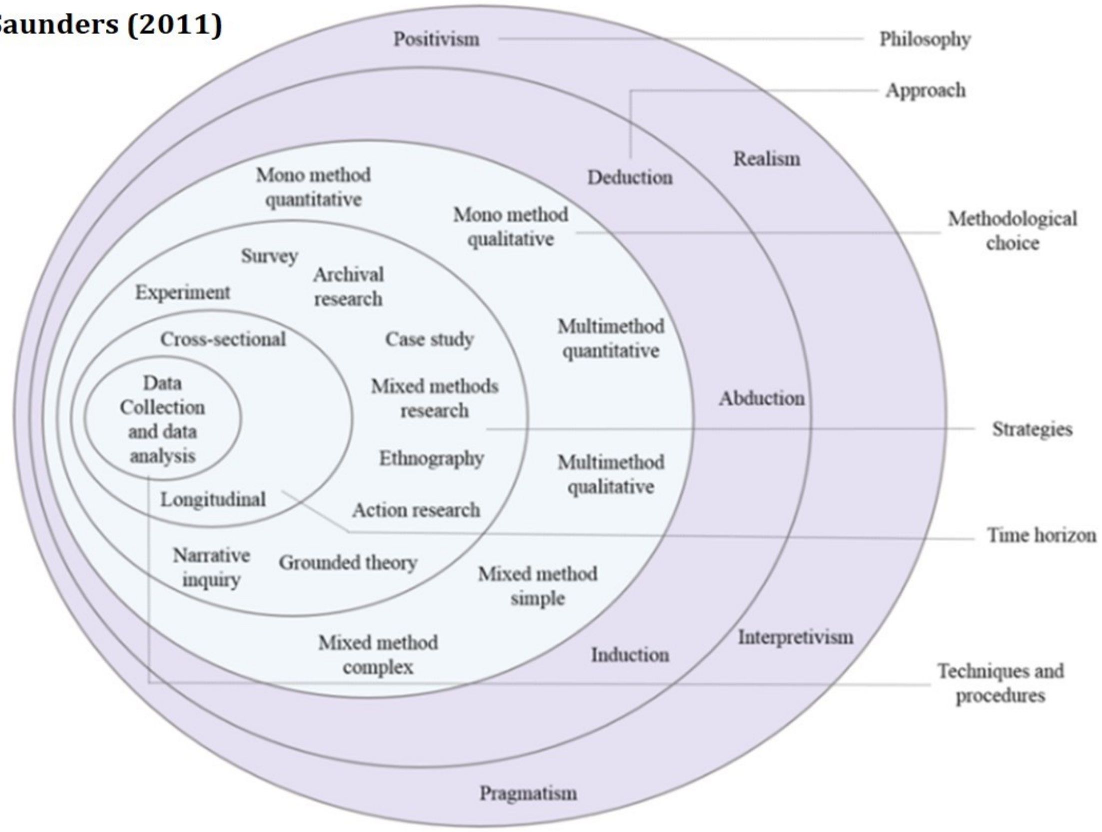


Figure 3.4. *Classification of research methods in research paradigms and approach*

3.2.4 Section Conclusion

Considering the relationship between different research worldviews, approaches and methods is important when designing the research methodology of one's own study. Looking at how humans rationally and logically solve problems and create knowledge, it is generally more suitable to conduct qualitative research using inductive reasoning and the constructivist worldview, or to implement quantitative research using deductive reasoning under the positivist worldview, not to mix and match.

However, this is not a strict law that we must follow. What we need to do is consider the research purpose, direction and questions. We often observe ourselves missing what we want to pursue ultimately in the research (referred to as the research purpose and direction) since we only consider the relationship between the research worldviews, approaches and methods. For example, even though the research is carried out using inductive reasoning to understand certain phenomena (which matches well with constructivism), if the research purpose is to develop a conceptual model that can be generalised, the methods of the positivists will be more adequate than those of the constructivist. On the other hand, if the research aim is to develop a more specified model, it is more appropriate to conduct the constructivist's method in the inductive reasoning, following the general rational relationship among research philosophy, approach and methods. Also, if the research questions are multi-dimensional in nature, mixed methods under the pragmatism worldview would be the most suitable way to proceed. Thus, we need to consider the interconnection between the research paradigm, approach and methods, but we should not overlook the research aims and objectives.

In the following two sections, the most appropriate research worldview, approach and the specific methods are presented in detail, to fulfil the purposes of Study 2.1 and 2.2 (Objective 2 and 3) and Study 3.1 and 3.2 (Objective 4 and 5).

3.3 Research Methodologies for Studies 2.1 and 2.2

1) Appropriate Research Methodology

This section illustrates the appropriate research worldview, approach and specific methods for Studies 2.1 and Study 2.2, based on an understanding of their relationship detailed in the previous section. *Figure 3.5* depicts the overall research methodology for those two studies.

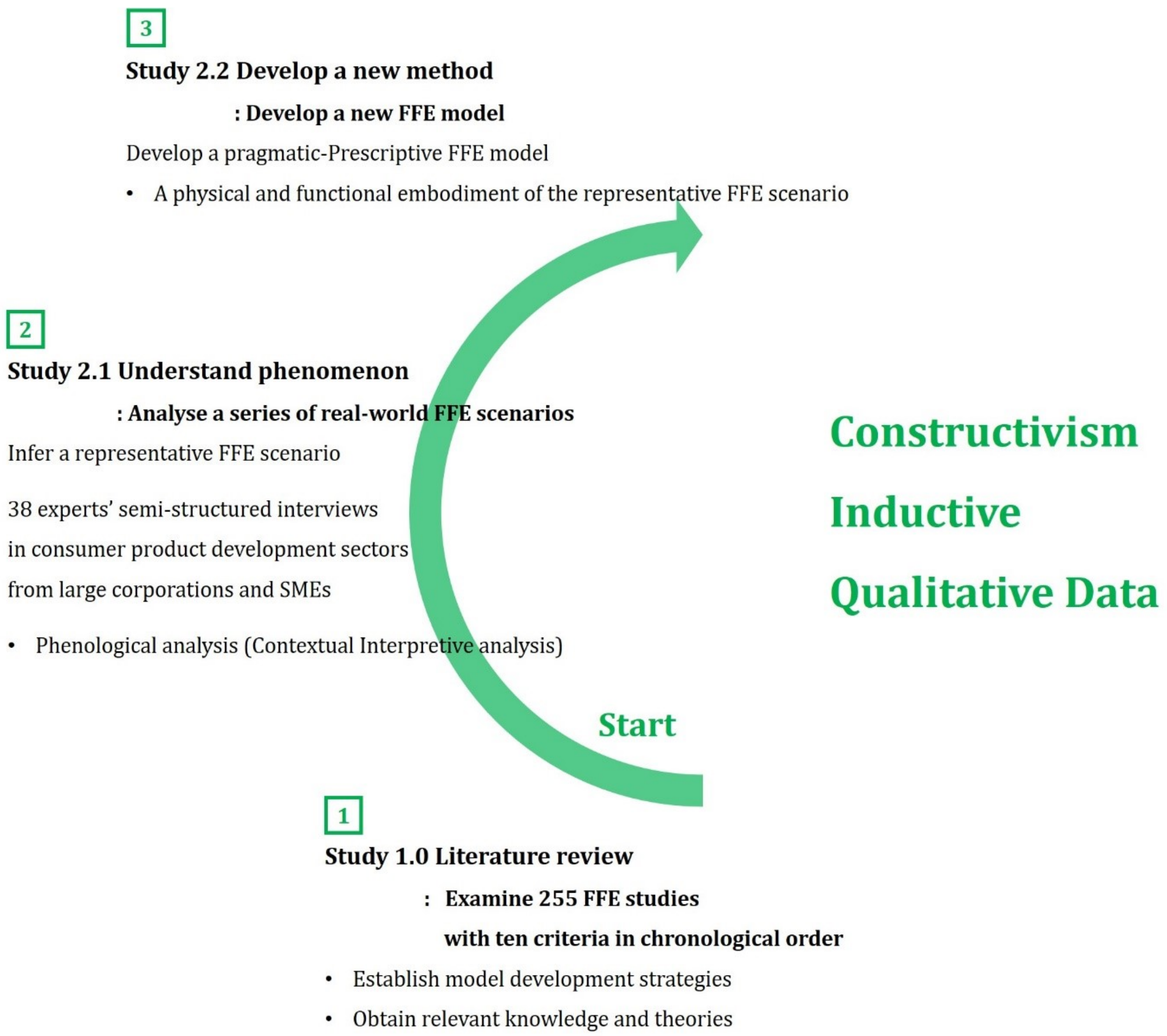


Figure 3.5. *An overall research methodology for Study 2.1 and Study 2.2*

The main purpose of Studies 2.1 and 2.2 is to analyse real-world FFE practices collected from NPD industries and to develop a pragmatic-prescriptive FFE model based on said analysis.

This means building a specified model based on understanding and contextual interpretation of real-world phenomena. The aims and research directions of Studies 2.1 and 2.2 are the same as the reasoning behind the inductive approach and the constructivists' research worldview.

When collecting and analysing information to contextually understand and reconstruct FFE practices, qualitative data in the form of narrative texts or conversations is more adequate to generate applicable and specified FFE practices which will be converted into a specific model structure.

Thus, in executing Studies 2.1 and 2.2 using the inductive approach under the constructivism/interpretivism worldview, real-world FFE scenarios were gathered and contextually interpreted and reconstructed using qualitative data sets obtained from 38 expert interviewees from large corporations and SMEs in various consumer product development sectors, which led to the development of a pragmatic-prescriptive FFE model structured with specific forms of FFE tasks, activities, performance methods, and toolkits.

More details of research methods, regarding how to collect and analyse data, are described in each chapter introduction section of Chapter Four (*Study 2.1, pp. 132-149*) and Chapter Five (*Study 2.2, pp. 267-277*).

2) Inappropriate Research Methodology

Suppose that Studies 2.1 and 2.2 used quantitative data analysis, approached using deductive reasoning with a positivist worldview. The outlined research progress is depicted in *Figure 3.6*.

First, the development directions and a theoretical FFE framework for those directions are built based on an understanding of the FFE through literature review. The framework is conceptually structured with the FFE tasks frequently highlighted in previous FFE studies as well as additional envisaged tasks.

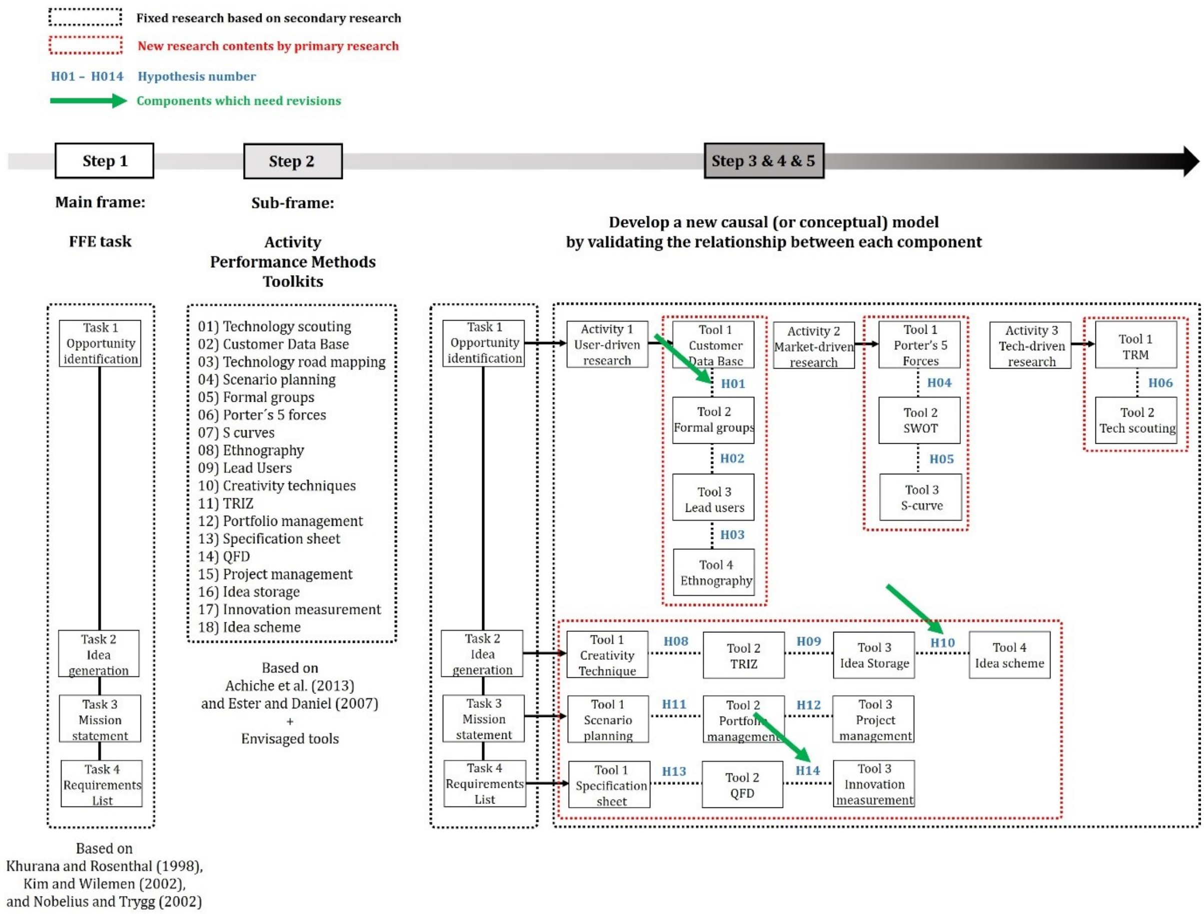


Figure 3.6. *Inappropriate research methodology for Studies 2.1 and 2.2*

Secondly, FFE activities subordinated to those tasks are identified along with their performance methods and relevant toolkits, in the literature review. This work also involves potential activities, and their performance methods and toolkits which can be envisaged from an understanding of the FFE in general. All of these are integrated into the theoretical framework, to create a hypothetical FFE framework.

Thirdly, hypotheses are established for validation for said framework. In each hypothesis, relevant questions for dependent and independent variables are set up to be answered via a questionnaire survey.

Then, iterative case studies to validate the hypothetical framework are conducted alongside the questionnaire survey. A statistical analysis was conducted on the survey data, such as a correlation or causal relationship analysis to grasp not whether the hypotheses are true or false.

After that, based on results of the analysis, the hypothetical framework is rebuilt, marinating components whose correlations/causal relationship are validated as true propositions and revising/removing components whose correlations/causal relationships were found to be false. The modified framework constitutes the final model.

As implied from the description, there are deficiencies in terms of developing the pragmatic-prescriptive FFE model, listed in detail below:

- Even though the envisaged FFE tasks, activities, performance methods and related-toolkits are involved in developing the theoretical framework, it is possible that the framework differs little from existing model as it is largely based on previous studies. This approach is consequently a factor that can hinder the production of a creative and innovative FFE model remarkably different from previous ones.[29] As shown in the findings of the literature review (*pp. 81–84*), adopting previous well-known toolkits may reveal deficiencies when applied to the new model development.

- It is highly possible that the physical and functional embodiment of the FFE performance structure and its operating mechanism from the contextual performance and concurrent collaboration perspectives has limitations. Even if the correlations and causal relationships between components of the framework can be understood from quantifiable data sets, its physical and functional embodiment for contextual performance and concurrent collaboration is not

[29] Of course, the degrees of difference between previous models and a new model can be judged differently depending on different viewpoints. Also, based on the degrees of change, we cannot judge whether the new model can generate contributions. What we would like to stress with the argument is that the model developed using deductive reasoning has fewer possibilities to generate a more creative and distinctive model than models approached using inductive reasoning.

sufficient if the embodiment does not involve contextual interpretations of real-world FFE practices: this means it is difficult to materialise the FFE model in terms of how inputs and outputs of each component are physically and functionally connected with each other.

- In the same context as above, it is possible that the physical and functional embodiment of the overall attributes also has limitations.
- Consequently, deductive reasoning-based research under a positivist paradigm for validating hypothetical FFE models using measurable data may be more appropriate for developing a theoretical-descriptive FFE model that defines the correlations and causal relationships between components that make up the model. This approach is not appropriate for developing the pragmatic-prescriptive FFE model in which the physical and functional FFE performance structures and its operating mechanisms are embodied.

3.4 Research Methodologies for Studies 3.1 and 3.2

1) Research Methodology

This section addresses an adequate research worldview, approach and detailed methods to Studies 3.1 and Study 3.2. The outlined research progress is depicted in *Figure 3.7*.

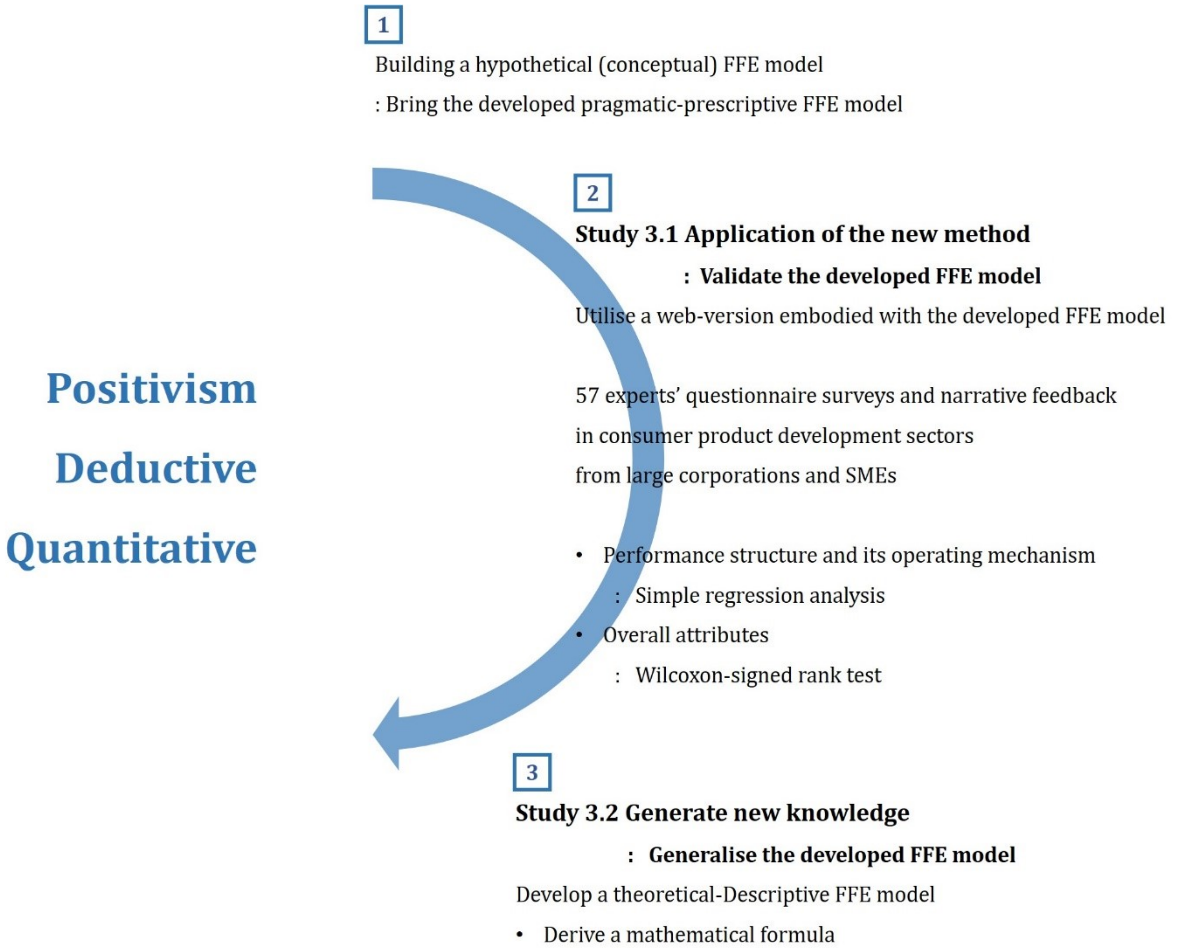


Figure 3.7. *An overall research methodology for Study 2.1 and Study 2.2*

The primary research goal of Study 3.1 is to validate the pragmatic-prescriptive FFE model developed in Study 2.2. Then, based on results of the validation, the model is generalised, producing a theoretical-descriptive FFE model in *Study 3.2*.

The study direction is well-matched to generalising the specified model by the verification involving measurable data analysis; it is aligned with the deductive reasoning process mainly involving quantitative data under the positivism paradigm.

Thus, in executing Studies 3.1 and 3.2 using the deductive approach under the positivism worldview, field-tests for an application of the pragmatic-prescriptive FFE model in actual NPD programmes, involving the questionnaire surveys and self-observational diaries of 57 expert participants, were conducted. The obtained quantifiable data were analysed using statistical methods, which led to the generation of a theoretical-descriptive FFE model based on the results of the field tests.

What we are now seeking to establish is that it is indeed difficult to produce the completely generalised model as a normative model, since the validation by the statistical analysis means it is literally based on probability. Moreover, producing the completely generalised model requires the involvement of a large number of data and a considerable amount of time. Thus, in Studies 3.1 and 3.2, we attempted to validate the pragmatic-prescriptive model to be of maximum reached to the generalised model.

More details about the research methods, regarding how to collect and analyse the quantifiable data, can be found in the chapter introduction sections of Chapter Six (*Study 3.1, pp. 348-369*) and Chapter Seven (*Study 3.2, pp. 435-436*).

2) Inappropriate Research Methodology

The validation method approached from an inductive reasoning approach under the constructivism paradigm is generally used when detailing and specifying a model generalised by deductive reasoning. The verification process is conducted by applying the model into various specific conditions or domains and confirming each of them. An action research method can be involved in this methodology, using interviews or observations as qualitative data research.

In this regard, if the pragmatic-prescriptive FFE model developed in this research is executed using this methodology involving the action research methods, it is quite probable that the model can be further specified again, rather than being validated. Furthermore, it will be significantly possible that the research falls into the logical fallacy in the circular reasoning, since sources of data and their contents gathered in this validation stage are considerably similar to the data collected in the development stage.

3.5 Chapter Conclusion
– Overall Research Methodology

This chapter has addressed research methodology based on the relationship among research worldviews, approaches and specific methods, according to research objectives and related-studies from 2.1 to 3.2.

Figure 3.8 illustrates how an overall research methodology follows a circular reasoning process sequentially consisting of inductive and deductive reasoning.

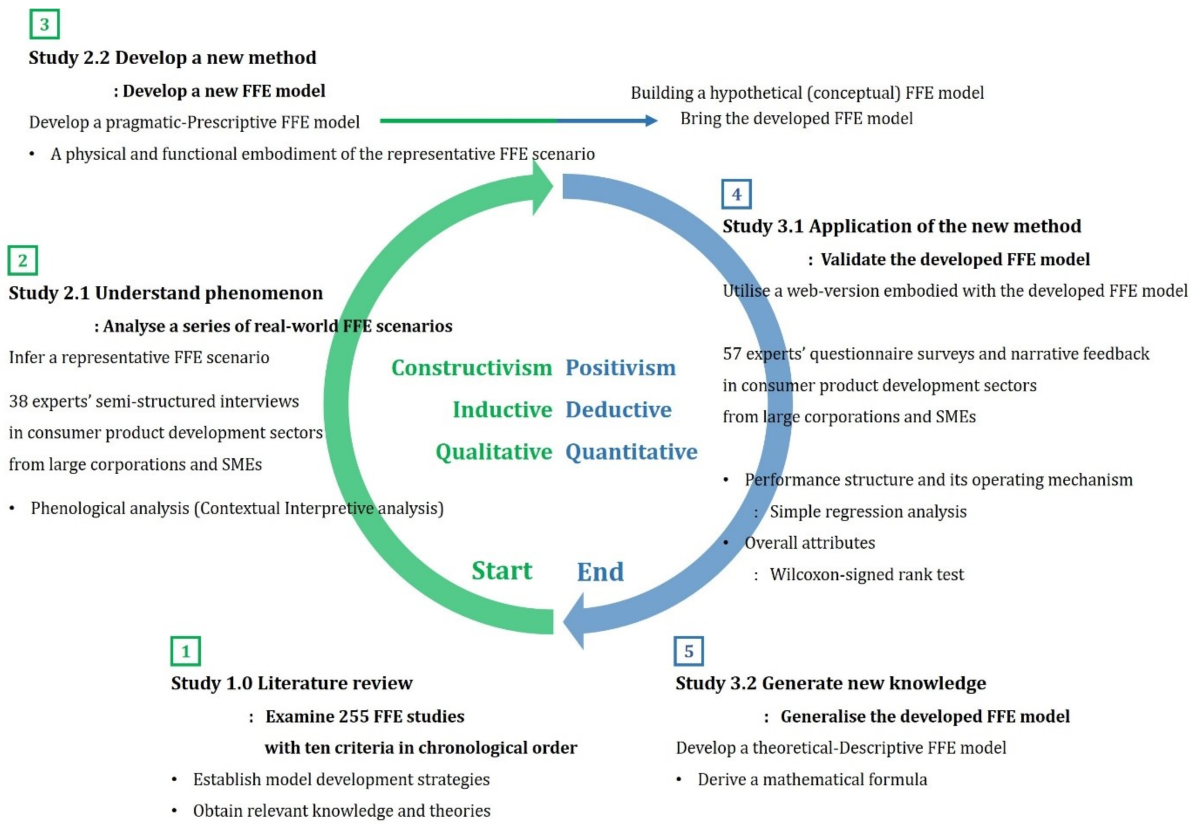


Figure 3.8. *Overall research methodology in circular reasoning*

In Studies 2.1 and 2.2, a pragmatic-prescriptive FFE model was developed, approached from inductive reasoning involving qualitative data under the constructivist worldview. The data was mainly gathered by interviews in a case study, with 38 experts in NPD domains. The interpretation of the qualitative data was utilised based on the contextual interpretive analysis method led by constructivists. The analysed data, along with knowledge-and-theories attained from the literature review (Study 1.0), were applied to the development of the pragmatic-prescriptive model, considering development strategies predefined in the literature review (Study 1.0).

In Studies 3.1 and 3.2, a theoretical-descriptive FFE model was devised, approached from the deductive reasoning involving quantitative data in the positivist paradigm. The data was primarily collected from 57 NPD experts by the questionnaire survey and self-observational dairy when they were conducting FFE projects on the given pragmatic-prescriptive FFE model. This quantitative data was analysed by statistical analysis methods. Based on the verification, the pragmatic-prescriptive model was generalised, producing a theoretical-descriptive FFE model comprised. However, we were not able to regard it as a completely generalised model based on the ultimate goal of the research approached from deductive reasoning under positivism. The reason is that the validation was based on statistical probabilities that are insufficient to generalise the model and on field tests that took place over a relatively short period of time (6 to 8 months). Therefore, we estimated a generalised theoretical-descriptive model based on our results.

Figure 3.9 describes an arrangement of research methods in the overall research structure of the DRM research framework (shown in Chapter One, Introduction, p. 36). This table helps to precisely understand which research methods are involved in Study 1.0 to 3.2.

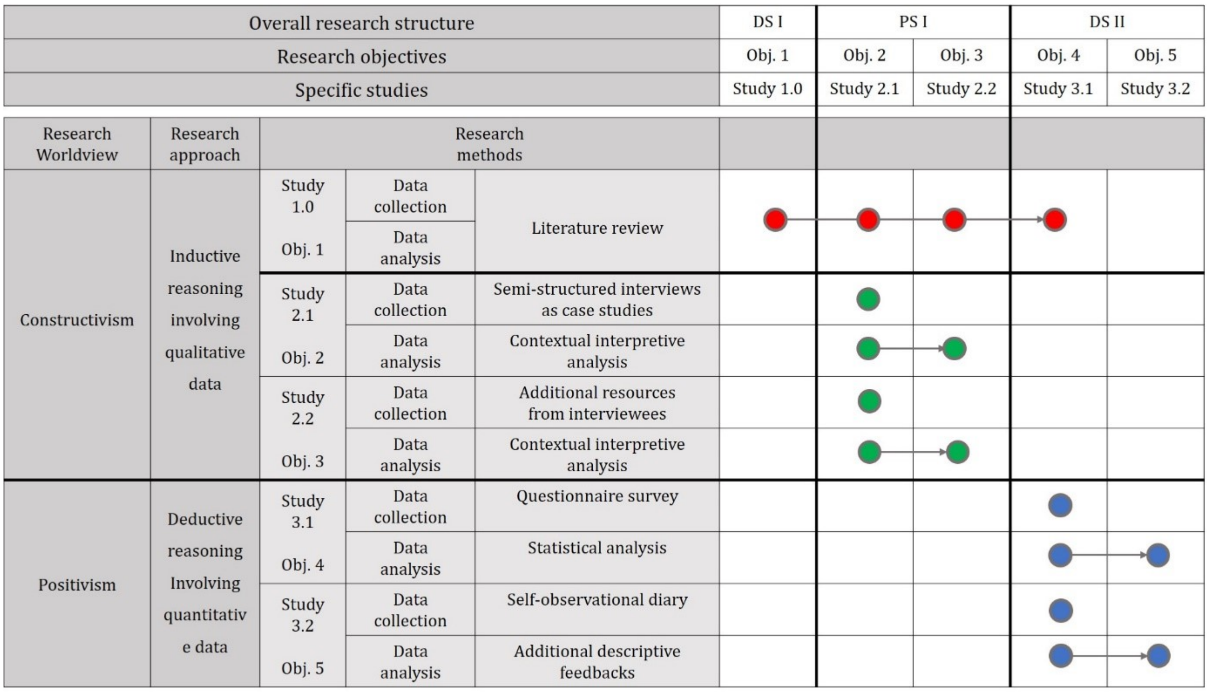


Figure 3.9 *Research methods in overall research structure (adopted from Blessing and Chakrabarti, 2009)*

Chapter 4. Study 2.1

– Real-world FFE Scenarios Analysis

4.1 Chapter Introduction

This chapter describes the progress and key findings of Study 2.1, which fulfils Objective 2 (shown in *Figure 4.1*).

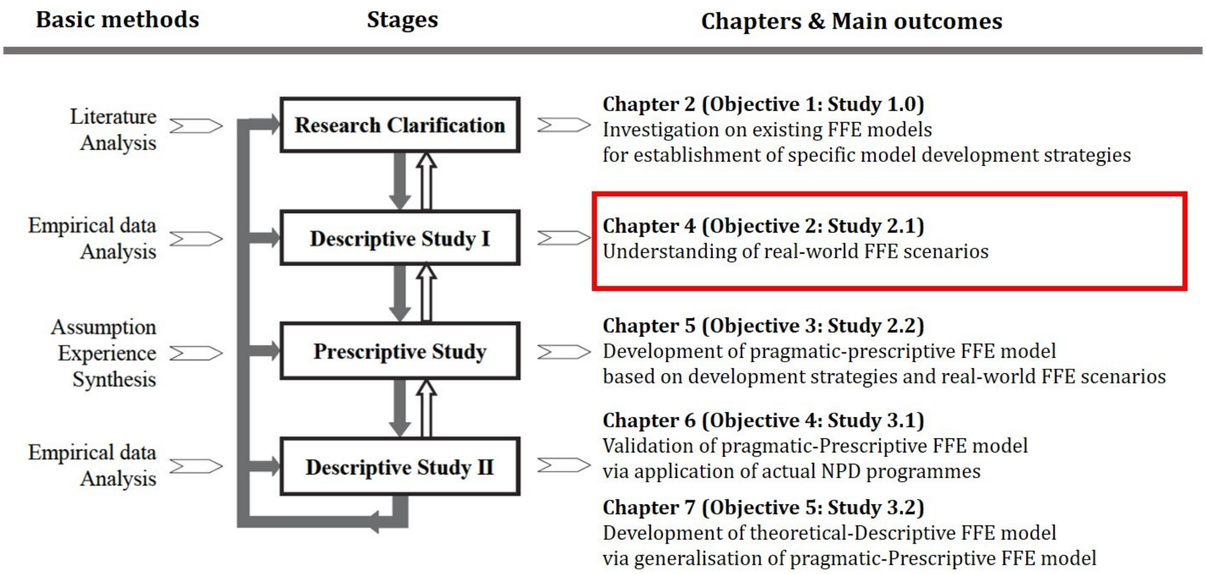


Figure 4.1 *Mini-map of Study 3.1 (Own depiction, adapted from Blessing & Chakrabarti, 2009)*

It begins by illustrating the research objective of the chapter, followed by the research method used to achieve said objective, before concluding with a short summary.

1) Research Objective
2) Research Method
3) Research Summary

4.1.1 Research Objective

The purpose of Study 2.1 is to fulfil Objective 2: analysing actual FFE practices in NPD industries to understand real-world FFE scenarios and ultimately infer a single representative FFE scenario. While the findings of Chapter Two (Literature Review) were theoretical in nature, aimed at building a pragmatic-prescriptive FFE model, this chapter addresses practical resources used to develop the model. The practical resources obtained from the analysis of real-world FFE scenarios are used to develop the pragmatic-prescriptive FFE model in the next chapter (Chapter Five, Study 2.2).

4.1.2 Research Method

1) Section Introduction

An outline of the research method for Study 2.1 conducted in this chapter is shown in the red block of *Figure 4.2*.

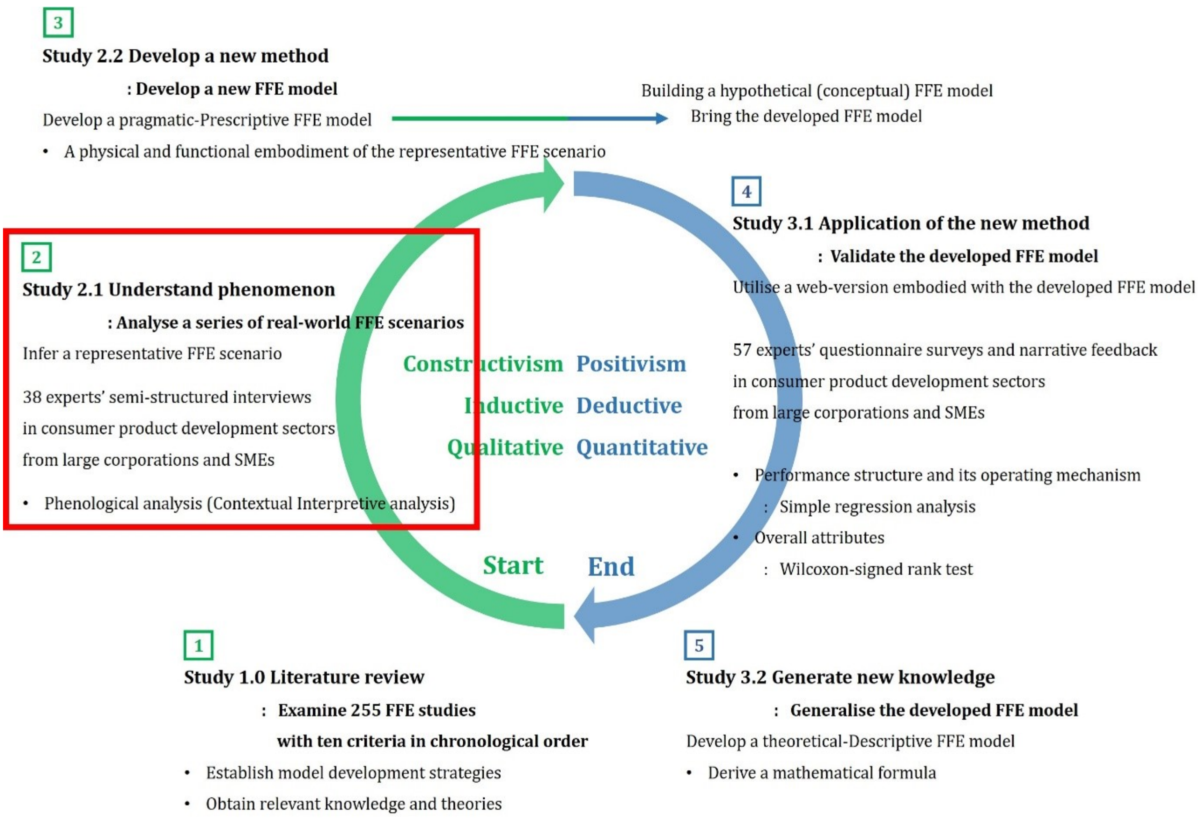


Figure 4.2. *Research method of Study 2.1*

Study 2.1 is dedicated to understanding actual FFE practices in order to produce a representative real-world FFE scenario. Fundamentally, the overall comprehensive direction of the research method was devised based upon qualitative data collection and analysis, approached from inductive reasoning under the constructivist research worldview.

More details on the research method can be found below, divided into the following sub-sections:

1) Overall Research Direction
2) Participants and FFE Practices Selection
3) Data Collection Method
    - Semi-structured Interview (Case Study)
4) Data Analysis Method
    - Phenomenological Analysis (Contextual Interpretive Analysis)

2) Overall Research Direction

The nine strategies which originated from the analysis of previous FFE models were establishing during the secondary research (Literature Review, *pp. 100-101*). Strategies 1 to 5 were related to the overall attributes regarding the current and future trends of FFE model improvement, while strategies 7 to 9 were associated with the FFE performance structure and its operating mechanism regarding contextual performance and concurrent collaboration.

Based on the strategies 7 to 9, a semi-structured interview was devised for the case studies, and qualitative data gathered from the case studies were analysed using a phenomenological analysis (contextual interpretive analysis) method.

Consequently, as shown in *Figure 4.3*, the analysis of the real-world FFE performance structure and its operating mechanism (regarding contextual performance and concurrent collaboration) from the case studies will be reflected in developing the pragmatic-prescriptive FFE model in Chapter Five (Study 2.2), by considering the ten strategies, including the overall attributes studied in the literature.

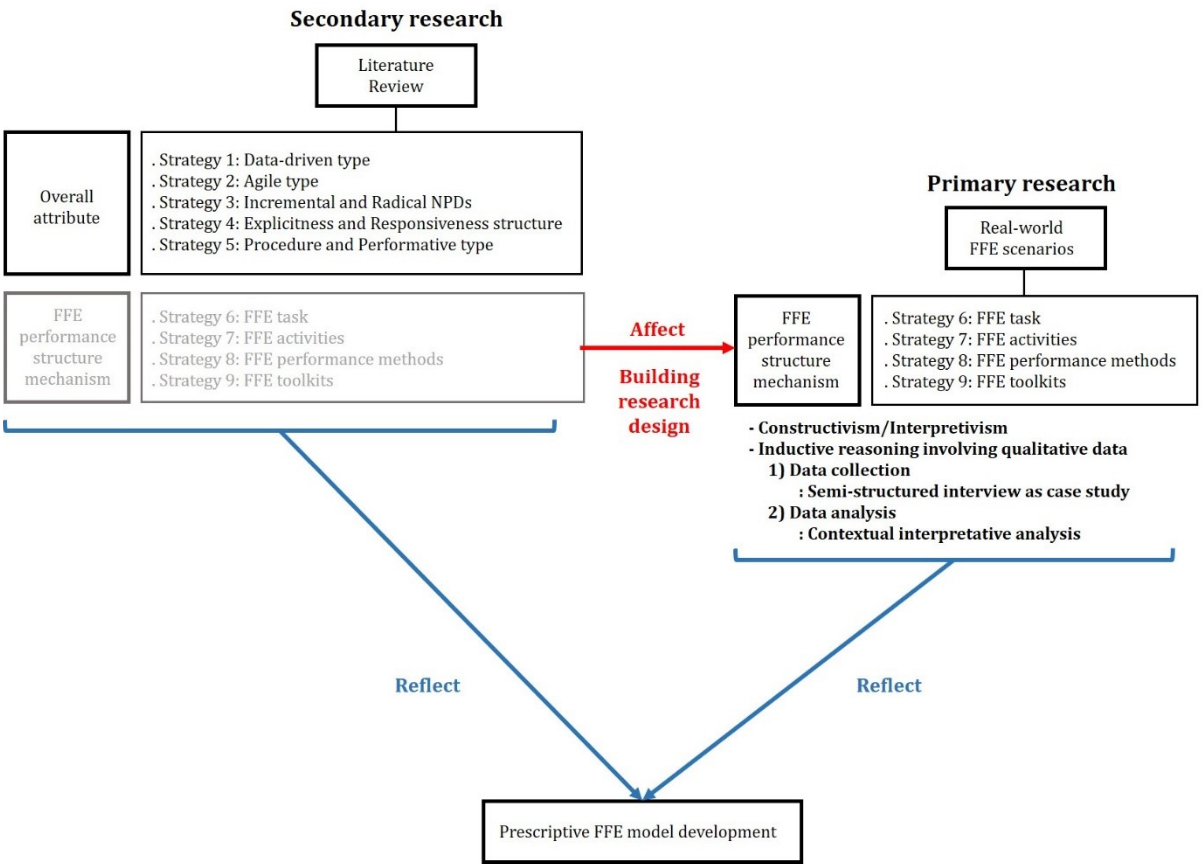


Figure 4.3. *Overall research direction for conducting Study 2.1*

Building Theory (Method/Model) from Case Study

The overall research direction is aligned with a view to building a theory (method/model) from case study research. In this approach, there are three main streams, one for each of the aforementioned research worldviews. The representative scholar in the first stream is Yin (1981, 2011, 2013), the positivist. Another expert is Stake (1995, 2008, 2010, 2013), a constructivist. The other is Eisenhardt (1989), whose view is between Yin's and Stake's, though slightly inclined towards Yin's (Steenhuis & de Bruijn, 2006). The method supported by Stake, who favours hermeneutic analysis under the constructivism paradigm, is more proper in this study: indeed, she is a master of pedagogy and in producing educational materials. This point is also in line with the development of the pragmatic-prescriptive model that provides specific performance structure and its operating mechanisms as explicit action guidelines.

3) Participants and FFE Practices Selection

The suitability of the interviewees can influence the degree to which information gathered on FFE practices satisfies the study's goals. Hence, the criteria for selecting participants for the case studies were rigidly established using a stakeholder model and persona analysis (Miles & Huberman, 1984, 2013, 2014)[30].

Based on these standards, the participants were required to describe their educational background and careers, including the roles and responsibilities they have in their past and current organisations. More than half of the participants had postgraduate qualifications, master's degrees or doctorates, in relevant NPD disciplines. All participants have worked for more than seven years and most were senior or head researchers, backgrounds which indicate expertise in a specific domain as well as experience in a multitude of functional areas. These functional areas were evenly distributed to domains majorly engaged in NPD projects such as engineering, industrial design, design engineering, manufacturing, R&D, marketing, product and strategic planning, product management, trend discovery, and so on: these areas, key areas in the FFE, were suggested by Khurana and Rosenthal (1998). Thus, most of the participants have in-depth knowledge on understanding and carrying out what doing design and running a business involve.

In total, 38 interviewees (contacted via email or telephone) were selected. Considering the research scope defined in the introduction chapter (*pp. 34–35*), these participants work in different countries including the UK, US, China, Japan and South Korea: 23 participants came from large corporations, 11 were chosen from SMEs (e.g. design specialty firms, NPD consultancies, etc.), while the remaining 4 were had a government background, coming from a single government organisation.

From them, around 50 FFE practices were gathered, regardless of whether the practices were deemed to be successful or not. The reason is that even failed FFE projects can provide useful resources when building a new FFE model.

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30 Miles and Huberman (1984, 2013, 2014) primarily tend to present research methods closer to Yin's and Eisenhardt's approach more under positivism. However, those worldviews do not highly affect the criteria for participants but do affect data types collected and the analysis methods used. We can thus use the method for selecting participants they describe in their studies.

4) Data Collection

: Semi-structured Interview as Case Study

4.1) Selection of the Data Collection Method

Of the various case study methods which Stake (2010) recommends, the interview method was selected. This method is useful for many purposes, in particular, for qualitative research (Stake, 2010). Its merits are in obtaining not only specific and unique but also a numerical accumulation of information from various participants. It also allows the interviewees to provide information related to particular situations where they hold, and the interviewer can interpret those data contextually. The final advantage is to gather testimony on the "thing[s]" or "phenomen[a]" which the researcher has not observed or experienced.

The interview themselves were largely semi-structured, though in some respects they did lean toward being unstructured.

Based on various strengths of the semi-structured interview studied by many experts (Arksey and Knight, 1999; Creswell, 2013; Miles at al., 1984, 2013, 2014), each interview question was sequentially divided into sections concerning the hierarchical FFE performance unit: 1) 'FFE task', 2) 'FFE activity' and 3) 'Performance method and 4) Toolkit', considering 'Top-down' approach (Best, 2011; Creswell, 2013; Sabatier, 1986). This structure is for maintaining not only the consistency of the interview direction but also to keep its purpose, of structurally understanding FFE performance structures and mechanisms, on track.

On the other hand, there were some unstructured aspects; questions were set up to enable participants to have more discretion in their answers. For instance, the main six FFE tasks predefined in the literature review were not explicitly conveyed to the interviewees. Instead, the questions left room for them to make up the FFE model more freely, e.g. "Please explain the tasks, activities, and their performance methods and toolkits, involved in the FFE phase, in as much detail as you are willing to give. The FFE phase can be regarded as covering the early design stage until the prototyping task."

Furthermore, the interview featured free communication between the interviewees and the researcher, a choice made based on the fact that the interviewees understood all of the prerequisite information, which includes a basic understanding of the FFE phase, its composition, definitions of terminology, the interview structure, the questions, and the manner in which it would proceed.

This kind of interview approach was more helpful to not only collect a wide range of FFE implementations undiscovered in the literature but also to grasp these implementations contextually constructed from the viewpoints of participants.

4.2) Progress of the Selected Methods

A number of pre-tests, using a method adopted from studies carried out by Miles, Huberman and Saldana (1984, 2013, 2014) were conducted with three participants to validate whether the developed interview structure and questions were reasonable.

The interviews would begin sometime after the research and interview information was provided to the participants for their review (usually 7 days). The interviews tended to last 30 to 60 minutes using the Microsoft Skype VoIP software, except in the case of a single participant who preferred a telephone call.

All conversations were recorded. After the interviews concluded, some of the participants provided the researcher with the training materials given to their employees or to other individually preferred resources, further useful resources by which to understand FFE practices. Kurkkio (2011) also recommends collecting documentary information, annual reports and any other materials as supplementary data when possible.

5) Data Analysis

: Phenomenological Analysis (Contextual Interpretive Analysis)

5.1) Selection of the Data Analysis Method

There are many qualitative analysis methods used widely in academic studies (King & Horrocks, 2010; Miles et al., 1984, 2013, 2014). As mentioned before (*pp. 118–119*), research methods are classified into each research paradigm according to their different natures and characteristics. The classification can differ in considering what the method can be suitable to the research aims and objectives.

Of the representative qualitative analysis methods – 'Ground theory', 'Thematic analysis', 'Content analysis', 'Conversation analysis', 'Discourse analysis [with 'Legitimation code theory' (LCT) in 'Systemic Functional Linguistics (SFL)'] and 'Phenomenological Analysis (PA)', the study 2.1 in this research used the last one to analysis real-world FFE scenarios. The reason why the five remaining methods are less appropriate to this study is presented first based on natures and characteristics of each method. Then, the selected method, the phenomenological analysis (contextual interpretive analysis), is addressed in detail.

a) Ground Theory and Thematic Analysis

Firstly, Eisenhardt's method (1989) in which 'Grounded Theory' consisting of three coding steps, 'Open coding', 'Axial coding' and 'Selective coding' (Glaser, 1999; Strauss & Corbin, 1990; Chiovitti & Piran, 2003; Salinger et al., 2008), and Yin's analysis method (2011, 2013) in which 'Thematic analysis' (Braun & Clarke, 2006) provides a methodical set of seven steps (Braun & Clarke, 2006; Judger, 2016; Vaismoradi et al., 2013) are generally used under positivism.

If the analysis is conducted using Yin and Eisenhardt's method to discover patterns which accord with a predefined coding scheme and then converting these patterns into the form of a model, it tends to miss content which may contribute to producing a more specific model. The reason is that if important and applicable content deviates from the defined codes, such content will not be included in those patterns, and thus will not be reflected in the final model. The method is highly influenced by the coding scheme. It is also quite possible that differently defined but otherwise similar content in the initial analysis step can lead to the same codes in the final step. Hence, each item of content included in the same code cannot be applied to the model development.

As a result, it is beneficial for developing a generalised conceptual model based on patterns identically revealed in interview scripts but it is not a reasonable method for developing the pragmatic-prescriptive model.

For example, a study conducted by Han (2014) aimed to develop a conceptual framework in terms of "Characteristics and abilities of design leaders communicating design to non-designers during the FFE of NPDs". *Figure 5.5* in his study shows a seven-step coding process which reduces the number of codes from 617 initial codes in the first step to 7 principle codes in the final step. Since similarly regarded content was grouped together in the coding process, the individual details of each piece of content were not reflected in detail in the final framework. Therefore, his outcome is more akin to a conceptual model consisting of seven elements, not suitable for a pragmatic-prescriptive type of model.[31]

b) Content Analysis

The second method, the content analysis (Vaismoradi et al., 2013), also utilised under positivism. The contents analysis method which takes notice of the number of content repeats (frequency of the repeated contents, as a percentage) is widely used in gathered qualitative information (Graneheim & Lundman, 2004; Hsieh & Shannon, 2005), and thereby this method is more suitable to understand how often certain phenomena occur, instead of grasping which kinds of phenomena occur and how those have the contextual relationship in different situations.

Therefore, finding quantifiable factors to see particular patterns and frequencies of the repeated contents in participants' responses in order to make generic conclusions by putting together all there is not an appropriate approach in developing the pragmatic-prescriptive FFE model. It is more acceptable to

[31] This is not a criticism of his work, merely a note of its differences. As shown in the research aims in his study, the research was primarily "to develop *a conceptual model* [emphasis added] of design leadership that illustrates the characteristics of design leaders and how they communicate design to non-designers at the FFE of NPD". Hence, his analysis method is well-selected, satisfying the aims along with the research objectives.

developing a kind of conceptual models which are mentioned before (shown in the study by Han (2014).

c) **Conversation Analysis and Discourse Analysis**

Thirdly, the following two methods, the conversation analysis (Hutchby & Wooffitt, 1998) and discourse analyses (Burman & Parker, 1993; Potter & Wetherell, 1987; Willig, 2003) are used by constructivists (Braun & Clarke, 2006).

The former is more appropriate for extracting connoted meanings from conversations, with consideration in the contextual relationship between the interviewer and interviewee(s), rather than focusing on the contextual relationship between contents in conversation.

The latter is more appropriate for analyses of the same script which can be differently interpreted depending on the historical, socio-cultural, environmental and political backdrop. Namely, the discourse analysis is more focusing on the contextual reflection of the backdrop in the analysis of scripts. One of the representative approaches, used in the discourse analysis, is 'Legitimation code theory' (LCT) studied by Martin and Maton (2017). The LCT developed by attempts of 'Systemic Functional Linguistics (SFL)' scholars (to extend and integrate Bernstein's code theory (Bernstein, 1995; 2000) to include a larger scope of phenomena) provides five 'Legitimation devices' (autonomy, density, specialisation, semantics and temporality; referred to as 'Principles;) assigned to five 'Legitimation codes' (referred to as 'Modalities'). These devices with codes can be constituents in analysing texts, from the viewpoint of linguistics. According to each constituent, what the phrase and clause imply from the historical, social, cultural and political point of view can be achieved. Thus, these two methods do not also seem to be adequate to this study.

Consequently, the two methods are not suitable for developing the pragmatic-prescriptive model in the NPD industry but they are appropriate for developing models in various disciplines of the social sciences, e.g. politics, history, and even organisational management.

d) Phenomenological Analysis (Contextual Interpretive Analysis)

Thus, aside all those methods mentioned previously, the study 2.1 used the 'Phenomenological Analysis' (PA) to understand real-world FFE scenarios.

The grounded thought of the phenomenological analysis method aligns with that of Stake's (1995, 2010, 2013, 2018) that is regarded as the most representative the qualitative, multiple-case studies approach concentrating on the nature of the phenomenological hermeneutic method, under constructivism. Stake's method which faithfully focuses on hermeneutical meanings, phrase by phrase, and clause by clause, in contents of an interview script is more appropriate for understanding FFE practices if the aim is to develop a 'pragmatic' and 'prescriptive' model. Analysis outcomes obtained from this approach are less likely to skip applicable data which are not highlighted by interviewees but cannot be regarded as trivial (e.g. in the product usage process examination, if only three among 20 participants suggest an examination of what users are doing before and after using the target product, this examination can be reflected in the pragmatic-prescriptive model structure). This method is of help when constructing complex information, by specifying such information systematically.

5.2) Progress of the Selected Methods – Phenomenological Analysis (Contextual Interpretive Analysis)

In Study 2.1, the phenomenological analysis (contextual interpretive analysis) method whose grounded thought is aligned with that of Stake's (1995, 2010, 2013, 2018) was chosen. However, Stake's contextual interpretive analytic method seems unstructured and unsystematic since there is less detail in its methods and fewer explicit steps in its processes. Thereby, other experts, including Boblin et al. (2013), Fontana and Frey (1994) [32], King and Horrocks (2010) and Yazan (2015), have devised a methodical process and instructions based on Stake's achievement. In one study (King & Horrocks, 2010) [33], a

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32 Fontana and Frey (1994) studied Stake's approach from an art of science perspective. Boblin et al. (2013) studied Stake's approach in "Qualitative case studies to explore implementations of evidence-based practice".

33 In their study, another method called "Interpretive Phenomenological Analysis (IPA)" was also introduced. However, they define the method as one which employs the system of thematic analysis more. Therefore, the method was regarded as not valid for this study.

method known as Phenomenological Analysis (PA) (Giorgi, 1985; Giorgi & Giorgi, 2008) is presented, with four steps: 1) reading through transcripts, 2) defining meaning units in detail, 3) transformation and 4) structural description. Based on their studies, a more elaborated contextual interpretive analytic process was devised, one that fits with the direction and purpose of this study. *Figure 4.3* depicts the overall process in flowchart format.

a) **Prerequisite Step (Step 0): Reading Through Transcripts**

Audio recordings of scripts are transcribed. Scripts in languages other than English were translated into English. Then, each script was read through to comprehensively understand the content.

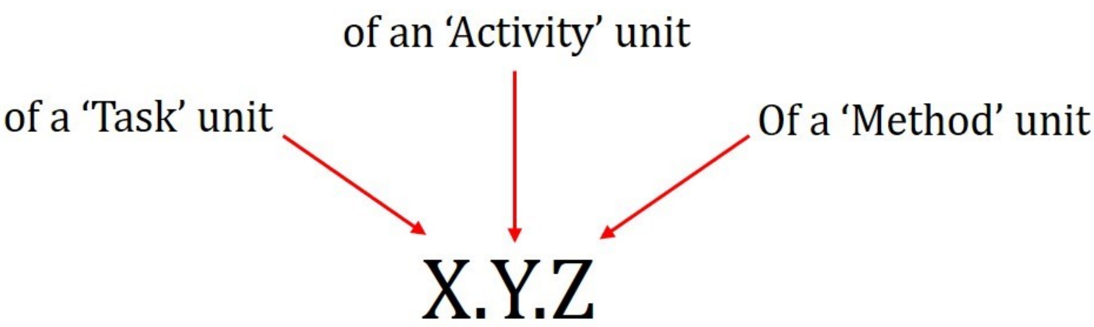
b) **Step 1: Defining Meaningful Units Detail**

Each script was contextually interpreted, phrase by phrase and clause by clause, under the interpretivism worldview. Each sentence was dismantled, classified into the four hierarchical FFE performance units: 'Task', 'Activity', 'Performance Method' and 'Toolkit'. The classified hierarchical units were assigned to three sub-units: 1) Meaningful Unit, 2) Contextual Classification Unit and 3) Contextual Connection Unit.

In this, labelling schemes using colours and numbers were required to explicitly define and categorise each unit.

In the case of the colour labelling scheme, those three sub-units – 'Meaningful Unit', 'Contextual Classification Unit', and 'Contextual Connection Unit' – were marked in 'Black', 'Red', and Blue', respectively.

In the number labelling scheme, the black labels for meaningful units had the scheme devised with a specific number order. As shown in *Figure 4.4*, the scheme is a combination of a number representing 'Task', 'Activity' and 'Performance method'. For example, 'Method 1.2.3' indicates the third performance method implemented in Activity 2 of Task 1; an interaction system analysis method in a user-driven research activity of the opportunity identification- screening task. In addition, there was a case in which the activities themselves play a major role as performance methods. In this case, even though relevant performance methods were identified in the script, those methods existed independently without relating to contextual performance and concurrent collaboration. Therefore, the scheme is a combination of two numbers representing 'Task' and 'Activity' only, and the performance methods are addressed without the appointed label numbers. For instance, the labelling number, 'Activity 6.1', means the first activity performed in Task 6; a soft-prototype design activity in the prototyping task (for example, an Iso Pink or foamboard manufacturing method can be utilised in the soft-prototype design activity depending upon the preferences of practitioners).



- X = number representing the performance order of 'Task' unit
- Y = number representing the performance order of 'Activity' unit
- Z = number representing the performance order of 'Method' unit

Example 1) Task 3

= A task performed in the third order in the FFE

= The third task

Example 2) Activity 2.4

= An activity performed in the forth order in a task performed in the second order

= The fourth activity in the second task (Task 2)

Example 3) Method 1.2.3

= A performance method implemented in the third order
in an activity performed in the second order of the first task

= The third performance method in the second activity of the first task

Figure 4.4. *Number labelling scheme in the phenomenological analysis method*

c) Step 2: Transformation

The deconstructed texts were aggregated, classified into the task, activity, performance method, and toolkit units: namely, meaningful units (marked with black labels) were classified into the FFE activity and performance method category, alongside units classified with red labels. Similar contents which can be regarded as nearly identical were grouped together. In the case of other content which did differ slightly, these were classified into differently specified groups to construct a much more specific FFE performance structure and mechanism.

Then, the classified units were linked together, considering contextual performance and concurrent collaboration as well as reflecting other model development strategies: namely, those units were connected with each other with blue labels for contextual performance and concurrent collaboration.

The left-hand side of *Figure 4.5* shows the analysis in terms of: 1) what the meaningful units are, shown in black, 2) how these are classified into the task, activity, performance method and toolkit units, shown in red, and 3) how each of them are interconnected in terms of contextual performance and concurrent collaboration, shown in blue.

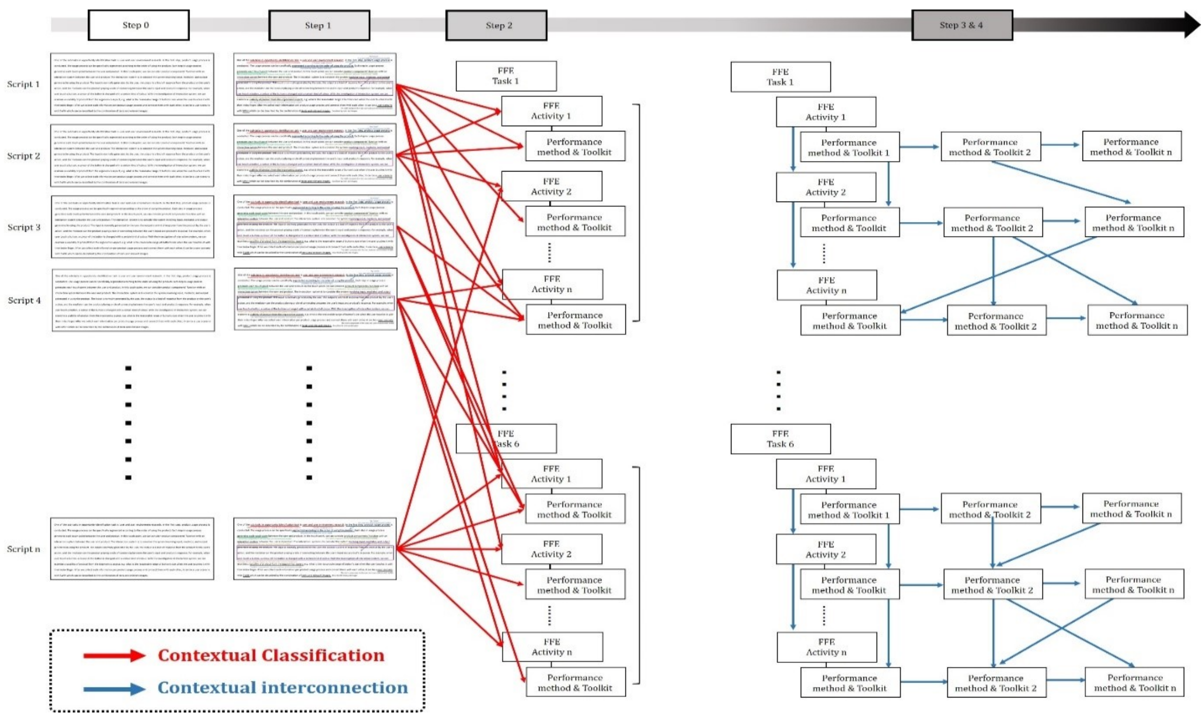


Figure 4.5. *Overall process of phenomenological analysis for interview script*

d) **Step 3: Structural Description (In this context, Contextual Construction)**

The analysis contents in step 3 were structurally built to embody the FFE performance structure and mechanism. This work was iteratively implemented to exquisitely elaborate on the representative FFE performance structure. It directly contributed to the form of the substantive prescriptive model which will be devised in 'Study 2.2'.

The right-hand side of *Figure 4.5* depicts the structure embodied by the analysis shown on the opposite side.

Concerning the four steps of the analysis process, presented above, if in one script Activity 1.1 was conducted in the order of Performance Method 1.1.1, 1.1.3 and 1.1.4, and in another script if Performance Method 1.1.3 was implemented based on results of Performance Method 1.1.2, and in yet another script if the outcomes of Performance Method 1.1.4 affected that of 1.1.5, these three scripts imply that Activity 1.1 can be performed in sequence: Performance Method 1.1.1 to 1.1.5 for contextual performance.

As a further example, if in one script the outcomes of Performance Method 1.2.3 differ depending on the outcomes of Performance Method 1.1.1, and if in another script the results of Performance Method 1.2.3 influence the results of Performance Method 1.4.4, this indicates that Performance Method 1.1.1 in Activity 1.1, Performance Method 1.2.3 in Activity 1.2 and Performance Method 1.4.4 in Activity 1.4 require collaborative work. To be specific, the collaboration can be structured in a form in which in the implementation of Performance Method 1.1.1 in Activity 1.1 affects that of Performance Method 1.2.3 in Activity 1.2, which in turn affects that of Performance Method 1.4.4 in Activity 1.4.

For reference, in this chapter, only a summary of the analysis of the interview scripts (using the PA method) are presented. Furthermore, partial scripts indicating applicable resources, extracted from the raw interview scripts, can be found in *Appendix 3* (*pp. 542-570*) as it would not be productive to show the analysis of the complete scripts from all interviewees: *Figure 4.6* below shows a sample extract from the scripts.

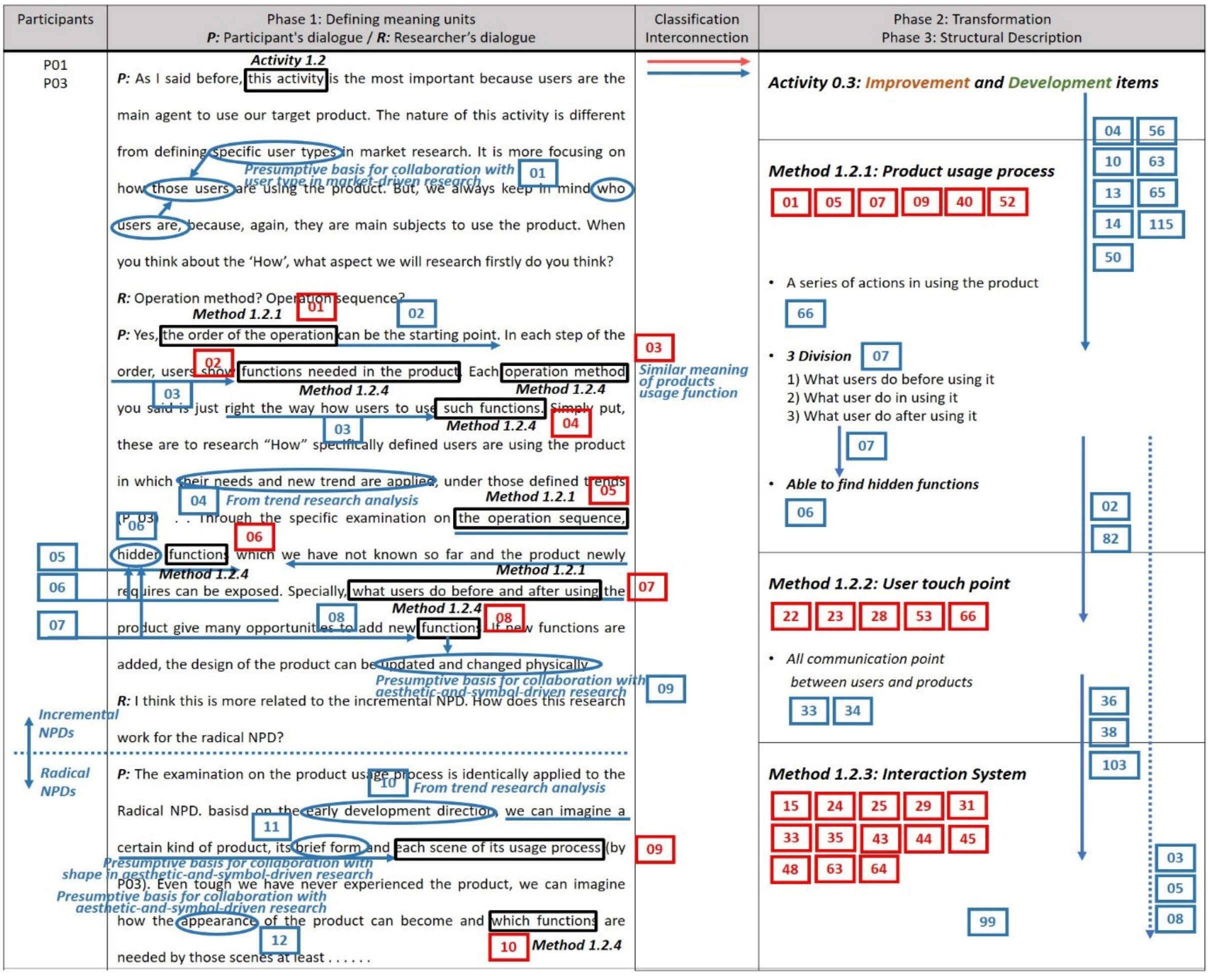


Figure 4.6. *An example of contextual interpretive analysis on interview script*

5.3) Increase Internal Validity

Even though the phenomenological analysis process was made to be as systematic as possible, there is a weakness caused by the subjectivity that comes with interpretations of language (Brun & Saetre, 2008). There is also a serious risk that retrospective FFE practices collected from participants can introduce prejudice (Bacon et al., 1994; Brun & Saetre, 2008). Therefore, three methods were used to compensate for these issues.

a) Triangulation Validation Approach

The first method, known as the 'Triangulation Validation Approach', was fundamentally adopted from studies by approaches, helping to increase the internal validity a set of results by cross-checking findings and converging different viewpoints. The triangulation approach helps to reduce the likelihood of bias that come from the perspectives of informants and from the researchers themselves. Flick (2004) and Yazan (2015) have outlined four types of triangulation: 1) 'Data triangulation', where many data resources are gathered and analysed in a piece of research, 2) 'Investigator triangulation', where several researchers and participants are involved in the research, 3) 'Theory triangulation', where multiple viewpoints and theories are used in interpreting data and the results of the research, and 4) 'Methodological triangulation', where scientific methods are used to implement the research. The first and second triangulation types were fulfilled given the many interview data and secondary document materials from an appropriate number of interviewees (n=38)[34]. The participants selected from various departments (e.g. R&D, design, product planning, etc.) of different companies in different countries also helped to reduce "Elite Bias" (Brun & Saetre, 2009). The third and fourth triangulation types were satisfied given the well-organised research design from a theoretical perspective, with many viewpoints on the relationship between research paradigms, approaches and methods as well as a systematically devised process for the analysis.

b) Peer Review System

The second method used to reduce bias when interpreting interview data was to conduct peer review. This method was also used in the data analysis of the FFE studies in Chapter Two (*pp. 56–58*). Unlike the method used previously, it was difficult to utilise the Kappa test since interpretively marked data could not be substituted with numerical values and input into SPSS. Instead, discussions between the author and colleagues aimed at reaching consensus on analyses were more conducted many times were conducted many times until at least 90% agreement was reached: within the given range, we counted phase by phase and

[34] It is a general opinion that around 20 participants are sufficient for case studies employing inductive reasoning on qualitative data. However, some experts believe that even twice that number might not be adequate to validate an argument in a study. However, there is no explicit agreement on standards about the reasonable number of participants (Achiche et al., 2013). However, according to Achiche et al. (2013) and Lai et al. (2006), in the case of expert informants, each can represent majority opinions. Therefore, the number of expert participants can be much less than that involving 'public' participants. For example, studies presented by Dalkey and Helmer (1963) and Strasser et al. (2005) involved six and seven experts respectively. In one study by Han et al. (2017), three experts were engaged in the research.

clause by clause. For instance, per page, when less than 5 phases or clauses in the total 50 numbers of them were matched, we regarded it as "90% agreement".

c) Role of the Researcher

Although internal validity is increased as a result of triangulation and peer review, the research's validity may still be weak given the nature of qualitative data analysis and the impossibility of having entirely objective researchers (Denzin & Lincoln, 2011). Denzin and Lincoln (2011) argued "the qualitative researcher is not an objective, authoritative and politically neutral observer standing outside and above the text". Alvesson and Skoldberg (2000) referred that researchers can interpret data using their judgement and intuition while preserving objectivity to a reasonable degree. Furthermore, researchers themselves can be a key instrument since they gather and analyse data by observing behaviour, interviewing informants, and examining materials (Creswell, 2013).

Therefore, many authors, including Creswell (2013) and Marshall and Rossman (2011) recommend "Reflexivity" to be introduced in qualitative studies. A researcher reflects on academic background, industrial experiences and culture in the qualitative study, which affects interpretations of themes and meanings ascribed to data (Creswell, 2013). Also, he/she develops a holistic and specific view on problems and issues by involving multiple perspectives formed by those with the appropriate backgrounds and experiences (Creswell, 2013).

Thus, if the backgrounds and specialities of individuals are appropriate, then internal validity can increase (the opposite is also true)" (Han, 2014; Kreimeyer, 2009).

The researcher conducting this study had a bachelor degree in 'Industrial design and design science' from 'Yonsei university' in South Korea. He gained a master's degree in 'Design management and innovation' from 'Brunel University London' in the UK. He is now a Ph.D. applicant in 'Imperial College London'. Moreover, he has experience in various NPD domains such as electronics, medical devices, vehicles, furniture and public transportation systems at well-known corporations, e.g. LG electronics. Regarding his experiences, his role was also diverse, serving as a mechanical designer, industrial designer, research-based functional designer, product planner and strategist, product manager, product development consultant and so on. This range of experience and knowledge can positively contribute to internal validity.

Apart from those methods to increase the internal validity and the role of the researcher, external validity will be fulfilled in 'Study 3.1' by validating the developed pragmatic-prescriptive model, allowing the model to be further strengthened in terms of reliability and validity.

6) Section Conclusion

This section has introduced the research method for analysing real-world FFE scenarios to infer the representative FFE scenario for contextual performance and concurrent collaboration. Fundamentally, the analysis proceeded, approached from inductive reasoning under the constructivism research worldview. More in detail, under the context as with building a theory (method/model) from case studies, the semi-structured interview involving 38 experts was conducted and the gathered interview scripts were analysed by the four steps of the phenomenological analysis which focuses on contextual hermeneutical meanings of texts, phrase by phrase, and clause by clause. In order to prevent inherent risks originated from the nature of the qualitative data and hermeneutical analysis, three types of methods (e.g. the triangulation approach, peer review system and researcher's background and expertise consideration) to increase the research's internal validity were used.

4.1.3 Research Summary

This chapter analyses various FFE practices to infer the representative FFE scenario, with the research method illustrated above.

This chapter is broadly divided to correspond to each of the main FFE tasks. Each part is specifically divided into three sections: 1) the nature and concept of the task, 2) activities and 3) performance methods and relevant toolkits. The first section covers the underlying concept that each task pursues in the FFE. The second section covers which activities are used to carry out each task and how these activities were connected to each other from the contextual performance and concurrent collaboration perspectives. In the third section, the performance methods which were revealed in each activity and how these performance methods interlock from those two perspectives are presented. In addition, toolkits provided for some of these performance methods are described. Those performance methods which will be embodied with the form of toolkits in Chapter Five (Study 2.2) can be the fundamental resources used to develop the pragmatic-prescriptive FFE model. The toolkits provided by the interviewees will also be reflected in the toolkits developed in this research. The third section puts performance methods at the centre, and considers the toolkits offered by interviewees.[35]

1) Preliminary Task (Task 0) and Six Main Tasks (Task 1 to 6)
2) Opportunity Identification-Screening Task (Task 1)
3) Idea Generation-Screening Task (Task 2)
4) Requirements List and Mission Statement Task (Task 3 and 4)
5) Conceptual Design Task (Task 5)
6) Prototyping Task (Task 6)

[35] As shown in the literature review (*pp. 81-84*), if we adopt the existing toolkits as it is, we can expect the same problems revealed in the previous toolkits provided by the previous models, e.g. partially connected for contextual performance and concurrent collaboration.

4.2 Preliminary Task and Six Main Task (Task 0 and Task 1 to 6)

4.2.1 Preliminary Task

In the literature review (*pp. 91–92*), it was found that different systems or routes for incremental and radical NPDs can be embodied by deploying different activities in either the early part or the end part. Given this, before dealing with the main tasks which are the centre frame of the new FFE model, we must first consider the issue of incremental and radical NPDs.

1) Nature and Concept

Figure 4.7 (*p. 153*) shows a summary of the analysis of the interview scripts, which was produced from the raw analysis data shown in *Appendix 3* (*pp. 542–544*). Most of the participants described the two separate routes as a preliminary task (Task 0) in the *initial* part rather than in the *later* part. Even though the purpose of both channels is the same – finding gap between needs/trends of users and the target product – the directions and characteristics of each channel are different, and so the outcomes are classified into two types.

2) Activities

In the incremental and radical channels, three different activities were identified, and it was found that within each channel, these activities can be connected to each other in terms of contextual performance. Even though its explicit collaboration forms between those activities were not revealed, the potential for inherent collaboration which occurs in conducting each activity itself was exposed. Full details are presented below.

2.1) Incremental NPD Channel

2.1.1) Contextual Performance

As shown in the upper section of *Figure 4.7*, for incremental NPD, the following three activities can be performed sequentially for contextual performance.

1) **Activity IC 0.1[36]: Examining the Target Products of Competitors Activity**
2) **Activity IC 0.2: Analysing Current Trends**
3) **Activity IC 0.3: Defining Items for Improvement**

Activity IC 0.1: Examining the Target Products of Competitors

At the beginning of an incremental NPD route, most of interviewees, including 02, 05, 14, 21 and 22, concentrated on comparing their products with competitors' (Activity IC 0.1) to find gaps for improvements. This type of competitor analysis usually targets all products positioned in the same market. According to participant 02, their organisation carries out something called "Killer Model Development" which targets a single particular competing product only. When a gap is found, they usually interpret the feedback given by customers about their products and those of their competitors. In particular, Interviewee 21 utilised 'Comparative Analysis Chart' in which the functions, features, and specifications of their product and those of competitors are listed and prioritised to find gaps more systematically.

Activity IC 0.2: Analysing Current Trends

Then, tried to understand trends which can be reflected in their product improvement direction. The reason seems that if they only modify those points listed explicitly laid out for improvement, new points will occur as a result of new trends, in as little as few months. Furthermore, interviewees 02, 05, 12 and 14 tended to concentrate more on the present trend (Activity IC 0.2) rather than future trends since incremental NPD projects generally aim for improved product versions to launch within a year at most. Current trends are

[36] In the numbered labelling scheme, '0' refers to the preliminary task that is conducted before Task 1. Also, 'IC' and 'RC' indicate 'Incremental' and 'Radical' NPD respectively. Therefore, relevant activities were assigned to Activity IC 0.1, 0.2 and 0.3 or Activity RC 0.1, 0.2 and 0.3. For instance, 'Activity IC 0.1' means the first activity in the preliminary task for the incremental NPD; the competitor analysis.

collected from various fields such as industry, technology, economics, politics, the environment, culture, the arts, and entertainment. Participant 02 suggested utilising both online and offline resources from the annual reports from industry, publications from academics, information from websites and other materials recommended by universities and economic labs. To determine whether those identified trends are relevant to the project or feasible to implement, they organised an expert group discussion.

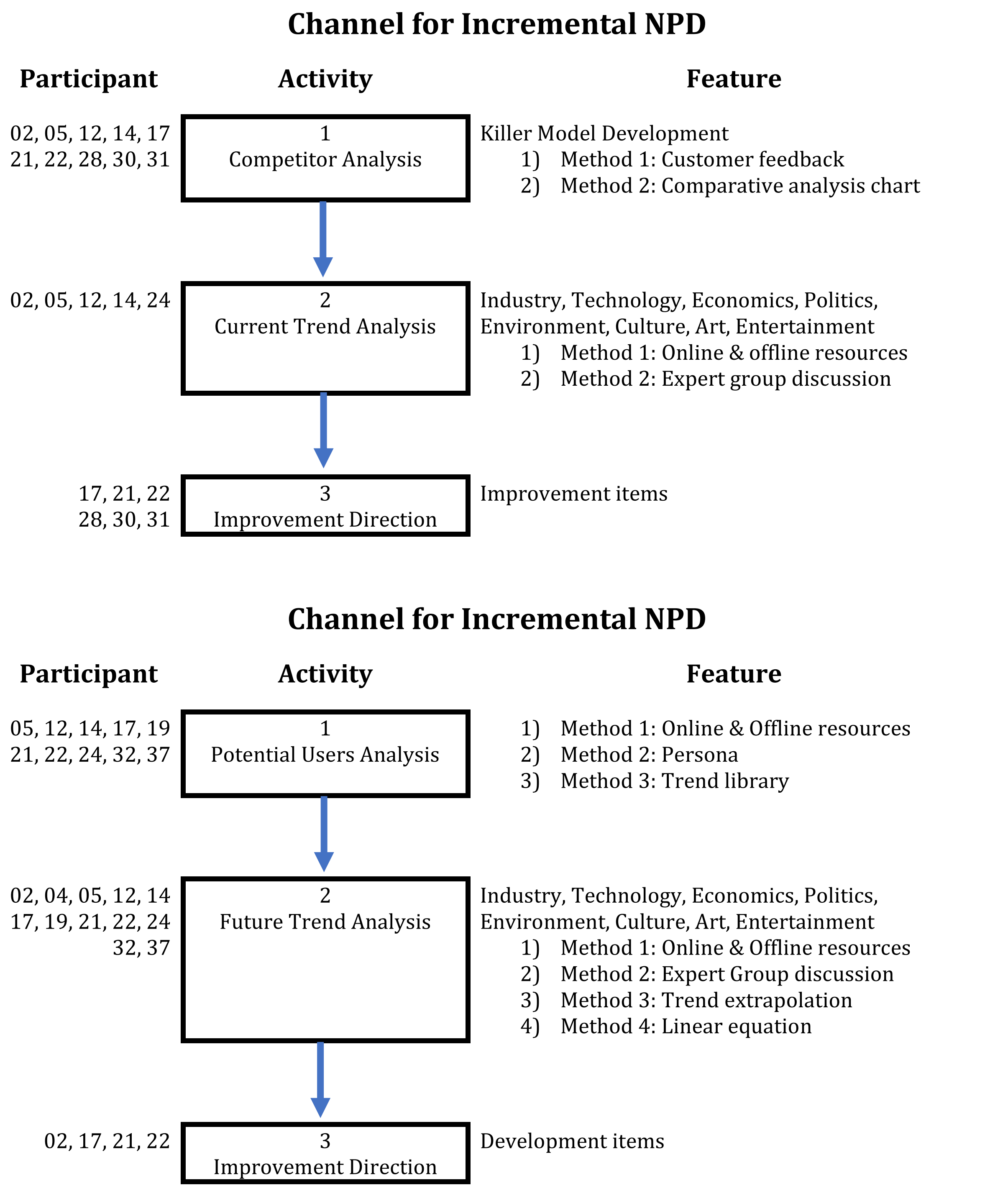


Figure 4.7. *A summary of the analysis of the preliminary task*

Activity IC 0.3: Defining Items for Improvement

Lastly, the combination of outcomes from the two previous activities can result in new improvement items (Activity IC 0.3). These items are used for establishing an initial improvement direction for the whole project. Sometimes, there are cases where the improvement items are directly defined from the competitor analysis without undertaking the trend analysis when the improvement item is quite clear or when there is not sufficient time to carry out the trend analysis.

Consequently, they took notice of the differences between their products and their competitors', and of current trends that can motivate them to improve their products. Participants 28, 30 and 31 illustrated an example improvement item generated by implementing Activity IC 0.1 and 0.2, "To develop a wider slimmer smartwatch display (compared with competitors') to enable men and women aged 20 to 40 to check various physical conditions when they are exercising (the current trend).

2.1.2) Concurrent Collaboration

An explicit collaboration form generated between activities were not readily observed in the given script. However, we were able to identify the possibility for inherent collaboration in conducting the current trend analysis (Activity IC 0.2). The 'diverse' areas in which present trends arise implies the potential for collaborative work. For example, trends from industry and technology fields can be treated as R&D work, considered with other areas such as culture and entertainment, while trends from the economics, politics and environmental sectors can be managed as a market-related issue.

2.2) Incremental NPD Channel

2.2.1) Contextual Performance

As shown in the bottom section of *Figure 4.7*, radical NPD projects can involve the following three activities in the initial part of the FFE.

1) **Activity RC 0.1: Envisaging Potential Users**
2) **Activity RC 0.2: Forecasting Trends**
3) **Activity RC 0.3: Estimating Development Items**

In terms of radical NPD projects, the interviewees maintained that radical NPD focuses on both who the potential users will be and what new trends they will generate. Potential users sometimes play a role in indirectly demanding or occasionally directly triggering the creation of new markets, technologies, cultures and so on. Of course, new technologies or cultures themselves sometimes provoke new trends capable of spurring NPDs. Most of the participants tended to concentrate more on users as the central agents which make use of products since users are have a key role in producing new trends.

Activity RC 0.1: Envisaging Potential Users

Potential users and their demands (Activity RC 0.1) can be envisaged as the first activity in a radical NPD project. Participants 19, 32 and 37 recommended utilising 'Persona' and 'Trend Library' toolkits. In this toolkit, both general users distributed across the range of possible users, and trendsetters positioned at the extreme edges of the range, are defined. Next, the trends which users may want, along with how to fulfil with their desires and the lifestyle associated with such a trend, are explored multidimensionally. If this implementation continues, certain user-and-trend 'layers' are accumulated, generating a kind of library dataset. Then, the expected desires and trends from each user are arranged and intersected with each other. Through this process, practitioners contextually foresee trends from the present to the near future (generally from the general user group) through to the more distant future (generally from the trendsetter group). Trendsetters play a bridge role in connecting current and near-future trends, known as 'Hard Trends', and more distant trends, known as 'Soft Trends'

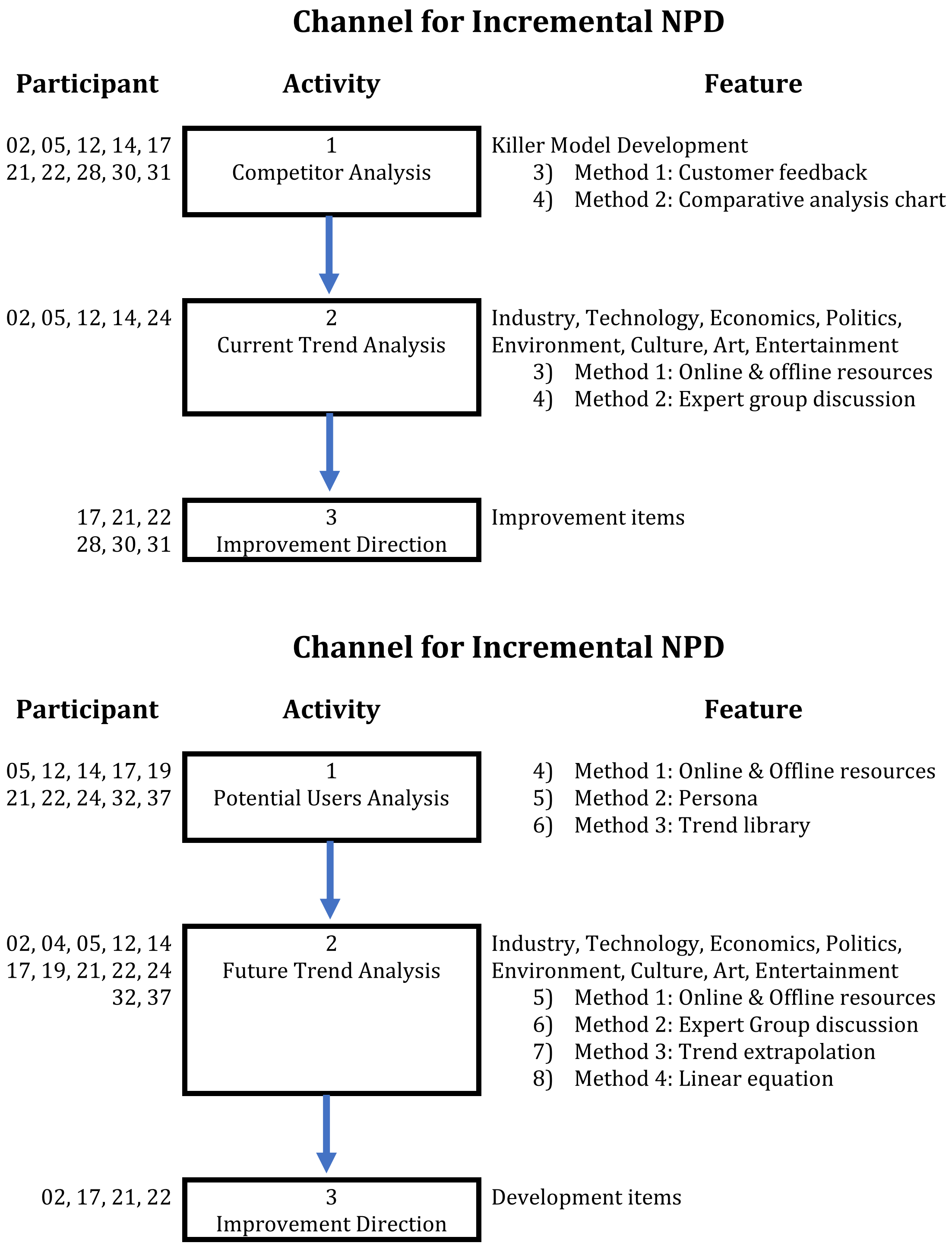


Figure 4.7. *A summary of the analysis of the preliminary task*

Activity RC 0.2: Forecasting Trends

To explore more detailed potential trends (Activity RC 0.2), participant 24 introduced 'Trend Extrapolation Method' consisting of four steps. Firstly, in the data collection process, mega-trends are first gathered. Then, through a data filtering process, hard trends which are reasonably likely to happen in the near future are sorted out. Simultaneously, soft trends which may occur in the more distant future are put through the data decoding process. Lastly, feasible requirements are drawn up to realise those hard and soft trends. In another case recommended by interviewee 02, there is a kind of mathematical method to more systematically envisage future trends. This method, in the form of a linear equation, is to envisage the coming future trend by projecting the relationship between the past and present trend into the present situation.

Activity RC 0.3: Estimating Development Items

Finally, development items (Toolkit RC 0.3) can be forecast, based on outcomes from previous activities. These items serve to set the initial direction of the radical NPD project. Participants 19, 32 and 37 described the initial direction of the example development item, "To develop a new device to enable early adopter-housewives to sterilise layettes on a daily basis."

2.2.2) Concurrent Collaboration

In the script, systems for collaboration were not explicitly revealed. However, as with the incremental NPD case, the potential for inherent collaboration was detected in conducting the future trend analysis (Activity RC 0.2). The involvement of 'various' research fields where future trends occur connotes the possibility of multi-dimensional involvement.

3) Performance Methods and Toolkits

Specific performance methods and their relevant toolkits for implementing these activities did not show the relationship of the contextual performance and concurrent collaboration. We found that these methods were often used independently, though this differed depending on the preferences of performers.

4) Section Conclusion

Two different routes consisting of different activities can provide new items for improvement or development. Then, based the directions established by those items, the subsequent same activities can be conducted to create new products or product versions, with the final task being to develop concept designs and prototypes. However, different deliverables can be generated at every step, depending upon the improvement items for incremental NPDs and the development items for radical NPDs. This consequently results in different final outputs for the FFE.

4.2.2 Six Main Task

After conducting the preliminary task (Task 0) to establish the initial improvement or development directions for the incremental and radical NPD projects respectively, the implementation of the FFE begins in earnest. The main driving force that makes up the FFE is six tasks which have been defined in the literature review. However, as mentioned in the research method section of the chapter introduction (*pp. 136-137*), the interview questions were designed to enable interviewees to offer other FFE tasks absent from our literature review, as well as their performance order. Therefore, this section identifies not only whether additional tasks were discovered in real-world FFE practices but also how the sequence of those tasks was structured.

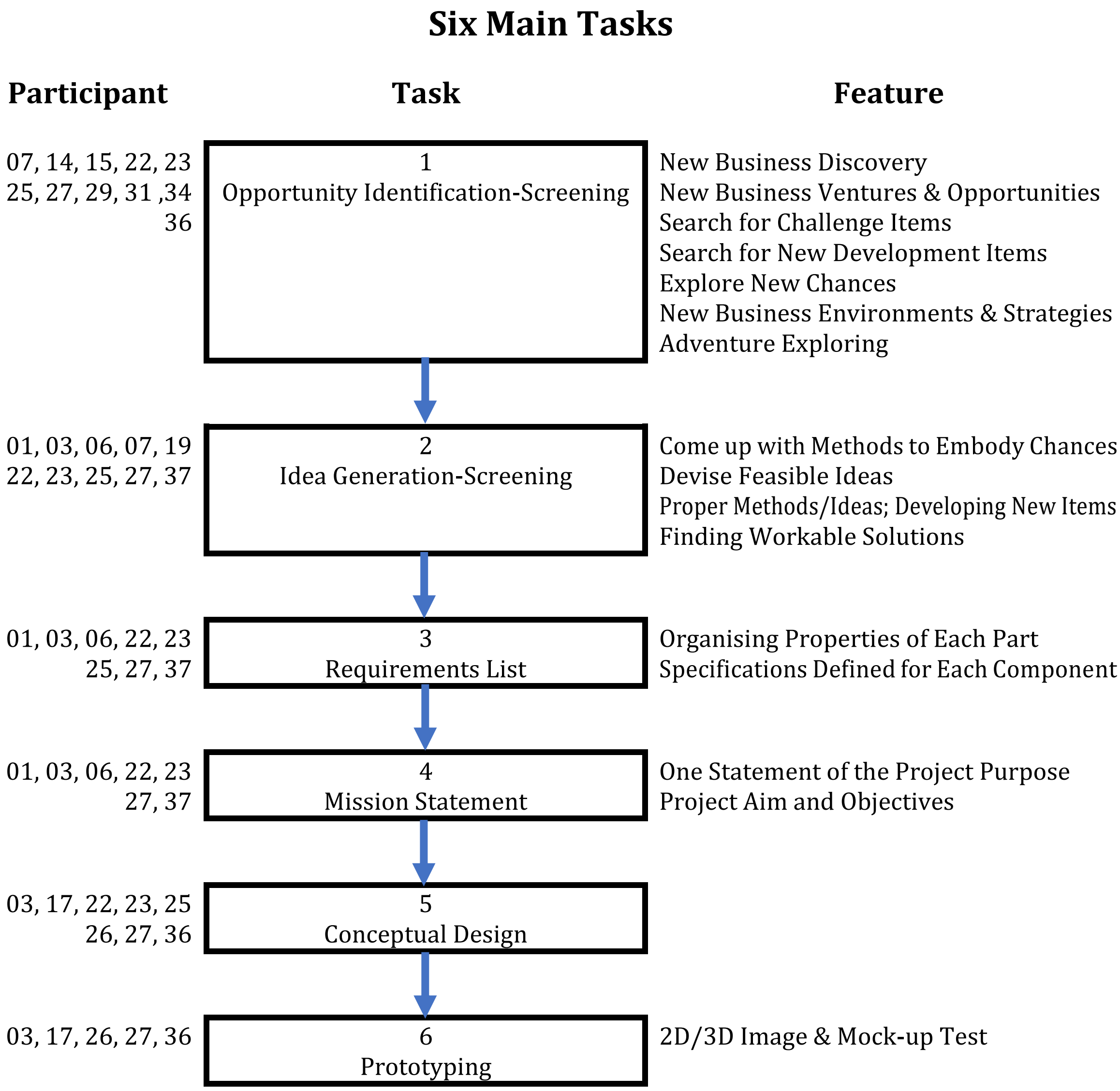


Figure 4.8. *A summary of the analysis of the six main tasks*

In the summary of the analysis of the interview scripts (see *Figure 4.8*) extracted from the raw interview scripts, which can be found in *Appendix 3* (*p. 545*), the FFE was found to consist of six tasks. Although participants used different terms for the tasks compared to how they are referred in the literature, the meanings were identical. For example, 'New Business Discovery', 'New Business Venture and Opportunities, 'Explore New Chances' and 'Adventure Phase' coined by participants 02, 14, 29 and 31 respectively were categories into the opportunity identification-screening task. 'Devise Feasible Ideas' and 'Find Workable Solutions' termed by interviewees 07 and 34 were grouped into the idea generation-screening task.

The structure of these tasks was also similar to that the structures noted in the literature. Firstly, opportunity identification-screening can be regarded as the first task. According to participants 07, 19 and 34, the ideation task comes after the first task. Participant 12 argued that there are times where these two tasks are performed almost simultaneously. Also, the conceptual design task can precede the prototyping task to confirm whether the concept design is feasible.

However, the performance order of the requirements list and the mission statement task was somewhat different with the order studied in literature. According to participants 22, 23, 27 and 37, the requirements list task was usually followed by the mission statement task in the forward performance order whereas articles in the literature describe the forward or reverse performance order. Based on one statement of the project purpose, each specific property of the product can be defined. On the other hand, based on specific product specifications, a brief product definition can be determined as a summary of those specifications. Given these two arguments, when considering how other FFE tasks are conducted, the latter argument seems to be more effective for contextual performance. To be specific, the ideation task aims to realise opportunities, opportunities and ideas which result in each of the product specifications. This leads to a product definition summarised by those product specifications, and thus is one statement of the project's mission.

Consequently, the FFE is comprised of six tasks in the following sequence:

1) **Task 1: Opportunity Identification-Screening**
2) **Task 2: Idea Generation-Screening**
3) **Task 3: Requirements List**
4) **Task 4: Mission Statement**
5) **Task 5: Concept Design**
6) **Task 6: Prototyping**

In the following chapters, activities and their performance methods along with relevant toolkits for each task are presented in detail from the contextual performance and concurrent collaboration point of view.

4.3 Opportunity Identification-Screening (Task 1)

4.3.1 Section Introduction

This section illustrates activities, their performance methods and relevant toolkits for the opportunity identification-screening task (Task 1).

Four main activities associated with this task were revealed to exist, and these activities were not conducted in consecutive order from the contextual performance perspective. Instead, these activities operate in parallel, and require a strong level of collaboration within the activities in order to be effective.

Diverse performance methods which can be connected from the contextual performance perspective were revealed in each activity. Various forms of concurrent collaboration between the different performance methods of the four activities were also explicitly identified. A number of toolkits for these performance methods were also provided by interviewees.

In this section below, the basic nature of and concept behind Task 1 are presented first. The following sections address the four activities and relevant performance methods/toolkits, in order, with respect to contextual performance and concurrent collaboration.

4.3.2 Nature and Concept

Many interviewees contended that opportunities identified in the preliminary task (Task 0) are abstract directional opportunities. Conversely, the opportunities identified in Task 1 are ideally further along in said direction, ascertained by analysing a target product from the perspective of multiple research domains. Information produced by said scrutiny provides detailed opportunities that can be used in the actual NPD phase.

4.3.3 Activities

As shown in the summary of the analysis of the interview scripts (*Figure 4.9*), obtained from the raw analysis data shown in *Appendix 3* (*p. 546*), examining the target product to find specific opportunities involves the following activities, which have a parallel relationship:

- **Activity 1: Market-driven Research**
- **Activity 2: User-driven Research**
- **Activity 3: Aesthetic-and-Symbol-driven Research**
- **Activity 4: Technology-driven Research**

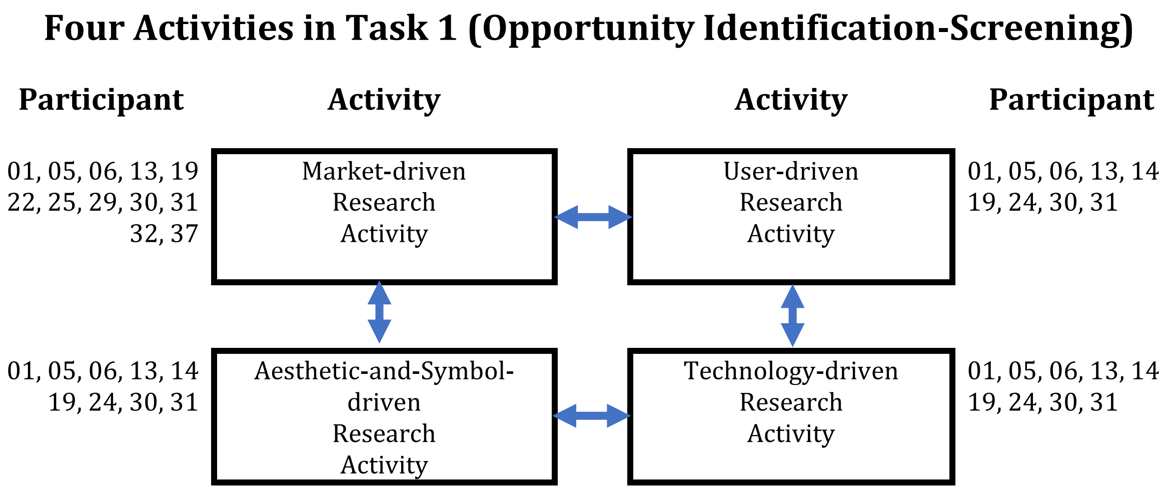


Figure 4.9 *A summary of the analysis of the four activities in Task 1*

These terms each refer to an activity to which the participants gave different names. For example, participants 19 and 24 used 'Product Appearance' and 'Product Exterior' research, respectively, instead of 'Aesthetic-and-Symbol-driven' research. Several participants, including 01, 05, 06, called it 'Design Aspect' research. However, the term 'Design' can cause ambiguity in communication between various disciplines such as engineering, industrial design, and management. After considering the nature and features of these variously-named activities and determining that they largely refer to the same thing, the term aesthetic-and-symbol research activity was used instead.[37]

[37] Further detailed evidence for selecting the term 'Aesthetic-and-Symbol-driven' research, is shown in *Figure 4.16* (*p. 182*). In short, the performance methods and relevant toolkits in 'Aesthetic-and-Symbol-

Interviewee 30 highlighted all four of the abovementioned activities, using his own term: the acronym 'MUTD', indicating 'Market', 'User', 'Technology' and 'Design'. Participants 01, 19, 22 and 29 regarded market-driven, user-driven, and aesthetic-and-symbol-driven research as the primary activities in this task. In the case of participant 14, user-driven and technology-driven research was said to be the two main streams in identifying new opportunities. User-driven and aesthetic-and-symbol-driven research were emphasised by participant 19.

Among these four activities, the user-driven research domain is the most important since it provides all of the information required to develop the new product. User-driven research encompasses the behaviours exhibited when consumers actually use the product (described by participant 01) as well as the environments in which they do this (described by participant 37). Participants 01, 05, 06 and 13 insisted that it is also essential to increase aesthetic value and infuse semantic functions into the product since users are fascinated at first by a product's exterior elements. Participant 24 maintained that opportunities are generated from technology-driven research, which looks at which technologies are required for the product and how they might be applied. Participants 22, 25 and 29 contended that market-driven research is one of the most significant domains, to explore possible markets in which new technologies can be applied and new target user groups selected.

As mentioned in *p. 162*, for contextual performance, the sequence in which these activities are to be conducted was not explicitly revealed. Four different research sectors appeared to be implemented in parallel. This implies the potential for concurrent collaborative work of those activities, called '4 Winning Team Players'. The word 'Team' hints at collaboration, while the word 'Winning' implies collaboration to achieve success. We also identify the possibility of collaborative work between two or three of research sectors. Although the specific forms and operation mechanisms of collaboration were not presented in this section (they are presented in the section below, *pp. 165-217*), various possibilities were gleaned.

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driven' research increase the aesthetic value of the target product and infuse symbolic function into the product.

4.3.4 Performance Methods and Toolkits

As indicated in *p. 162*, the performance methods within each activity can be linked together from the perspective of contextual performance. Also, the possibility of concurrent collaboration between the different performance methods of the four activities was distinctly revealed in the scripts.

In the sections below, each activity from Activity 1.1 to 1.4 is addressed showing not only how those performance methods make up the individual activity for contextual performance, but also how those are intertwined with each other for the collaboration.

1) Contextual Performance

This section illustrates the contextual performance relationship between relevant performance methods/toolkits in terms of the four research activities identified in the section above. Full details are described below.

1.1) Market-driven Research Activity

Market-driven research (Activity 1.1) is crucial for defining the types of users for the target product and the types of markets in which the product will be shipped, to determine development, logistics, and promotions costs, the product price, and thus ultimately, a profit forecast. Market research can be divided into two parts:

1) The former relates to the specific user type and the target market
2) The latter relates to the finances

These two parts seem to exist independently. However, they can have a contextual connection with each other. Further details follow, based on a summary of the analysis of the interview scripts (see *Figure 4.10*), which was produced from the raw analysis data shown in *Appendix 3* (*pp. 547-549*).

Market-driven Research in Opportunity Identification-Screening

Participant	Method	Feature	Case Study
01, 02, 03, 14, 16 18, 19, 28, 29, 31 33, 35, 37, 38	1 User Segmentation	Stakeholder analysis . Details of user types . 8 components	. Layette steriliser
01, 02, 03, 14, 16 18, 19, 28, 29	2 Target Market with Indirect Factors	BEPSTELVE tool . Indirect factors . 8 components	. Layette steriliser
01, 02, 03, 14, 16 18, 19, 28, 29	3 Target Market with Direct Factors	SWOT tool . Direct factors . Four components -Strength / Weakness -Opportunity/Threat	
01, 02, 03, 13, 14 16, 18, 19, 28, 33 35	4 Target Market with Strategies	PDP tool . 3 components - Position - Distribution - Promotion	. Mobile phones High-end vs Low-price
01, 02, 03, 05, 06 09, 13, 14, 16, 18 19, 22, 25, 29, 35 37, 38	5 Cost Estimation	. Calculation tool	. Mobile phones High-end vs Low-price
01, 02, 03, 05, 06 09, 13, 14, 16, 18 19, 22, 25, 29	6 Price Estimation	. Calculation tool	. Mobile phones High-end vs Low-price
01, 02, 03, 13, 22 25	7 Profit Forecasting	. Calculation tool	Mobile phones High-end vs Low-price

Figure 4.10. *A summary of the analysis of the market-driven research activity in Task 1*

Along with the basic concept above of this activity, relevant performance methods for the market-driven research activity (Activity 1.1) can be conducted in the following order, divided into two parts.

1) **The former relates to target users and markets**
    1.1) **Method 1.1.1: User Segmentation**
    1.2) **Method 1.1.2: Target Market with Indirect Factors**
    1.3) **Method 1.1.3: Target Market with Direct Factors**
    1.4) **Method 1.1.4: Target Market with Strategies**
2) **The latter relates to the financial aspects**
    2.1) **Method 1.1.5: Cost Estimation**
    2.2) **Method 1.1.6: Price Estimation**
    2.3) **Method 1.1.7: Profit Forecasting**

Method 1.1.1: User Segmentation

User segmentation (Method 1.1.1) aims to collect details of users who will use the target product. Users can be sorted into categories, such as gender, age, occupation, income, preferences, and their likelihood of purchasing the product. This segmenting work can be done on target products which have had their initial improvement or development directions already clarified. [38]

Participant 03 provided documents to describe an example case study of previous FFE work for developing a new device to sterilise layettes.[39] Their project, which proceeded as a radical NPD, was the result of a new demand from users as well as a new trend that was discovered at the time. The project was officially established with the expectation that certain target users would be willing to buy a particular device specifically to sterilise baby supplies. Based on this expectation, project performers estimated that these target users would be housewives in their mid-twenties to mid-forties, domiciled in middle-

[38] As mentioned on *page 145*, the preliminary task has already identified potential paths for improvement or development, divided into two different channels for incremental and radical NPDs, which form the directions that the NPD will take. Based on these directions, the target product can be produced.

[39] The document provided by participant 03 did not illustrate their FFE work in its entirety, detailing only certain parts. In the upcoming findings, the relevant content of participant 03's document is presented in the appropriate sections.

class areas or higher. They would be part of a household with a higher income, such that the purchase of this device would not be a financial issue. They were thus rated to have significant potential to purchase the target product. Based on this subdivided user information, project participants continued to conduct further, deeper segmentation work.

The next step, based on data derived from the user segmentation, the target market (Method 1.1.2 to 1.1.4) can be considered.

Method 1.1.2: Target Market with Indirect Factors

In selecting the possible market, participants 01 to 03 first suggested investigating various indirect factors that influence the expected market in which the defined specific user type is situated (in the case of incremental NPDs) or will be situated (in the case of radical NPDs). They recommended using the 'BEPSCTELVE' method, which stands for 'Business', 'Economic', Political', 'Social', 'Culture', 'Technology', 'Environment', 'Legal' and 'Value'. This was an integration and evolution of four methods well-known to academics: PEST, BEPESTEL, STEP, and STEVE. Method 1.1.2 allows practitioners to understand how the user type to understand what conditions the product will be exposed to in typical use cases by the target consumer according to eight indirect factors.

To once again use the above example case study of a device to sterilise layettes, the target market was determined to be Northeast Asia. Housewives in the region were affected by a cultural belief that new-borns should be housed together in postpartum care centres, regardless of the cost. It implies these target users were highly concerned about the hygiene of the environment around their babies. Also, the hygiene issue for babies was reported on the news intensively because new healthcare legislation was being voted on, so that the nominated market had stronger marketability.

Method 1.1.3: Target Market with Direct Factors

Then, the SWOT analysis (Method 1.1.3) can be employed to estimate the direct factors affecting the target market which the indirect factors were inferred by the previous method (Method 1.1.2). The market is examined by determining the strengths, weaknesses, opportunities, and threats faced by a project, which can help to narrow the possible market down even further

Method 1.1.4: Target Market with Strategies

Based on the narrowed scope of possible markets, the state of the actual market can be inferred through the following. Firstly, the segmented users and the target product which they will use can be positioned in the market. Considering the market position, then, acceptable distribution channels can be devised, which can also lead to more effective promotion methods.

Participants 33 and 35 depicts examples of contextual linkage between market position, distribution and promotion. For example, if a series of mobile phones sold by a brand is high-end (i.e. the brand's flagship product), then they will generally be shipped by air and thus rapidly placed in official and luxury stores. These mobiles will be promoted on television, particularly in advertisements before and after popular TV programmes. These will also be advertised on billboards, posters and electronic displays in high-traffic public areas such as city centres and mass transit railway stations. On the other hand, if another series of mobile phones sits at the low-price, high-volume end of the market, they will typically be transported by sea and be placed in less luxurious stores and arcades. These mobiles will be promoted on cable TV, in local newspapers, and in areas with lower foot and vehicle traffic. They call these three implementations PDP (Method 1.1.4), for 'Position', 'Distribution' and 'Promotion'.

The following three implementations (Methods 1.1.5 to 1.1.7) are related to estimating the invested cost, the price of the product, and the total profit. Most of the participants highlighted the importance of considering these works in the early FFE stage. When the development cost and product price was not considered during the FFE but only from the actual NPD phase onwards, they had difficulty in progressing the project all the way to the end. The reason is that the development cost for technologies proposed in the FFE and the purchase cost for materials suggested in the FFE were more expensive than they expected. Eventually, they postponed the project until alternatives could be found.

Method 1.1.5: Cost Estimation

At the beginning of the second part, cost estimation (Method 1.1.5) defines all expenses required to develop the target product. Cost estimation covers not only the direct cost, such as the purchase and development of resources and technologies, but also the indirect cost, such as human resources (HR), contracts with vendors or OEMs, international currency exchange, taxation and tariffs, and the politics affecting taxes. Considering all of the above elements, the total development cost is then calculated and compared to the appropriated budget.

Method 1.1.6: Price Estimation

Based on the development cost, price estimation (Method 1.1.6) is then possible. The aim here is to devise a product price that would allow the product to turn a profit commensurate with the development cost estimated previously. In other words, the profit per sale of a single product is equal to the price of the product minus the invested cost in the product.

Method 1.1.7: Profit Forecasting

With the profit per sales figure, companies can forecast profits (Method 1.1.7) weekly, monthly and annually, after considering weekly, monthly and annual sales. Details of calculation methods for these figures are presented in the material offered by participant 13.

In summary, in market-driven research, the types of target users which will use the target product can be segmented, based on information about the user types, and the indirect and direct factors affecting the possible target market. With these factors, the actual target market where the product will be positioned can be studied, so that relevant distribution channels and promotion methods can be selected. Then, the total investment cost (including the estimated expenditure on distribution and promotion) can be calculated, and the product price estimated accordingly. Lastly, based on the investment cost and the product price, profits can be forecasted on a weekly, monthly and annual basis.

1.2) User-driven Research Activity

More than half of the participants, including notably 01, 19, 31 and 32, regarded user-driven research (Activity 1.2) as the most important activity in the opportunity identification-screening task. They contended that users and user environments indicate everything needed to develop a product. User-driven research aims to understand how users manipulate the functions of the target product. In a broader sense, the research seeks to grasp how users communicate with the target product in a particular set of environments and use cases. While the user segmentation method (Method 1.1.1) in the market-driven research activity (Activity 1.1) seeks to investigate who the target users may be, this research mainly deals with user behaviours when those target users are actually using the product in the given environment, as shown in the script for participants 01 and 28.

Along with the underlying concept of the user and the user environment research (Activity 1.2), relevant performance methods can be contextually connected in consecutive order, as follows:

1) **Method 1.2.1: Product Usage Process Understanding**
2) **Method 1.2.2: User Touch-point Identification**
3) **Method 1.2.3: Interaction System Analysis**
4) **Method 1.2.4: Product Usage Function Identification**
5) **Method 1.2.5: User Environment Analysis**
6) **Method 1.2.6: Usability Considering**
7) **Method 1.2.7: User Scenario Work**

The basic goal of these seven methods is to specify more precisely the target product in which the initial improvement or development directions are reflected, from the viewpoint of users. More details follow below, based on a summary of the analysis of the interview scripts (see *Figure 4.11*), which was produced from the raw analysis data shown in *Appendix 3* (*pp. 550-554*).

User-driven Research in Opportunity Identification-Screening

Participant	Method	Feature	Case Study
01, 03, 14, 28, 30 37	1 Product Usage Process	. 3 Divisions . Prior to action . In using . After action	. Layette steriliser . Medical device . Washing machine
05, 06, 24, 28, 30 37	2 User Touch-point	. Communication points between users & products	. Layette steriliser . Control panel of medical device
05, 06, 19, 24, 28	3 Interaction System	. 3 components - User signal - Product touch-point - Product response . Product =Living organism	. Layette steriliser . Control panel of medical Device . TV/Touch-pad display
01, 03, 05, 06, 14 19, 24, 28	4 Product Usage Function	. The way of using products which follows a set of rules . The way in which the series of actions is made	. Layette steriliser . Control panel of medical device . Electric wheelchair
19, 31, 32, 38	5 User Environment	. Where all user actions are generated . Where the product is situated	. Layette steriliser . Handle of medical device . Electric wheelchair . Washing machine
14, 19, 28	6 Usability	. Ergonomics . Anthropometry . Human-Centred Design (HCD) . Intuitive design	. Layette steriliser . Control panel of medical device . TV/Touch-pad . Handle of medical device . Electric wheelchair . Washing machine
16, 19, 38	7 User Scenario	. User story	. Layette steriliser . Electric heater system . Dishwasher

Figure 4.11. *A summary of the analysis of the user-driven research activity in Task 1*

Method 1.2.1: Product Usage Process Understanding

The product usage process (Method 1.2.1), which considers phased-motions in which target users actually use the product, can serve as groundwork for user-driven research activity. The viewpoint of examining the phased-motions can differ according to two NPD attributes, as follows.

In the case of radical NPD, participants 01 and 10 envisage the order in which the product is used by imagining the target user and what they might do with the product. Taking the example case study of developing the new device for sterilising layettes, mentioned in the previous section, the housewives first recognise the need to use the product, and then they turn on the power. If the device is not a battery-powered product, they will plug in an electrical cord before switching it on. Next, they open the lid of the product, put their layettes in, and then close the lid. Then, they select from the various sterilisation functions by manipulating a control panel, and they operate the device with an action button. The product then proceeds to operate as per the set conditions. During the sterilisation process, some other actions may be required. Finally, once the sterilisation is complete, the user retrieves their now clean baby supplies.

On the other hand, the work for incremental NPD is more explicit due to it being based on an existing product. The work is implemented in largely the same way but is more focused on improvement. However, many participants highlighted that the product usage process in an incremental NPD project should also be minutely examined step by step as with the case of radical NPD since the existing process is frequently altered in accordance with what needs to be improved.

In capturing new opportunities through analysis of the product usage process, it is also worthwhile to understand what users do before and after using the product. For instance (shown in *Figure 4.12*), according to participant 01, there was a particular user behaviour pattern in which housewives in the Asia region hand-wash the sleeves and collars of clothes intensively before using the washing machine. In order to wash these clothing sections by hand, they had to use the sink in the kitchen or the washstand in the bathroom. This led to users being uncomfortable with the need to move their clothes several times from the sink to the washing machine or vice versa. They would also have the wipe or otherwise dry any water that had dripped on to the floor as they moved the clothes. These user actions indeed provided a valuable opportunity to develop a new type of washing machine. Project participants created a specific component which served as a washstand on top of the washing machine, enabling them to hand-wash the sleeves and collars without having to move back and forth.

Figure 4.12. *Washing machine with a component which serves as washstand*

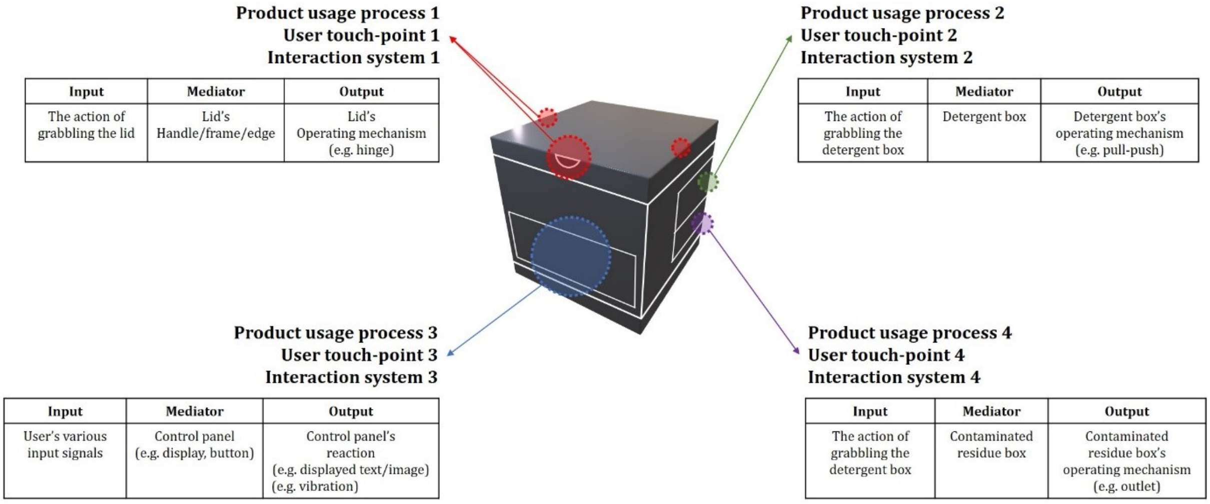
Method 1.2.2: User Touch-point Identification

Identifying user touch-points (Method 1.2.2) is the next step. User touch points refer to all tangible and intangible points of the contact between the target user and product. Once again using the example of a new device to sterilise layettes, the user touch-points will be each instance where the user sees, touches, feels, or otherwise recognises the product. When they perceive the product, the touch-point is the whole product.

Returning to the case study of a new device for sterilising layettes, when they are plugging in the electric cord, the cord itself and the plug are the touch-points. When opening the lid, the touch point is the main frame of the lid, the edge of the lid, or the handle of the lid. When they are setting up the sterilisation functions, the display and all buttons on the control panel are touch-points.

Method 1.2.3: Interaction System Analysis

In each touch-point, each interaction system (Method 1.2.3) can be generated. According to participant 24, an interaction system analysis is conducted, one which considers the product as one living organism. Participants 05 and 06 argued that the product reacts by sending out particular signals as responses when users transmit particular signals as inputs. Hence, as shown in the reference material from participant, an interaction system basically consists of three parts: 1) Input, 2) Mediator, 3) Output. Participants 24 and 38 illustrated that each input makes use of the four senses; they are vision, audition, tactility and olfaction. The mediator is each touch-point itself, and the output is generated from each operational state in which the touch-points work.



Input	Mediator	Output
The action of grabbling the lid	Lid's Handle/frame/edge	Lid's Operating mechanism (e.g. hinge)

Input	Mediator	Output
The action of grabbling the detergent box	Detergent box	Detergent box's operating mechanism (e.g. pull-push)

Input	Mediator	Output
User's various input signals	Control panel (e.g. display, button)	Control panel's reaction (e.g. displayed text/image) (e.g. vibration)

Input	Mediator	Output
The action of grabbling the detergent box	Contaminated residue box	Contaminated residue box's operating mechanism (e.g. outlet)

Figure 4.13. *Product usage process, user touch-points, and interaction system in the layette steriliser*

In the case study of the layette sterilisation device (*Figure 4.13*), when users open the lid, the input is the action of grabbing the lid, the mediators are all possible touch points such as the lid frame, its edge and its handle, and the outputs are the ways in which the lid can open and its operating mechanism (e.g. a hinge). When operate the control panel to set up the sterilisation functions, the inputs are caused by various user actions, the mediators are all the touch-points of the panel (the display, the buttons etc.), and the outputs are the reactions of the control panel itself such as each text-and-image displayed on the screen.

Method 1.2.4: Product Usage Function Identification

Through developing a deep understanding of the interactions between each user action and each touch point, the product usage functions (Method 1.2.4) can be laid out more explicitly and specifically. For example, by understanding the communication system between users and the various buttons on the control panel, we can understand not only the functions of the buttons themselves but also which product functions are operated by those buttons. Also, by understanding the interaction by the user, specifically the action of grabbing and lifting the lid, we understand that the lid serves an ancillary function as a handle in addition to its primary function of being a cover. This provides an opportunity for project practitioners to develop a new operational mechanism for the lid, or perhaps design a new shape.

Some participants, including 19 and 28, described the investigation of the product usage, said the investigation of the product usage took place before examining the interaction system.

However, as shown in the example above, the reverse order (investigating the interaction system first) is more reasonable as the product usage functions can be defined more explicitly if the interaction system is already well understood.

Method 1.2.5: User Environment Analysis

The next step is the analysis of the user environment (Method 1.2.5). Participants 31 and 32 maintained that the user environment analysis aims to understand where all user actions are generated, where the target product is situated, the interactions between them, and their surroundings during use.

Sometimes there is a case where a new product function can be defined according to the user environment analysis. For example, in the case study of a wheelchair, new functionality needs to be added for situations where users may need to climb stairs or a boarding decker *(Figure 4.14*).

Figure 4.14. *A boarding decker and stair lift for wheelchair users*

Although the above case is an exception, having product usage analysis take place first before user environment analysis is ideal, as most product usage functions with user interactions have special circumstances with respect to the environment.

Method 1.2.6: Usability Considering

Based on an understanding of the usage behaviours in the given surroundings, usability consideration work (Method 1.2.6) can be conducted. Usability work aims to discern how consumers can use products more comfortably with fewer problems, both physically and emotionally. Therefore, focusing on how users interact with each touch-point, the possible range of ergonomic data, called 'Human Factor Engineering' (HFE) data, can be calculated.

Many participants maintained that if the possible range of ergonomic data are not estimated in the FFE, many critical problems will occur in prototyping (Task 6) and in the following NPD phase. First of all, they argued that developing a feasible prototype takes an excessive amount of time since they have to consider this work simultaneously with the prototype itself. Next, when design teams do not consider this work in an early design stage but left it to the actual design stage, they were frequently faced with identifying a great number of parts which had to be revised in the actual embodiment phase. Also, when revising one part, they had to revise another part and another part, successively, resulting in significant time and money costs. There were also cases where it was too late to modify defective parts, and so products would ship with those defects built in. The only way to avoid that was to return to the FFE or even halt the project in its entirety. Thus, these cases indicate the need to produce a proper range of ergonomic data in the FFE.

Participant 28 provided an example case study of how usability consideration work takes place, and how it is based on the preceding interaction system analysis. This case shows the importance of estimating the range of data for usability while considering user interaction. If the text displayed on the screen of a tablet PC is too small, users will have difficulty reading it. They may lower their heads toward to screen or bring the tablet closer to their eyes: designs which force users to engage in additional behaviour but without providing any additional functionality or benefit is not considered good design.

Returning to the example of the layette steriliser (shown in *Figure 4.15*), when project participants calculated the proper range layette steriliser of the diameter of the lid's handle, the universal width of the palm was first considered. Then, since the proper placement of the device was determined to be next to the sink in the corner of the kitchen, the proper range of the width and length of the lid had to be smaller than the diagonal distance between the corners in order to prevent any physical obstructions. Also, the arc of the lid's movement had to be shorter than the diagonal distance between the corner's edges, not just so that the lid could be used at all, but so that it could be used comfortably. They also needed to consider potential interference with other appliances or pieces of furniture that might be found in the kitchen. Without these considerations, the overall product would have been harder to use, and thus inferior in the eyes of consumers.

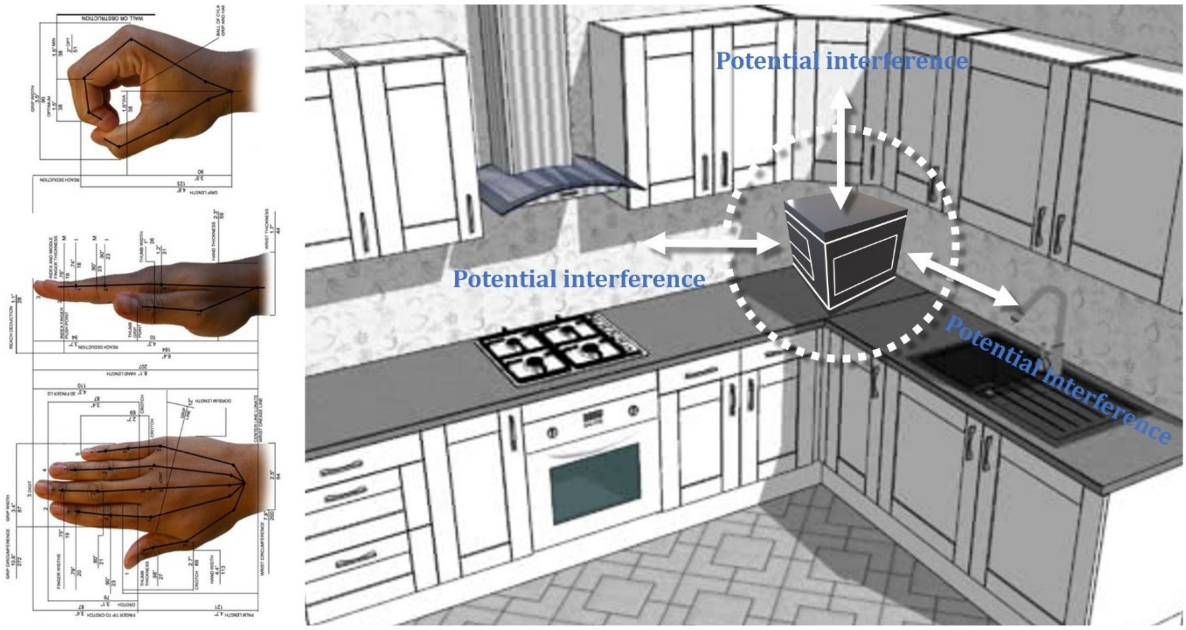


Figure 4.15. *Consideration of the ergonomics and kitchen environment (layette steriliser design)*

Another thing noted in the script was the relationship between usability and intuitive design. Intuitive design refers to designs wherein users can quickly infer what to do without the need for deep thought; the product operates the way their instincts would suggest. One such case study was described in written form by participants 05 and 06. A "large", "red" button that is "extruded" on the surface of a medical device conveys very specific signals. Doctors and nurses can find the button "rapidly" in "emergency" situations because of its visual distinctiveness. They also intuitively "push" the button because of its "extruded" form. In this example, we realise that intuitive design is also closely related to the user interaction system in the sense that users perceive first what those parts of the product intend to do and then carry out those particular actions accordingly.

Method 1.2.7: User Scenario Work

The last performance in user-driven research is the development of the user scenario (Method 1.2.7). According to participants 16 and 18, the user scenario, also known as the user story, aims to draw an overall scene of how the product is used in a given environment. This would incorporate data produced from all of the above implementations, meaning that it is logical for this to take place last. The user scenario is sometimes developed in the form of a cartoon along with a narrative story using the '5W1H' format (Who, What, Where, When, Why, How). One page of the drawing can include all of the information, which helps to comprehensively convey all user behaviours and potential use cases. Participant 16 provided a part of the user scenario when describing the development of an electric heater and dishwasher.

In conclusion, user-driven research begins by investigating the order in which target users use the target product. Each step of the product usage process can generate a user touch point. Each touch point can involve the interaction system between the users and the target product. After determining what form the interaction takes, we can see how consumers make use of the product in a given set of environments. This leads to a usability analysis, looking at the product's ergonomics. By encompassing all information researched above, the user scenario (or user story) can be devised to comprehensively understand user behaviours with respect to the target product.

1.3) Aesthetic-and-Symbol-driven Research Activity

Aesthetic-and-symbol-driven research (Activity 1.3) aims to manage the exterior elements of a product to increase aesthetic value (as per participant 01) and to aid the user in operating the product, through semiotics (as per participants 05, 06 and 13). According to participant 02, this activity is significant in that the product exterior plays a role in attracting users to the product in the first place, by providing a positive first impression. In addition, participant 19 argued that dealing with product appearance is a critical issue for finding new opportunities since today there are generally few significant differences between products in the same market from the viewpoint of product function and quality, at least not when the products are at the same price point

Product appearance generally consists of four elements: shape, colour, material and finishing touches. In dealing with these elements, many interviewees stressed the importance of discovering what the most appropriate forms are for each element, in the early design stage. Based on their experience, when they did not propose a possible range of shapes, colours and materials in the initial stage of the FFE, it would take a long time for them to devise conceptual designs in the later stage of the FFE. They also insisted that if practitioners do not quickly determine the scope for each element early on, there is a risk of overlooking better conceptual designs as the elements (in this scenario) would not yet have been studied step by step. Above all, when they modified the elements of one part in the conceptual design stage, those of another part had to be changed successively because of the visual harmonisation required between each part; a change in the colour might require a change in the material etc. They noted that not only can this lead to losses in time and cost through unnecessary iterative work, but also in the worst case, there also may be a significant possibility of having to go back to the very beginning stage of the FFE to start the project again. These cases imply how important it is to manage the proper scope of the product exterior elements in the initial FFE phase.

In handling those four elements, most of the participants progressed in the following order, managing first the shape, the colour, the material and the finishing specifications. Most interviewees, including 04, 05 and 13, bundled the colour, material and finishes together and attended to these elements, calling them "CMF". Some participants, e.g. 01, 02 and 03, addressed the shape, colour and material together (in that order), considering them to be the three major elements of the product's exterior. In the case of participant 19, they considered the shape, colour, material and the finishes to be a 'bundle', in that order, handling symbols separately.

However, it was noted that possible shapes can sometimes be determined by the characteristics of the materials, and sometimes the range of possible colours is similarly limited. The converse is also true; the required colours may limit what the final shape can be or what materials can be used. According to interviewee 13, despite the same finishing specifications, products may be visually different (wider or narrower; deeper or shallower) again depending on the colours and materials covering the surface of the product, even if the product otherwise has the same functionality.

Therefore, our principle is to look at these four elements sequentially: the shape, colour, material, and finishes, but leave it open as to whether it should be conducted together in a batch.

The aesthetic-and-symbol-driven research (*Activity 1.3*) is thus to be performed in the following sequence:

1) **Method 1.3.1: Shape Scope Exploration**
2) **Method 1.3.2: Colour Scope Investigation**
3) **Method 1.3.3: Material Scope Examination**
4) **Method 1.3.4: Finishing Specification Scope Setting**
5) **Method 1.3.5: Symbol Function Understanding**
6) **Method 1.3.6 Aesthetic-and-Semantic Board and Image Map Development**

Full details are illustrated below, based on a summary of the analysis of the interview scripts (see *Figure 4.16*), which was analysed from the raw analysis data shown in *Appendix 3* (*pp. 555-558*).

Aesthetic-and-Symbol driven Research in Opportunity Identification-Screening

Participant	Method	Feature	Case Study
01, 02, 03, 09, 15, 17, 19, 24, 28, 32, 37	1 Shape Scope	. Morphological form . Contours . Proportions	. User interface in touch-screen display . Control panel types . Tempered glass of display . Home appliances . Mobile phones . Power drills
01, 02, 03, 05, 06, 13, 19, 24, 28, 32, 37	2 Colour Scope	. C of 'CMF' . Chromatics	. Medical devices . User interface in touch-screen display . Control panel types . Tempered glass of display . Home appliances . Power drills
01, 02, 03, 05, 06, 09, 13, 15, 17, 19, 24, 28, 29, 32, 37	3 Material Scope	. M of 'CMF'	. Medical devices . User interface in touch-screen display . Control panel types . Tempered glass of display . Power drills . Public bicycles
05, 06, 13, 22, 33, 19	4 Finishes Scope	. F of 'CMF' . Gap between assemblies - The degree of completion in design (Appearance quality)	. Electronics . Home appliances . Mobile phones
05, 06, 13	5 Symbolic Function	. Shape, colour, material finishes	. Electronics . Vehicles . Medical devices
19, 28	6 Image Map & Sematic Board	. Image map tool . Aesthetic & Semantic board tool	

Figure 4.16. *A summary of the analysis of the aesthetic-and-symbol-driven research activity in Task 1*

According to participants 19, 32 and 37, the exterior of the product can be comprehensively influenced by new trends and user preferences (which is generally identified in the initial two channels (Task 0) for establishing improvement or development directions for incremental and radical NPDs). If the keywords in a given trend are ‘slim’ and ‘sleek’, say in an archetypal smartphone, such that the initial improvement direction aims to produce a thin, streamlined mobile, the aesthetic-and-symbol-driven research activity can centre around these two agendas. Interviewee 32 described another example. The initial direction in their project was based on a new customer preference: a desire to create a living room and kitchen atmosphere akin to an art gallery. Hence, the shapes of appliances in their product line became more curved. Their colours were more varied, using patterns to make the products seem like action paintings. The surfaces were also made of high glossy materials.

Method 1.3.1: Shape Scope Exploration

Based on this concept of a relationship between trends, user preferences and product exterior elements, the first work to be performed is finding the proper scope of the shape (Method 1.3.1). This work is nominating a possible sort of shapes for the product and its components, with an outline (contour). In the case of radical NPD, based on the initial development direction, the possible shapes for the product are usually devised in advance, and then shapes for specific parts are then formed. In incremental NPD, the reverse is true; practitioners generally focus on the possible kinds of shapes for the parts which need to be improved, and then the overall shape changes gradually, in harmony with those altered parts.

Next is the investigation of the CMF: the colour (Method 1.3.2), material (Method 1.3.3), and finish (Method 1.3.4). The colour and material form a plane on the outline (contour) mentioned above, infused with more detail to create aesthetic values.

Method 1.3.2: Colour Scope Investigation

The colour investigation (Method 1.3.2), which is the first performance after the shape exploration, aims to find the possible colours which match with not only the devised shapes but also with user demands and prevailing trends. If the colour of the year is expected to be purplish, the overall colour of the product could possibly be within the purple bracket, such as violets or indigos, harmonised with the nominated shapes. Alternatively, various purplish colours can be suggested for use in one or several components (as opposed to the whole product) as a point colour to draw customer attention.

Method 1.3.3: Material Scope Examination

Then, the possible materials (Method 1.3.3) can be examined, with consideration of which materials match with the chosen colours or are feasible to embody those colours without critical problems. The particular characteristics of materials can hinder certain colour choices.

For instance, bright colours may be difficult on chromed surfaces because of the nature of that metal. In the case of bright colours, steel or plastic (where colours can be painted on easily) is normally utilised. Most white goods are thus made of those materials.

According to participant 19, there was a case wherein a need to concentrate more on the shape arose. The developers had to create a product with a radically curvilinear shape, which led them to use plastic instead of steel.

Method 1.3.4: Finishing Specification Scope Setting

Following the colour and material exploration, the possible finishing specifications (Method 1.3.4) can be established. These finishing touches are classified into two aspects: 1) setting gap between the assembly (also called the 'Parting line'), and 2) manage the quality of colour and material. Whereas the latter one is considered in the later part of the process, the FFE phase focuses more on the former, setting the range of the gap between part assemblies.

Participants 22 and 33 highlighted the importance of determining the scope of the finishing specification in the early stage. If such a work is neglected, the product will suffer aesthetically. They also argued that the status of the parting lines represents the degree of completion in the design, which affects whether customers want to purchase or not. In pursuit of recent trends, participants 22 and 33 worked to reduce the gap as much as possible or to completely remove any visible parting lines on the surface of the product. In the case of small products, from the initial design phase, the designers strived to design the product surface such that there were no parting lines at all, enabling the production of the entire shell of the product by taking a mould in the actual embodiment phase.

Method 1.3.5: Symbol Function Understanding

These major four elements, which determine the appearance of the product, contain symbolic functions (Method 1.3.5), the last element to be researched. A symbol is a kind of message which each element (or a combination of elements) conveys to users.

Participants 05, 06 and 13 spoke of an appropriate example (shown in *Figure 4.17*). When they developed medical devices, they usually used white or grey colours to signal good hygiene. Also, they utilised red to represent first-aid supplies. They used green and blue, complementary colours to the red colour of blood, to increase visibility between parts stained with blood and clean parts. In particular, medical supplies for children were yellow, the same colour of many toys. This helped to reduce the potential fear that children may feel when faced with medical equipment.

Figure 4.17. *Different symbolic functions of various colours*

Method 1.3.6 Aesthetic-and-Semantic Board and Image Map Development

Lastly, based on the analysis of the product exterior elements above, an aesthetic-and-symbolic board and image map (Method 1.3.6) can be developed. This map conceptualises an overall image of the target product by reflecting the proposed scope of the shape, colour, material and the finishing specification. For each product element presented on the image board and map, assigned symbolic meanings are also indicated.

To conclude, the aesthetic-and-symbol-driven research explores the possible shapes for the target product, both in its entirety and for its component parts. Then, appropriate, colours and materials that best match with those shapes can be suggested. Furthermore, finishing specifications can be examined to increase the degree of completion of the target product. Lastly, the symbology of the shapes, colours, materials and even finishing specifications are described. Because of the connection between these five elements, any consideration of them must be managed interactively, with the final concept resulting in a complete image of the target product.

However, as mentioned above, the preceding four elements – shape, colour, material, and finish – can be treated together, regarded as a bundle. Even so, if we keep the contextual connection of those elements in mind, contextual performance within the bundle can be achieved.

1.4) Technology-driven Research Activity

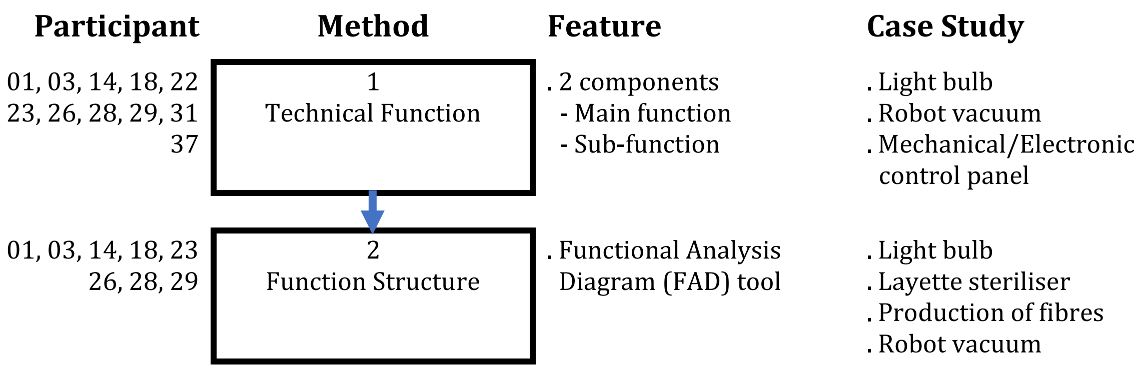
Technology-driven research (Activity 1.4) is vital in that many new firms that have been recently created are based on new technologies, a trend that speaks to the technology-led nature of today's industries. Participant 14 stressed that these days many projects are triggered by new technologies, so that there are many cases in which the technology-driven research leads to the establishment of entire projects. Considering the relationship with other activities such as the market-driven, user-driven and aesthetic-and-symbol-driven research activities, technology-driven research can play a pivotal role since it takes the lead in enabling the product functions.

To realise these physical functions, seven relevant performance methods can be undertaken in the following sequence:

1) **Method 1.4.1: Technical Function Definition**
2) **Method 1.4.2: Technical Function Structure Formation**
3) **Method 1.4.3: Technical System Structure Formation**
4) **Method 1.4.4: Technical Parameter Estimation**
5) **Method 1.4.5: Operation Mechanism Suggestion**
6) **Method 1.4.6: Technical Dimension Estimation**
7) **Method 1.4.7: Required Technology Identification**

Full details are illustrated below, based on a summary of the analysis of the interview scripts (see *Figure 4.18*), which was obtained from the raw analysis data shown in *Appendix 3* (*pp. 559-562*).

Technology-driven Research
in Opportunity Identification-Screening



			. Mechanical/Electronic control panel
01, 03, 14, 18, 23 26, 28, 29, 31	3 System Structure	. Product system architecture	. Production of fibres . A solar-powered desalination device . Robot vacuum . Mechanical/Electronic control panel
03, 14, 18, 22, 23 26, 28, 29, 31, 37	4 Technical Parameter	. Expertise on - Electrical & Electronics - Computing - Materials science - Mechanical engineering : Five major mechanics - Dynamics - Statics - Thermodynamics - Fluid dynamics - Material dynamics	. Lamp . Washing machine . Mechanical/Electronic control panel . Public bicycle . Robot vacuum
03, 14, 18, 23, 26 28, 29, 31, 38	5 Working Principle	. Expertise on - Electrical & Electronics engineering - Computing - Materials science - Mechanical engineering : Five major mechanics - Dynamics - Statics - Thermodynamics - Fluid dynamics - Material dynamics	. Production of fibres . Mechanical/Electronic control panel . Robot vacuum . Furniture . Layette steriliser
03, 14, 15, 17, 18 28, 29, 31, 38	6 Technical Dimension		. Production of fibres . A solar-powered desalination device . TV display . Lamp . Furniture . Layette steriliser
14, 17, 22, 23, 26 28, 29, 31, 37, 38	7 Required Technology	. Technology Road Map (TRM) tool	. Robot vacuum . TV display . Washing machine . Mechanical/Electronic control panel . Furniture . Layette steriliser

Figure 4.18. *A summary analysis result of the technology-driven research activity in Task 1*

In NPD, technology-driven research is sometimes triggered by new technological trends or because of new or renewed popularity in certain technologies which users want to possess by using a particular product (which is defined from the initial two channels for defining the improvement or development directions (Task 0)).

Method 1.4.1: Technical Function Definition

Based on the target product in which such trends and technologies are reflected, the first implementation in technology-driven research is defining the technical functions (Method 1.4.1) of the product. As shown in the blue label 04, the technical role is divided into the main function, and the sub-functions which support or enable the main function.

Participant 01 provided an example case study of a light bulb to explain this basic concept (*Figure 4.19*). The purpose ('Usage Function') of a light bulb is to illuminate a room. However, 'Technical Function' is simply to emit light. To achieve this, the bulb's filament (in the case of incandescent bulbs) serves as the luminous source. The lead-in wire provides electric current to the filament. The cutoff valve placed at the beginning of the bulb's neck plays a role in protecting the pinch and base from heat. These are all the main mechanisms, the technical functions which allow the bulb to operate. There may be sub-functions when a product is more complex. The bulb is comparatively simple, and so sub-functions are not required.

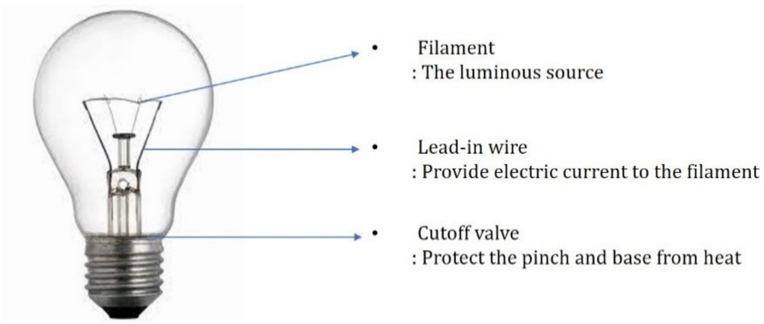


Figure 4.19. *Technical functions of the bulb*

The technical function definition task differs depending on the type of NPD taking place.

For radical NPD, we envisage each technical component which makes up the overall technical operation of the target product. In the document describing the development of the new device to sterilise layettes, the technical features were extensively studied by expert practitioners. Firstly, a body case was required to anchor the inner components (main function) as well as to protect them (sub-function). Next, a container for the sterilisation process to take place (main function) was needed. The developers then envisaged a second container to store the germicide (main function). They also required an inlet to allow users to fill the second container with germicide, and an outlet to expel dirty water. A conduit was also required to allow the germicide to flow into the main chamber (main function). They needed a prime mover – in this case an electric motor – to operate the device (main function) and a power cable to convey electricity to the motor (main function). In this way, technical functions of all the remaining components were also specified.

Conversely, the technical function definition in incremental NPD focuses on the parts which are to be improved, working atop the current configuration of the device. This does not mean that the rest of the technology configuration does not need to be specified with the technical role, except for the improvement parts. According to participants, there were indeed many cases in which the technical functions of in an existing 'composition' were altered, depending upon the functions of the improved part. Therefore, they had to redefine most of the technical functions. This indicates that each of the technical roles are connected. It further implies that technical functions should be defined for all technical compositions no matter what the NPD attribute is.

Method 1.4.2: Technical Function Structure Formation

Once the technical roles have been defined, the next task is to set out the technical function structure (Method 1.4.2). As mentioned above, the roles of the technical compositions are functionally connected with each other. Some exist independently, but not many. Technical compositions are structured inside of the product, taking into account the relationship of each composition's role.

We can understand more about how each technical role can be linked and positioned by revisiting the example case studies of the bulb and the steriliser. First, the bulb. 'The lead-in wire allows electric current to flow into the filament'; this role indicates that the lead-in wire is situated between the electrical inlet and the filament. For the steriliser, 'An inlet through which new germicide enters and an outlet from which contaminated water flows out' implies that the inlet is in the container that stores the germicide, while the outlet is placed at the end of the conduit enabling the flow of polluted water. Participant 01 said that this work resembles the work that produces 'Functional Analysis Diagrams' (FAD).

Method 1.4.3: Technical System Structure Formation

The technical system structure (Method 1.4.3) can be devised by advancing the function structure. In the technical functional structure, each technical function has a processing system which operates those functions. Also, the connection between each function has its own processing system, enabling the operation of those functions together. In this, the system structure is developed by understanding of each processing systems and their relationships.

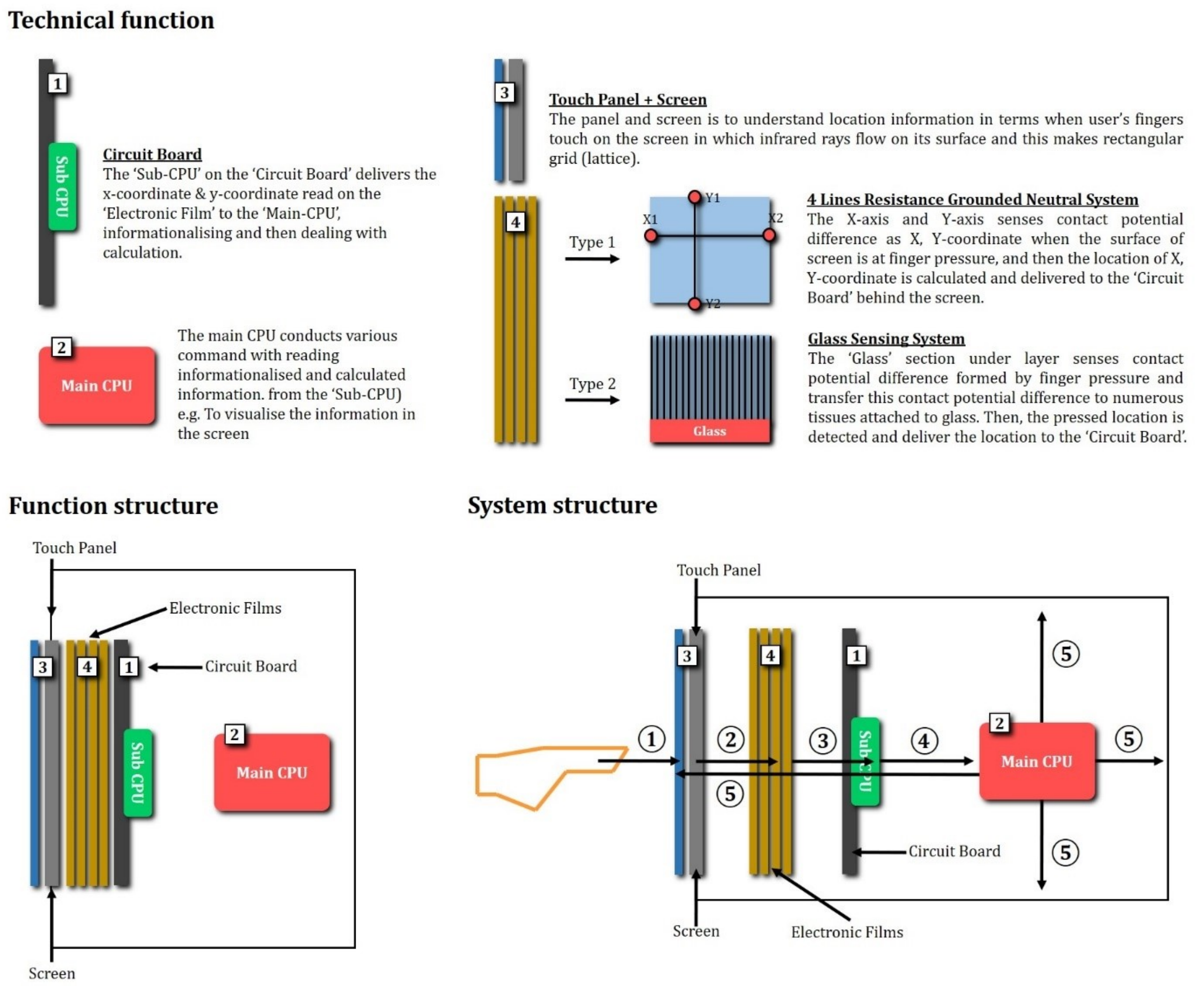


Figure 4.20. *System structure of the touch-screen*

Participant 24 offered an example case study of a system structure used in one of their projects. *Figure 4.20* illustrates the technical function and system structure of a touch-screen developed for a kiosk in a railway station. The top part of the figure depicts the technical roles and processing systems of the four main compositions, 'Main CPU', 'Sub-CPU', 'Touch panel and Screen' and 'Electronic film'. The lower-left part of the diagram shows the overall functional structure of the touch-screen in which these compositions are connected and positioned. The lower-right part depicts the system structure in terms of how the touch-screen is operated. The labels and arrows present the directions and a sequence of each processing system.

According to participant 02, sometimes, the functional deployment of technical compositions is altered based on processing systems defined in the system structure. To keep the system working smoothly, the connection and placement of technical components are sometimes reconfigured.

After developing the system structure, the technical parameters can be estimated, the operation mechanisms can be suggested and the possible range of technical dimensions anticipated, in that order. Many participants contended that unless these implementations are conducted in the early stages, factors that hinder the physical operation of the product will frequently arise when designing and testing the prototype. Also, they cited difficulties wherein if they modified one flawed part, they would have to modify another and another, in a chain reaction. It was not just a matter of wasted time and effort; they often had to conduct the initial part of the FFE again.

Method 1.4.4: Technical Parameter Estimation

Along with the significance of those three technical implementations, firstly, the technical parameters (Method 1.4.5) can be estimated. Between the individual processing systems, a system flow is generated, which means that a particular form of input energy enters the processing system and output energy exits. The type of energy depends on the type of processing system. Therefore, the calculation of technical parameters requires various fields of expertise such as electrical and electronics engineering, computing, materials science, and mechanical engineering, including all five major mechanics types: dynamics, statics, thermodynamics, fluid dynamics, and material dynamics. Participant 14 contended that in both incremental and radical NPD, technical parameters can be quite accurately estimated as long as the system structure is defined specifically. According to interviewees 23, 26 and 28, the calculated technical parameters can sometimes cause the replacement of functional structures or lead to reconfigurations of directions and the sequence of system flows.

Method 1.4.5: Operation Mechanism Suggestion

With estimated technical parameters for the processing systems in hand, an operation mechanism (Method 1.4.5) for both the technical compositions themselves and their systemic relationships can be proposed. At this stage, we can expect to understand quite accurately not only how the product operates but also its technical compositions.

Method 1.4.6: Technical Dimension Estimation

The possible range of technical dimensions (Method 1.4.6) can be calculated based on the preceding operation mechanism and the technical parameters.

In the case products operated mechanically, their operational mechanism and kinetic radiuses and directions help to determine the proper range of their technical dimensions. For example, during the PhD period, this author worked on a project to develop an automated system for the production of fibres used in the engine of an automobile (*Figure 4.21*). We developed an automated conveyor belt, involving a series of tools for cutting, drying and tying fibres. Considering not only the operational principle of the conveyor belt and the tools but also their kinetic radiuses and directions, the possible range of dimensions for each composition that made up the belt and the tools were estimated.

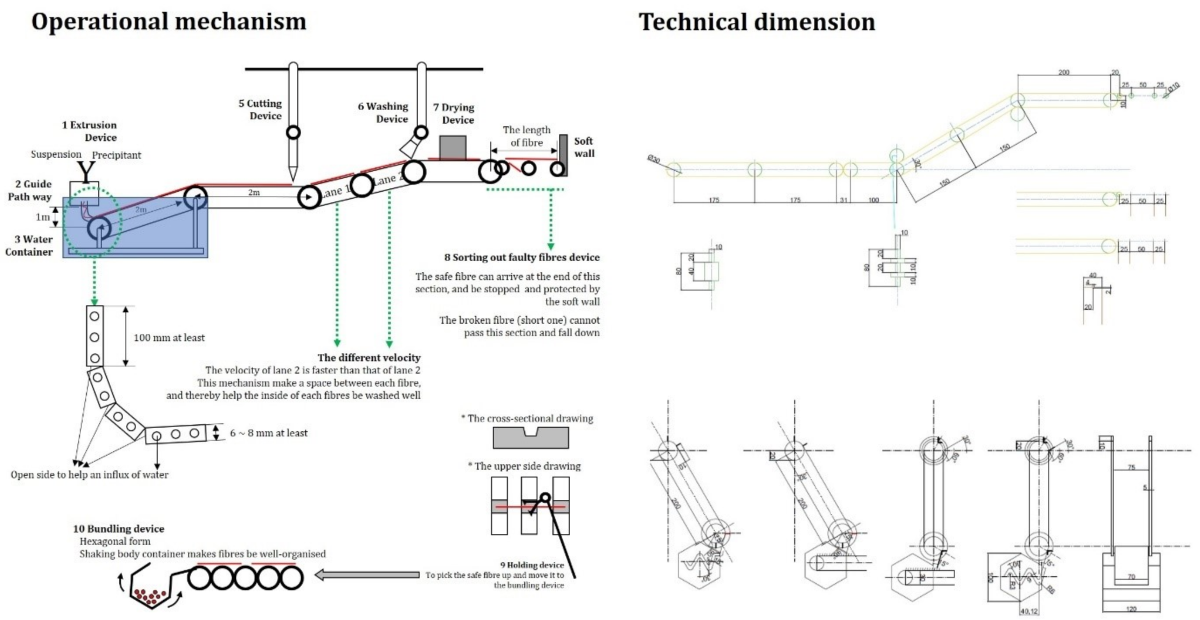


Figure 4.21. *Technical dimension measurement of an automated system for the production of fibres*

In the case of products which do not appear mechanical motions, the adequate range of the technical size for compositions can be decided by considering working principles in terms how driving energies – electricity, solar heat, and wind and tidal power – fire up these compositions. For instance, the author participated in another project to develop a solar-powered desalination device. We calculated the range of the solar panel's size which can generate sufficient electricity to support the production of 15 L of fresh water per day from ocean water, based on an understanding of the working mechanisms of desalination along with various technical parameters, e.g. solar irradiation, the efficiency of solar thermal devices (evacuated tube), thermal energy output for a 1 m^2 solar thermal panel, panel temperature, the latent heat of vaporisation, permeate flux (freshwater output), etc.

Sometimes, there are cases wherein the technical dimensions are directly determined after the calculation of parameters, without a need to understand the operating mechanism (tagged with blue, 122 and 131). This tends to be cases where the technical compositions exist independently and their material properties such as elasticity, inertia, and friction force, wear coefficient, and density of chemical composition, affect the functional and system structure significantly.

Method 1.4.7: Required Technology Identification

The final task in technology-driven research concerns the technologies (Method 1.4.7) required to operate the entire product. Here, the technologies can be identified, after considering the outcomes of previous implementations either selectively or comprehensively. Interviewee 14 contended that it is generally difficult to know exactly what technologies are required before defining technical functions, functional and system structures, relevant parameters and working principles. 'Required technologies' can be divided into technologies that have been developed previously and simply need to be incorporated into the product, and technologies that do not yet exist and need to be newly developed. Therefore, the 'Technology Road Map' (TRM) toolkit may be effective here, as it enables tracking of the technologies of the past and present, and the technologies expected in the near future.

To sum up, technology-driven research starts by defining the roles of the technical compositions that make up the target product. Based on an understanding of the connections between technical roles, each composition can be deployed, forming the functional structure of a product. By grasping the processing systems of each composition and their systemic relationships in the wider functional structure, the system structure can be devised, with consideration of how the product can be operated technically. Then, technical parameters can be estimated for those processing systems and their systemic connections. Based on these parameters, the working principles of both the product and its compositions can be understood. Then, with the operational mechanisms and the associated parameters, the proper range of the technical dimensions can be calculated. Lastly, considering the outcomes of previous implementations either selectively or comprehensively, technologies required to operate the product and its compositions can be examined.

There are, on occasion, exceptional cases. Participant 31 presented a case where an appropriate operating mechanism was suggested prior to parameter estimation. He suggested that the working mechanism preceded the system structure formation. There are also cases where an understanding of the operational mechanism proceeds without parameter estimation and in advance of the system structure construction, and where the operation mechanism understanding is conducted after the technical function definition. In addition, the required technologies are defined after the estimated parameters are calculated, without understanding the working principles. These tend to be cases where technical compositions exist independently, and those compositions can be embodied by considering their material properties only.

Thus, based on the analysed context revealed in the script, the contextual sequence of the seven works defined above can be used as a standard for conducting technology-driven research (Activity 1.4), and those exceptional cases can be utilised selectively in relevant situations.

2) Concurrent Collaboration

This section addresses different forms of concurrent collaboration which can be operated in Task 1 (Opportunity Identification-Screening). A total of 21 forms of concurrent collaboration centred on each functional domain (the market-driven, user-driven, aesthetic-and-symbol-driven and technology-driven) were identified (shown in *Appendix 3, pp. 547-562*). By means of the phenomenological analysis (contextual interpretive analysis) on the various FFE execution principles and case studies, revealed in those 29 forms, a total of 8 potentially viable forms of concurrent collaboration were inferred. Full details of each of these forms are described with the relevant case studies.

2.1) Form 1

Depending on the user type (Method 1.1.1) and target markets (Method 1.1.4), the product usage functions (Method 1.2.4) can differ, resulting in different technical functions (Method 1.4.1) on the back of those usage functions, which involve different technologies (Method 1.2.7) to embody those functions.

Form

<table>
<tr><td rowspan="2">Module</td><td>Composition-modules
1.1.1 & 1.1.4
in MK</td><td>Composition-module
1.2.4
in UE</td><td>Composition-module
1.4.1
in TC</td><td>Composition-module
1.4.7
in TC</td></tr>
<tr><td>User segment & PDP</td><td>Product usage function</td><td>Technical function</td><td>Required tech</td></tr>
<tr><td rowspan="3">Concurrent Collaboration</td><td colspan="2">→ 1</td><td></td><td></td></tr>
<tr><td colspan="4">→ 2</td></tr>
<tr><td colspan="4">(→ 2) → 3</td></tr>
</table>

MK=Market-driven research, UE=User-driven research, AS=Aesthetic-and-Symbol-driven research, and TC=Technology-driven research

Participant

34, 35

Case Study

. Mobile phones (high-end, high-spec market versus low-price, high-volume market)

Figure 4.22. *Concurrent collaboration form 1 in Task 1*

Participants 33 and 35 depicted a relevant example regarding a series of mobile phones. Depending upon the different user types and the position within the market (e.g. between the high-end, high-spec market and the low-price, high-volume market), the product usage functions required in mobile phones and the technical functions and technologies used can differ, e.g. security systems can range from simple PIN entry systems to more sophisticated biometric systems like fingerprint verification, facial recognition, or iris scanning, each of which requires specific sensors and software to operate.

2.2) Form 2

Depending on the user types (Method 1.1.1) and target markets (Method 1.1.4), the preferred shapes, colours, and materials of a product can vary (Method 1.3.1 to 1.3.3). These differing product appearance elements (Method 1.3.1 to 1.3.3) have different inherent properties (Method 1.4.4), requiring different technologies (Method 1.4.7) to embody those elements.

Form

<table>
<tr><td rowspan="2">Module</td><td>Composition-modules
1.1.1 & 1.1.4
in MK</td><td>Composition-modules
1.3.1 to 1.3.3
in AS</td><td>Composition-module
1.4.4
in TC</td><td>Composition-module
1.4.7
in TC</td></tr>
<tr><td>User segment & PDP</td><td>Shape, Colour & Material</td><td>Technical parameters</td><td>Required tech</td></tr>
<tr><td rowspan="3">Concurrent Collaboration</td><td colspan="2">→ 1</td><td></td><td></td></tr>
<tr><td colspan="3">→ 2</td><td></td></tr>
<tr><td colspan="4">(→ 2) → 3</td></tr>
</table>

MK=Market-driven research, UE=User-driven research, AS=Aesthetic-and-Symbol-driven research, and TC=Technology-driven research

Participant

31

Case Study

. Watches (Divers' watch versus Firefighters' watch)

Figure 4.23. *Concurrent collaboration form 2 in Task 1*

One salient example is provided by participant 31 (*Figure 4.24*). Divers and firefighters each need different watches with unique functions, built from specific materials. Divers prefer watches with round shapes to endure the flow of moving fluid when submerged. Firefighters prefer a more angular shape to use with other functions, e.g. hanging rescue apparatuses such as a length of rope, buckles, and pegs. Divers tend to demand a reddish or at least one whose colour contrast with the colour of water. Firefighters typically demand a watch types (texts-and-images) coloured in green or bright grey, which increases visibility in burning structures. Divers need waterproofing for higher depths than what standard watches provide, and perhaps also a helium release valve. Firefighters need a high level of heat resistance so that the watch can be worn on the outside of their "bunker gear" [heat-resistant firefighter gear]. For these different shapes, colours, and materials, inherent technical properties will vary and thus different technologies may be required when developing these watches.

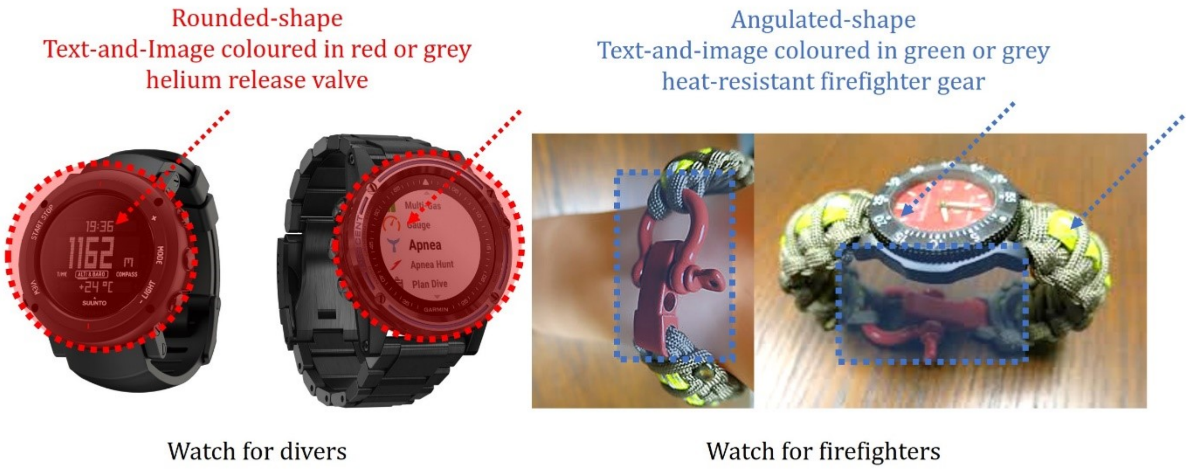


Figure 4.24. *Watch designs for divers and firefighters*

2.3) Form 3

Different user types (Method 1.1.1) are exposed to different environments (Method 1.2.5), which can generate different usability considerations for each component (Method 1.2.6), in turn affecting what working mechanisms are deemed proper working principles (Method 1.4.5) as well as the proper range of technical dimensions (Method 1.4.6) for those components.

Form

Module	Composition-modules 1.1.1 & 1.1.4 in MK	Composition-modules 1.3.1 & 1.3.3 in UE	Composition-module 1.4.5 in TC	Composition-module 1.4.6 in TC
	User segment & PDP	User-environment & Usability	Working mechanism	Technical dimension
Concurrent Collaboration	→ 1			
		→ 2		
			→ 2 → 3	

MK=Market-driven research, UE=User-driven research, AS=Aesthetic-and-Symbol-driven research, and TC=Technology-driven research

Participant

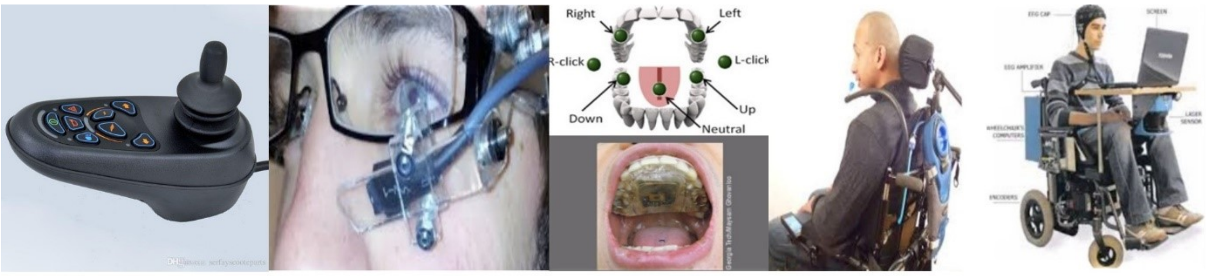
03, 31, 32, 38

Case Study

. Wheelchair
. Layette steriliser
. Disinfecting device for clothes
. Furniture (a drawer in cabinet)

Figure 4.25. *Concurrent collaboration form 3 in Task 1*

In the first case study, interviewees 31 and 32 provide a relevant example with respect to the development of an electric wheelchair (*Figure 4.26*). Depending on the user type (e.g. handicap in the hands, legs, quadriplegia etc.), different product usage functions in the control panel of the wheelchair were required, for use in different environments, e.g. doors of buses and trains, gates at mass transit stations, etc. This led to variations in the working principles of the control panel, e.g. a knob, wheel, or lever, a foot pedal and pad, and even a variation which responded to the facial muscle reactions. Moreover, considering the different environments to which those different working principles are exposed, different technical dimensions were considered in developing the different types of control panels.



Control by finger movement | Control by eye movement | Control by tongue movement | Control by voice recognition | Control by brain signal

Figure 4.26. *Various types of wheelchair controller*

The second case study (developing a new device for sterilising baby supplies), provided by participant 03, can also represent the second form of concurrent collaboration. Depending on the different preferences and lifestyles of various users, the device might be situated next to the sink, dishwasher, and washing machine in the kitchen or next to the layettes themselves in the baby room (shown in *Figure 4.27*). According to the environment in which the device is situated, the possible range of the product's dimensions differed. When developing the lid and its handle, the device's technical dimensions (changes in which affect the product's physical dimensions) were modified so that the device could fit into the anticipated surroundings, increasing usability in terms of convenience. This modification changed the operating mechanism of the lid, e.g. lift-up, pull-down, or a rotating mechanism (left and right).

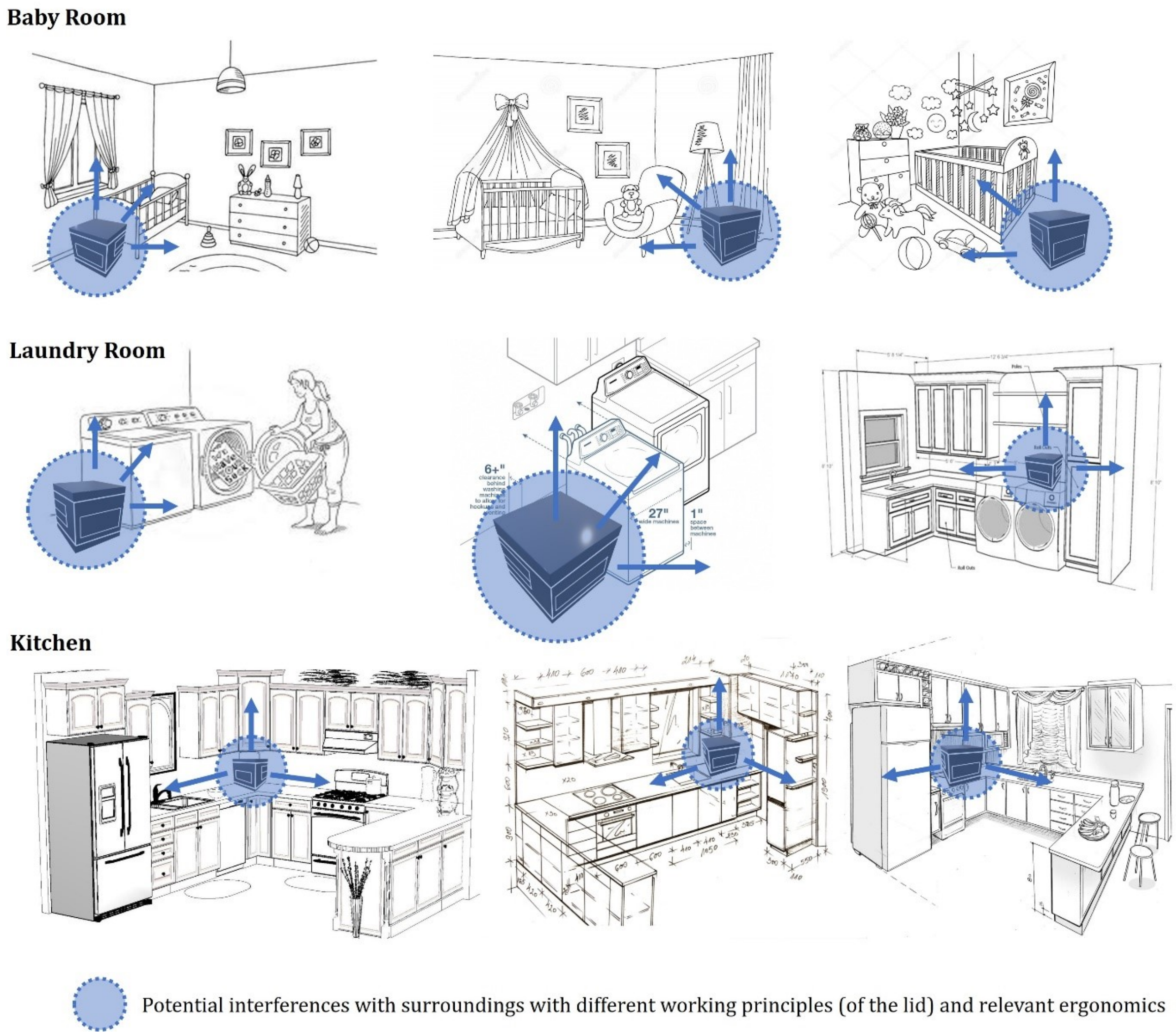


Figure 4.27. *Layette steriliser in different environments*

In the third case study provided by interviewee 38, the project was to develop a particular appliance: a disinfecting device for clothes to eliminate damp and mould. The design team first defined the different user types in terms of whether the users prefer to put the device inside of a wardrobe or next to a rail-type hanger system which is exposed to the open environment. This led to different market positionings such as high-price versus low-price, and high-volume. According to this diverse user segmentation and market positionings, different product usage functions and usability considerations were required, e.g. the entire product usage (a fixed versus portable device), and sub-product usage (recyclable versus disposable containers for absorbing moisture). Considering the different usage functions, different technical operating mechanisms to embody those usage functions were involved. Then, the range of the dimensions for each component such as the battery and the linear compressor, which affects the product's physical dimensions, were managed. Since each dimension of the existing battery and compressor was larger than the dimensions they calculated, this led to a new requirement to develop smaller components.

In the fourth case study (developing furniture, specifically a drawer in a cabinet), participant 38 contended that many designers frequently overlooked the environment surrounding the target product when estimating its technical dimensions and compositions. It is easy to consider only the drawer itself and not the environment in which the cabinet would be situated. However, if designers do not consider both an appropriate size range for the drawer and the scope of its movement – push-in and pull-out – in the given environment, some users might not be able to use the drawer at all if the movement radius is larger than the space the cabinet occupies. To tackle this problem, the design team should reduce the size range for the overall drawer or its some compositions, e.g. handle or other decorations. Also, they may need to change the working principle from the push-in/pull-out to the pull-down/pull-up.

2.4) Form 4

Each user touch-point on the surface of the product (Method 1.2.2) can influence the arrangement of technical compositions inside the product, arrangements which form the function structure (Method 1.4.2).

Form

Module	Composition-modules 1.2.1 & 1.2.2 in UE	Composition-module 1.4.2 in TC
	Product usage process & User touch-point	Function structure
Concurrent Collaboration	→ 1	

MK=Market-driven research, UE=User-driven research, AS=Aesthetic-and-Symbol-driven research, and TC=Technology-driven research

Participant

02, 03, 13, 25, 28

Case Study

. Medical device (endoscopic instrumentation, patient monitor, and medical cart) . Layette steriliser

Figure 4.28. *Concurrent collaboration form 4 in Task 1*

For instance, participants 02 and 13 provided a relevant case study regarding the development of an endoscopic instrument (*Figure 4.29*). Depending on the user type, e.g. doctors and nurses, different product usage functions were required for the medical device. In the case of endoscopic instruments for neurosurgery, the doctors typically made use of the device's main functions (during a surgical operation) while nurses made use of the sub-functions, e.g. resizing the display output or adjusting brightness. These different usage functions are accompanied by different product usage processes, generating different user touch-points. On the back of each single user touch-point, there were several technical components, and their technical function structures were could be constructed differently with considerations of the arrangements of those user touch-points.

Figure 4.29. *Different functions between of an endoscope when used by doctors and nurses*

Returning to the case study of the layette steriliser, provided by participant 03, the product usage process when using the device produced each user touch-point. For example, when users are plugging in the electric cord, the cord itself and the plug are the touch-points. When opening the lid, the touch point is the main frame of the lid, the edge of the lid, or the handle of the lid. When they are setting up the sterilisation functions, the display and all the buttons on the control panel are touch-points. When they are putting germicide into the inlet, the inlet is the touch-point. In this regard, the arrangement of these user touch-points on the surface of the device and the technical function structure inside of the device could differ. Furthermore, by having each user touch-point consist of a single user action, there had to be several technical components on the back of the individual touch-points. Their technical function structures were also now differently configured. For instance, even if users only had to push a single button on the control panel, there are several technical components and varied technical function structures – various mechanical and electrical operations – upon which the button depends, although users only perceive the button as a single touchpoint.

2.5) Form 5

In each interaction system (Method 1.2.3), technical parameters (Method 1.4.4) are generated, each of which require proper mechanisms for operation (Method 1.4.5).

Form

Module	Composition-module 1.2.3 in UE	Composition-module 1.4.4 in TC	Composition-module 1.4.5 in TC
	Interaction system	Technical parameter	Working principle
Concurrent Collaboration	→ 1		
	(→ 1) → 2		

MK=Market-driven research, UE=User-driven research, AS=Aesthetic-and-Symbol-driven research, and TC=Technology-driven research

Participant

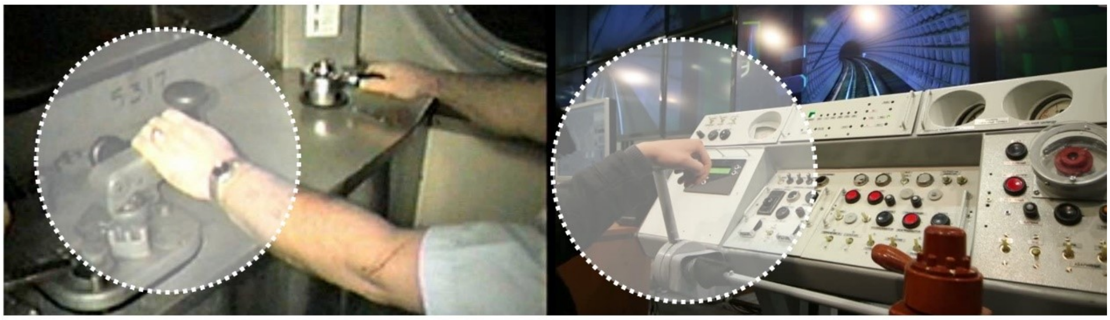
26, 28

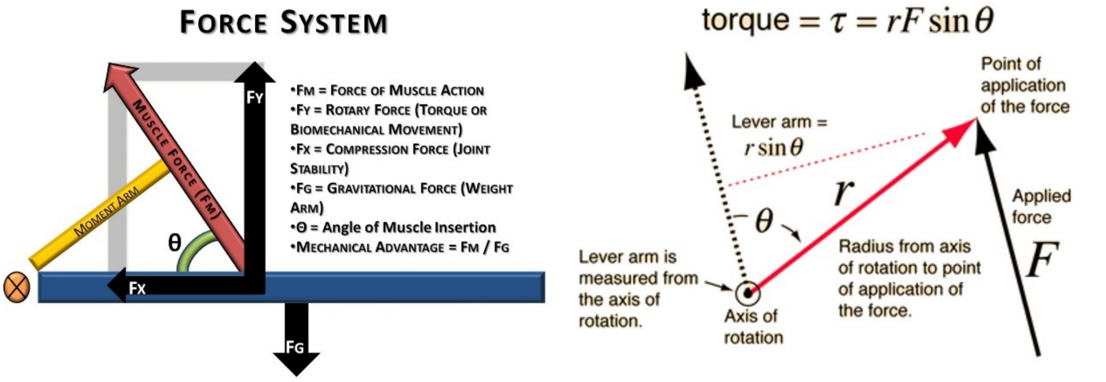
Case Study

. Subway Train
. TV display

Figure 4.30. *Concurrent collaboration form 5 in Task 1*

Lever-arm Mechanism





Touch-screen Mechanism

Figure 4.31. *Lever-arm and touchscreen of a control panel on a London Underground train*

This collaboration form appeared in the example case study of a control panel in a subway train (*Figure 4.31*). According to interviewees 26 and 28, when examining the interaction system in which drivers of the train pull or push on a lever, project participants estimated the average amount of physical force which users exert on the lever arm in order to consider the technical properties of this interaction system between the drivers, the lever, and the lever's movement. These parameters were assessed from a working mechanism point of view along with other technical properties inherent to mechanical operation of a lever. This work (the calculation of the force exerted upon the arm under use) allowed the project participants to consider the proper materials needed to build the lever arm and, if necessary, to change the working principle (an up and down pull of the lever arm). Concerning the materials, they used aluminium due to its low cost, a choice that resulted in the lever arm being bent, a fact discovered during the prototyping because of unexpectedly high levels of force users employ when operating the lever arm. They also noted the possibility of other materials on the back of the lever arm potentially breaking under use. Consequently, they changed the working mechanism of the whole control panel into an electromagnetic touch-panel to counter these risks, abandoning the mechanically-operated lever-arm system entirely.

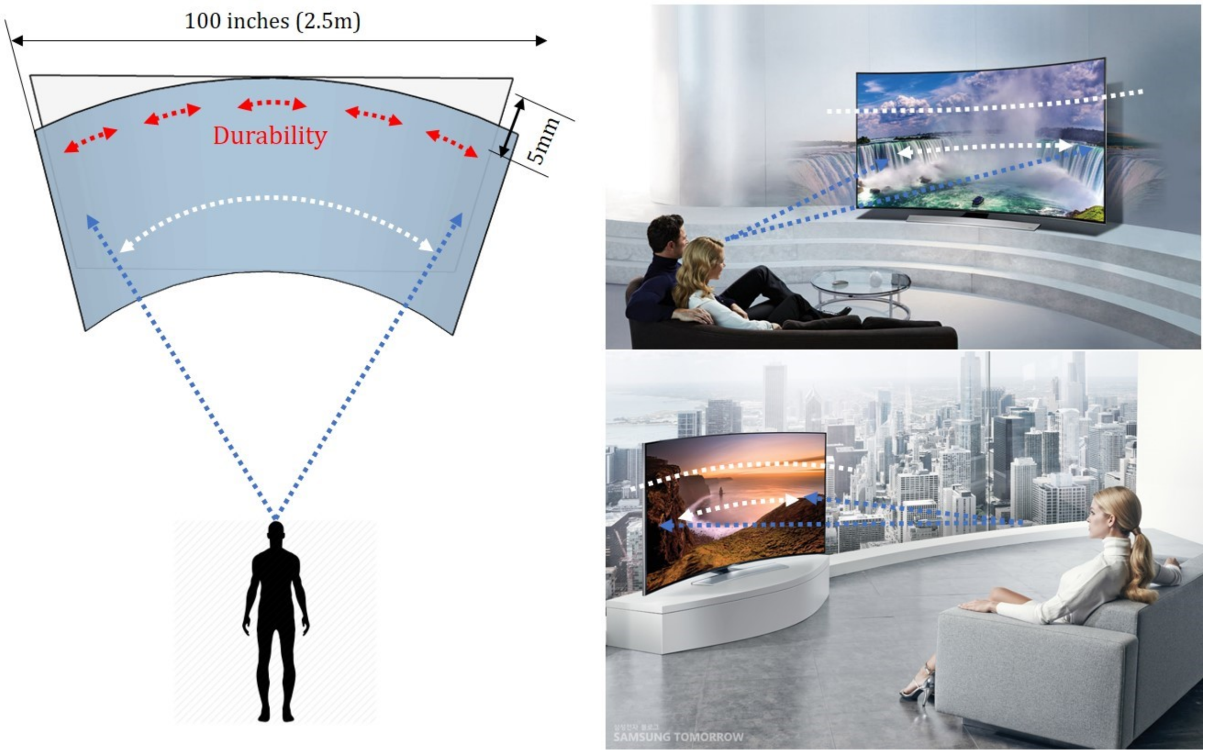


Figure 4.32. *The development of a curved 100-inch TV display*

Participant 17 also spoke of an appropriate example case study which can explain this fifth form of concurrent collaboration (*Figure 4.32*). When they participated in a project to develop a TV display, their first consideration was to create a screen wider than 100 inches (ca. 2.5m) to allow users to feel (the interaction between the users and the TV display) as if they were in a movie theatre. However, when they calculated the technical properties of the interaction between the users and the display, they noticed that at very high screen widths, users cannot see the entire screen all at once. Therefore, to make the screen fully visible without changing the average distance the users sit from the screen, they changed the display's particles, *oh and by the way*, they also considered a curved screen. In addition, considering the interaction system and technical parameters, the thickness of the screen was stipulated to be smaller than 5mm. All these considerations – width, thickness, curvature – narrowed down the possible range of technical principles that needed to be embodied

2.6) Form 6

In each interaction system (Method 1.2.3), product appearance elements (Method 1.3.1 to 1.3.3) (which serve as input signals perceived by the five senses) and their proper scopes (Methods 1.3.1 to 1.3.3), along with inherent symbolic functions (Method 1.3.5) (which serve as the product's output responses) can be proposed, to consider usability (Method 1.2.6). The usability aspect (Method 1.2.6) can affect what working mechanisms (Method 1.4.5) are considered proper as well as the proper range of technical dimensions (Method 1.4.6) for those components.

Form

Module	Composition-module 1.2.3 in UE	Composition-modules 1.3.1 to 1.3.3 in AS	Composition-module 1.4.4 in TC	Composition-module 1.4.7 in TC
	Interaction system	Shape, Colour & Material	Technical parameters	Required tech
Concurrent Collaboration	→ 1			
	→ 2			
	→ 2 → 3			

MK=Market-driven research, UE=User-driven research, AS=Aesthetic-and-Symbol-driven research, and TC=Technology-driven research

Participant

03, 28

Case Study

. Public facilities (park benches and rental bicycles)
. A lamp

Figure 4.33. *Concurrent collaboration form 6 in Task 1*

For example, with the case study of public facilities such as park benches and rental bicycles, interviewee 03 first investigated which interaction systems exist between users and those public facilities (*Figure 4.34*). Then, they tried to use strong and durable materials for increased endurance and to reduce maintenance costs by calculating technical parameters in terms of physical forces which the users exert on the facilities. Also, they tried to use rounded-shapes in their design to reduce the effects of abrasion from frequent physical contact by a huge number of users, through calculation of the physical forces, i.e., when designing a bicycle saddle, they thoroughly considered the technical aspects such as the friction and likely loads, along with selecting the appropriate shape and materials, e.g. a rounded saddle shape made of rubber, steel, or plastic. However, since these considerations (regarding the shape/material) were insufficient to prevent abrasion from use by many individuals, in the sense of devising alternative working principles they needed to come up with new ideas to not only adjust the height/angle of the saddle from the bicycle body but also for replacing the saddle itself frequently in an easy way.

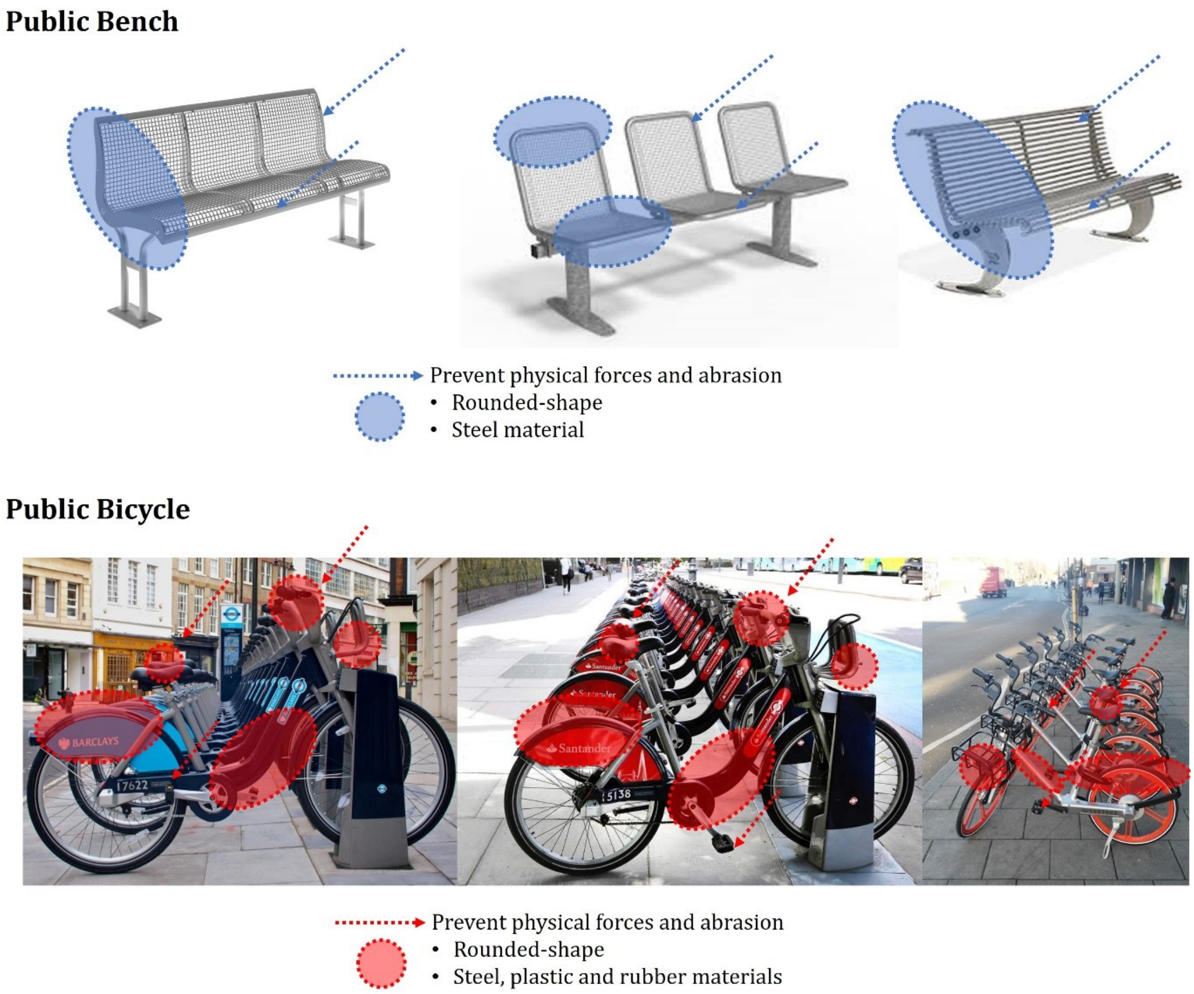


Figure 4.34. *Public bench and bicycle design*

The example case study of a lamp developed by interviewee 28 helps to clarify this collaboration system. They needed to develop a new lamp whose light can give a sense of calm to users since existing lamps provided a much stronger stimulus to the users, emotionally speaking, owing to their high luminous intensity. In order to preserve the technical performance of the lamp as it was, they did not set out to reduce the bulb's luminous intensity (which might have lessened the strength of the stimulus). Instead, to make users more comfortable, they first considered downsizing the bulb, the central component in the lamp: of course, a lamp shade was one alternative but they did not consider this from the outset due to the increase in development cost it would entail. After they reduced the size of the bulb, the scale of the whole lamp had to be reduced to ensure the lamp as a whole had suitable proportions. This created other problems; the design of the lamp, particularly the shape, lost its visual appeal. Due to these aesthetic issues, changes in the colour and material of the lamp were suggested as an alternative solution. The most critical issue was that after all of these modifications, the lamp provided even less illumination than was desired, meaning poor usability. It was very hard work to find the optimum balance between the various sizes of the bulb and the lamp, when user interaction, aesthetics, and inherent technical parameters were considered together. As a result, they needed to develop new technologies that make up the bulb's technical system, which not only maintained the technical luminous intensity but also providing a comfortable (calm) feeling for the users.

2.7) Form 7

The interaction systems (Method 1.2.3) force developers to examine the scope of the product appearance elements (Methods 1.3.1 to 1.3.3), on a per component basis. The nominated shape, colour, and material of each component (Methods 1.3.1 to 1.3.3) provided semantic messages to users (Method 1.3.4). According to the different symbolic functions (Method 1.3.4), this affected the consideration of usability aspects (Method 1.2.6) and the working principles (Method 1.4.5) of each component accordingly, which further leads to calculation of proper dimensions (Method 1.4.6).

Form

Module	Composition-module 1.2.3 in UE	Composition-modules 1.3.1 to 1.3.3 & 1.3.4 in AS	Composition-module 1.2.6 in UE	Composition-module 1.2.5 in TC	Composition-module 1.2.6 in TC
	Interaction system	Symbolic function from Shape, Colour & Material	Usability	Working principle	Technical dimension
Concurrent Collaboration	→ 1				
	→ 2				
	→ 3				
	(→ 2 →3) → 4				

MK=Market-driven research, UE=User-driven research, AS=Aesthetic-and-Symbol-driven research, and TC=Technology-driven research

Participant

01, 02, 03, 28, 37

Case Study

. A power drill
. A mechanically-operated control panel versus an electromagnetic control panel
. Mobile phone case

Figure 4.35. *Concurrent collaboration form 7 in Task 1*

The first case study concerns the development of a power drill provided by interviewee 37 (*Figure 4.36*). Firstly, the drill itself should have an entirely mechanical look as it is a tool used for construction. The shape, which resembles a firearm, is for maximum utility. The shape also allows users to instinctively know which part of the drill to hold (the majority of people can tell the muzzle end of a firearm from the handle even if they are otherwise entirely unfamiliar with guns). Furthermore, the shape of the front part of the drill, corresponding to a gun's muzzle, has a cylindrical form engraved with spiral lines, which helps the user intuitively anticipate the rotating movement of the drill and even confirm this rotation as the drill operates. Therefore, the drill's exterior design can be regarded as contributing to the usability and working principle in that the shape itself effectively reflects the main functions of the drill. Also, the usage functions, usability, and working principle reflected from the shape can affect the determining of the technical dimensions of each of the drill's parts (e.g. handle, chuck, etc.). To adopt the words used by participants 01, 02, and 03, "the form follows the function", a core design philosophy of the Bauhaus School of design.

Figure 4.36. *Intuitive design of a power drill*

Interviewee 28 featured two other example case studies: a control panel (*Figure 4.37*), and a protective case for a mobile phone.

Firstly, a knob or dial on the control panel instantly signals rotational motion. A level arm illustrates the action of pulling down or up. By having contrasting colours between the various functional inputs on the physical keypad, users can more quickly understand high-priority actions. This leads to increased usability in the sense that users can intuitively control the device by looking at the symbolic functions of each exterior element. When this intuitive design is not enough to naturally induce users' behaviours in operating the control panel (for example if there is a need for further instructions), other working principles in the control panel (e.g. electromagnetic type) might be required. In a touch-screen, when users press a button, the button can give four kinds of responses by changing its shape, colour, or providing some other indication: 1) a generated ring surrounding the button for visual perception, 2) a change in colour of the button itself, also for visual perception, 3) a generated sound for acoustic perception, and

4) a generated vibration for tactile perception. Otherwise, merely changing the technical dimensions of the control kits' parts will be enough to address the issued problem.

Physical Control Panel

Physical Control Panel

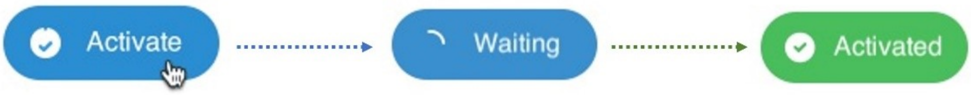


Figure 4.37. *Physical and touchscreen control panels*

Secondly, in the example of the mobile phone case, a more rounded case allows for a more comfortable grip. If a rubber material also covers the parts which the users touch most frequently, this can also increase comfort and retention. In short, the shape, colour, and material of a product can help convey information and facilitate ease of use. In this way, the relationship between the user interaction system and symbolic functions of product exterior elements affects usability. When the developed design or system has low usability, a new design or system involving alternative working principles might be needed, e.g. a customised phone case which can fit more precisely into each user's grip or flexibly allow changes to the shape of the case according to different users' grips. Otherwise, merely changing the technical dimensions of the phone case can be sufficient to increase usability.

2.8) From 8

Depending on the user environments (Method 1.2.5) in which the target product is situated, different product exterior elements (Methods 1.3.1 to 1.3.3) can be suggested, to ensure visual harmonisation. These different product appearance elements (Method 1.3.1 to 1.3.3) have different inherent properties (Method 1.4.4), demanding different technologies (Method 1.4.7) to embody those elements.

Form

Module	Composition-module 1.2.5 in UE	Composition-modules 1.3.1 to 1.3.3 in AS	Composition-module 1.4.4 in TC	Composition-module 1.4.7 in TC
	User environment	Shape, Colour & Material	Technical parameters	Required tech
Concurrent Collaboration	→ 1			
	→ 2			
	→ 2 → 3			

MK=Market-driven research, UE=User-driven research, AS=Aesthetic-and-Symbol-driven research, and TC=Technology-driven research

Participant

17, 22, 31, 32, 37

Case Study

. A washing machine
. TV display
. Home appliances

Figure 4.38. *Concurrent collaboration form 8 in Task 1*

Participants 31 and 32 presented a case relevant to this collaboration form. The different kitchen environments in the US and in EU countries results in different ideas of what materials and colours are 'appropriate' for washing machine design (*Figure 4.39*). Since most of the furniture and devices in American kitchens[40] are made of stainless steel or wood, it is better to design a washing machine made of the same materials. On the other hand, customers in the EU prefer a washing machine painted with tinted colours, harmonised with the colours of the wallpapers of the kitchen. If the colour of the washing

[40] It's convention in the UK to have the washing machine in the kitchen, as indicated here, however Americans also tend to have their washing machines in "utility rooms" or "utility closets", a location that is separate from the kitchen (this is in part because American homes are bigger; many UK homes don't have a utility closet).

machine is one of the primary colours or is glossy, users in the EU may be reluctant to purchase it.

Washing Machine (EU): Tinted Colour (White / Grey)

Washing Machine (US): high glossy Colour (Stainless)

Figure 4.39. *Washing machine made of different materials according to different environment*

According to interviewees 22 and 37, who participated in the same project, in the case of developing a washing machine for US customers, there was one critical issue *(Figure 4.40*). Since the material trend for home appliances was metal rather than wood at that time the project was taking place and thus target users desired products made of silvery metal, they needed to use stainless steel for the shells of the washing machine. However, the cost of purchasing stainless steel is typically high. Moreover, they were not able to use cheaper aluminium because of its lower toughness (which makes it prone to dents) when considering inherent technical properties of aluminium. Therefore, they suggested developing a new technology, enabling the continued use of a strengthened plastic material which they had utilised in a previous appliance. Their newly developed technology was to cover the plastic with a vinyl material which gives the appearance of metal, but without the cost and toughness issues associated with stainless steel and aluminium, respectively. The invested cost to develop the vinyl material was much cheaper than the cost to purchase the stainless steel.

Figure 4.40. Vinyl material which gives the appearance of metal

Returning to the example of the curved television situated in a particular user environment similar to a movie theatre, the weakness of the curved design was reduced image quality and reduced durability of the TV itself. Hence, participant 17 proposed the development of new technologies to maintain high resolution in the wide images displayed on the screen and to increase the durability of the television by using tougher components. However, a substantial increase in the development cost followed after the development of those technologies. Therefore, they had to simultaneously consider how those new technologies could allow them to still turn a profit.

The previously noted example case study of fostering living spaces which resemble art galleries using new designs for home appliances shows the relevance of such collaboration. The shapes of their products, such as air conditioners and refrigerators, were unique with their dynamic curvilinear contours. The colours were also extravagant and loud, making them seem less like electronics. The products had roughened surfaces for users to feel like it was a sort of sculpture. The individual products seemed to be sufficiently well-made to provide the atmosphere of an art gallery. However, they overlooked visual harmonisation with other items of furniture and elements of the house itself. The exterior design of their products was ‘too unique’ to be visually balanced with other elements of the home. It eventually made the customers reluctant to purchase the products, and thus their design strategy, for all its merits, was a failure. For this problem, their solution for the second series of home appliance was to reduce the chroma level in the overall colours of the appliances, instead of modifying whole design concepts. At that time that the second project was taking place, they believed that there was still an opportunity for their initial design, which looks like a kind of art piece, to succeed. Hence, experts in chromatology dedicated themselves to calculating technical parameters inherent in each colour used in the appliances, in order to adjust the level of chroma. The project needed to develop new colours along with new technologies to embody those colours to fit into the calculated the level of chroma.

2.9) Section Conclusion

This section has addressed a total of eight concurrent collaboration forms which were inferred from various concurrent collaboration forms centred on each functional domain (the market-driven, user-driven, aesthetic-and-symbol-driven, and technology-driven domains). This section begins by summarising the various concurrent collaboration forms centred on each functional domain, followed by a conclusion which integrates those collaboration forms to generate the representative eight forms.

The following is a summary of concurrent collaboration centred on each functional domain.

Firstly, collaborations in market-driven research may occur when defining specific user types and the positioning of the product within its market, findings which can affect the type and level of the product functions, product exterior elements, and technologies. Also, when considering whether or not to introduce these functions, elements and technologies, or whether or not to develop them, project leaders must not lose sight of the budget and development cost. The financial elements influence nearly every aspect of the opportunity identification-screening task.

Next, collaborative work, led by user-driven research, can be initiated for each of the user behaviours generated from the user touch-points. These user behaviours can appear differently in different environments, depending upon the user type. Each user behaviour generated from the interaction and usability studies have a high possibility of requiring the proper selection or development of exterior product elements, such as the shape, colour and material. Those user behaviours in user environments can produce user requirements, so that those can also necessitate changes in the inner structure, dimensions, and even the overall operating mechanism of the product. Sometimes, new technologies are required to embody what users demand.

Thirdly, collaborations led by aesthetic-and-symbol-driven research may result in users perceiving the product emotionally with their five senses and give them the ability to use it more easily or effectively. Also, collaboration can also occur when each of the product exterior elements are suggested or newly devised from a visual harmonisation perspective, considering the surroundings in which the product is likely to appear. Other possible collaborations can occur when those elements are purchased or proposed to be developed newly in accordance with their inherent technical properties. It can also lead to new technologies and altered development costs.

Lastly, the technical function of compositions that make up the product can be influenced by the product usage function. In the same context, the construction of the technical inner structure of the product can be affected by the positions of the user touch-points where the product usage functions actually occur. Furthermore, the user interaction analysis and usability examination, which considers the given user environment, can collaborate to determine whether the outcomes of the following three technology-related implementations are acceptable: 1) The technical parameter estimation, 2) various proper working mechanism suggestion, and 3) the possible range of the technical dimension expectation. Also, inherent technical properties of each product exterior element itself such as the shape, colour and material – inextricably linked to user interaction and usability – can be taken into account. This collaboration can also include the proposing of different operating mechanisms and the estimation of the technical dimensions. Lastly, in the development of the technologies required in the process of collaborations above, the development cost will be adjusted; this is unavoidable.

To conclude, diverse forms of concurrent collaboration which can be fostered between the four functional research domains were revealed in Task 1. Possibilities of integrating those collaboration forms into the following 8 forms were reasoned from the phenomenological analysis (contextual interpretive analysis) of the interview scripts and from relevant case studies:

a) Product usage functions can be different according to different user types and target markets, generating different technical functions on the backs of those usage functions and different technologies embodying these technical functions.
b) Product exterior elements can be different according to different user types and target markets, producing different inherent technical parameters in those elements and different technologies.
c) Defining user types and target markets. This collaboration notices that different users and markets can expose the target product and its components to different environments, leading to the consideration of different ergonomic data and relevant technical dimensions.
d) Researching user touch-points activated by the product usage process and thus developing the function structure of the target product.
e) Each technical parameter can be generated in the interaction system of each component, producing an appropriate working principle of each component.
f) Product exterior elements can be proposed differently according to each interaction system in the components, involving the consideration of different inherent technical parameters in those elements and relevant technologies embodying these elements.
g) Interaction systems force developers to examine the scope of the product appearance elements, on a per component basis. The nominated shape, colour, and material of each component provide semantic messages to users. According to the different symbolic functions, this affected the consideration of usability aspects and the proper working principle of each component, which further leads to calculation of their proper dimensions.
h) Different product exterior elements are considered according to different environments, which influence different inherent technical properties of the elements and different technologies for materialising them.

Most of the performance methods in the above concurrent collaboration forms affect the development cost and budget. Also, these eight concurrent forms can take place at the component level. This was also frequently found in the previous section on relevant performance methods making up each research activity from the contextual performance perspective.

3) Screening Work

A particular activity and performance method for the screening opportunities were not revealed in the interview. As shown in the sections presented previously, the opportunity identification task mainly focuses on analysis and estimates of information related to the target product. The analysis is performed in each market, user, aesthetic-and-symbol and technology research domains. The analysis work also involves collaboration between the four research domains. During the course of the analysis, there is sufficient room for screening data that is less relevant to target development. Therefore, Task 1 does not seem to need a particular activity or method for filtering data yielded in the opportunity discovery task. The screening function seems to be included in the process of analysing the target product.

4.3.5 Section Conclusion

This section has described possibilities of how to connect activities, their performance methods, and relevant toolkits for contextual performance and concurrent collaboration in the opportunity identification-screening task (Task 1). This led to a new finding in the representative execution scenario of Task 1, inferred based on the analysis of various actual opportunity identification-screening practices which provide different execution principles, approaches, and case studies.

There were four research activities in the market-driven, user-driven, aesthetic-and-symbol-driven domains which can be conducted in a parallel fashion. In each research activity, various performance methods were identified, and the possibility of connecting these performance methods related to each activity respectively within each activity were exposed. Various execution principles and relevant case studies showed that those performance methods in different activities could be worked on collaboratively, beyond each activity, from the concurrent collaboration perspective. In addition, many possibilities for collaboration on a component basis were observed.

4.4 Idea Generation-Screening (Task 2)

4.4.1 Section Introduction

This section illustrates activities, their performance methods and relevant toolkits identified in the actual FFE practices concerning the idea generation-screening (Task 2).

As with the opportunity identification-screening task (Task 1), the activities of the four major domains were observed. Although these activities were not contextually connected in any particular order, possibilities for collaboration between the activities were revealed, in a parallel relationship.

In the case of performance methods, the reasoning process used to find them was different to the process for Task 1, to some extent. In Task 1, for each activity, the different performance methods revealed by each interviewee were linked to each other for contextual performance. However, in Task 2, considering the nature and fundamental concept of ideation work in the NPD, a common pattern was extracted from the different performance methods provided by each interviewee. Based on the common pattern observed, a representative ideation processing method was deduced, one that could be applied to all activities. In carrying out the ideation processing method, the possibility for collaboration was also revealed.

The nature and concept of Task 2 is introduced in detail, followed by a description of activities and their performance methods/toolkits, with respect to contextual performance and concurrent collaboration.

4.4.2 Nature and Concept

1) Nature

Many interviewees maintained that the nature of the ideation work in the NPD should be different from that of general idea generation. Participant 13 insisted that ideation in the NPD does not mean creating new things the way “God created the world”. Interviewees 05 and 06 said that it is not about creating something out of nothing. Participant 13, elaborating further, said that nothing is generated by chance in the NPD. Namely, these interviewees argued that there is a supporting reason and/or rational evidence on the back of every creative idea in the NPD. Even new products regarded as something created out of ‘nothing’ have indeed been developed based on reasonable evidence.

For instance, the first version of Apple’s iPhone provided entirely new user behaviour patterns in the smartphone space, the result of near-endless examinations on how to increase usability of the user interface. The motivation behind a physical keypad (present on all ‘feature phones’ before the slate form factor became popular, and, in the smartphone era, present in Blackberries) stemmed from the more interactive user interface they provided. The idea that came out of this was to actually remove the physical keypad, which allowed the form factor of the phone itself to change. Apple then concerned themselves with what they needed to develop to replace the physical keypad. This led to plans to integrate the input and output mechanisms of the phone into one: a touchscreen. The result is today’s currently dominant slate form factor, wherein virtually the entire front face of the phone consists of a touchscreen, thus allowing for more screen real estate over phones with physical keypads. During Apple’s ideation process, there was a series of continuous and connected inquires on what they needed to do, why they needed to do it, and most importantly, how.

Consequently, the ideation work in the NPD proceeds based on supporting reasons and/or rational evidence for the generated ideas.

2) Concept

Based on the nature of the ideation work in the NPD, the ideation task (Task 2) aims to make concrete the information estimated in the opportunity identification-screening task (Task 1). Participants 05 and 06 insisted that idea generation serves to make the potential opportunities into "realistic opportunities", through specificity work. Interviewee 13 said that opportunity is an abstract item which is yet insufficient to apply to the NPD. However, once the abstract opportunity is further specified with an actionable method, this means it is ready to apply to NPD. Participant 19 maintained that ideation work aims to come up with a "specific action plan" or an "actionable method" in order to seize these opportunities. According to interviewee 28, idea generation is regarded as "specific digging work" on opportunities. Interviewee 34 meanwhile considered it to be "workable solutions" for opportunities.

4.4.3 Activities

The idea generation task (Task 2) seems to be closely connected to opportunity discovery (Task 1). Also, Task 2, like Task 1, can be divided into four ideation domains. Many presumptive bases were revealed with several examples provided by interviewees.

The example provided by participants 05 and 06 shows the possibility of a connection with the aesthetic-and-symbol-driven (Activity 1.3) and market-driven (Activity 1.1) research activities, in the context of devising ideas for materialising the identified opportunities. For the entire shell of the target product; a bicycle helmet, when the opportunities were 'streamlined', 'reddish' and 'metallic' for the shape, colour and material respectively, project performers worked on the specifics of each opportunity. In specified ideas on 'reddish' colours, several reds were nominated based on the shape, material and other aspects, e.g. user interaction and usability, which had been estimated in the opportunity discovery task. In specified ideas on the materials, a shortlist of possibilities was drawn up from among many different types of metal, again considering the shape, colour and other considerations such as user interaction and technical properties. In this work, they recommended utilising a colour code scheme consisting of the combination of 'CMYK' and 'RGB'[41] colour variance and a material code scheme which comes from the combination of alphanumeric identifiers provided by an international standard, e.g. a type of aluminium, 7075-T6 aluminium; or steel, S35VN stainless steel, etc. This allows for accurate colour and material discrimination and can lead to more actionable ideas. The code scheme also supports not only internal communications between project members but also external collaborations with the vendors or OEMs that develop the paints, varnishes, and materials. With such specified colours and materials along with the profile of those vendors or OEMs, the purchase or development cost can also be estimated more accurately by narrowing down the range of the cost, which was defined in the previous task (Task 1).

Another example offered by interviewee 13 shows the potential of connecting with the user-driven (Activity 1.2) and technology-driven (Activity 1.4) research activities, in the sense that actionable methods are derived from the discovered opportunities. This example describes the creation of specific realisation methods on each part of a medical cart, e.g. the body frame, the shelves to hold medical devices, the handle, attachable storage, and the frame that houses wheels. When the project participants devised specific realisation methods for each part, they considered not only the interaction system and usability in the given environment but also the technical properties, operational mechanism, and technical dimensions. These considerations had already been estimated in the previous task (Task 1). For instance, when generating feasible handles, various elements were considered: 1) which types of handles were suitable for A&E where doctors and nurses usually move the cart more rapidly and roughly (compared to other medical departments), 2) how many handles are appropriate for that user behaviour, and 3) which locations on the cart are adequate for those handles. In generating various possible frames that house wheels, the following aspects were considered: 1) How many wheels would be appropriate for the cart given the user behaviour and environment, and 2) when users move the cart in such a way, how much concentrated load each wheel can bear.

[41] The CMYK stands for 'Cyan', 'Magenta', 'Yellow' and 'Black', while RGB is an acronym for 'Red', 'Green' and 'Blue'.

Consequently, as an extension of the opportunity identification-screening (Task 1), ideation work (Task 2) can be divided into four domains, as follows (*Figure 4.41*: a summary of the analysis obtained from the raw analysis data shown in *Appendix 3, pp. 563-565*):

- **Activity 2.1: Market-driven Ideation Activity**
- **Activity 2.2: User-driven Ideation Activity**
- **Activity 2.3: Aesthetic-and-Symbol-driven Ideation Activity**
- **Activity 2.4: Technology-driven Ideation Activity**

As with the four research activities in the opportunity identification-screening task (Task 1), the four ideation activities are not connected with respect to contextual performance, instead existing independently. However, those four ideation activities have the strong possibility of requiring collaborative work, actions which may take place in parallel. The two examples illustrated above further allude to the possibility of collaboration. Fuller details of possible forms of collaboration are presented in the following section, which addresses the performance method.

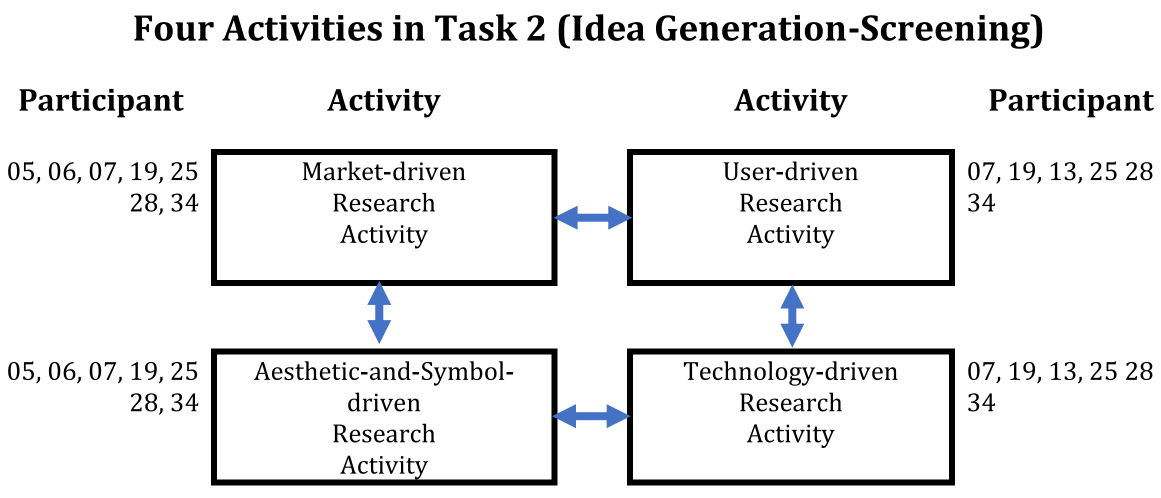


Figure 4.41.*A summary of the analysis of the four activities in Task 1*

4.4.4 Performance Methods and Toolkits

1) Contextual Performance

Looking at the four ideation activities, two different types of ideation processing method were exposed:

1.1) Logical Ideation Processing

1.2) Intuitive Ideation Processing

Usually, logical ideation processing is used before intuitive ideation processing. In addition, between these two types, there are interconnections, compensating for the defects present in each. This is examined in closer detail below, based on a summary of the analysis of the interview scripts (see *Figure 4.42*), which was produced from the raw analysis data shown in *Appendix 3* (*pp. 563-565*).

Performance Methods/Toolkits
in the Four Activities of the Idea Generation-Screening Research Activity

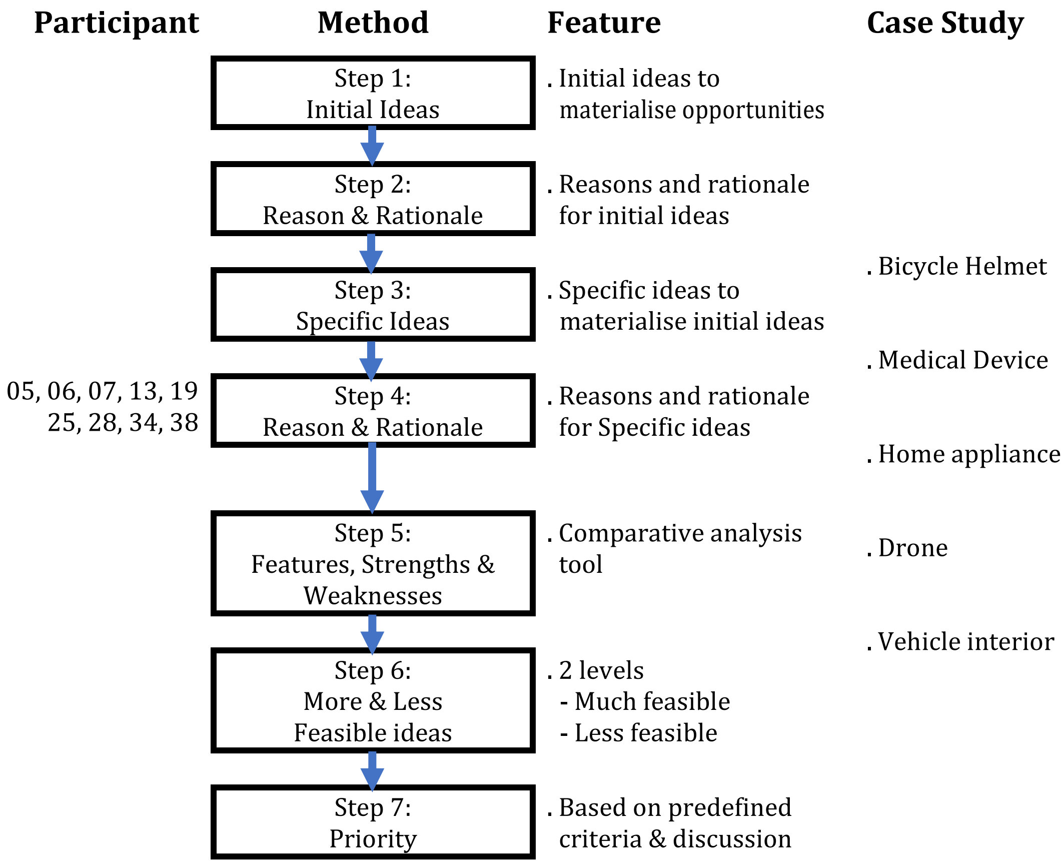


Figure 4.42. *A summary of the analysis of the performance methods and toolkits in Task 2*

1.1) Logical Ideation Processing

1.1.1) Logical Idea Generation Processing

Three patterns (which map to three performance methods) were revealed for generating ideas logically. These patterns were primarily set up to break down the given opportunities and their realisation methods using a series of different reasoning structures. In the three methods, there was potential for integration into a single representative ideation method based on a common purpose and the direction of steps that make up those methods.

As a result, the representative logical ideation method can be comprised of the following four steps, in the following order (*Figure 4.42*):

1) **Step 1: Initial ideas to materialise opportunities**
2) **Step 2: Supportive reasons and rational evidence for initial ideas**
3) **Step 3: Specific ideas to materialise initial ideas**
4) **Step 4: Supportive reasons and rational evidence for specific ideas along with features, strengths and weaknesses of specific ideas**

Using the example of the medical cart, in the first step (Step 1), when devising possible options for handles, different types of handle are nominated, considering handle-related information generated in the opportunity identification task. Those options can be examined in other complete products, such as similar medical carts or indeed any other device with these handles. Through the second step (Step 2), the reason why each handle type is deemed acceptable and what the rational evidence is can be examined based on the handle design-related considerations estimated in the opportunity discovery stage. In the third step (Step 3), the handle types proposed initially are sorted into specific categories, such as the number of handles, placement, options for detachability etc. In the final step (Step 4), for each specified option, supportive reasons, including strengths and weaknesses, are provided.

In the other example, generating ideas for a 'reddish and metallic' container for the bicycle helmet, in the first and second steps (Steps 1 and 2), from the multitude of reds available, a shortlist is selected along with colour codes and the reasons for selection.

Then, in the third and fourth steps (Steps 3 and 4), for the specific action plan, vendors or OEMs which can provide those proposed colours and materials are nominated, again with the reasons for selection.

The following describes the three patterns of idea generation methods that were based on inferring the representative idea generation method mentioned above.

The first method provided by interviewee 07 is the ideation work, which proceeds in reverse order compared to the order of the proposed representative method. This method is set up to address supportive reasons and rational evidence first and then to come up with action plans accordingly. The first implementation is to think about what the initial requirements are for realising the given opportunities. It is also concerned with advance considerations, which can be supportive reasons and evidence when the initial ideas are proposed. It is similar to Step 2 of the representative method discussed above. Next is the contemplation of prerequisites which enable the realisation of the requirements found in the first implementation. These prerequisites can be supportive reasons and evidence for specific ideas to materialise those initial ideas. Hence, it virtually identical to Step 4 of the representative method. The final implementation is devising specific execution ideas for fulfilling requirements and prerequisites respectively. The purpose and characteristics are nearly the same as Steps 1 and 3. This ideation method is similar to one part of the TOC method in TRIZ. However, it is difficult to examine the features, pros and cons of the generated ideas in this ideation structure. To do so, one more step for that work should be added.

The next set of ideation methods exposed by interviewee 19 corresponds to the upper part of the representative method proposed above. The method is comprised of two steps in which all possible ideas which specify opportunities are generated first in a divergent approach (Step 1) and reasonable reasons and evidence are then examined (Step 2). In the case of informants 34 and 25, after conducting these two steps, one more step to think about the reasons in more depth (for the reasons identified in the second step) is then implemented. In this step, the features, advantages and disadvantages of ideas generated in the first stage are also investigated, considering those supportive reasons. Then, similar reasons are categorised together and reconnected to relevant ideas. These methods appear similar to the ladder abstraction, fish-bone or root-and-cause analysis methods.

The final pattern revealed by participant 38 comprises three steps. The first step concerns how we might practically reflect those items in the target product. Next, to fulfil those ideas generated from the first step, more specific actions are considered. The final step concerns how we satisfy the ideas devised in the second step. This method focuses on realisation methods using three-phased digging work, something very similar to the "How might we (HMW)", "In What Ways Might We (IWWMW) and "How To" methods in academia. However, with 'just' these three steps in the ideation process, it is difficult to investigate the rational evidence behind, and the features inherent to, each idea. To do so, three more steps related to such work should be added in each ideation step.

As shown in the three kinds of ideation methods exposed in the analysis, under a rational thinking process, all methods are concentrated on digging up ideas on how to materialise opportunities, with a stepwise procedure; in the third pattern particularly. In devising the phased realisation methods, supportive reasons and rational evidence are also explored more deeply with a phased procedure; in the first and second patterns in particular. Also, regarding ideas generated with a phased process, the features, merits and deficiencies are studied; in the second pattern particularly.

As a result, representative logical ideation processing can be structured with a two-phase process of devising ideas and action plans to materialise opportunities, connecting with a two-phase examination of reasons and features.

1.1.2) Logical Idea Screening Processing

Different from the opportunity discovery task (Task 1), screening work was detected in the ideation task (Task 2).

Task 1 is primarily about analysis of the target product in which initial improvement or development directions are reflected. The analysis is conducted with a consideration of various aspects such as the market, the user, aesthetics, and technology. There is enough room here to filter information less related to the target product development. Also, according to participants 07 and 34, all information produced through such an analysis has the possibility of providing new opportunities to generate a new design, so that has value in that it can be transformed into a workable solution to materialise individual opportunity. Therefore, it seems that formal screening is not needed.

On the other hand, the purpose of Task 2 is to come up with all possible ideas and alternatives, as actionable methods for those opportunities (the blue tag 23). Also, a large number of ideas and their options can usually be devised, particularly in the NPD domain, and it is nearly impossible to apply more than a few ideas to the target product. Therefore, formal screening is very much required at the end of Task 2.

Based on the analysis of scripts for many different participants, the screening work, also called feasibility checks, can be conducted first by comparing the strong and weak points of each idea. This first performance implies the possibility of linkage with the final step (Step 4) of the logical ideation processing task. Also, as shown in the blue labels 61 and 78, a connecting link was also revealed in examples provided by participants 13 and 28. In the next step, based on the results of this comparison, ideas are divided into two levels: 1) more feasible and 2) less feasible. Lastly, within the more feasible idea group, the ideas are prioritised in order.

Consequently, the screening work in Task 2 can be conducted with the following three steps (*Figure 4.42*).

1) **Step 1: Comparative analysis of strong and weak points of ideas**
2) **Step 2: Classification of ideas into two levels: more and less feasible ideas**
3) **Step 3: Prioritisation of ideas within the more feasible idea group**

1.1.3) Logical Idea Generation-Screening Processing

The logical idea generation and screening processing tasks, mentioned in the two sections above, can be linked contextually. Since the final step (Step 4) of the logical idea *generation* processing task is to examine the features, strengths, and weaknesses of specific ideas, this final step can be connected with the first step of the logical idea screening *processing* task, to enable a comparative analysis of strong and weak ideas.

As a result, the idea generation-screening task (Task 2) can be implemented in the following order:

1) **Step 1: Initial ideas to materialise opportunities**
2) **Step 2: Supportive reasons and rational evidence for initial ideas**
3) **Step 3: Specific ideas to materialise initial ideas**
4) **Step 4: Supportive reasons and rational evidence for specific ideas along with features, strengths and weaknesses of specific ideas**
5) **Step 5: Comparative analysis of strengths and weaknesses of ideas**
6) **Step 6: Classification of ideas into two levels: more or less feasible ideas**
7) **Step 7: Prioritisation of ideas within the more feasible idea group**

1.2) Intuition Idea Processing

Participants 07 and 19 described a case in which ideas are generated by the use of gut-feelings. When there is a reduced possibility to generate any more ideas through logical ideation or when ideas generated via logical thinking are not different from existing ideas, intuitive ideation processing is used, which has the potential to generate "wow" ideas.

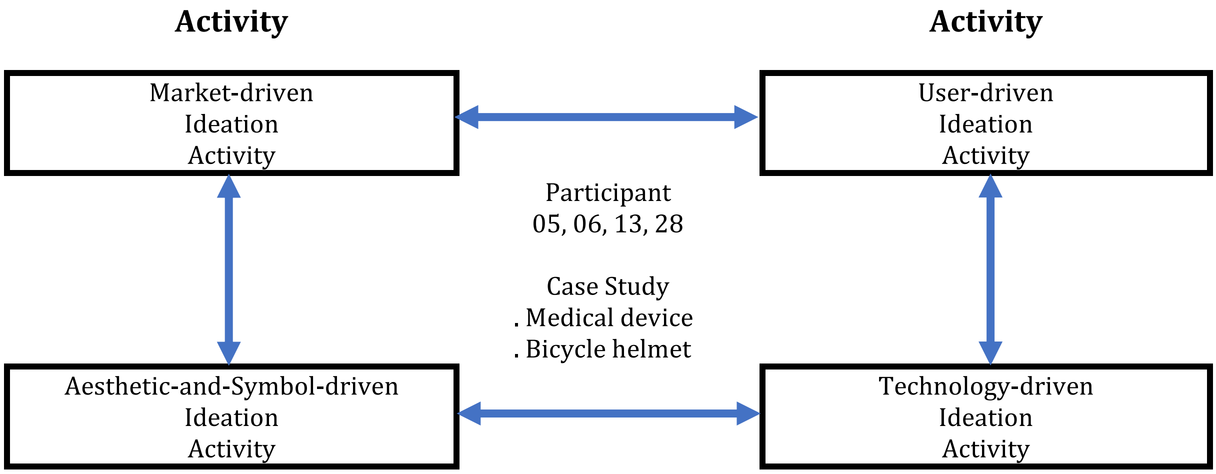
Normally, intuitive ideation involves well-known ideation methods such as brainwriting, SCAMPER and group horning, or it depends on the inspiration of practitioners. However, they said that there is less probability to generate pragmatic ideas this way, so that the efficiency (in terms of application) to the target product is indeed very low. They maintained that nine out of ten ideas will be useless if the ideation work depends on intuition only. According to participant 25, even when they tracked back ideas created with intuition, they insisted that the origin of those ideas and the process of creating them were necessarily based on the flow of logical thinking. The reason was that even though practitioners generated those ideas randomly without any rules, problems to tackle or aims to achieve were seized in their conscious and subconscious.

Thus, most of the participants did not recommend using the intuition ideation processing method independently but recommended involving it selectively in the logical ideation processing step or using it when there are no any other alternative ideas. They contended that more creative ideas can be proposed by providing discretion to practitioners, within the more formalised structure of ideation work.

Consequently, in each step of the logical ideation process, various intuitive ideation methods can be involved.

2) Concurrent collaboration

The need for collaboration in the idea generation task was revealed (*Figure 4.43*). In generating ideas and actionable methods to materialise opportunities, the process of considering supportive reasons and rational evidence is involved. In such a process, reasons and evidence for workable methods are examined from various points of view, such as the market, the user, aesthetics, and technology.



*** Collaboration for idea generation and feasibility checks can be actuated on a component basis

Figure 4.43. *A summary of the analysis of concurrent collaboration between four activities in Task 2*

As shown in the example offered by interviewee 13, when investigating reasons and evidence which support each possible handle type in a medical cart, user interaction and usability in the given surroundings (in this case, a hospital A&E) as well as technical operation mechanisms and dimensions are considered at the same time.

In the other example, of colours and materials for the entire shell of the bicycle helmet, described by participants 05 and 06, the aesthetic aspects of the product exterior elements are considered alongside the technical aspects (of the materials' properties for example). Also, in nominating vendors in charge of providing those colours and materials, the estimation of the invested development cost is done together. These cases indicate the need for collaboration in ideation work. If possible actionable methods and their alternatives are devised from one aspect only, it can result in incomplete application of ideas for the NPD, which may force teams to backtrack or repeat tasks.

The screening work also needs collaboration in the same context. In comparing the pros and cons of ideas and determining the rankings of those ideas, the market, the user, aesthetics, and technology are involved simultaneously. If a feasibility check is conducted, inclined towards one aspect only, it can cause bias, leading to unnecessary materialisation methods or ideas proposed at the end.

One more presumptive basis which we need to notice is that collaboration for idea generation and feasibility checks can be actuated on a component basis. In generating the possible actionable methods and examining supportive evidence, these works are conducted by each product component unit. Most of the examples described by participants 05, 06, 13 and 28 also show the possibility of collaboration which can be formed again on a component basis.

4.4.5 Section Conclusion

This chapter has addressed the activities and performance methods/toolkits associated with the idea generation-screening task (Task 2).

The four ideation domains (market-driven, user-driven, aesthetic-and-symbol-driven, and technology-driven) can have a parallel relationship, leading to strong concurrent collaboration between each domain.

In each ideation activity, the representative logical idea generation-screening process consists of seven steps (which can be sorted into two groups): 1) idea generation and rationale of the ideas, consisting of four steps and 2) feasibility check based on strengths and weaknesses of the ideas (the remaining three steps). These were inferred from different idea reasoning processes. There was a possibility that various intuition ideation methods can be involved in those steps to increase creativity and novelty.

4.5 Requirements List and Mission Statement (Tasks 3 and 4)

4.5.1 Section Introduction

This section describes the third and fourth FFE tasks: the requirements task (Task 3) and the mission statement task (Task 4).

These two tasks are dealt with together in this chapter because the outcome of Task 4 is generated by summarising the outcomes of Task 3. Despite this connection, they cannot be regarded as a single task since the performance directions and characteristics are separate. Besides, unlike Tasks 1 and 2 discussed previously, a number of relevant activities and their performance methods were not exposed during interviews about Tasks 3 and 4. Hence, the phenomenological analysis (contextual interpretive analysis) method was not applied for contextual performance and concurrent collaboration. Instead, the analysis method was used to find other content such as the basic concept, contents, and format.

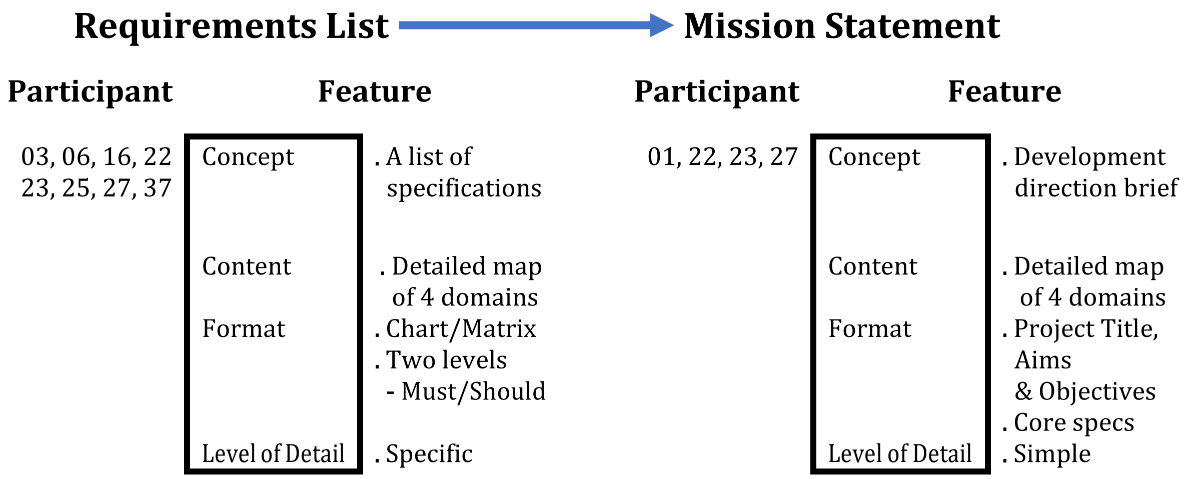


Figure 4.44. *A summary of the analysis of Tasks 3 and 4*

Full details are illustrated in the following sections, based on a summary of the analysis of the interview scripts (see *Figure 4.44*) produced from the raw analysis data shown in *Appendix 3* (*p. 566*).

4.5.2 Requirements List Task (Task 3)

1) Nature and Concept

The purpose of drawing up a requirements list (Task 3) is to properly arrange product-related information obtained in the opportunity identification-screening (Task 1) and idea generation-screening tasks (Task 2). It is a form of preparation, listing the product specifications in advance of the actual NPD phase. The participants each used different terms to refer to the requirements list: 'Mini-map of NPD' (interviewee 06), 'Initial map of NPD' (participant 016), 'Blueprint of NPD' (participants 22, 23 and 27), and 'Specs list' (participant 03). They all describe a list of the features and properties of the estimated target product.

2) Contents

The contents of the requirements list can be divided into three categories: 1) Scope, 2) Schedule and 3) Resources.

In the scope group, according to participants 03 and 06, product function, technology, design and market-related aspects are reflected in a broad sense. Participants 16 and 25 said that target market information, market positioning-and-distribution strategy, product functional-and-technological features and relevant specifications, and exterior design elements can populate the scope group.

In the schedule category, interviewee 03 said that the time allotted to developing the target product (in which contents in the scope are reflected) should be included in the list.

In the resource group, the investment cost (based on the budget) and the estimated product price make up the final category. Participant 06 insisted on the importance of the financial index in that a project triggered in the FFE may no longer proceed due to insufficient budget compared to the development cost.

These three categories imply that the requirements list can be divided into four domains (the market, user, aesthetics-and-symbols, and technology), identical to the domains of the opportunity discovery and ideation tasks.

3) Format

According to interviewees 22, 23, and 27, the requirements list generally spans several pages of text. For each requirement item, the essential (must) criteria and the selective (should) criteria can be marked separately. Participants 16, 22, 23 and 27 contended that this two-level system helps to differentiate between requirements which must be reflected in the target product and the requirements which can be applied to the product selectively. Participant 25 also suggested including relevant images and schematic diagrams which can aid understanding of complex requirements. Requirements compiled in a table or chart can provide an at-a-glance view of the product development-related information estimated in Task 1 and 2.

4) Level of Detail

Most of the participants, including notably 02, 16 and 37, maintained that the more specific the requirement list, the more efficient the execution of subsequent tasks. In the same context, interviewee 37 argued that if a requirement list is not produced in the FFE or if requirements are not listed specifically, the relative lack of product development-related information can be reflected in the conceptual designs of the next task. The flaws in these conceptual designs create potential for defective prototypes with visual, functional and technical malfunctions. If so, many reworks will occur, and the project may not proceed forward to the actual NPD stage.

4.5.3 Mission Statement Task (Task 4)

1) Nature and Concept

The basic concept of the mission statement is to define a specific project direction with one or two statements. It is a more distilled form of the directions (initial improvement direction or develop direction) estimated in the preliminary task (Task 0). The statement is quite abstract, e.g. to develop a desalination device for users in California to purify seawater to freshwater. Through the opportunity discovery (Task 1) and ideation (Task 2) tasks, not only is more information gathered and analysed to develop such a device, but the information becomes more specific and action methods are proposed. This work results in specific requirements (Task 3) for the development of the device. Considering these requirements, a detailed project direction can be established, e.g. to develop a portable desalination device for users residing near the coast of California to generate 15 litres of fresh water per day, using a one square metre PV solar panel. Therefore, the mission statement can be regarded as a summarised version of the requirements list. The statement consists of a detailed project direction, including core requirements. Participants 22, 23 and 27 called it a 'Project brief' or 'Project definition'. According to interviewee 01, by drawing up the project direction with a simple statement, practitioners working on the project can always keep the main purpose and direction of the project in mind during the project implementation. The mission statement helps to prevent the project from straying from its established direction.

2) Contents

Along with a statement of the project direction, a few more pieces of information related to the project can be included in the mission statement. The mission statement consists of a project title, aims, and objectives. Firstly, the project title can be the initial improvement or development direction established in Task 0, e.g. the development of a desalination device for users in California to purify seawater to freshwater. Next, the aim can be one or two statements describing the project direction in more detail, e.g. to develop a portable desalination device for users residing near the coast of California to generate 15 litres of fresh water per day using a one square metre PV solar panel. Lastly, the project objectives can consist of three to five specific action plans for embodying the aim. Participants 22, 23 and 27 argued that the establishment of objectives is as important as the aim. They said that since some project participants can regard the detailed project direction (Aim) as being still abstract, action plans are required.

3) Format

In general, the mission statement covers not more than a page or a page and a half (this includes the project title, aims, and objectives).

4) Level of Detail

The mission statement generally pursues simplicity. If it includes details, it is essentially no different from the requirements list, which already exists. Interviewee 01 considered the mission statement to be an extremely condensed requirements list.

4.5.4 Section Conclusion

This chapter has described the requirements list and mission statement tasks (Tasks 3 and 4).

These two tasks can be contextually connected with each other, in the sense that the contents of task 4 can be formed by summarising those of Task 3. Task 3 produces a detailed mini-map of the NPD, consisting of outcomes obtained from Task 1 (Opportunity Identification-Screening Task) and Task 2 (Idea Generation-Screening Task), while Task 4 was a simple design brief formulated by condensing the contents of Task 3.

4.6 Conceptual Design Task (Task 5)

4.6.1 Section Introduction

This section describes the activities and performance methods revealed in the interview script which relates to the conceptual design task (Task 5). In the interviews, two conceptual design directions were observed: 1) systematic conceptual design, and 2) intuitive conceptual design.

In the former, three major activities, which are connected in phases, were identified. However, unlike in Task 1 (Opportunity Identification-Screening) and Task 2 (Idea Generation-Screening), collaboration between these activities was not revealed. Instead, collaboration *within* each activity was exposed. In the case of performance methods, as with the idea generation-screening task (Task 2), a common pattern was observed in the different performance methods offered by each interviewee: this is different from the opportunity identification-generation task (Task 1) wherein different performance methods were applied to each relevant activity. The pattern resulted in a representative performance method. However, unlike the ideation task in which a single representative method is applied to all activities, the type of performance method here was different depending on each activity, resulting in different common patterns for each of the different activities. A representative method was thus devised for each activity, based on the common pattern observed.

On the other hand, in the intuitive conceptual design task, no particular activities or performance methods were identified due to the nature of intuitive work. There was discretion to select different performance methods depending on the preference or expertise of the performers.

4.6.2 Nature and Concept

1) Nature

The nature of the conceptual design task is similar to that of the ideation task. This is because devising possible ideas and coming up with conceptual designs are both substantial considerations to be reflected in the target product (even though ideas are usually intangible and concepts are tangible). Thus, as with the ideation task, two streams were revealed in the conceptual design task.

The first aims to produce designs systematically (described by participants 02, 13, 25 and 28). The other stream aims to achieve this by relying on the innate abilities of the designers (described by participants 02, 05, 06 and 33). The analysis of the systematic conceptual design task revealed particular phased activities and the relevant performance methods subordinate to each of these activities. Using such a phased scientific system, around ten to twenty possible concepts can be devised methodically in a divergent approach, narrowed down to three to five optimal designs in a convergent approach.

On the other hand, intuitive design work does not show any noticeable activities and relevant performance methods despite similar divergent and convergent processes. It typically generates fifty to a hundred concepts, depending on the inspiration of the practitioners, with each one compared to another to whittle the list down to three to five. In addition, the ability of the individual designer is significant in intuitive conceptual design. Systematic conceptual design would thus appear somewhat more effective to its intuitive counterpart given the smaller number of designs it produces and reduced uncertainty that comes as a result of variations in the abilities of individual designers.

2) Concept

The concept of the conceptual design task in the NPD is to visually express product specifications from the requirements list and produce a product form. According to participant 16, depending on how the conceptual design is expressed, this task can help to estimate the target product not only visually but also in terms of its function and technical elements. The reason is that the function and system structure of the target product is considered when devising the conceptual design. Therefore, the main role of Task 5 is to visually confirm what the form of the target product will be before going to the actual NPD stage.

4.6.3 Activities and Performance Methods

1) Contextual Performance

1.1) Systematic Conceptual Design

In ‘Activity’ unit, principal conceptual design, schematic conceptual design, and styling conceptual design were identified as major activities. Participants 13, 16 and 28 suggested proceeding first with principal conceptual design and then the styling conceptual design. Interviewees 02 and 25 recommended implementing the schematic conceptual design activity in between two activities mentioned previously. The order is thus: principal, schematic, and styling.

In ‘Performance Method’ unit, various performance methods consisting of different steps were revealed for each activity. These steps can be categorised together when they pursue a common purpose. Moreover, it was revealed that each step can be linked together, after considering the relationship between their roles and purposes. Three representative methods comprised of relevant steps were deduced from the three activities. Moreover, due to the three sequentially connected activities, the relevant steps in the three representative methods were naturally linked to each other in consecutive order.

As a result, conceptual design work, Task 5, can be carried out in the following order (*Figure 4.45*: a summary of the analysis of the interview scripts, extracted from the raw analysis data shown in *Appendix 3, pp. 567-568*):

1) **Activity 5.1: Principal Conceptual Design**
   - **1.1) Step 1: Basic figure-typed designs, by product component unit**
   - **1.2) Step 2: Optimal designs for each component**
   - **1.3) Step 3: Basic figure-typed designs for the entire product**
   - **1.4) Step 4: Optimal designs for the entire product**
2) **Activity 5.2: Schematic Conceptual Design**
   - **2.1) Step 5: Reflection of function and system structure**
   - **2.2) Step 6: Marking of dimensions**
3) **Activity 5.3: Styling Conceptual Design**
   - **3.1) Step 7: Hand-drawing**
   - **3.2) Step 8: Computer-aided drawing**

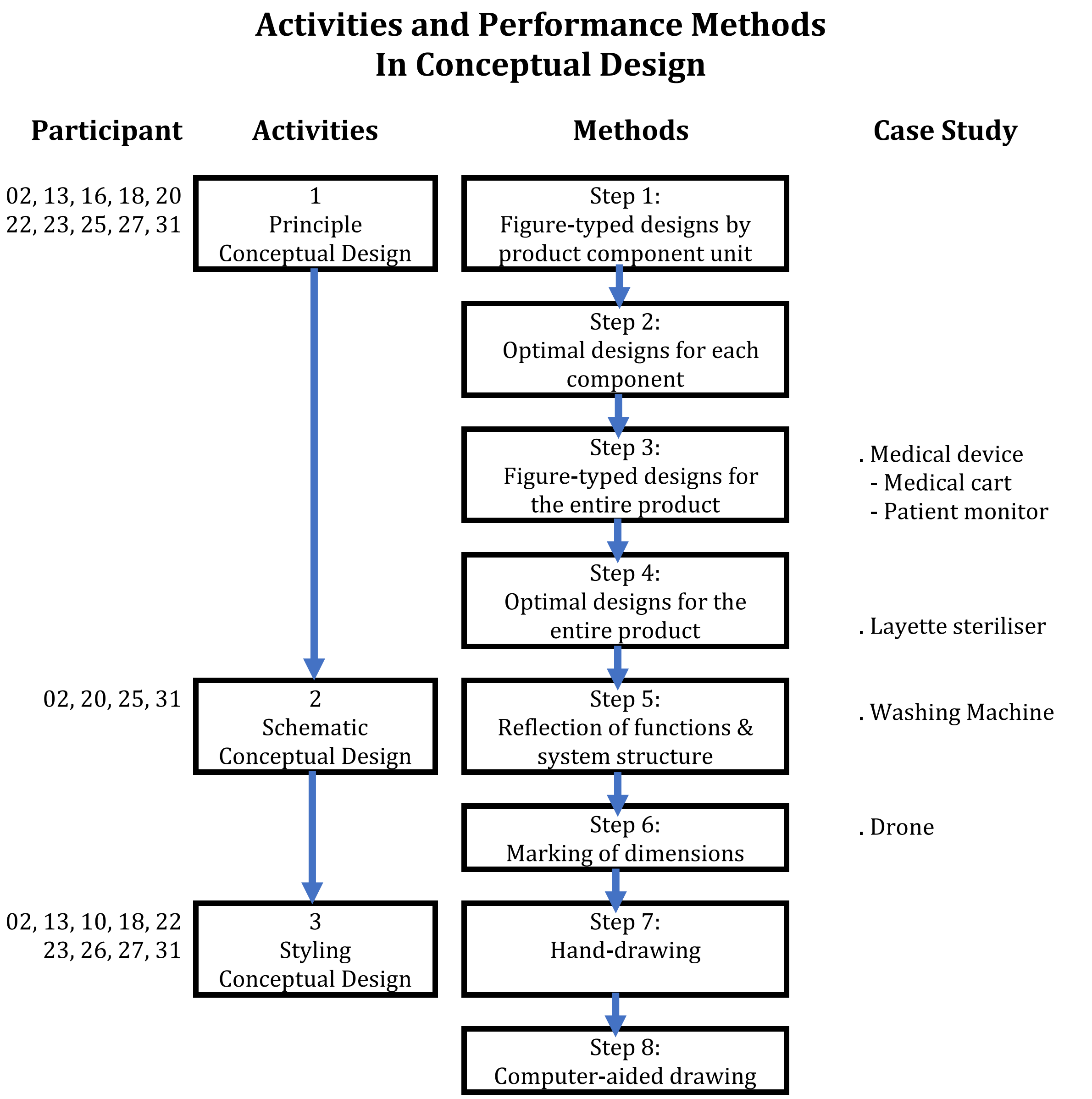


Figure 4.45. *A summary of the analysis of Task 5*

Activity 5.1: principal conceptual design

The first activity, 'principal conceptual design' (Activity 5.1), aims to devise possible concepts for a simple initial form. This activity is based on the principle described in the requirements list. The form is usually made using basic figures such as circles, triangles, rectangles, and parallelograms. Each form is devised from requirements in which opportunities and actionable methods are reflected. Through such simple forms, a variety of initial concepts for each part can be achieved in an easy way. Next, optimal concepts for each component are sorted, based on their features, strengths, and weaknesses, drawn from the requirements. Then, the designs of each component are interjoined, considering the most basic structure of the target product. Through this step, many concept variations are created by assembling the parts together in different combinations. Lastly, depending on the features, strengths and weaknesses of each combination, an optimum conceptual design for the overall product is proposed.

Figure 4.46 illustrates an example of the principal conceptual design activity using the medical cart developed by participant 13. This example effectively describes how to devise principle conceptual designs using the steps above.

The first activity can thus help to devise initial conceptual designs in a systematic way. This performance method adopts some elements of morphological analysis. According to participant 02, there are two merits to using the type of figures – circle, square, and triangle, etc., – for generating initial conceptual designs. First, it increases understanding of the basic conceptual design form. Second, it enables pursuit of different varieties of conceptual designs in a very simple way. this principal conceptual design activity typically begins with individual components before graduating to the product in its complete form, some participants including 16 and 22 argued that there is a case in which conceptual designs for the whole product are generated first and then 'dismantled', with designs for components created after. This typically occurs when developing compact products, e.g. stationery.

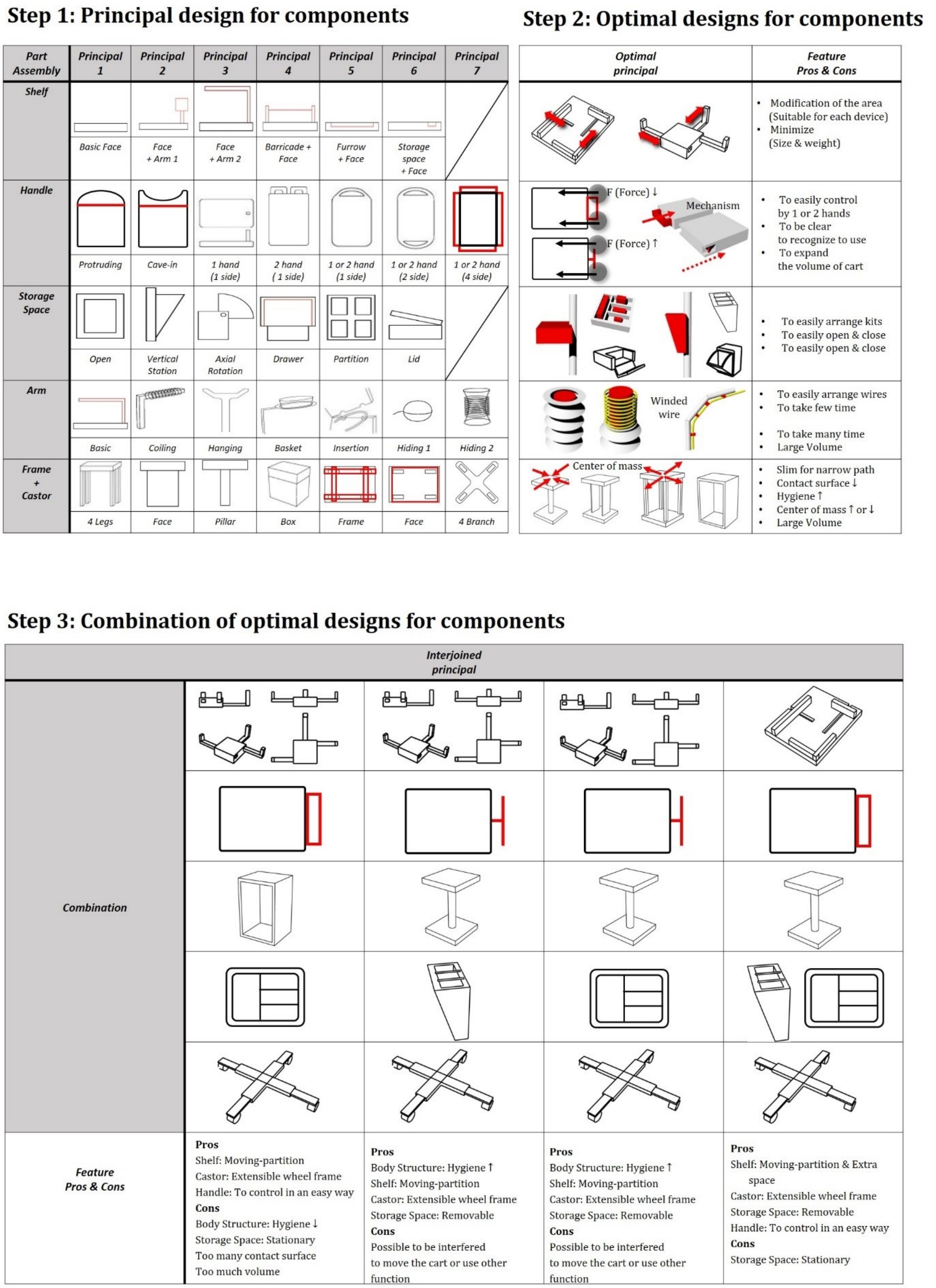


Figure 4.46. *Example of principal conceptual design in developing a medical cart*

Activity 5.2: Schematic Conceptual Design

Next, in 'Schematic conceptual design' (Activity 5.2), the principal conceptual designs generated above can be modified according to the function and system structure devised in Tasks 1 and 2. On the conceptual designs proposed in the last step of the activity above, more diverse forms can be created by assembling and disassembling components in a different way, and thus varying the function and system structure from the baseline.

Figure 4.47 shows an example of the schematic conceptual design activity; a patient monitor developed by participant 13. The total of seven variations were devised based on different assemblies of the three main components (the display, the body, and the function modules), after considering different possible functions and system structures.

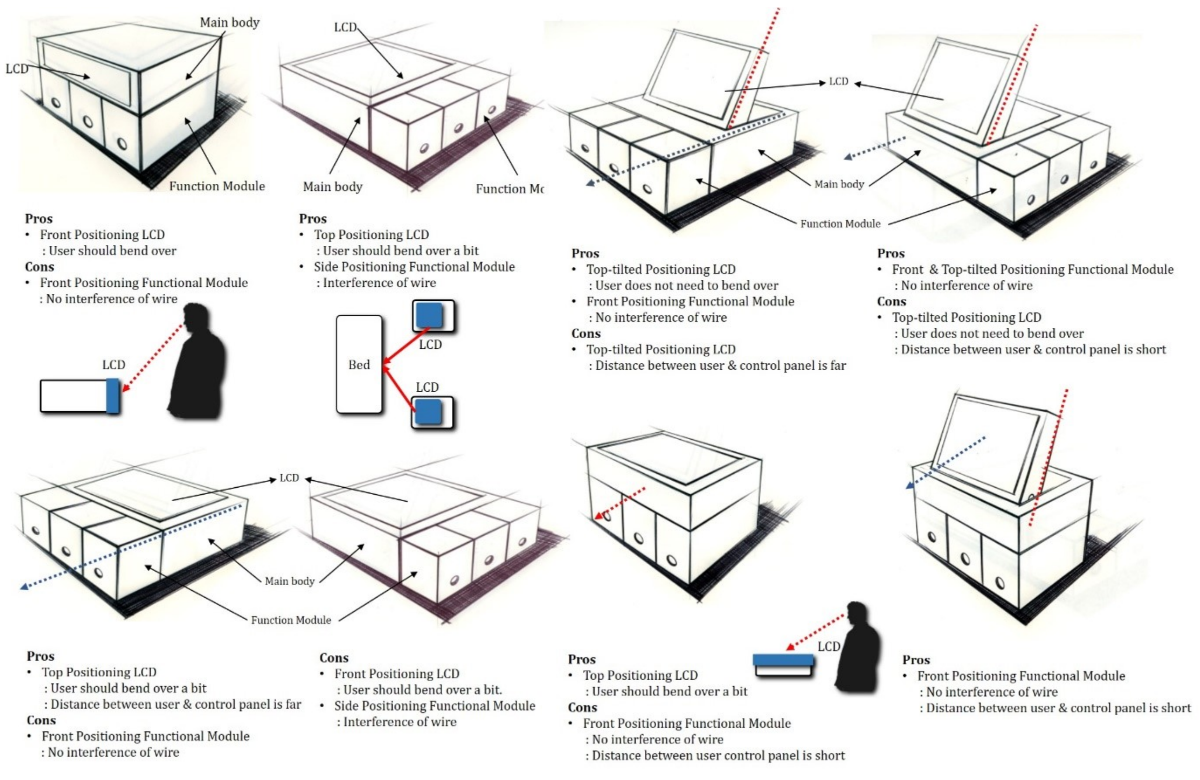


Figure 4.47. *Example of schematic conceptual design for a patient monitor*

In addition, according to interviewees 02 and 25, schematic concepts can reach close to the actual structure of the product by applying product dimensions such as technical dimensions and usability data.

Activity 5.3: Styling Conceptual Design

The final activity, 'Styling conceptual design' (Activity 5.3), aims to elaborate on the possible concepts that 'survived' the two previous activities. It aims to not only refine the outlines of the overall product so that it is closer to being an actual product but also to apply colours and materials.

In the past, most designers preferred to carry out styling work by hand first, and only then moving on to 2D-sketching software (e.g. Adobe Illustration) or 3D-modelling and rendering programmes (e.g. Rhino and 3DS Max). However, recent developments in these software packages have caused more and more designers to skip the first step. Nonetheless, most practitioners still conduct styling work using hand drawings. Many designers make use of graphics tablets where they can "draw by hand" and "use software" at the same time. They contended that more accurate and detailed conceptual designs can be generated when hand drawing precedes computer work. When no hand drawing work was done, points for improvement can only present during the computer work stage, resulting in many repetitions. For this reason, it is recommended that both steps be carried out if possible.

1.2) Intuitive Conceptual Design

As mentioned in the section introducing the nature of conceptual design in the NPD, no particular activities and performance methods were exposed in the intuitive conceptual design implementation. However, this does not mean that generating concepts by gut-feeling is not applicable in this task. Most of the participants, including 02 and 33, recommended using the creative inspiration and the talents of designers in each activity of the systematic conceptual design. They maintained that more innovative outcomes can be created by giving discretion to designers, within the formalised structure of conceptual design work. Thus, as with the ideation task (Task 2), Task 5 also shows the possibility of involving selective applications of intuitive design in the systematic design activity.

Participants 20 and 31 recommended involving a particular approach, called 'Round Robin', in the phased conceptual design activity. A Round Robin method aims to complete the conceptual design piece by piece with each designer taking a turn. In general, approximately ten designers sit together with the requirements list in hand. One designer draws a concept for the whole product or for a part, considering the requirements. The second designer continues to draw the concept, continuing from the concept the first designer drew. The third designer continues to draw the concept, continuing from the immediately preceding concept, and so on. In this way, all participants continuously pass their drawings, in one direction, to others down the line. This approach can be used in the systematic conceptual design activity, e.g. designs for product components using basic figures and shapes (Step 1) in the principle conceptual design activity (Activity 5.1). Participants 20 and 31 argued that this approach is useful for generating creative concepts by gathering diverse concepts from different designers and merging them into one.

2) Concurrent Collaboration

In the interview scripts, no forms of collaborative work – which occur between activities – were identified in the conceptual design activity. Instead, collaboration occurred *within* each activity.

According to participant 28, industrial designers usually lead in this task, and practitioners who come from other fields verify whether requirements yielded from their fields are suitably reflected in the designs. However, even though no explicit collaboration system occurring between the activities was identified, this task seems to have a potentially collaborative characteristic (within each activity) since the fundamental concept of the conceptual design task is to apply product-related information considered from various NPD-related functional aspects to the target product.

4.6.4 Section Conclusion

This section has addressed activities and performance methods/toolkits related to Task 5 (Conceptual Design Task).

Three activities can be conducted in consecutive order of the principal, schematic, and styling conceptual design. Three representative performance methods consisting of phased steps, reasoned from different performance methods obtained from the interviewees, can be applied to each activity, so that all steps – a total of 8 – in those three representative methods can be contextually connected with each other in sequential order. Furthermore, in order to devise more creative and novel concepts, the intuitive conceptual design approach allowed performers with different preferences and areas of expertise to participate in each step.

4.7 Prototyping Task (Task 6)

4.7.1 Section Introduction

This section presents activities and performance methods/toolkits related to the prototyping task (Task 6).

While activities related to contextual performance were identified, activities related to concurrent collaboration fostered between activities were not revealed. Instead, collaborative work occurring within the activities were observed.

Also, there was no contextual relationship to the relevant performance methods. Different performance methods were utilised independently depending on the purpose.

Full details begin by introducing the nature and concept of Task 5, followed by illustrating the activities and relevant methods, with respect to contextual performance and concurrent collaboration.

4.7.2 Nature and Concept

According to most of the participants, including participants 03, 17, 26, 36, and 38, the main concept of the conceptual design task (Task 5) is to confirm visually what the form of the target product will be, wherein NPD-related information estimated in the opportunity discovery (Task 1) and ideation tasks (Task 2) are reflected. Conversely, the primary concept behind the prototyping task (Task 6) is to check what the form of the target product will be, physically, and how the product can be operated, functionally and technically. In general, the prototype is manufactured based on conceptual designs which have survived to the end of the process. The designs rendered as 3D models in the last conceptual design activity can act as a liaison with the prototyping task. The information related to each conceptual design is fully reflected in each prototype, via a phased process. Such prototypes can provide important opportunities to detect potential problems which may occur in the actual NPD phase, which can then be investigated and solved.

4.7.3 Activities and Performance methods

1) Contextual Performance

As shown in a summary analysis result of interview scripts (*Figure 4.48*), obtained from the raw analysis data shown in *Appendix 3* (*pp. 569-570*), the prototyping task consists of the following three activities.:

1) **Activity 6.1: Soft-prototyping**
2) **Activity 6.2: Hard-prototyping**
3) **Activity 6.3: Workable-prototyping**

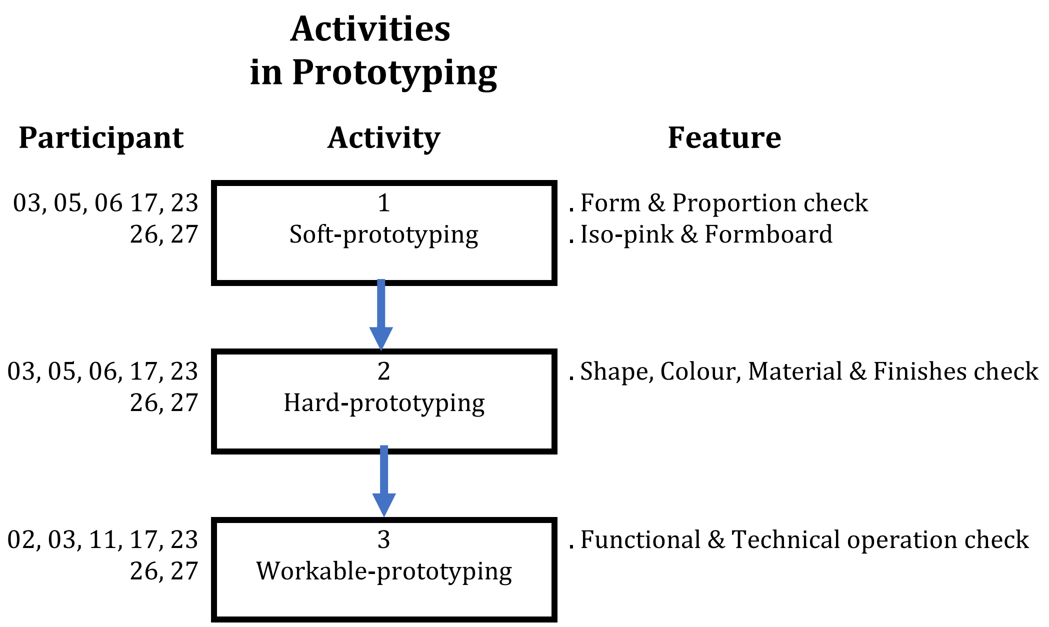


Figure 4.48. *A summary of the analysis of Task 6*

Activity 6.1: Soft-prototyping

In the first activity, a rough mock-up for each conceptual design is developed. This is known as soft prototyping. Most of the participants used Iso Pink or foamboard to develop soft mock-ups. The main purpose for using these materials is to check only the sense of proportion and the stereoscopic effects. Using rough prototypes made of those materials, problems in terms of the proportions which were not detected in the final conceptual designs can be checked and revised.

Activity 6.2: Hard-prototyping

In the next activity, hard mock-ups, which are nearly identical to the actual product on the exterior or surface, are manufactured. The actual dimensions, colours and materials are reflected in these hard prototypes. For larger product such as vehicles and furniture, mock-ups at one-eighth, one-quarter, and one-half scale are sometimes used. Here, the product can be verified not only in terms of the proportions and the stereoscopic effect but also the colours and materials.

Activity 6.3: Workable-prototyping

In the final activity, the mock-ups incorporate the estimated product functions and systems. For target products which operate mechanically, the prototype is developed such that the shell of its body can be disassembled, so that the prototype can be observed working in real time. In the case of products which operate electronically, the inner system structure is manufactured separately from the internal circuits, enabling direct verification of the system. Recently, with the advent of manufacturable design trends, developing workable prototypes in the FFE has become more and more important.

2) Concurrent Collaboration

In the prototyping task, no particular collaboration forms between the three activities (soft-, hard-, and workable-prototyping) were revealed during the interviews. Instead, collaboration in this task (Task 6) was occurred within each activity.

The first and second activities are led mainly by industrial designers, to confirm that the estimated target product can indeed be manufactured physically in terms of its shape, colours, and materials.

The third activity is carried out by R&D technicians, verifying that the estimated product can be embodied functionally and technically.

Unlike with Task 1 (Opportunity Identification-Screening) and Task 2 (Idea Generation-Screening) wherein concurrent collaboration is facilitated *between* activities, Task 6 (Prototyping) have inherent collaborative characteristics occurring *within* those three activities, as with Task 5 (Conceptual Design). The reason is that the underlying concept of the prototyping task is to embody all of the four functional domains' NPD-related aspects in a physical form that approximates the target product.

4.7.4 Section Conclusion

This section has described activities, their performance methods, and relevant toolkits in Task 6 (Prototyping).

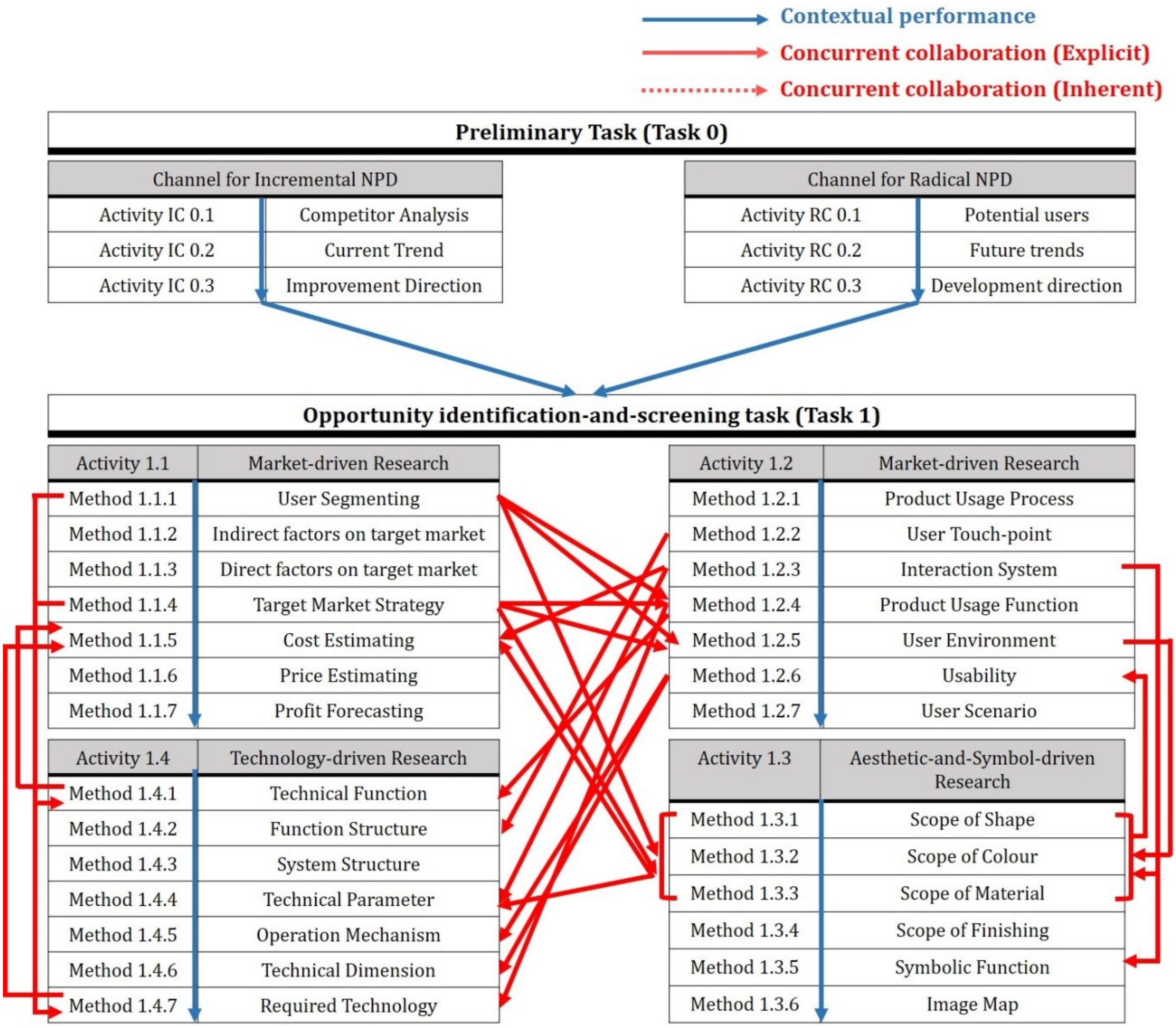
Three activities can be conducted in serial order of soft-, hard-, and workable-prototyping. Within each activity, concurrent collaboration between four functional domains (market-driven, user-driven, aesthetic-and-symbol-driven, and technology-driven) can occur to physically embody conceptual designs wherein all NPD-related requirements are reflected.

In the case of performance methods, no particular forms of contextual performance were identified between those methods, and thus performers can flexibly choose specific methods based on their expertise and preference in manufacturing prototypes in the phased-prototyping activities.

4.8 Chapter Conclusion

– Real-world FFE Scenario Inference

This chapter has described how the FFE is performed in a series of real-world scenarios. Different FFE practices were collected from 37 interviewees and then analysed using the phenomenological analysis (contextual interpretive analysis) method, looking at contextual performance and concurrent collaboration. From the different performance principles and example case studies revealed in each interview script, many linkages enabling connections between each task, activity, and performance method were extracted. Toolkits for some performance methods provided by interviewees were also applied to these linkages. A summary of the main findings is presented below (*Figure 4.49*).



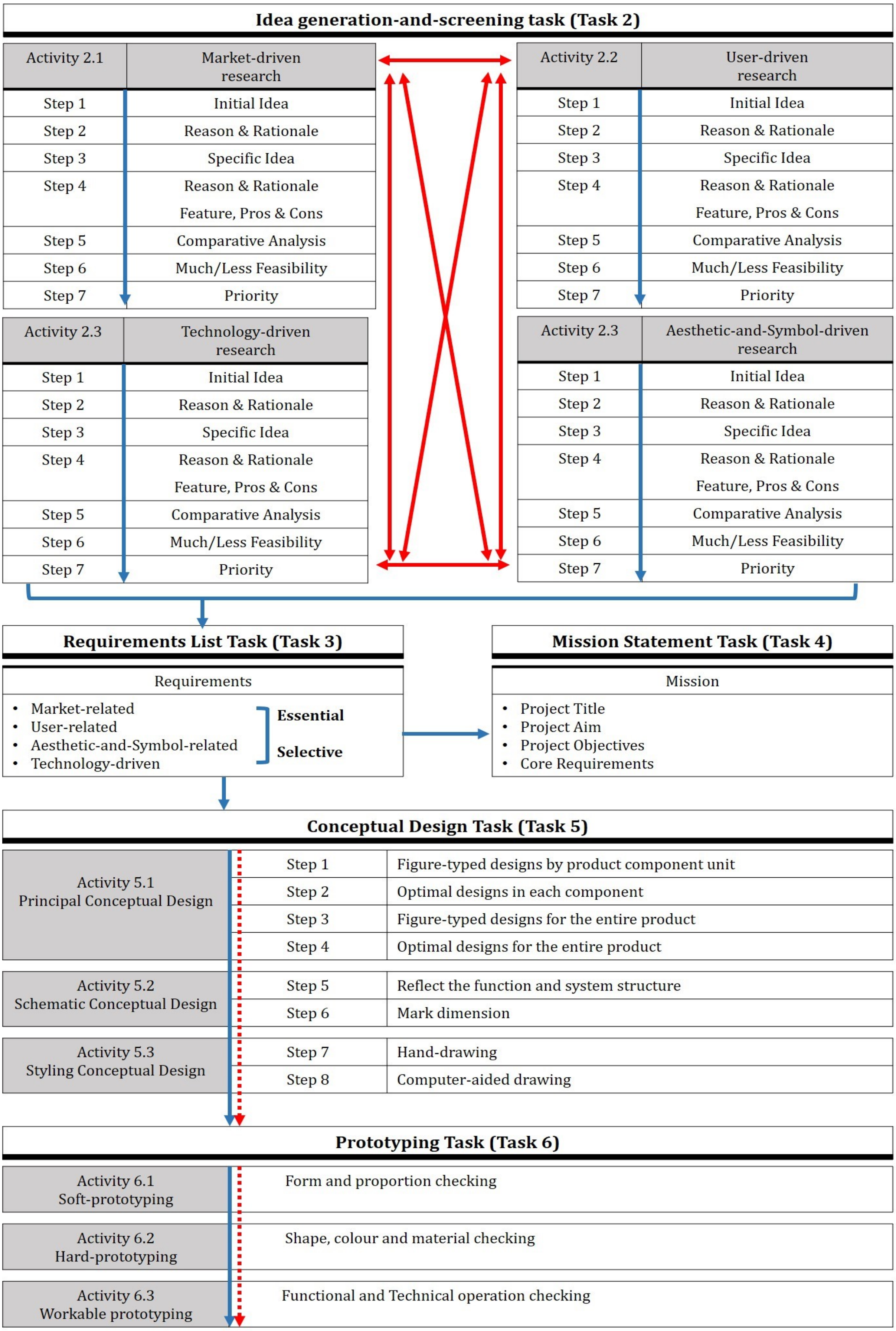


Figure 4.49. *FFE scenarios, considering contextual performance and concurrent collaboration*

Task 0: Preliminary Task

Two different channels for incremental and radical NPD make up the preliminary task (Task 0) in the initial FFE phase, to set up the improvement or development directions respectively.

1) Contextual Performance

In the incremental NPD route, the initial improvement directions (Activity IC 0.3) are established by acknowledging, first, the gaps between one's own products and those of competitors (Activity IC 0.1), and second, current trends (Activity IC 0.2).

On the other hand, the initial development directions for radical NPD (Activity RC 0.3) are established by forecasting potential users and their demands (Activity RC 0.1) along with future trends (Activity RC 0.2). Then, these improvement or development directions, as abstract opportunities, are incorporated into an existing product line (in incremental NPD) or used to generate a new product line (in radical NPD).

The product that is to be produced (through either improvement or development direction) is called the target product. Even if the tasks, activities, and relevant methods which will be executed next are identical, different outcomes can be generated at every step since each target product contains different directions.

2) Concurrent Collaboration

In the script, although collaboration between those activities in each channel was not exposed explicitly, the potential for inherent collaboration which required in conducting each activity was detected. The involvement of 'various' research fields where current and future trends occur connotes the possibility of multi-dimensional involvement.

Task 1: Opportunity Identification-Screening

In order to detect more specific opportunities, the target product can be scrutinised in the opportunity identification-screening task (Task 1). The target product is generally examined using four domains: 1) market-driven (Activity 1.1), 2) user-driven (Activity 1.2), 3) aesthetic-and-symbol-driven (Activity 1.3), and 4) technology-driven (Activity 1.4) research. These activities can exist in parallel, and their performance methods, which can be contextually linked within each activity, have a strong possibility for concurrent collaboration beyond each activity border.

1) Contextual Performance

Possibilities for contextual performance between various performance methods were identified in the analysis of real-world FFE practices.

- **Activity 1.1: Market-driven Research Activity**
  The market-driven research activity (Activity 1.1) can be divided into two parts. In the first part, relating to target users and markets, full details of the user types who will use the target product can first be specifically segmented (Method 1.1.1), and then the indirect and direct factors affecting the possible market in which those user types and the target product are situated can be investigated (Methods 1.1.2 and 1.1.3). Based on this proposed possible market, market positioning-distribution-promotion strategies can be established, to estimate an actual target market (Method 1.1.4). In the second part, which relates to the finances, an investment cost can be estimated first, an estimate which will adjust the project's budget (Method 1.1.5). Then, a product cost can be determined, considering the target margin (Method 1.1.6). Based on the development cost and product price, a profit can be forecasted, on a weekly, monthly, and annual basis (Method 1.1.7). Even though these two parts are separate, the final performance method in the first part does connect somewhat to the second part since the cost invested in the market positioning-distribution-promotion is included in the direct development cost.

- **Activity 1.2: User-driven Research Activity**

  The user-driven research activity (Activity 1.2) aims to grasp user behaviours when they use the target product in a given environment. The order in which target users operate the product is investigated first (Method 1.2.1). In each step of the product usage process, the user touch-points are generated (Method 1.2.2), enabling understanding of each interaction system (Method 1.2.3). With each interaction system, each product usage function can be explicitly identified (Method 1.2.4). By apprehending how users employ those functions in the given environments (Method 1.2.5), the usability of the target product can be grasped from an ergonomics point of view (Method 1.2.6). Encompassing all the information produced by using the performance methods above – a user-scenario, an overall scene where target users display particular behaviour patterns in the given environment – can be envisaged (Method 1.2.7).

- **Activity 1.3: Aesthetic-and-Symbol-driven Research Activity**

  The aesthetic-and-symbol-driven research activity (Activity 1.3) aims to increase the aesthetic value of the target product and infuse symbol functions into the product. In general, tangible product exterior elements consist of the shape (Method 1.3.1), colour (Method 1.3.2), materials (Method 1.3.3), and finishing touches (Method 1.3.4). An estimation of the possible scope for these elements can be conducted individually in the order listed above, but these product appearance elements can also be handled together in a bundle. After proposing the possible scope for each element, symbolic meanings can be assigned to those elements (Method 1.3.5). Lastly, based on the analysis of the product exterior elements above, an aesthetic-and-symbolic board and image map (Method 1.3.6) can be developed to conceptualise an overall image of the target product, by reflecting the proposed scope of the shape, colour, material and finishing specifications as well as symbolic meanings assigned to those appearance elements.

- **Activity 1.4: Technology-driven Research Activity**

  The technology-driven research activity (Activity 1.4) can play a pivotal role in enabling the technical operation of the target product. Based on the target product, technical compositions and their main and sub-functions can be defined in the first performance (Method 1.4.1). With those functions and their relationships in hand, each composition can be arranged, forming the functional structure of the product

(Method 1.4.2). By grasping the processing systems generated in each composition and their systemic relationships in the functional structure, the overall system structure can be devised, considering how the product can be operated technically (Method 1.4.3). Then, the technical parameters can be estimated for those processing systems and their systemic connections (Method 1.4.4). Based on these parameters, the operational mechanisms of not only the product as a whole but also its various compositions can be understood explicitly (Method 1.4.5). These working mechanisms, along with the technical parameters, enable us to estimate the possible range of technical dimensions for the overall product and its various components (Method 1.4.6). Considering all the information yielded in the previous implementations, the technologies which are required for the technical operation of both the product and its parts can be grasped (Method 1.4.7).

2) Concurrent Collaboration

While carrying out those performance methods for contextual performance, possibilities for concurrent collaboration were revealed as follows. These 8 collaboration forms were reasoned by integrating the related various collaboration forms centred on each functional domain.

- **Collaboration Form 1**
  Depending on the user type (Method 1.1.1) and target markets (Method 1.1.4), the product usage functions (Method 1.2.4) can differ, resulting in different technical functions (Method 1.4.1) on the back of those usage functions, which involves different technologies (Method 1.2.7) to embody those functions.
- **Collaboration Form 2**
  Depending on the user types (Method 1.1.1) and target markets (Method 1.1.4), the preferred shapes, colours and materials can vary (Method 1.3.1 to 1.3.3). These different product appearance elements (Method 1.3.1 to 1.3.3) have different inherent properties (Method 1.4.4), requiring different technologies (Method 1.4.7) to embody those elements.
- **Collaboration Form 3**

Different user types (Method 1.1.1) are exposed in different environments (Method 1.2.5), which can generate different usability considerations for each component (Method 1.2.6), in turn affecting what working mechanisms are deemed proper working principles (Method 1.4.5) as well as the proper range of technical dimensions (Method 1.4.6) for those components.

- **Collaboration Form 4**

  Each user touch-point on the surface of the product (Method 1.2.2) can influence the arrangement of technical compositions inside the product, arrangements which form the function structure (Method 1.4.2).

- **Collaboration Form 5**

  In each interaction system (Method 1.2.3), technical parameters (Method 1.4.4) are generated, each of which require proper mechanisms for operation (Method 1.4.5).

- **Collaboration Form 6**

  In each interaction system (Method 1.2.3), product appearance elements (Method 1.3.1 to 1.3.3) (which serve as input signals perceived by the five senses) and their proper scopes (Method 1.3.1 to 1.3.3), along with inherent symbolic functions (Method 1.3.5) (which serve as the product's output responses) can be proposed, to consider usability (Method 1.2.6). The usability aspect (Method 1.2.6) can affect what working mechanisms (Method 1.4.5) are considered proper as well as the proper range of technical dimensions (Method 1.4.6) of those components.

- **Collaboration Form 7**

  The interaction systems (Method 1.2.3) influence examining the appropriate scope of product appearance elements (Method 1.3.1 to 1.3.3) per component. The nominated shape, colour and material of each component (Method 1.3.1 to 1.3.3) provided semantic messages to users (Method 1.3.4). According to the different symbolic functions (Method 1.3.4), this affected the considering of usability aspects (Method 1.2.6) and the proper working principal (Method 1.4.5) of each component accordingly, which further leads to calculating their proper dimensions (Method 1.4.6).

- **Collaboration Form 8**

  Depending on the user environments (Method 1.2.5) in which the target product is situated, different product exterior elements (Method 1.3.1 to 1.3.3) can be suggested, to ensure visual harmonisation. These different product appearance elements (Method 1.3.1 to 1.3.3) have different inherent properties (Method 1.4.4), demanding different technologies (Method 1.4.7) to embody those elements.

Most of the performance methods described above can be bound up with adjustments to the development cost and budget. Apart from these collaboration forms, the potential for several other forms of collaboration were exposed during the interviews.

In this way, concurrent collaboration can proceed between not only one-to-one performance methods but also many-to-many methods, or via a series of performance methods.

In addition, it was revealed that concurrent collaboration can occur by implementing those performance methods on the component units. Collaboration that takes place on a component basis can first centre around the cost estimation in Activity 1.1, user touch-point identification in Activity 1.2, the product exterior element proposal in Activity 1.3, and the technical function definition in Activity 1.4.

One point worthy of mention is that the screening function for Task 1 seems inherent to the process of contextual performance and concurrent collaboration wherein the process and outcomes of performance methods are considered not only exquisitely in one functional domain but also multidimensionally in the four functional domains. Thus, information less related to the target product development can be filtered out by conducting the performance methods from those two aspects.

Task 2: Idea Generation-Screening

In an extension of the opportunity discovery task (Task 1), the idea generation-screening task (Task 2) can be performed to devise ideas in the form of actionable methods to materialise those opportunities. Hence, as with Task 1, this task is comprised of four domains: the market-driven (Activity 2.1), user-driven (Activity 2.2), aesthetic-and-symbol-driven (Activity 2.3) and technology-driven (Activity 2.4) ideation activities, domains which can operate in parallel. However, unlike Task 1, which has different performance methods for each activity, Task 2 exposed the possibility of having a single representative ideation and feasibility check method which can be applied to all four activities. This representative method centres around a phased systematic ideation-screening approach and an intuitive ideation-screening approach, the latter of which can be applied selectively when appropriate.

1) Contextual Performance

The phased methodical performance method consists of four steps for ideation and three steps for screening. The systematic ideation method originates from the task which maps out 'How' ideas transformed into actionable methods, for 'What' opportunities, based on 'Why' (supportive reasons and rational evidence). Under this concept, a total of seven steps of the representative ideation processing method were reasoned from the different ideation methods.

- **Steps 1 and 2 (Idea Generation Processing)**
  Initial ideas to materialise opportunities (Step 1) are devised by considering supporting reasons and rational evidence (Step 2).
- **Step 3 and 4 (Ideation Generation Processing)**
  In Step 3, those initial ideas are taken a step further to map out more specific ideas. Lastly, along with reasons and evidence for those specific ideas, their features, strengths, and weaknesses are examined (Step 4).
  This examination can serve as a bridge between the idea generation work above and the idea screening work below.

- **Step 5 (Idea Screening Processing)**
  The first performance in the screening work compares each idea based on their features, pros, and cons (Step 5).
- **Step 6 (Idea Screening Processing)**
  Then, those ideas are classified into two idea groups: 'more feasible' and 'less feasible'.
- **Step 7 (Idea Screening Processing)**
  Lastly, ideas in the 'more feasible' idea group are prioritised (Step 7).

In each step, intuition ideation processing can be involved to increase the creativity and novelty of the devised ideas.

2) Concurrent Collaboration

The systematic idea generation-screening task also provided the possibility of particular concurrent collaboration forms.

As with the opportunity discovery task (Task 1), this task can be conducted with the market-driven, user-driven, aesthetic-and-symbol-driven and technology-driven domains. In devising actionable methods and considering supportive reasons, the viewpoint of the four domains can be considered at the same time.

Furthermore, this collaboration form can occur within the product component unit in the sense that each idea is devised for each opportunity, opportunities that are discovered by scrutinising the target product component by component.

Task 3 and 4: Requirements List and Mission Statement

Unlike the two tasks previously presented, from the contextual performance and concurrent collaboration perspectives, no particular activities or performance methods were exposed in the requirements list (Task 3) and mission statement tasks (Task 4). Hence, these two tasks were not analysed from those two perspectives. Instead, the analysis targeted their basic concepts, content covering these two tasks, the format, etc.

Task 3: Requirement List

The requirements list (Task 3) can be drawn up based on information related to the target product produced in Tasks 1 and 2. It is a form of preparation wherein product specifications in advance of the actual NPD phase are listed. The list covers target market information, market positioning-and-distribution strategies, product functional-and-technological features and relevant specifications, exterior design elements and so on. Requirements can be sorted into two categories: essential (must) criteria and selective (should) criteria.

Task 4: Mission Statement

The mission statement is essentially a summary of the requirements list. It includes the project's title, aims and objectives. It can also include some core requirements (though this is not strictly necessary).

Task 5: Conceptual Design Task

The nature and concept of the conceptual design task (Task 5) is very similar to that of the generation-screening task (Task 2). For each activity, a representative method consisting of several steps was deduced from common patterns revealed in the various performance methods provided by different interviewees. The overall system of the method centres around a phased systematic conceptual design approach, and an intuitive conceptual design approach which can be engaged optionally (at any step of the systematic approach). However, unlike the ideation task (Task 2) in which the four activities sit in parallel, here, three activities were revealed, related in terms of contextual performance. Also, whereas the opportunity discovery and ideation tasks revealed the possibility of explicit concurrent collaboration forms occurring between activities, collaboration fostered within each activity seems to be inherent to this task.

1) Contextual Performance

The aim of the conceptual design task in the NPD can be to visually express product specifications by creating a product 'form', using the following eight phased contextual performance methods in three sequential activities.

Activity 5.1: Principal Conceptual Design

The first activity is a principal conceptual design (Activity 5.1) to devise possible concepts in an initial, simple form.

- **Step 1**
  Simple forms of possible conceptual designs for each component are proposed, using basic figures such as circles, triangles, rectangles, and parallelograms.
- **Step 2**
  Step 2 determines which concepts are optimal for each component, based on their features, strengths, and weaknesses.
- **Step 3**
  Then, these concepts for each component are interjoined, considering the most standard structure of the target product (Step 3).
- **Step 4**

Depending on the features, strengths, and weaknesses of each combination, optimal conceptual designs for the overall product are proposed.

Activity 5.2: Schematic Conceptual Design

The next activity is the schematic conceptual design (Activity 5.2), which consists of two steps.

- **Step 5**
  The first step (Step 5) pursues more variations of the conceptual designs proposed in Step 4 by assembling and disassembling component units in different ways, based on the function and system structure.
- **Step 6**
  In the next step (Step 6), by reflecting the technical dimensions and ergonomic data shown in the requirements list, the conceptual designs generated in the previous step are brought 'closer' to the actual structure of the target product.

Activity 5.3: Styling Conceptual Design

The final activity (Activity 5.3) refines the conceptual designs produced by the previous two activities. This is known as styling work.

- **Step 7**
  Hand-drawing (Step 7) is done first.
- **Step 8**
  Hand-drawing is followed by computer-aided drawing (Step 8), though some designers opt to skip Step 7 entirely.

2) Concurrent Collaboration

As mentioned before, explicit forms of collaborative work, occurring between conceptual design activities, were not identified in real-world FFE scenarios. However, this task seems to have imminent collaborative characteristics which occur within each activity since the underlying concept is to comprehensively reflect all product-related information obtained from the viewpoints of the four functional domains into a visual format.

Task 6: Prototyping Task

The prototyping task (Task 6) confirms not only what the form of the target product is to be physically but also how the product operates functionally and technically, whereas the conceptual design task (Task 5) visually checks possible forms of the target product in which requirements produced theoretically are reflected.

1) Contextual Performance

Prototyping can consist of three serial activities for contextual performance:

- Activity 6.1: Soft-prototyping
- Activity 6.2: Hard-prototyping
- Activity 6.3: Workable-prototyping

The first and second activities serve to verify physical forms of the target product in terms of shape, colour and material. The third activity verifies the product in a more substantive manner, determining whether the functional and technical elements operate as intended. In the case of relevant performance methods, there was no relationship between the methods in terms of contextual performance. Instead, different performance methods were used independently for different purposes, depending on the different preferences and areas of expertise of the performers.

2) Concurrent Collaboration

For concurrent collaboration, just like with the conceptual design task (Task 5), explicit systems occurring between activities were not identified in the prototyping task. However, the task seems to have inherent collaboration characteristics which occur within each activity in that the fundamental concept of prototyping is to comprehensively reflect NPD-related information in a physical form by considering the various aspects of the product.

So far, the analysis of real-world FFE practices has generated a new finding in the form of the representative FFE scenario presented above. The finding, in which FFE activities, their performance methods, and relevant toolkits were connected with each other for contextual performance and concurrent collaboration in a single FFE execution stream can be a practical resource to build a pragmatic-prescriptive FFE model consisting of the preliminary task (determination of NPD direction) and the six main FFE tasks.

Chapter 5. Study 2.2

– Pragmatic-Prescriptive FFE Model Development

5.1 Chapter Introduction

This chapter illustrates the progress and key findings of Study 2.2, which fulfils Objective 3 (shown in *Figure 5.1*).

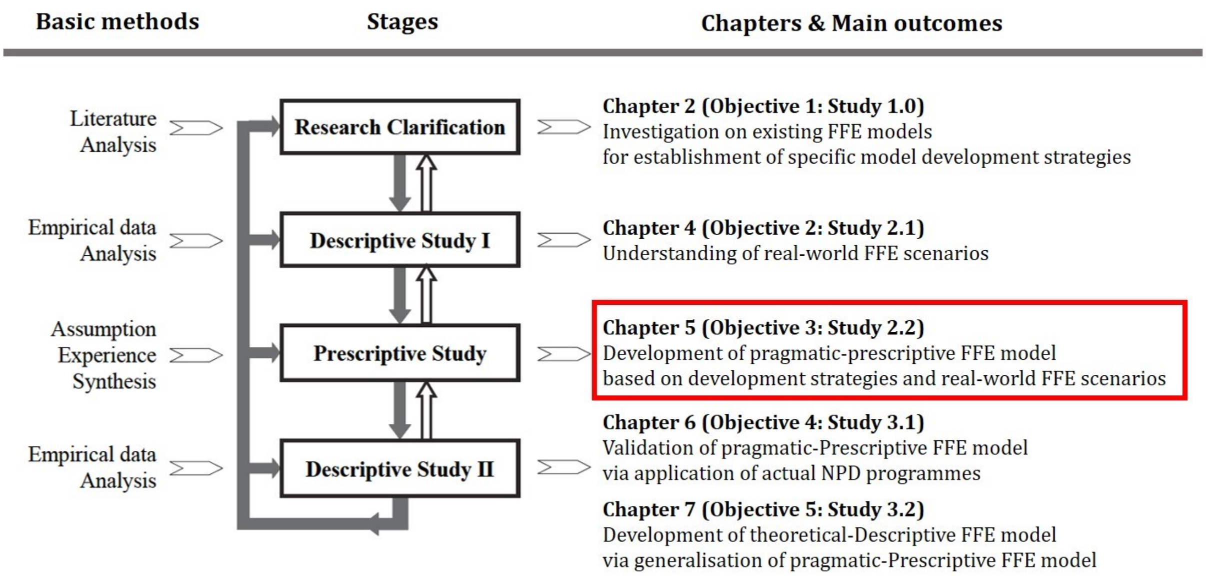


Figure 5.1. *Mini-map of Study 3.1 (Own depiction, adapted from Blessing & Chakrabarti, 2009)*

The chapter introduction begins by describing the research objective of this chapter, followed by the research method to accomplish the objective, before concluding with a summary of the chapter introduction.

1) Research Objective
2) Research Method
3) Research Summary

5.1.1 Research Objective

The goal of Study 2.2 is to fulfil Objective 3 developing the pragmatic-prescriptive FEE model. The FFE model is structured by incorporating not only the development strategies and relevant knowledge and theories obtained in Chapter Two (Study 1.0), but also the representative FFE practice inferred from the analysis of real-world FFE scenarios in Chapter Four (Study 2.1). The model targets large corporations, as well as SMEs engaged in practical design activities across the entire range of the FFE (e.g. design speciality firms and NPD consultancies) in consumer product sectors such as electronics, medical devices, vehicles, and furniture.

5.1.2 Research Method

1) Overall Approach

An outline of the research method for Study 2.2 implemented in this chapter is shown in the block coloured with red below, in *Figure 5.2*.

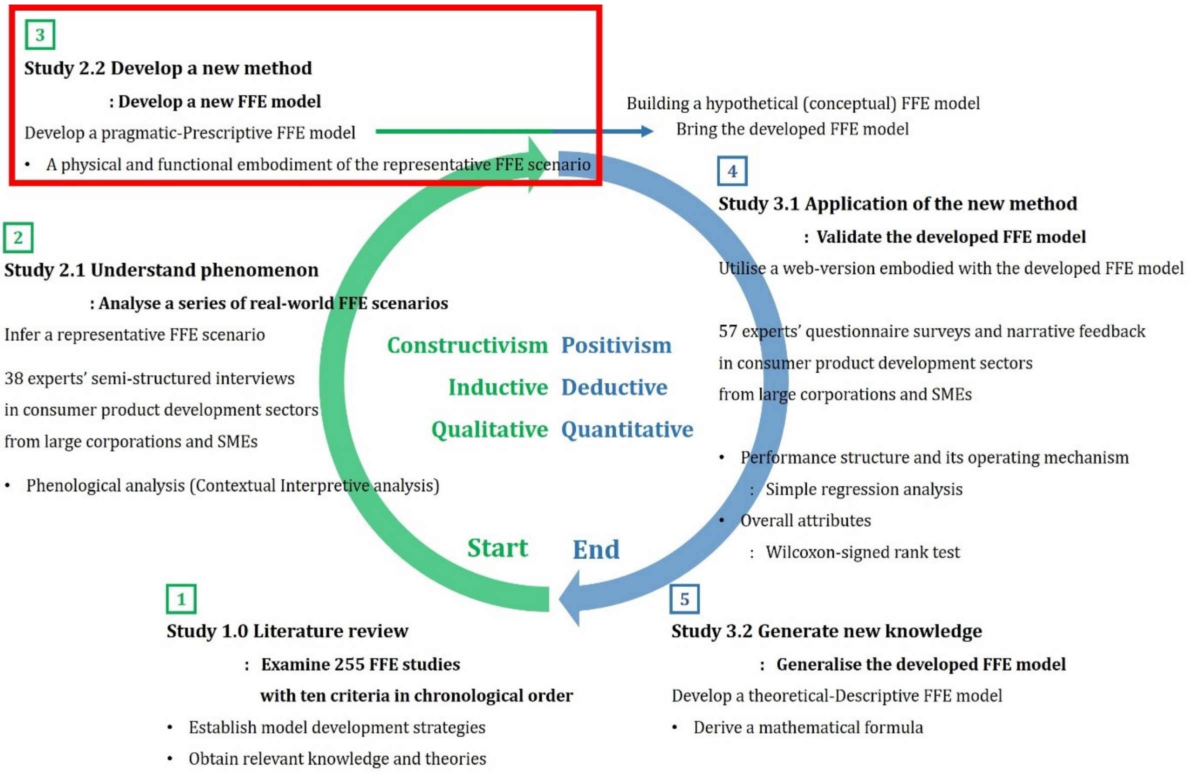


Figure 5.2. *Research method of Study 3.1*

Study 2.2 attempts to build the pragmatic-prescriptive FFE model. Basically, the overall direction of the research method was approached using inductive reasoning under the constructivist research paradigm.[42] The FFE model is structured considering: 1) model development strategies established in Chapter Two (Study 1.0) and 2) the representative FFE scenario derived from analysing real-world FFE scenarios in Chapter Four (Study 2.1).

1.1) Model Development Strategies Consideration

The pragmatic-prescriptive FFE model was developed considering the model development strategies established in the literature review. Along with those development strategies, knowledge-and-theories obtained from when the strategies were established were also reflected in the FFE model development.

1.2) Representative FFE Scenario Reflection

The pragmatic-prescriptive FFE model was structured to reflect the representative FFE scenario deduced from the various real-world FFE scenarios studied. The structure is as follows.

In the first step (shown in the left part of *Figure 5.3*), the raw interview scripts were analysed using the phenomenological analysis (contextual interpretive analysis) method, focusing on the contextual meaning of clauses and phrases and their contextual relationships. The scripts were thoroughly dismantled, looking at the four hierarchical FFE performance units making up the FFE performance structure and its operating mechanism: 1) Task, 2) Activity, 3) Performance Method, and 4) Toolkit. Each dismantled unit was reclassified into each hierarchical unit group and then linkages between the units were identified from the viewpoint of contextual performance and concurrent collaboration.

In the next step, the structural transformation step, the units were connected with each other with the linkages as the centre, reconstructing a single representative FFE scenario

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[42] More details of the inductive reasoning process under constructivism paradigm can be found in Chapter Three (Research Methodology, *p. 113*).

organised for the contextual performance and concurrent collaboration. However, the format remains textual.

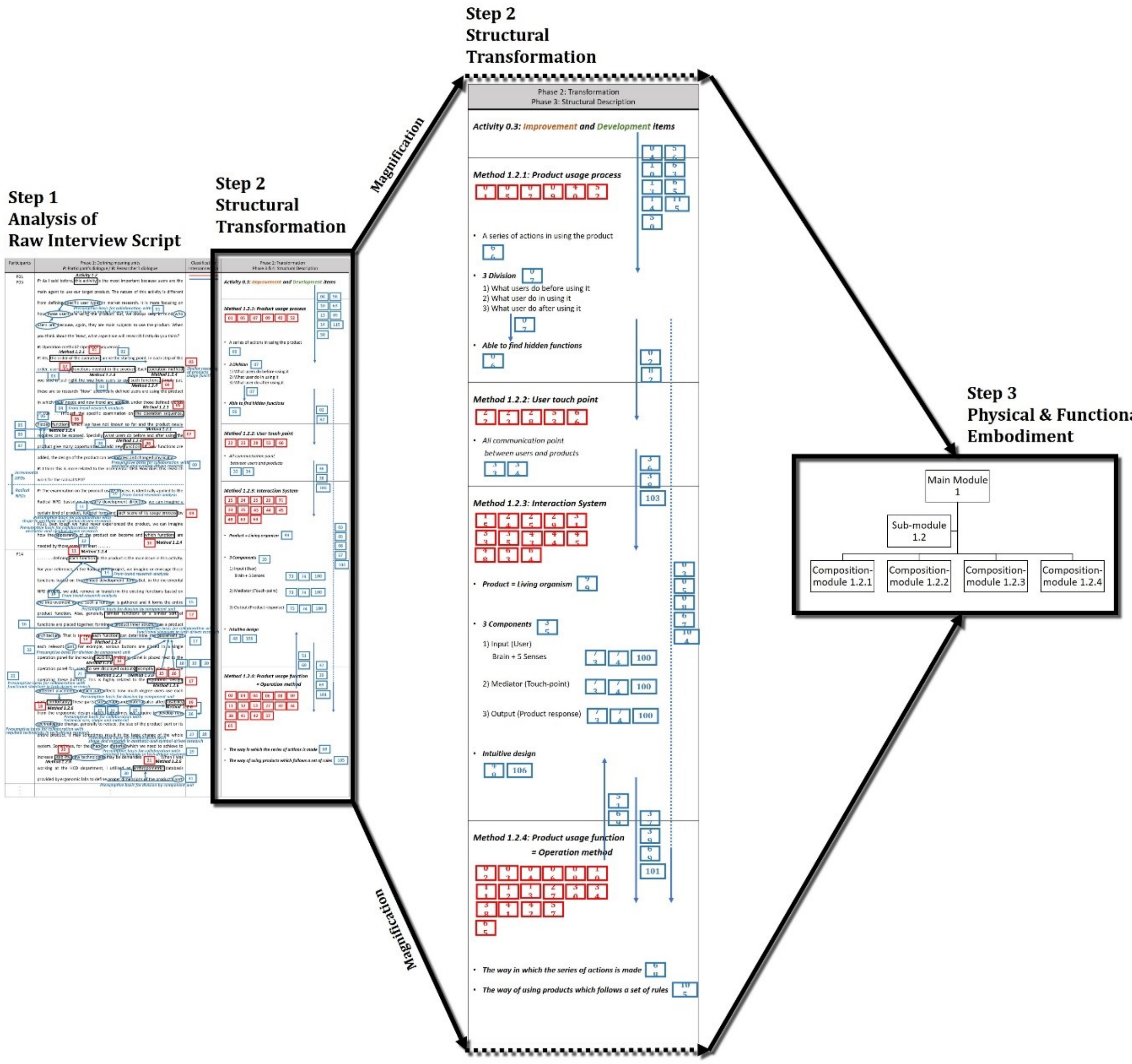

Figure 5.3. *Process of building model structure from real-world FFE scenario*

In the last step, the physical and functional embodiment step, the representative FFE scenario, still in textual form, was transformed into a physical and functional model type. In the process of transformation, particular building mechanisms for reflecting not only the model development strategies but also the representative FFE scenario studied for contextual performance and concurrent collaboration were devised. Details of the model building mechanisms are introduced in the section below.

2) Model Building Mechanism

The pragmatic-prescriptive FFE model was structured with three kinds of constituents. The task unit defined in the interview scripts was assigned to the 'Main module' unit. The activity and performance method/toolkit unit were assigned to the 'Sub-module' and 'Composition-module' units respectively. The tasks, activities, performance method/toolkit units, and module units all received corresponding numbered labels, e.g. Task 1 was designated as Main module 1, Activity 1.1 was assigned to Sub-module 1.1, and Performance method/toolkit 1.1.1 was appointed to Composition-module 1.1.1. With this hierarchy of module units, the FFE model was built using two model structurisation mechanisms serving as assembly instructions for contextual performance and concurrent collaboration (regarding the FFE performance structure and its operating mechanism.

2.1) Mechanism 1
: FFE Performance Structure and Its Operating Mechanism
– Contextual Performance

The first mechanism is for structuring the model for contextual performance. It can be applied to the following: 1) between composition-modules, 2) between sub-modules, and 3) between main-modules.

- **Mechanism 1.1: Contextual Performance between Composition-modules within a Sub-module**
  As shown in the upper part of Figure *5.4*, each sub-module has a horizontal and vertical axis. In the horizontal axis, each composition-module (in which relevant performance methods are embodied as toolkits) was arranged sequentially for contextual performance. The vertical axis was structured to cover the product components. Therefore, at each intersection of the vertical and horizontal axes, a parameter, calculated by using each performance method, can be produced for each component. By arranging composition-modules next to each other, and enabling interlocking, a parameter produced in the first composition-module can serve as the input resource for the second composition-module. An output

parameter in the second composition-module can be obtained based on the output parameter obtained in the first composition-module, and fed as an input into the third composition-module. In short, the output parameter of one composition-module serves as the input parameter for the next. In this way, all composition-modules interlock, and once we have parameters in the first composition-module, parameters from the second all the way to the final composition-modules can be obtained with ease.

- **Mechanism 1.2: Contextual Performance between Sub-modules within a Main Module**
  The mechanism for fostering contextual performance can also be applied to connect sub-modules together. In the case of sub-modules structured with composition-modules, the final composition-module in the previous sub-module is linked with the first composition-module in the next sub-module. Hence, an output parameter from the final composition-module in the former sub-module becomes the input resource for the first composition-module in the latter sub-module. Conversely, sub-modules which do not need any composition-modules are interlocked directly with each other without going through composition-modules. Therefore, an output parameter in the previous sub-module can flow into the following sub-module as an input resource, directly.

- **Mechanism 1.3: Contextual Performance between Main Modules**
  The mechanism described above can be used to link one main module to another. It can be embodied by interlocking the final sub-module in the previous main module with the first sub-module in the following main module. Therefore, in the same context, in the case of sub-modules structured with composition-modules, the final composition-module in the final sub-module of the previous main module interlocks with the first composition-module in the first sub-module of the following main module. Conversely, sub-modules which do not need any composition-modules are connected directly with each other without going through composition-modules. Therefore, an output parameter in the previous sub-module can enter into the following sub-module as an input resource, directly.

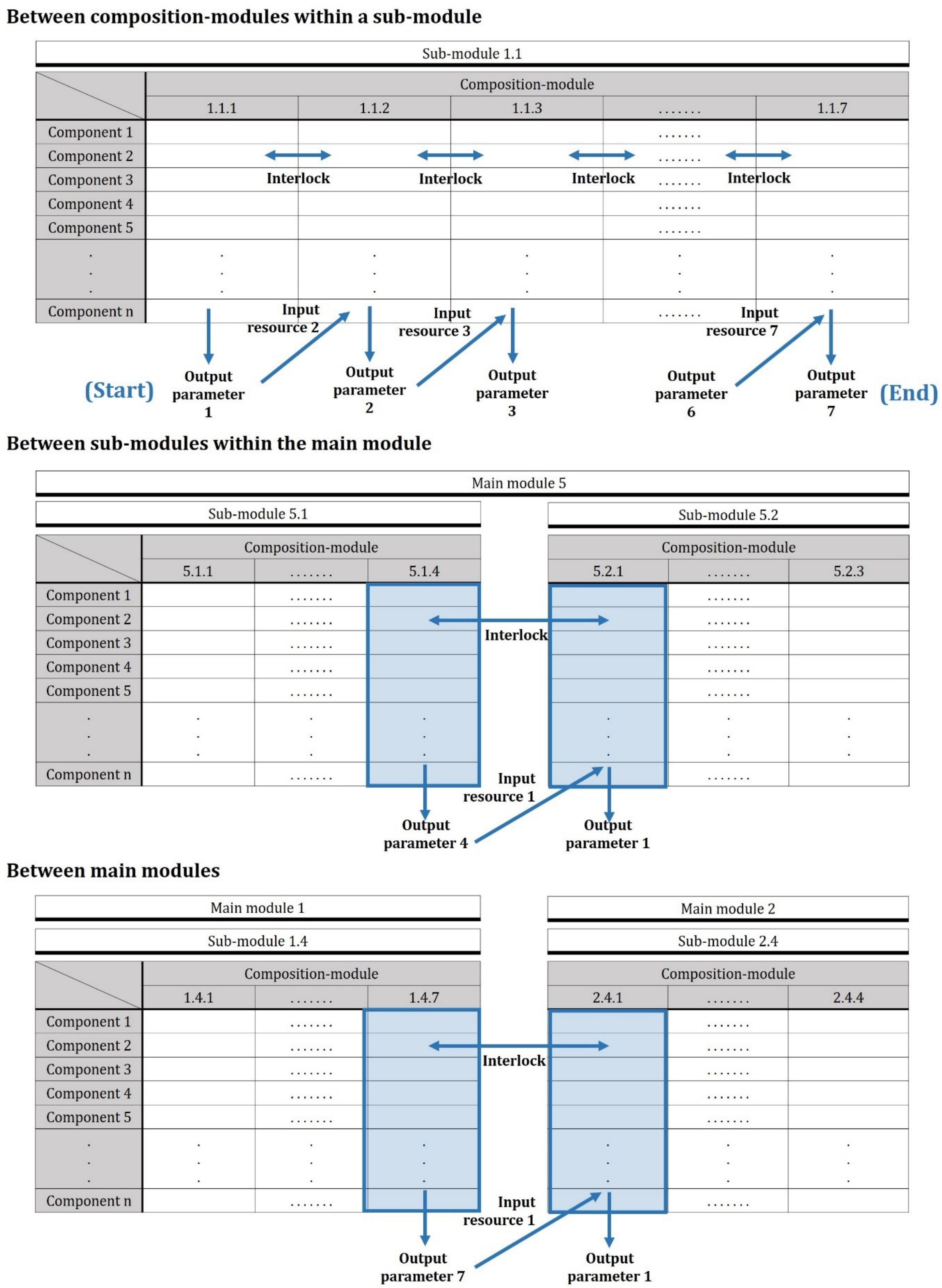

Figure 5.4. *Mechanism of structuring the FFE model for contextual performance*

2.2) Mechanism 2
: FFE Performance Structure and Its Operating Mechanism
– Concurrent Collaboration

The second mechanism structures the model for concurrent collaboration (*Figure 5.5*). Two model building sub-mechanisms can be applied depending on the relationship between the FFE activities: 1) concurrent collaboration *between* modules and 2) concurrent collaboration *within* modules.

- **Mechanism 2.1: Concurrent Collaboration between Modules**
  In the case of activities lying in parallel (e.g. Task 1: Opportunity identification-screening, and Task 2: Idea generation-screening) sub-modules representing the FFE activities were placed first in a clockwise direction in quadrants 1 to 4, as indicated in the upper part of *Figure 5.5*. Then, as shown in the block coloured in red, these sub-modules interlock with each other with composition-modules playing a common role as the centre. In each sub-module, the remaining composition-modules are stretched out in the left or right direction with the centric composition-modules in the centre.
  This placement of sub- and composition-modules in quadrants allows us to identify and note the progress and status of all parameters being produced by the four different functional domains. Hence, when a performer from a certain functional domain produces parameters in sub-modules related to his/her own expertise, he/she can concurrently consider parameters generated in the three remaining sub-modules, which are conducted by performers from other functional domains. Such concurrent consideration can be fostered not only in components, but also between components (shown in blocks coloured in blue and green respectively).
- **Mechanism 2.2: Concurrent Collaboration within Modules**
  In other cases, where activities exist in sequence rather than in parallel (e.g. Task 5: Conceptual design and Task 6: Prototyping), sub-modules representing the FFE activities are not arranged in quadrants but instead sequentially, considering contextual performance. As mentioned in the first structural mechanism for contextual performance, the y-axis in the sub-modules is structured on a product component basis, while the x-axis consists of relevant sub- and composition-

modules connected for contextual performance. Therefore, in the second sub-mechanism, different performers from the four functional domains can produce parameters together within each sub- and composition-module (as shown in the block coloured in purple), with consideration of not only individual components but also the relationship between these components (shown in the blocks coloured in orange).

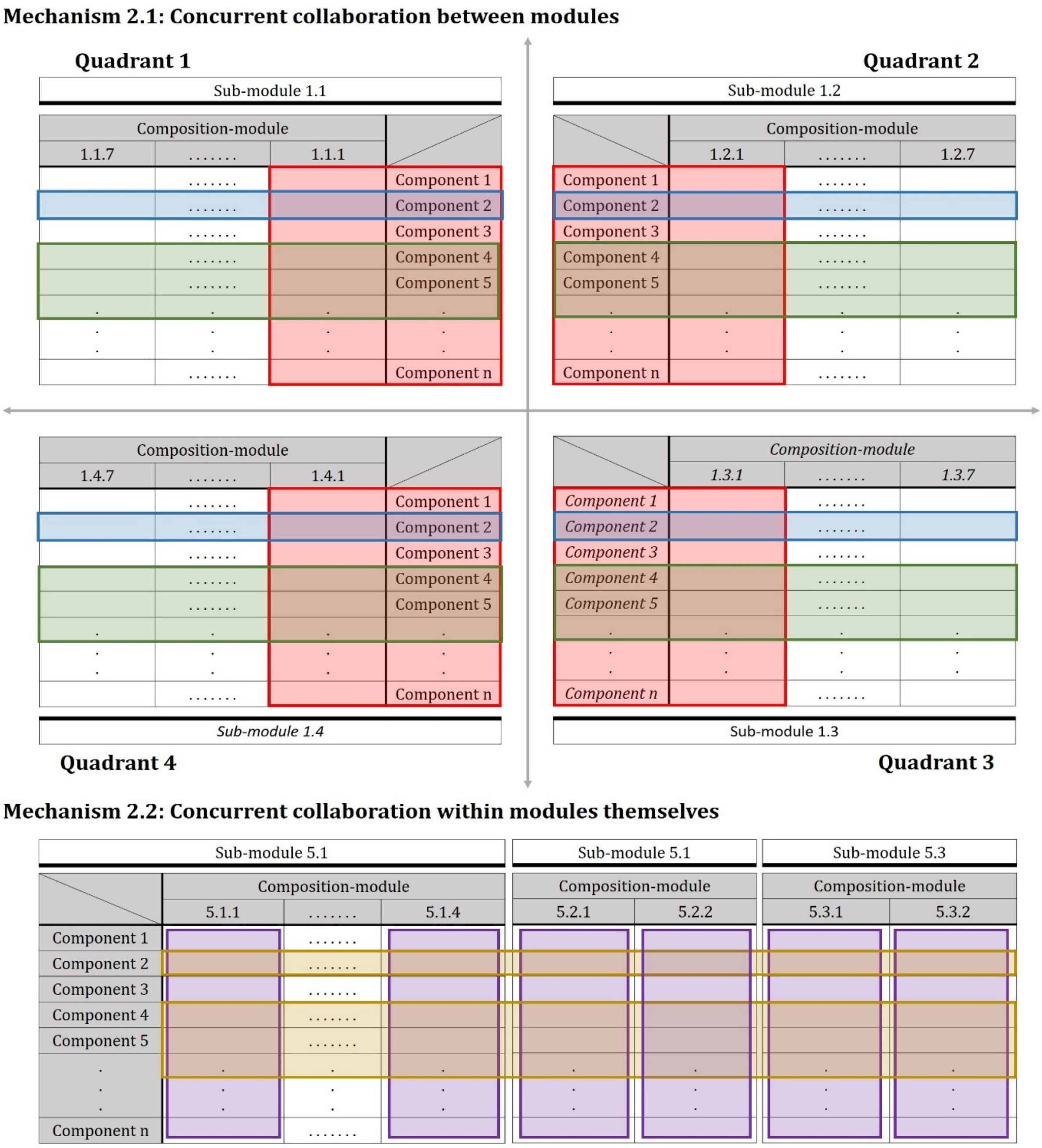

Figure 5.5. *Mechanism of structuring the FFE model for concurrent collaboration*

2.3) Mechanism 3

: Overall Attributes

– The Current and Future Trends of FFE Model Improvement

By applying the model structure mechanisms above, five overall model attributes concerning the current and future trends of FFE model improvement were realised, in the manner of a chain reaction.

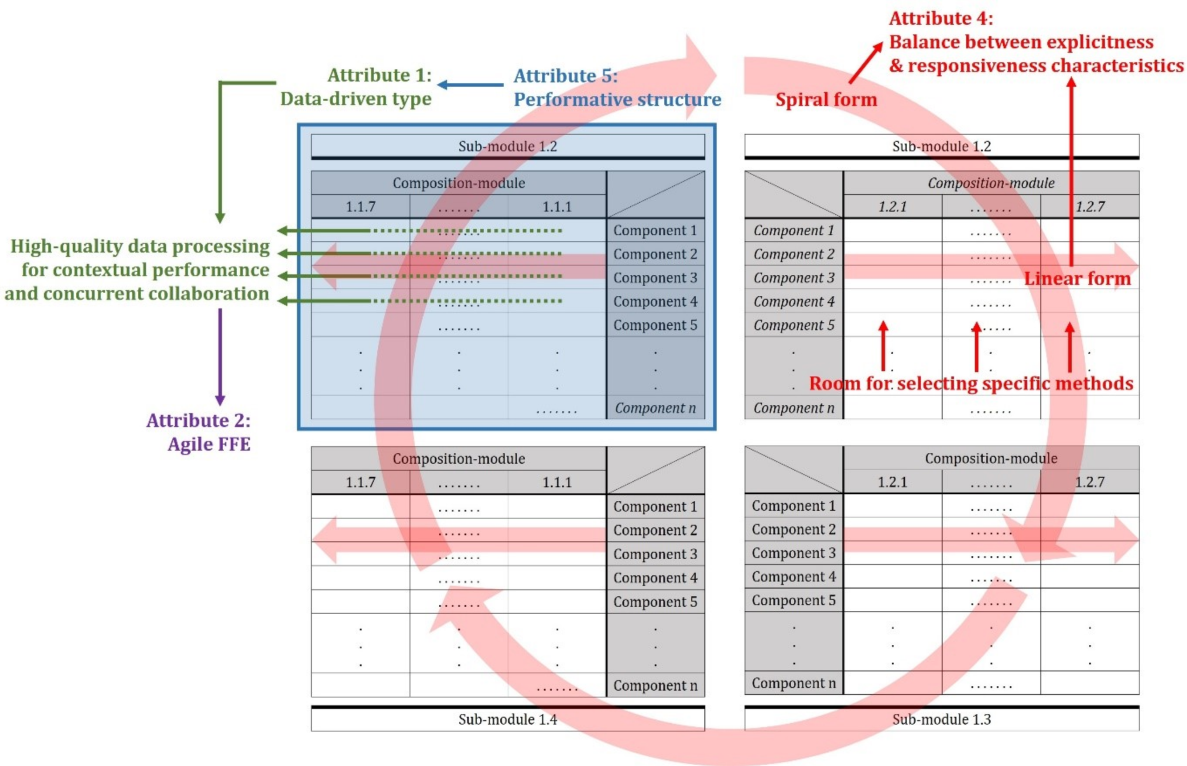

Figure 5.6. *Overall attributes of the model structure*

- **Attributes 1, 2 and 5: Data-driven Performative FFE Model for Agile FFE Practices**

  The FFE model was built with a sequential structure of main modules consisting of sub- and composition-modules structured in a parameter matrix format. This type of model can be regarded as the procedural structure with performative-type sub-structures. (Attribute 5).

  In this, the performative type can contribute to a data-driven type of model in which parameters lead the entire FFE's practice by processing and determining inputs and outputs for contextual performance and concurrent collaboration, rather than simply producing parameters (Attribute 1). The parameter matrix can help develop what is essentially akin to an NPD 'encyclopaedia', in which various sets of parameters is gathered and analysed per project, and which can be studied in later projects (Attribute 1). To be specific, those parameters can be accumulated continuously to build a FFE library dataset during each FFE project. Applicable data sets in the data library can be extracted and applied to different FFE projects in the future. As a result, the methods in this FFE model promote the ultimate aim of the data-driven type of accumulating and generating NPD-related data in the form of new knowledge (Attribute 1).

This data-driven type of model can promote the generation of parameters considered from the contextual performance and concurrent collaboration perspectives, which can contribute to agile FFE practices by reducing not only the unnecessary iterative work caused by flawed data collection and interpretation methods (Attribute 2) but also unnecessary meetings to explain parameters and their evidential descriptive interpretations.

- **Attribute 4: Balanced Explicitness and Responsiveness Characteristics**

  Main modules structured with sub-modules lying in parallel can be considered as well-balanced between explicitness and responsiveness (Attribute 4). The arrangement of sub-modules in the clockwise direction in the quadrants (the spiral type) contains the responsiveness characteristic, while the arrangement of composition-modules in right or left direction (the sequential structured type) contains the explicitness characteristic.

  In addition, by providing discretion to performers to select optional performance methods when carrying out each composition-module, this FFE model can increase the creativity of individuals operating under an explicitly formalised performance direction. For instance, when investigating the product usage process (Performance Method 1.2.1; Composition-module 1.2.1), performers can select specific performance methods such as creating video recordings, employing cultural probes, conducting surveys and so on. Because of the discretion afforded, despite use of the same composition-modules, different outcomes can be achieved within the formalised performance direction. This therefore contributes to harmonisation between explicitness and responsiveness (Attribute 4).

- **Attribute 3: Both for Incremental and Radical NPDs**
  Aside from the influence of two building mechanisms, two different channels were equipped and defined in the very initial part of the FFE model, in order to realise the varied FFE practices for incremental and radical NPDs (Attribute 3). This part serves as preparation for establishing improvement or development directions for incremental and radical NPDs, respectively. These two routes were built into the preliminary module (Main module 0).

In summary, in order to physically and functionally embody the representative FFE scenario with the FFE model structure, three model building mechanisms were devised according to the model structure for contextual performance, concurrent collaboration, and the model attributes, respectively. These model building mechanisms are original model building approaches which were devised in this research.

5.1.3 Research Summary

Chapter Five (Study 2.2) aims to develop the pragmatic-prescriptive FFE model, fulfilling Objective 3. The FFE model development considers not only the model development strategies established in Chapter Two (Study 1.0) but also the representative FFE scenario inferred from analysing diverse real-world FFE practices in Chapter Four (Study 2.0). The model development is approached using inductive reasoning under the constructivism research worldview. In order to effectively reflect the model development strategies and the representative FFE scenario in the model structure, three model building mechanisms are developed, depending upon the FFE performance structure and its operating mechanism (regarding contextual performance and concurrent collaboration) and overall attributes (regarding current and future trends of FFE model improvement).

This chapter introduces the progress and key findings of the developed FFE model and is divided into seven sections representing the basic structure of the proposed FFE, consisting of the preliminary task of establishing the NPD direction (incremental or radical), and the ensuing six substantive tasks. Each section is divided into three parts describing the model structure (which consists of FFE activities and their performance methods/toolkits) from the viewpoints of: 1) module building mechanisms, 2) contextual performance, 3) concurrent collaboration, and 4) the overall attributes.

1) Module 0: Preliminary Task
2) Module 1: Opportunity Identification-Screening Task
3) Module 2: Idea Generation-Screening Task
4) Modules 3 and 4: Requirements List and Mission Statement
5) Module 5: Conceptual Design Task
6) Module 6: Prototyping Task

5.2 Module 0
– Preliminary Task

5.2.1 Module Building Mechanism

Main Module 0 was structured, physically and functionally embodying the preliminary task of the representative FFE scenario (*pp. 251-264*), by applying the following model building mechanisms.

Main module 0 is for the preliminary task (Task 0) for establishing the improvement or development directions (for incremental or radical NPD projects, respectively). Hence, two different channels for each NPD attribute were built separately into this module; the structure of the two channels is identical. As shown in *Figure 5.7*, in order to actuate contextual performance *between* modules and concurrent collaboration *within* modules, sub-modules representing FFE activities were sequentially structured in each channel, by applying 'Mechanism 1.2: Contextual Performance between Sub-modules', and 'Mechanism 2.2: Concurrent Collaboration within Modules', respectively. Particular composition-modules were not built into each channel since there were no particular performance methods/toolkits for conducting the modules representing the activities in the representative FFE scenario.

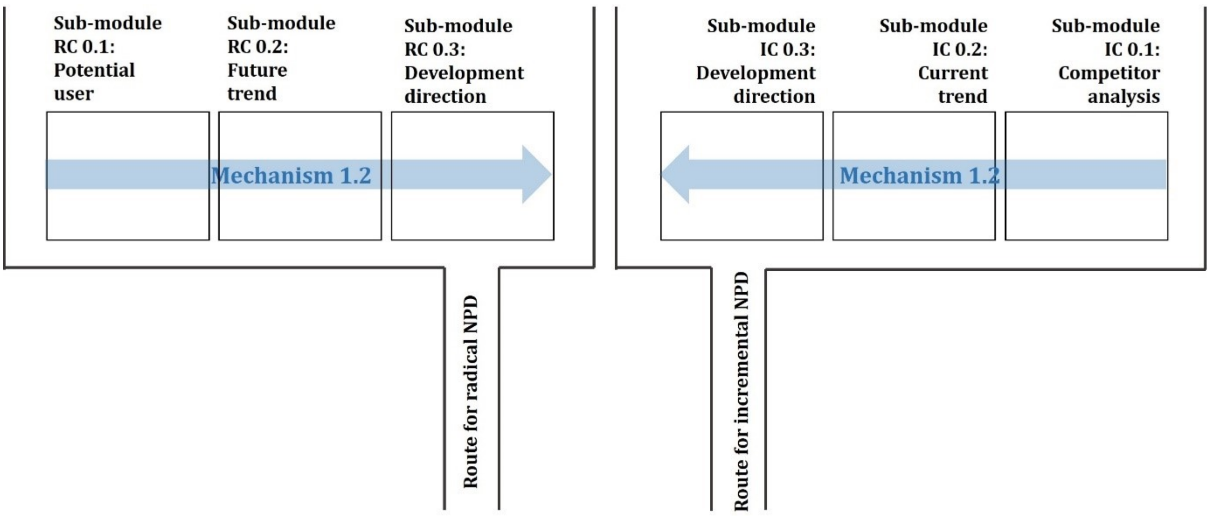

Figure 5.7. *Building mechanisms for two different channels for incremental/radical NPD*

5.2.2 Contextual Performance

1) Incremental NPD Channel

As shown in *Figure 5.8*, three sub-modules were sequentially structured in the left direction for contextual performance with the aim of finding suitable improvement directions. This structure makes it possible to interlock all parameters obtained in the sub-modules. Full details of how to this interlock occurs is described below.

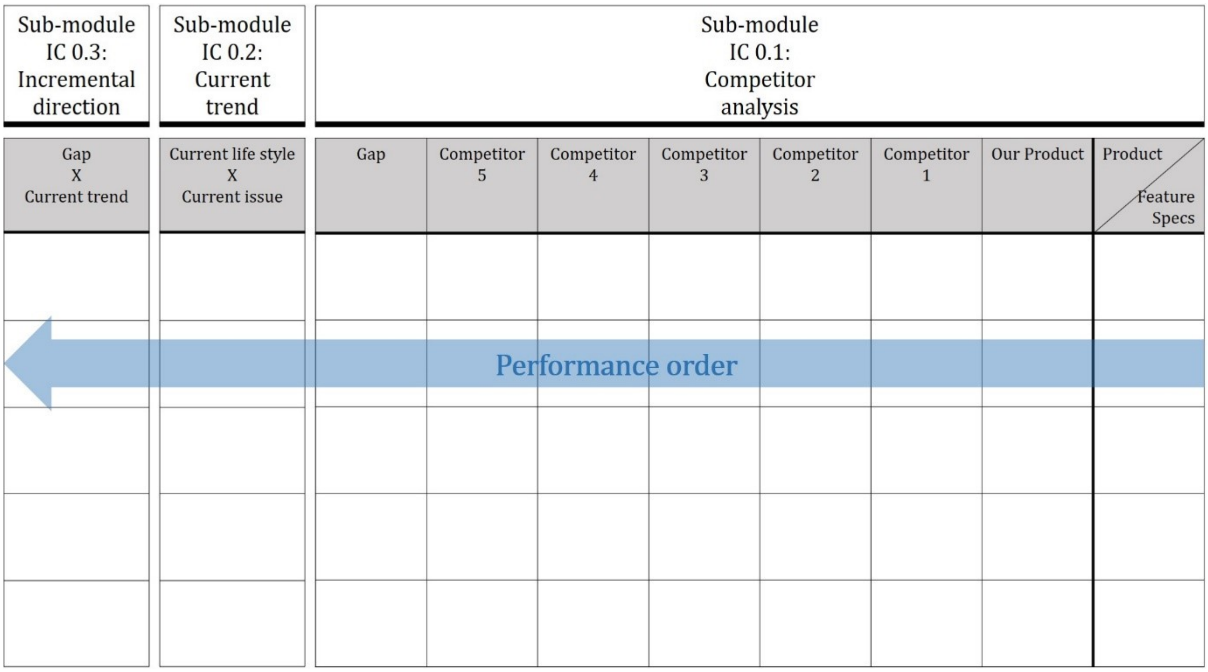

Figure 5.8. *Channel for incremental NPD in Module 0*

The First Sub-module: Comparative Competitor Analysis

Sub-module IC 0.1 is for the comparative competitor analysis, to find gaps between one's own product and the products of competitors, from the viewpoint of features and specifications. The horizontal axis displays a list of products from one's own company and from one's competitors, while the vertical axis consists of target features and specifications. This leads to identification of what the differences are between products, across all of its different aspects.

The Second Sub-module: Current Trend Analysis

Sub-module IC 0.2 is for identifying current trends related the gaps previously discovered from different analyses conducted in Sub-module IC 0.1. Each horizontal axis contains trends related to the features and specifications which address the previously-identified gaps.

The Third Sub-module: Improvement Direction Establishing

Sub-module IC 0.3 is for setting up improvement directions based on the outcomes of the previous two modules. In each horizontal axis, improvement directions for each feature and specification can be grasped by interpreting a combination of the current trends and gaps. For instance, if the gap is about the form of the product's body, and the current trend favours a more rounded shape, one of the improvement directions can be to design a more rounded shape.

As this structure facilitates contextual performance, once gaps between one's own product and the competitors' products are identified (in the form of features and specifications), final improvement directions can be established by grasping current trends.

2) Radical NPD Channel

As shown in *Figure 5.9*, three sub-modules were sequentially constructed in the right direction for contextual performance, aimed at identifying development directions. With this structure, all parameters produced in these sub-modules are linked with each other. Full details of how this occurs are found below.

The First Sub-module: Potential User Search

Sub-module RC 0.1 envisions the potential users of the product through a cross-correlation analysis between general users and trendsetters. The horizontal axis is comprised of a general user profile, while the vertical axis consists of a trendsetter profile. Since trendsetters serve as a bridge between current and future users, future users can be envisaged by analysing the correlations between general users and trendsetters. Thus, by observing the information flow between a particular general user and a trendsetter, the way to identify future users in trendsetters can be achieved by reflecting how trendsetters are generated in general users.

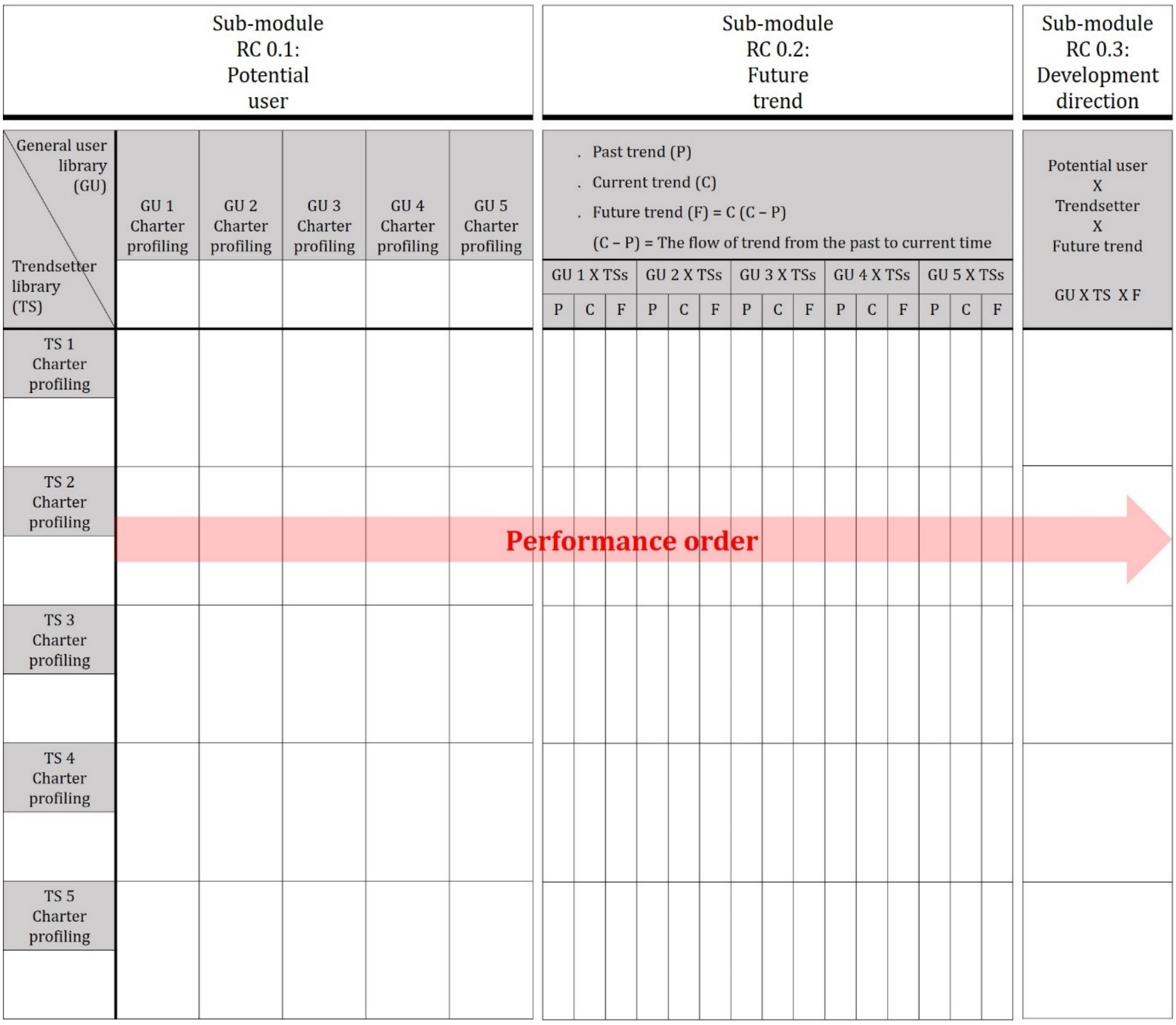

Figure 5.9. *Channel for radical NPD in Module 0*

The Second Sub-module: Future Trend Analysis

Sub-module RC 0.2 anticipates future trends by extrapolating from the flows between past and current trends. The mechanism for conducting this module is identical to that of the previous module. For each potential user generated from the correlation between general users and trendsetters, future trends that future users will enjoy can be anticipated by projecting the flow between past and present trends onto present trends.

The Third Sub-module: Development Direction Establishing

Sub-module IC 0.3 builds development directions based on the results of the previous two modules. In each vertical axis, the development directions can be grasped by envisaging situations in which particular potential users might enjoy particular future trends.

As this structure fosters contextual performance, once the potential users have been defined (by interpreting the correlation between general users and trendsetters), the development directions can be established via extrapolating future trends from past and current trends.

5.2.3 Concurrent Collaboration

Two channels in which the same structure is built can be operated with concurrent collaboration. This structure, consisting of each three sub-modules sequentially structured in a single matrix platform, contributes to simultaneous collaboration.

In the first channel for incremental NPD projects, concurrent collaboration occurs when the list of features and specifications lies on the vertical axis of the first sub-module. This is because the features and specifications can come from many NPD-related functional areas such as engineering, design, marketing and so on. Also, in the second sub-module, current trends can be treated from the viewpoint of those functional areas at the same time. Therefore, improvement directions can consequently be derived from concurrent cross-functional work.

In the case of the second channel for radical NPDs, in the second sub-module, extrapolating future trends from past and present trends can proceed with simultaneous consideration of many functional areas. Consequently, the development directions can be established through concurrent collaboration between various functional fields.

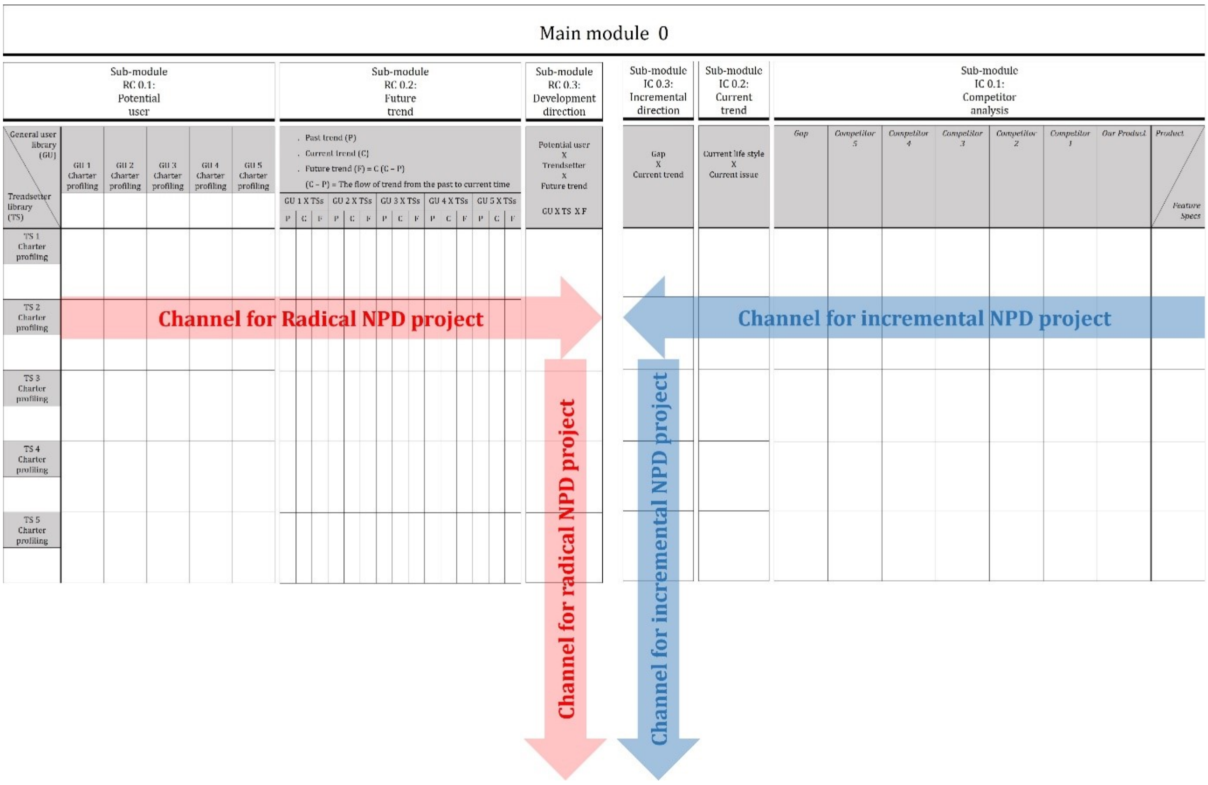

Figure 5.10. *Building two channels for incremental and radical NPD*

5.2.4 Overall Attributes

The two channels for building incremental and radical NPD directions were equipped in Main module 0 (Attribute 3). The sub-modules in each channel were structured with the performative type (Attribute 5) overall, leading to data-centric performance (Attribute 1). The sub-modules were linked with each other for contextual performance and concurrent collaboration, so that parameters in each sub-module can be produced by considering other parameters, not only exquisitely in a single functional sector but also multidimensionally in diverse functional sectors. This can produce high-quality parameters and thus not only reduce unnecessary repetition to correct defective parameters which have not considered with contextual performance and concurrent collaboration in mind but also prevent unnecessary meetings to explain parameters and their descriptive evidential interpretations. As a result, agility in the preliminary task (Attribute 2) can be realised. Moreover, by providing discretion to choose specific performance methods when carrying out sub-modules with the formalised structure, the responsiveness and explicitness characteristics (Attribute 4) can be infused into the overall structure.

5.3 Module 1
– Opportunity Identification-Screening Task

5.3.1 Module Building Mechanism

Main Module 1 was structured, physically and functionally embodying the opportunity identification-screening task of the representative FFE scenario (*pp. 162-218 or 254-258*), by applying the following model building mechanisms.

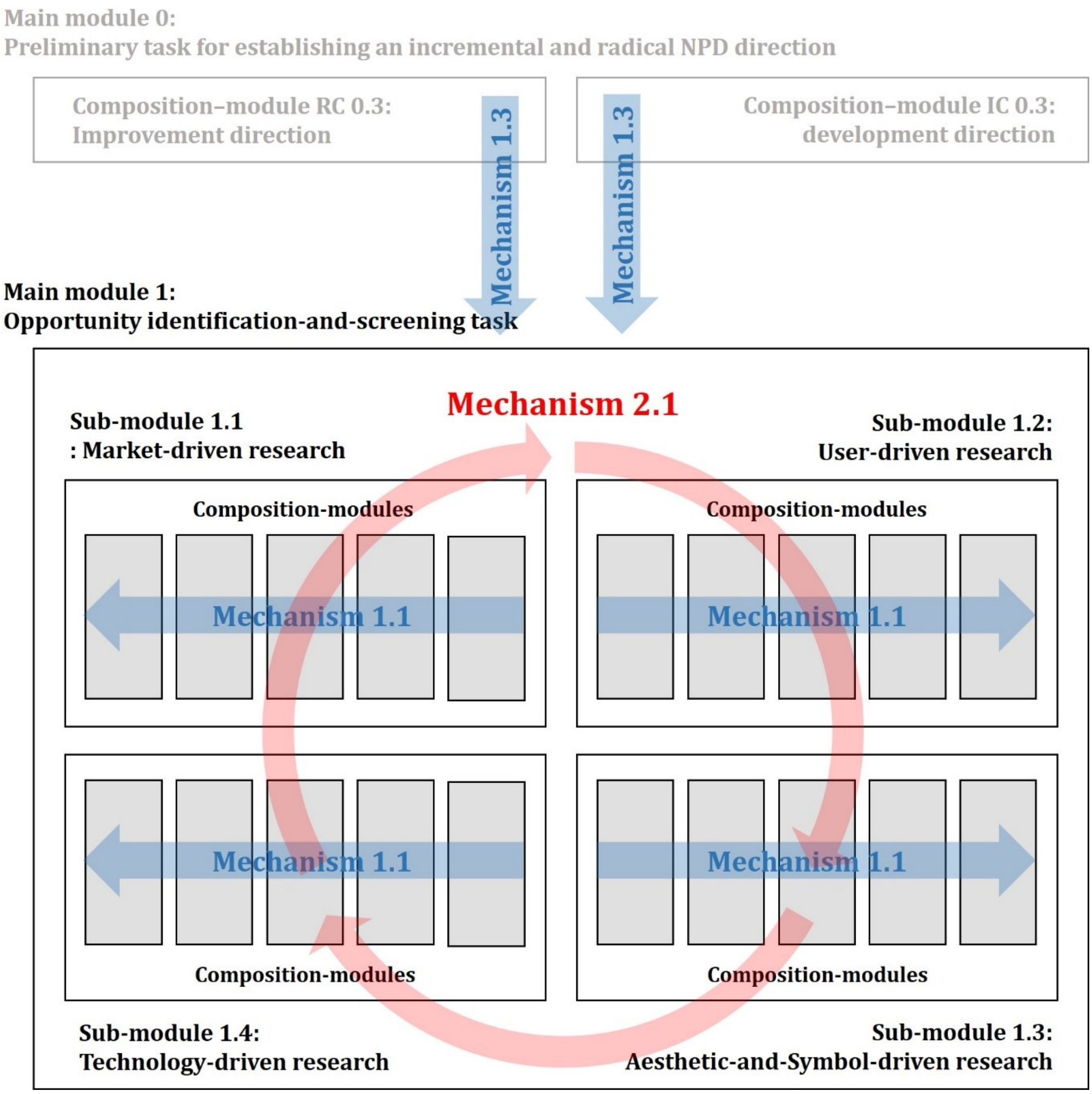

Figure 5.11. *Building mechanism for the opportunity identification-and-screening module*

Main Module 1 for the opportunity identification-screening task (Task 1) is the first part to be conducted after the preliminary module. The fundamental concept of this module is to scrutinise the target product in which the improvement or development directions established in the previous preliminary task (Module 0) are reflected. Therefore, an overall structure for conducting this module was set up to fulfil the underlying concept.

By applying 'Mechanism 1.3: Contextual Performance between Main Modules', a structure was designed in which parameters for the improvement or development directions in the final composition-module of the preliminary module (Main module 0) can serve as input parameters for the first composition-modules in this module (shown in the part coloured with grey of *Figure 5.11*).

The bottom part of *Figure 5.11* describes the overall structure, which consists of hierarchical module units. Under the improvement or development directions, four sub-modules representing the market-driven (Sub-module 1.1), user-driven (Sub-module 1.2), aesthetic-and-symbol-driven (Sub-module 1.3) and technology-driven (Sub-module 1.4) research activities were structured in parallel by applying 'Mechanism 2.1: Concurrent Collaboration between Modules', to promote the first form of concurrent collaboration. Each sub-module was comprised of composition-modules structured serially by reflecting 'Mechanism 1.1: Contextual Performance between Composition-modules', for contextual performance.

5.3.2 Contextual Performance

By applying 'Mechanism 1.1: Contextual Performance between Composition-modules' into the embodiment of the opportunity identification-screening task's relevant activities and performance methods, which were defined in the representative FFE scenario, each sub-module was structured as a sequential arrangement of different composition-modules.

1) Sub-module 1.1: Market-driven research activity (*Figure 5.12a*)

Sub-module 1.1 for the market-driven research activity was divided into two parts. In each part, all composition-modules (in the form of particular toolkits) were sequentially structured in the left direction.

The upper part was comprised of four composition-modules: user segmentation, BEPSTELVE, SWOT, and PDP analysis toolkits (Composition-modules 1.1.1 to 1.1.4). The user segmentation module consisted of seven units: gender, age, region, occupation, income, preference, and power to make purchases. The remaining modules were divided into seven, four and three units, according to what was required in the BEPSCTELVE, SWOT and PDP analysis.

The bottom part was built with three composition-modules representing the cost, price, and profit forecasting toolkits (Composition-modules 1.1.5 to 1.1.7). The cost estimation module was comprised of the target cost (budget) and indirect cost units. The second composition-module, which estimates the product price, was structured such that the selling price is calculated based on the expected margin, which results in the actual margin. These two composition-modules were structured on a component basis. An arrangement of components can be determined from components in other sub-modules since the calculation of the investment cost and the product price thereof should cover all product components which can be defined in the other sub-modules. The final composition-module for anticipating profits was structured so that sales and profits per day can be calculated, producing forecasts of sales and profits per month and per year.

Sub-module 1.1

Composition-module												
1.1.4	1.1.3		1.1.2		1.1.1							
PDP	SWOT		BEPSCTELV		User segmentation							
Position	Strength	Weakness		Business	Power to purchase	Power on product	Preference	Income	Occupation	region	Age	Gender	
				Economic									Male
				Political									
Distribution				Social									
	Opportunity	Threat		Culture									
				Technology									Female
Promotion				Environment									
				Legal									
				Value									

Contextual performance order

Composition-module								
1.1.7		1.1.6			1.1.5			Component Number
Profit forecasting		Price estimation			Cost estimation			
Annually	Monthly	Actual margin	Selling price	Expected margin	Target cost	Indirect cost	Direct cost	
								Whole product
								Component 1
								Component 1.1
								Component 1.2
								Component 1.3
								⋮
								Component 2
								⋮
								Component n
								Whole product

Contextual performance order

***Figure 5.12a.* Sub-module 1.1: Market-driven research activity**

Through this structure, if we calculate the parameters for the age unit in the user segmentation module first, the remaining parameters (from the gender unit in the user segmentation module to the promotion unit in the PDP module) can be generated in succession and with ease. Also, once the development cost parameters for each component are calculated, the remaining parameters, from the expected margin in the pricing module to the annual profits in the profit forecasting module, can be estimated easily.

2) Sub-module 1.2:
User-driven research activity (*Figure 5.12b*)

In Sub-module 1.2 representing the user-driven research activity, seven composition-modules in the form of toolkits were arranged in the right direction in a structure in which input and output parameters related to user behaviours can interlock.

Sub-module 1.2								
Composition module								
1.2.1	1.2.2	1.2.3			1.2.4	1.2.5	1.2.6	1.2.7
Product usage process	User touch-point Product Component	Interaction system			Product usage function	User environment	Usability	User scenario
		Input signal	Mediator	Output response				
	Whole product							
	Component 1							
	Component 1.1							
	Component 1.2							
	Component 1.3							
	⋮							
	Component 2							
	⋮							
	Component n							
	Whole product							

Contextual performance order →

Figure 5.12b. ***Sub-module 1.2: User-driven research activity***

Composition-modules 1.2.1 to 1.2.4 were structured so that the user touch-points that originate in each step of the product usage process generate an individual interaction system, after which explicit product usage functions can be defined. In this, each user touch-point represents product components from the viewpoint of users. In general, since the product usage process begins and ends with a view of the product as a whole, with consideration of components and their arrangements done in between: the whole product, products components, again the whole product. Also, in the case of Composition module 1.2.3, by reflecting the structure of the interaction system, the module was designed with the following three units: 1) input signals from users, 2) mediators identical to the touch-points, and 3) output responses from these touch-points. With Composition-module 1.2.5 enabling the consideration of the previous parameters in the given environments, the possible range of ergonomic data for each component are estimated in Composition-module 1.2.6. The reason for dividing this composition-module, which considers user environments, into product component units is that individual components can be exposed to different surroundings, which creates different usability parameters.

Using the structure above, it is possible that once the parameters are generated in the product usage process module, the remaining parameters, from the user touch-point module to the usability module, can be generated in consecutive order. These parameters can contribute to a conceptualisation of the user scenario, which enables understanding of the specific user behaviour patterns at a glance.

3) Sub-module 1.3: Aesthetic-and Symbol-driven research activity (*Figure 5.12c*)

In Sub-module 1.3, the aesthetic-and-symbol-driven research activity, six composition-modules embodied with the performative type were organised in the right direction, allowing for understanding of the possible scope of the product's exterior elements, which can interlock in serial order or as a bundle.

Composition-modules 1.3.1 to 1.3.3 were arranged such that parameters on the possible scope of shapes, colours and materials (which are meant to be harmonised) can be considered on a component basis. Each component in this sub-module follows the components in the sub-module for the user-driven research activity since the recognition of shapes, colours and materials occurs at each user touch-point representing those components. Then, by using Composition-module 1.3.4, parameters on the possible range of finishing specifications are estimated, after considering the parameters for shape, colour and material. After that, Composition-module 1.3.5 makes it possible to consider what symbolic meanings are produced by each of the parameters obtained in the previous composition-modules. Lastly, based on all of the parameters produced in Composition-modules 1.3.1 to 1.3.5, an overall aesthetic-and-semantic board and image map is envisaged in Composition-module 1.3.6.

Sub-module 1.3						
Composition-module						
Component Number	1.3.1 Shape	1.3.2 Colour	1.3.3 Material	1.3.4 Finishes	1.3.5 Symbol	Composition-module 1.3.6 Aesthetic-and-Semantic board & image map
Whole product						
Component 1						
Component 1.1						
Component 1.2						
Component 1.3						
⋮						
Component 2						
⋮						
Component n						
Whole product						

Contextual performance order

Figure 5.12c. *Sub-module 1.3: Aesthetic-and-symbol-driven research activity*

The possible scope of the shape, colour, material and finishing specifications along with their semiotic functions can be considered component by component. This contributes to a comprehensive image map of the target product, from the perspective of aesthetics and semiotics.

3) Sub-module 1.4: Technology-driven research activity (*Figure 5.12d*)

For Sub-module 1.4, representing the technology-driven research activity, seven composition-modules realised in toolkit form were built in the left direction, under a structure in which input and output parameters related to the technical operation of the target product can interlock.

Composition-modules 1.4.1 to 1.4.3 were interjoined, enabling the development of a technical function structure which considers the parameters of the technical functions of each component, and their relationships. The technical system structure can be designed based on both the processing system of each component and their system connections, which are identified in the technical function structure. In general, several technical functions can exist on the back of each product usage function defined in the user-driven research activity (Composition-module 1.2.4 of Sub-module 1.2). Hence, from a technical standpoint, the sub-components subordinated to those main components can be defined. Therefore, for considering components defined in the sub-module for the user-driven research activity, components in this sub-module can be arranged in the following order: Whole product, Component 1, Component 1.1, Component 1.2, Component 1.3. . . . . . Whole product. After carrying out Composition-modules 1.4.1 to 1.4.3, Composition-module 1.4.4 allows calculation of the technical input and output parameters which occur in the individual processing systems and in their connections in the wider system structure. By understanding the technical roles of the components, and their function and system structure, as well as any relevant technical parameters, possible operational mechanisms can be proposed for each component as well as for the entire product (Composition-module 1.4.5). These working mechanisms facilitate the estimation of technical dimension parameters for each component itself and that of their radiuses of movement (Composition-module 1.4.6). Based on all the parameters calculated in previous composition-modules, the technologies needed to operate the target product technically can be grasped by this product component unit as well as by the overall product unit (Composition-module 1.4.7).

Sub-module 1.4								
Composition-module								
1.4.7	1.4.6	1.4.5	1.4.4		1.4.3	1.4.2	1.4.1	Component Number
Required technology	Technical dimension	Working principle	Technical parameter		System structure	Function system	Technical function	
			Output	Input				
								Whole product
								Component 1
								Component 1.1
								Component 1.2
								Component 1.3
								⋮
								Component 2
								⋮
								Component n
								Whole product

← Contextual performance order

Figure 5.12d. *Sub-module 1.4: Technology-driven research activity*

Because of this structure, once the parameters for the technical functions of each component are generated (in the first composition-module), the remaining parameters for the function and system structure (the technical parameters for the product's operational mechanisms and the technical dimensions for the product's required technologies) can be built up consecutively for each component as well as for the entire product.

5.3.3 Concurrent Collaboration (*Figure 5.13*)

With 'Mechanism 2.1: Concurrent Collaboration between Modules', Sub-modules 1.1 to 1.4 were placed first in a clockwise direction in quadrants 1 to 4, considering the parallel relationship between each FFE activity as defined in the representative FFE scenario (*pp.196-217 or 256-258*). As shown in the blocks coloured in red and orange, these sub-modules are linked to each other with composition-modules playing a common role as the centre. In each sub-module, the remaining composition-modules are unfolded in the right or left direction with the centric composition modules as the centre.

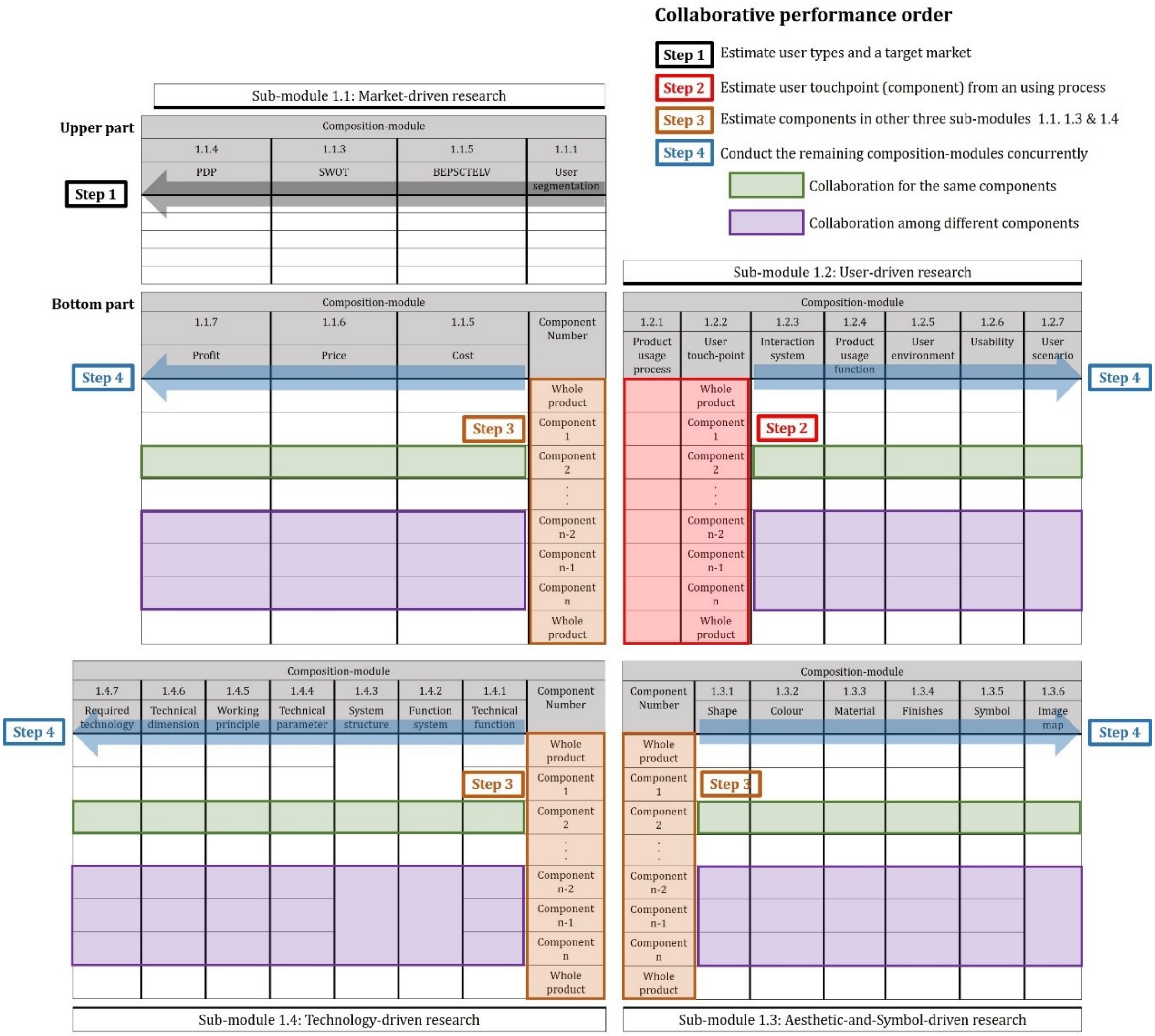

Figure 5.13. *Opportunity identification-screening module for concurrent collaboration*

1) Performance Order with 'BY column' Composition-module

Step 1

In the upper part coloured in grey in quadrant 1, the specific user segmentation and the target market modules (Composition-modules 1.1.1 to 1.1.4) can be conducted.

Step 2

Next, by jumping to quadrant 2, the product usage process and user touch-point modules (Composition-modules 1.2.1 and 1.2.2), coloured in red, can be performed in order to consider how specific users actually use the target product in the target market. As mentioned before, each user touch-point represents a component generated from the user-driven analysis. Since the product usage process generally starts and ends by understanding the entire product situated in a certain place, the number labels of the product components can also start and end on 'Whole product'. This user touch-point module can be regarded as a fiducial line ('BY column') for using the overall module (Main module 1).

Step 3

Based on this fiducial line, product components coloured in orange in the aesthetic-and-symbol-driven, technology-driven and the bottom part of the market-driven research activities can be defined accordingly.

As referred to above, it is quite possible that product components in the aesthetic-and-symbol-driven research module are similar to those of the user-driven research module. In the interaction systems (Composition-module 1.2.3) generated from each user touch-point (Composition-module 1.2.2), users perceive the shapes, colours and materials of the target product. Hence, product components in this sub-module correspond to those components in the sub-module in the user-driven research.

On the other hand, as mentioned previously, it is possible for the number of components in the technology-driven research module to be greater than in the user-driven research module since there can be many technical functions on the backs of the user touch-points which provide the product usage functions. Therefore, the number labels of the product components in this sub-module describe the main component and sub-component units, along with the whole product unit, e.g. Whole product, Component 1, Component 1.1, 1.2, 1.3. . .2.1, 2.2, 2.3. . . n.1, n.2, n.3. . . Whole product, etc., whereas the number labels of product components in the user-driven and aesthetic-and-symbol-driven research modules are organised with a main component label only, e.g. Whole product, Component 1, 2, 3. . . n, Whole product.

In addition, it is highly probable that components in the market-driven research module are similar to those of the technology-driven research module since the bottom part of this sub-module should cover all product components for calculating the investment costs in each component.

Consequently, the composition-module for defining user touch points (Composition-module 1.2.2) can be the starting point of the component-based performance in not only the user-driven research module but also the entire opportunity identification and screening module. The composition-module for proposing the possible range of shapes, colours, and materials (Composition-module 1.3.1 to 1.3.3) can be the origin of the aesthetic-and-symbol-driven research (which will take place on a component basis). In the technology-driven research, the composition-module for defining the functions of technical compositions (Composition-module 1.4.1) can 'activate' the remaining composition-modules, again on a component basis. The composition-module for determining cost (Composition-module 1.1.5) in the sub-module for market-driven research can serve as the starting point for component-based performance. These four composition-modules in each sub-module have in common the role of initiating component-based performance. In other words, with the user touch-point module as the centre ('BY column' in Main module 1), other composition-modules which commence product component-based performances can each be fiducial lines in each sub-module.

Step 4

In this way, once product components are defined in each sub-module, the calculation of parameters in the composition-modules can be implemented consecutively within each sub-module in the way mentioned in the previous section and also executed concurrently in all sub-modules. The mechanism for concurrent execution in the four sub-modules is presented below.

2) Concurrent Consideration in Calculation of Parameters

Due to such a deployment of sub-modules and composition-modules, it is expected that when performers produce parameters in particular composition-modules, they can simultaneously consider other parameters obtained in the same latitude of the horizontal axis in each sub-module. Namely, for the same component, each parameter can be calculated by considering other parameters generated by different performance methods in different activities (shown in the block coloured in green in *Figure 5.13*). In addition, this simultaneous collaboration when producing parameters can be possible not only in components, but also between components (shown in the block coloured in purple in *Figure 5.13*). This collaboration system makes it possible that more accurate individual parameters are generated, through concurrent operations from the viewpoint of either various performance methods or research domains.

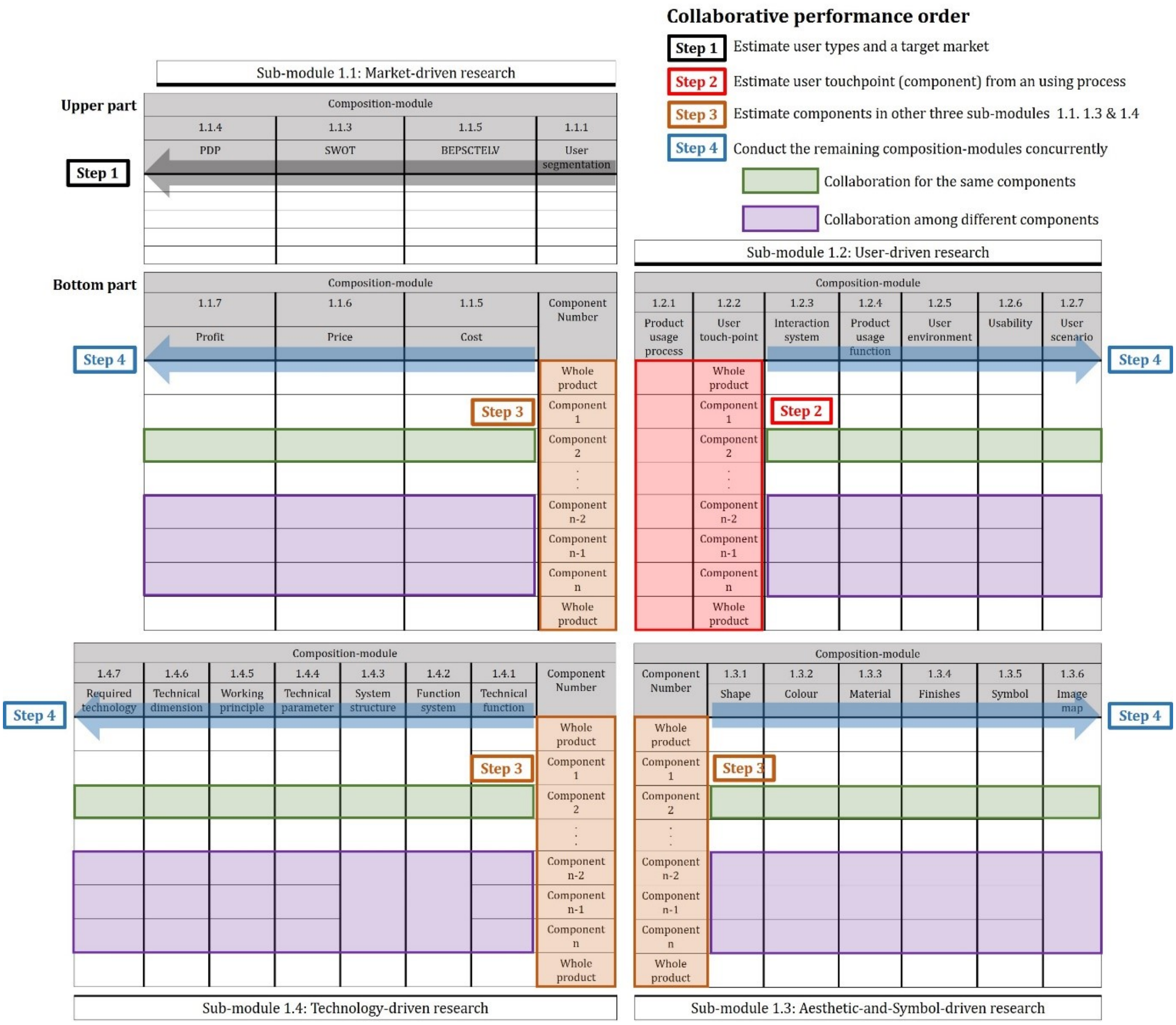

Figure 5.13. *Opportunity identification-screening module for concurrent collaboration*

This concurrent collaboration system facilitates many possible collaborative works and allows them to discover the opportunities discussed in Chapter Four (Study 2.1). Once parameters on specific user types and the target market in the upper part of Sub-module 1.1 are produced, the calculation of parameters on the user touch points generated in each step of the product usage process in Sub-module 1.2 can be generated, which makes it possible to define components in other three sub-modules (Sub-modules 1.1, 1.3 and 1.4). In calculating parameters in each composition module, other parameters in the composition modules of different sub-modules can be considered concurrently within the same component. This concurrent consideration system can be applied to produce parameters among different components as well, in the sense that there is a strong interrelationship between components, in particular, between adjacent components.

5.3.4 Overall Attributes (*Figure 5.14*)

Main module 1 was embodied as a performative platform (Attribute 5) in which input and output parameters interlock in succession. It contributes to the establishment of the data-driven type of platform (Attribute 1).

The parameter matrix form that makes up the platform produces the results of the collection and analysis of numerous NPD-related parameters from the four major NPD research domains. This can lead to a decrease in unnecessary iterative work caused not only by a lack of information but a lack of appropriate interpretation of that information. This matrix form, by processing and deciding parameters from the viewpoints of contextual performance and concurrent collaboration, also allows performers to reduce unnecessary meetings to describe the parameters and their descriptive evidential interpretations. Therefore, the data-driven type can facilitate agile opportunity discovery practices (Attribute 2).

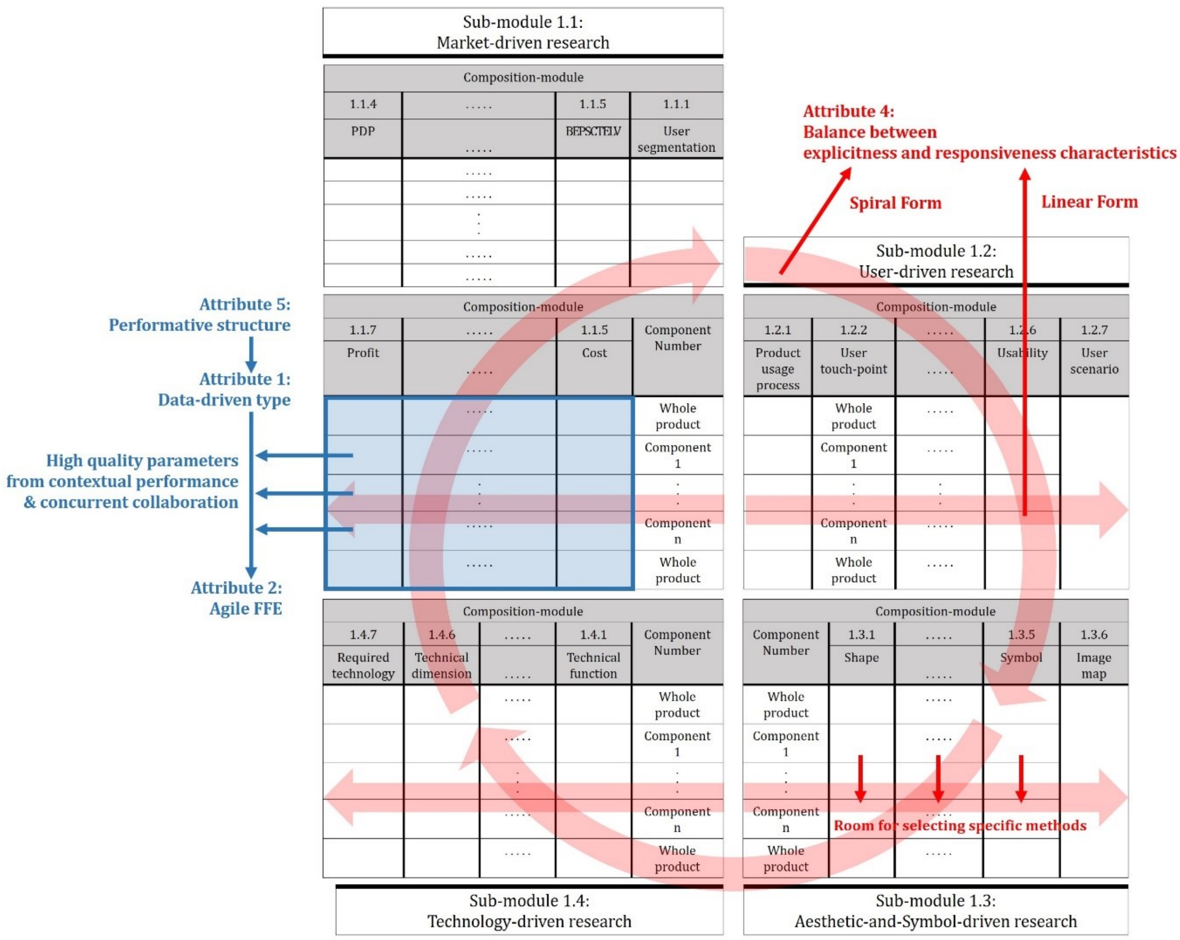

Figure 5.14. *Overall attributes of opportunity identification-screening module*

Composition-modules, in the form of toolkits, were sequentially arranged for contextual performance. This is a formalised process which pursues explicitness. In order to foster concurrent collaboration, sub-modules consisting of these composition-modules were placed in the clockwise direction in quadrants. Its form is similar to the spiral process which pursues a flexible structure. As a result, the overall structure of Module 1 has phased sub-processes which make up the entire spiral structure. The structure can therefore be regarded as well-balanced between explicitness and responsiveness (Attribute 4). In addition, each composition-module, representing the performance methods, was built to provide discretion to practitioners and allow them to choose sub-performance methods, enabling the generation of parameters in diverse ways and different outcomes (Attribute 4), e.g. performers can choose whether or not to use Composition-module 1.3.1, which proposes the possible scope of the product's shape in different ways such as using the brain-drawings, analogies (metaphors), combinations, etc.

5.4 Module 2
– Idea Generation-Screening Task

5.4.1 Module Building Mechanism

Main Module 2 was developed, physically and functionally structuring the idea generation-screening task of the representative FFE scenario (*p. 219-231 or 259-260*), by reflecting the following model building mechanisms.

Main module 2 is the second part of the model structure, for the idea generation-screening task (Task 2). The underlying concept of this module is to come up with ideas in the form of actionable methods/solutions to materialise the parameters produced in the opportunity identification-screening module (Main Module 1).

As with Main Module 1, this main module (Main Module 2) consists of four sub-modules representing the four ideation activities: the market-driven, user-driven, aesthetic-and-symbol-driven, and technology-driven domains. By adopting 'Mechanism 1.3: Contextual Performance between Main Modules', these sub-modules were arranged as an extension to the structure of Main module 1. This is to functionally and visually realise the underlying concept of this module in the structure.

Those four sub-modules, which exist in parallel, were placed in quadrants by applying 'Mechanism 2.1: Concurrent Collaboration between Modules' to foster the first concurrent collaborative working form between modules. Composition-modules that make up each sub-module were structured in serial order by reflecting 'Mechanism 1.1: Contextual Performance between Composition-modules'.

However, unlike the opportunity identification-screening module in which different kinds of composition-modules make up each sub-module, the same set of composition-modules (representing a single representative performance method) was applied to each sub-module based on the analysis of the FFE ideation scenarios in Chapter Four (Study 2.1, *pp 225-227*).

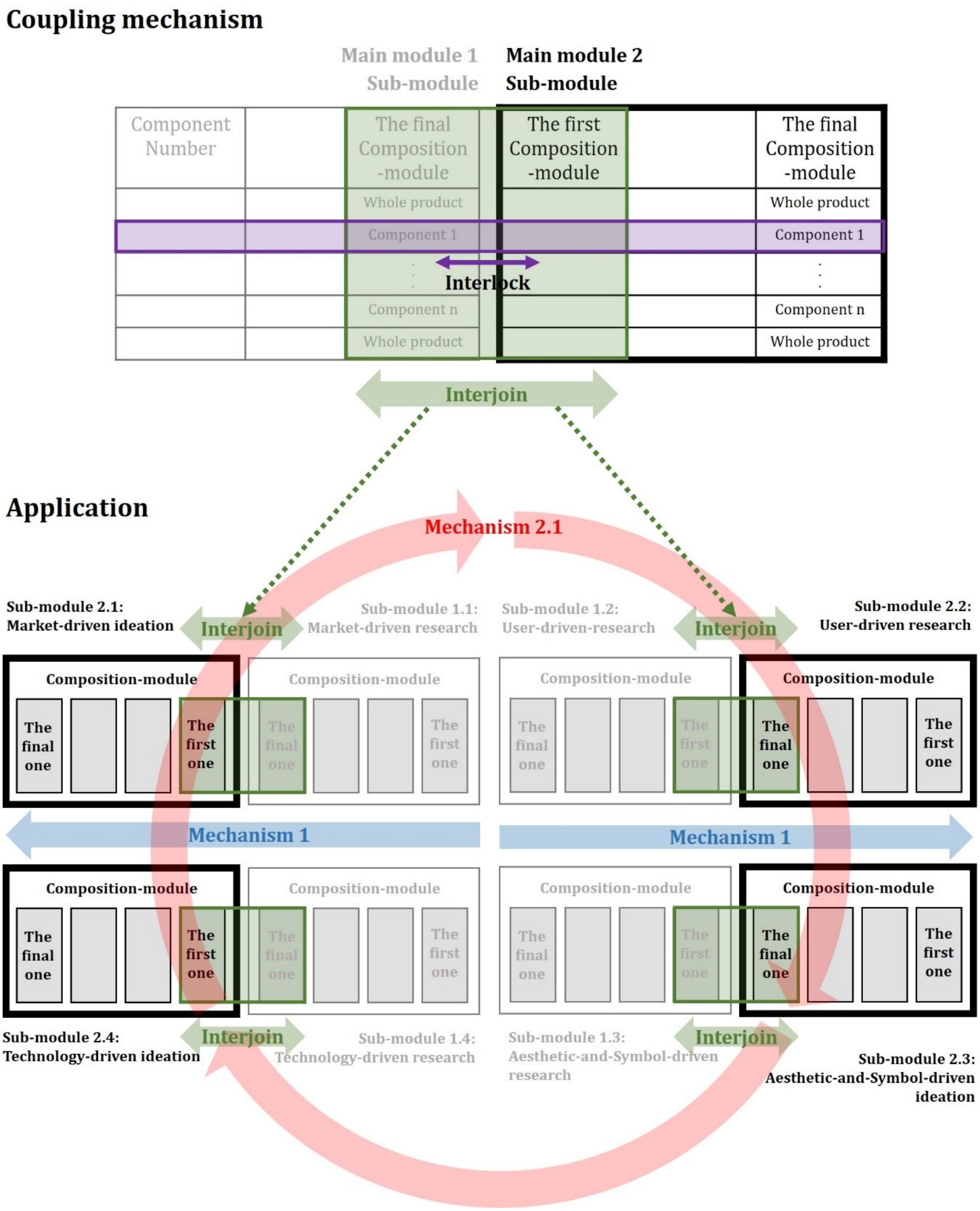

Figure 5.15. *Building mechanism for the idea generation-screening module*

Figure 5.15 above illustrates the structure for this module in greater detail. The upper part presents a coupling between Main modules 1 and 2. Each vertical axis of the sub-modules (structured on a component basis) directly interjoined between Main modules 1 and 2 (shown in the block coloured in green). Namely, as shown in the block coloured in purple, the same components lie on the identical horizontal line interlocked between the opportunity discovery and ideation modules (Main Modules 1 and 2). Due to this structural approach, the underlying concept of the ideation module (which generates ideas to materialise opportunities) was structured both visually and functionally. The bottom part addresses how different sub-modules were built from the same set of composition-modules (depicting the representative performance method) under an overall structure formed by the coupling mechanism.

5.3.2 Contextual Performance

By reflecting 'Mechanism 1.1: Contextual Performance between Composition-modules' in the idea generation-screening task's relevant activities and performance methods, which were defined in the representative FFE scenario, each sub-module was structured as a sequential arrangement of different composition-modules.

1) Identical Set of Composition-modules (*Figure 5.16*)

Sub-modules were built based on the concept of mapping out 'How' (ideas as actionable methods) for 'What' (opportunities) based on 'Why' (supportive reasons and rational evidence). The vertical axis of each sub-module was divided first on a component basis. Then, for contextual performance, four composition-modules were arranged for each component on the horizontal axis of each sub-module. This set of four composition-modules and the set of composition-modules in the opportunity identification-screening module (Main Module 1) are interlocked with each other (the components in one module are interlocked with the corresponding components in the other).

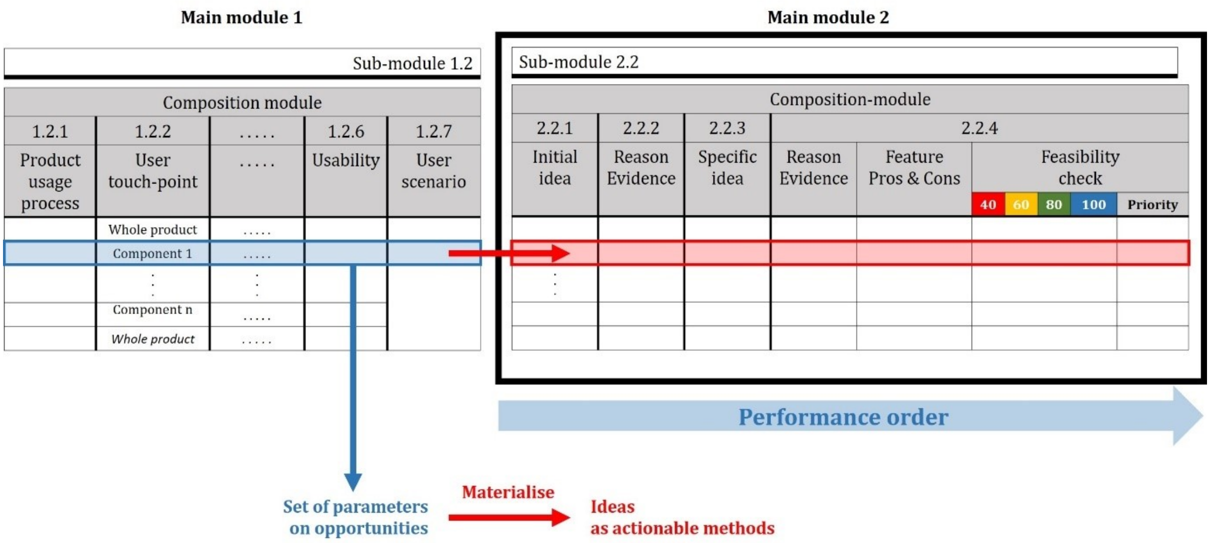

Figure 5.16. *Identical composition-modules that make up the sub-module for ideation and feasibility checks*

The First Composition-module

The purpose of the first composition-module is to come up with initial ideas to realise the set of parameters placed on the same horizontal line in each sub-module of Main Module 1. As shown in the red block in *Figure 5.16*, each set of parameters refers to parameters for the same component, produced from the composition-modules and contextually connected in the same sub-module of Main Module 1 (shown in the blue block).

For example, in the project to develop a new device to sterilise baby supplies, the parameter set for the device's container (in which users put their layettes) in the aesthetic-and-symbol-driven research activity (Sub-module 1.3) can be to increase understanding of how this composition-module is performed. The set of parameters can be square shaped, silver-coloured metal for the container which does not require an assembly line to produce, and whose exterior elements convey hygiene in some way. Therefore, based on this set of parameters, initial ideas can be explored in terms of variants of the square shape, silver colour, metallic material, considering non-parting lines and semiotics indicative of sanitation. Possible shapes include rectangle-, rhombus-, parallelogram- or trapezium-shaped containers. For colour, several silver colours were nominated. A number of metals can also be investigated, including various steels, aluminium, chromium etc.

In the example of the medical cart, in the user-driven research activity (Sub-module 1.2), the set of parameters for the cart's handle can be as follows: 1) doctors and nurses grab and push the handle with their one or both hands when moving the cart towards patients, and then they grab and pull it again with one or both hands moving the cart away (in the product usage process and interaction system composition-module), 2) the handle is usually exposed to open space, but it sometimes must 'interact' with doors or walls when the cart is moving or stationary (in the user environment composition-module), 3) the handle's diameter should be comfortably within the width of the palm of the average user, with a mechanism to reduce issues with the surroundings, e.g. the handle is foldable or detachable. Based on this set of parameters, various handle types, e.g. the foldable and non-foldable, detachable and non-detachable, of the 'ㄷ', 'ㅜ', and 'ㅠ' forms, can be devised. The initial ideas devised more from the morphological perspective can be devised by considering other sets of parameters concerning the handle component in the aesthetic-and-symbol-driven research module (Sub-module 1.3).

The Second Composition-module

The purpose of the next composition-module is to examine supportive reasons and rational evidence for the initial ideas devised in the previous composition-module. Using the same examples above, the reason why those sorts of concrete square shapes, silver colours, metallic materials and those types of handles were nominated is examined along with rational evidence.

The Third Composition-module

The third composition-module aims to transform the initial ideas into specific actionable methods and plans based on reasons and evidence examined in the composition-module above. Returning again to the examples above, each international colour and material code (an alphanumeric code which specifies an exact colour or material) is examined to see if there are any issues with each. Also considered is whether the chosen colours and materials can effectively convey the required symbols and meanings. Furthermore, possible OEMs and vendors which can provide these product exterior elements are examined to see whether those elements can be realised with the given budget.

For instance, in the case of the handle, proposed handle types are further advanced, e.g. 'ㄷ' type is segmented into various 'ㄷ' types such as the angular, rounded, or vertically- or horizontally-curved types, before being further specified as foldable/non-foldable, detachable/fixed etc.

The Fourth Composition-module

The final composition-module aims to not only investigate supportive reasons and rational evidence for the specific actionable methods and plans but also to analyse their features, strengths, and weaknesses. A 'traffic light marking scheme' along with a 100-point scoring system were introduced in the comparison work. Each idea is marked either with red (very low possibility: 0-39), yellow (low possibility: 40-59), green (moderate possibility: 60-79) and blue (high possibility: 80-100) colour. Based on the colour and score, the methods and plans can be classified into the 'more feasible' or 'less feasible' idea groups. The more feasible idea group includes ideas marked with blue and green. The less feasible idea group covers ideas marked with yellow and red. Ideas in the more feasible idea group are prioritised based on their features, pros and cons.

In this way, each set of parameters produced in the four research domains of the opportunity identification-screening module can be transformed into ideas for actionable methods and plans. Due to the contextual connection between the four composition-modules, actionable ideas can be advanced into something more concrete using a phased approach.

5.4.3 Concurrent Collaboration (*Figure 5.17*)

With 'Mechanism 2.1: Concurrent Collaboration between Modules', Sub-modules 2.1 to 2.4 were placed first in a clockwise direction in quadrants 1 to 4, considering the parallel relationship between each FFE activity defined in the representative FFE scenario (*pp. 230-231 or 260*).

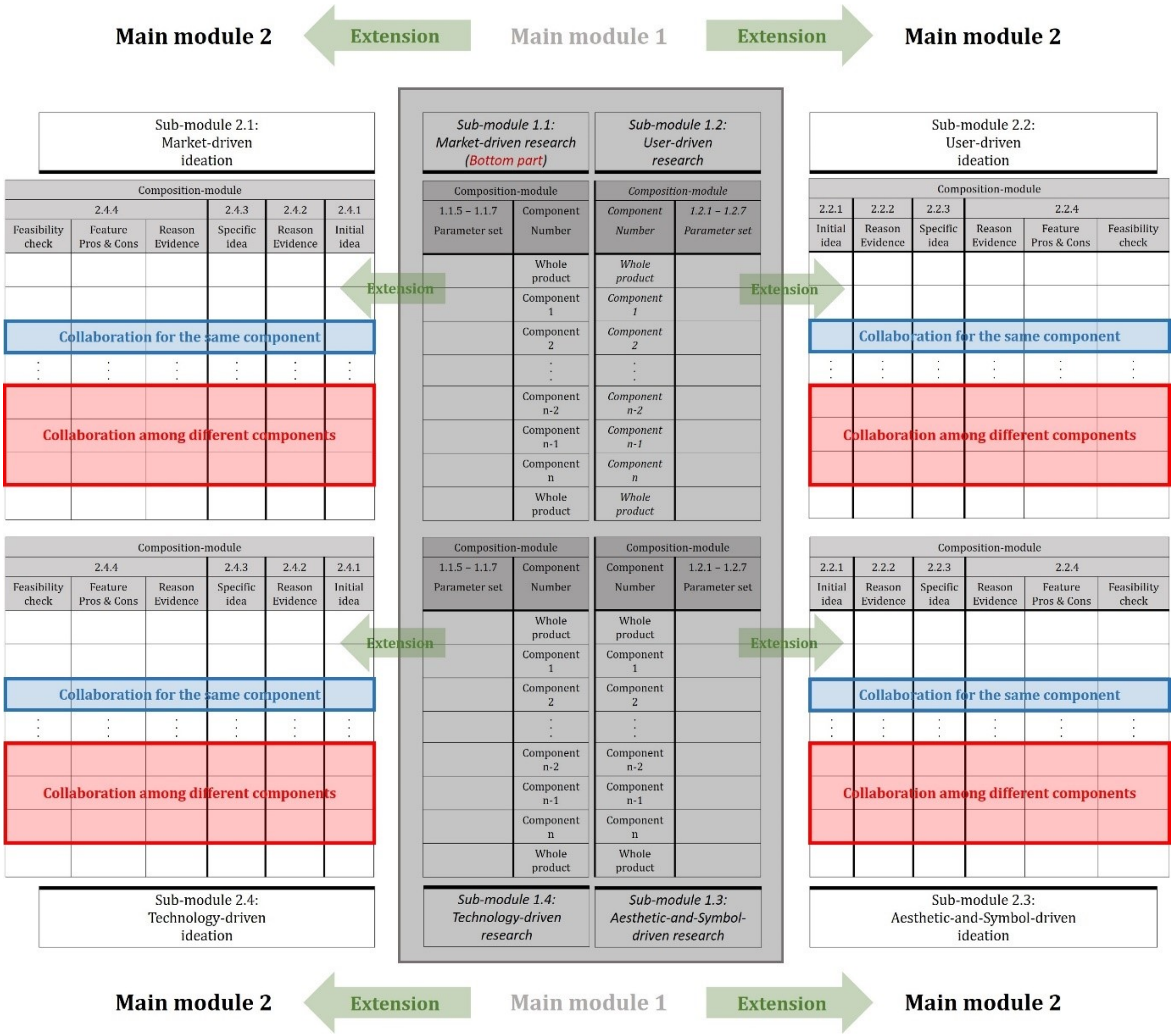

Figure 5.17. *Idea generation-screening module for concurrent collaboration*

Extension from the Opportunity Identification-Screening Module

In Main Module 2, there are four sub-modules for the market-driven (Sub-module 2.1), user-driven (Sub-module 2.1), aesthetic-and-symbol-driven (Sub-module 2.1), and technology-driven (Sub-module 2.1) ideation activities. As shown in the section above, each sub-module was structured with phased composition-modules. With the coupling mechanism mentioned in the introduction of this section (*Figure 5.15, p. 303*), each sub-module was arranged as an extension to each sub-module in the opportunity identification-and-screening module (Main Module 1), e.g. the user-driven ideation activity (Sub-module 2.2) is on the same line as the user-driven research activity (Sub-module 1.2). As a result, as with the arrangement of sub-modules in Main Module 1, these sub-modules were placed in the clockwise direction in quadrants as if 'Mechanism 2.1: Concurrent Collaboration between Modules' was applied.

With this placement of sub-modules, the method to foster concurrent collaboration in Main module 2 is the same as that in Main module 1. The process of devising ideas as well as examining their supportive reasons in each composition-module of the different sub-modules can be captured at a glance. Furthermore, producing ideas and their supporting reasons in each composition-module of a certain sub-module facilitates simultaneous consideration of other ideas and associated evidence devised in other composition-modules of the three remaining sub-modules (shown in the block coloured in blue). This collaborative system can operate within a component as well as between different components (shown in the block coloured in red).

5.4.4 Overall Attributes (*Figure 5.18*)

The overall structure of Main module 2 is identical to that of Main module 1, except that the same set of composition-modules was applied to each sub-module in Main Module 2. Therefore, how overall attributes 1, 2, 4 and 5 were reflected in this module is the same as in the previous module. The ideation module was embodied with toolkits, which can contribute to data-centric performance (Attribute 1 and 5). It is expected that a data-driven platform of the performative type reinforces the parameter processing system from the contextual performance and concurrent collaboration perspectives, which can reduce the need for not only iterative work to complement defective parameters which have not handled from the two perspectives but also meetings to describe the parameters and their descriptive evidential interpretations. This helps facilitate agile ideation (Attribute 2).

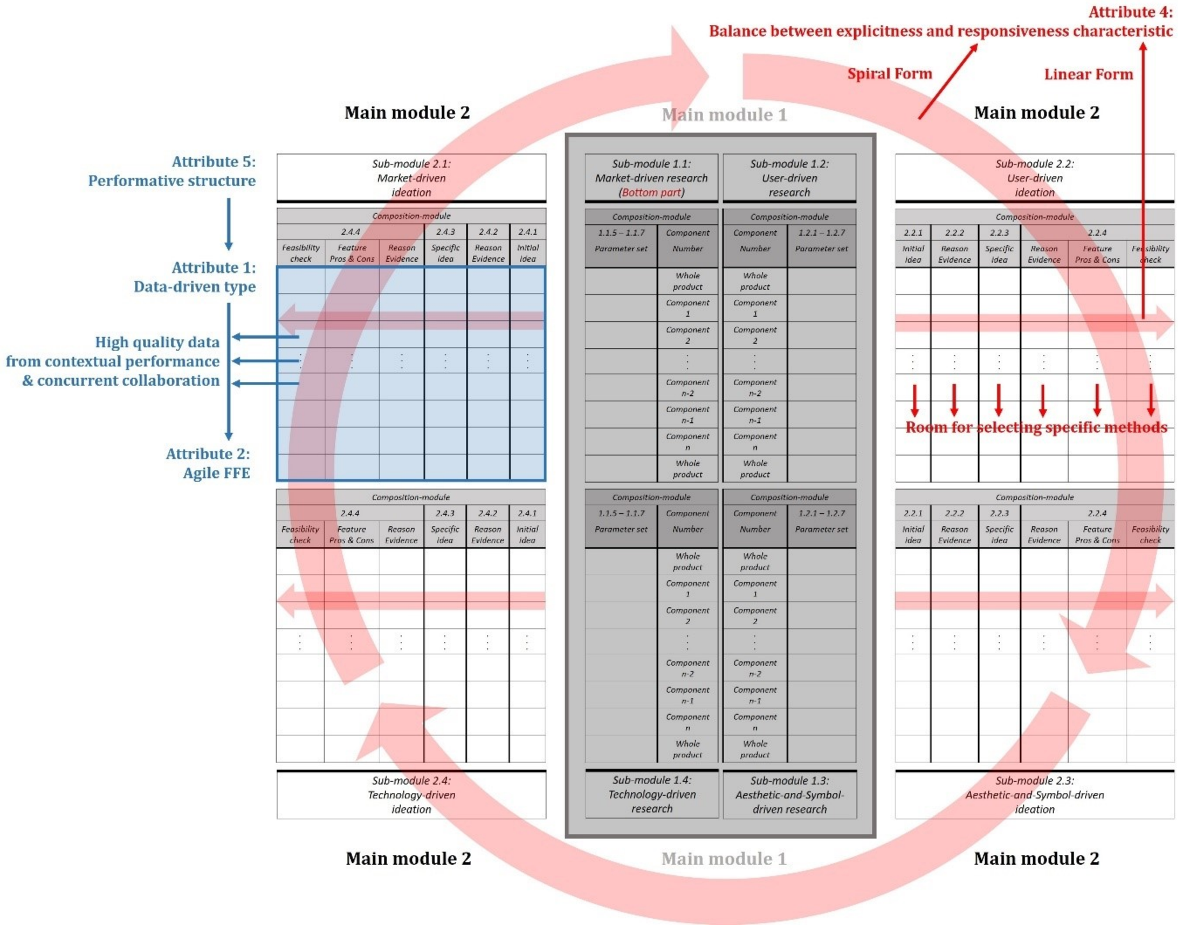

Figure 5.18. *Overall attributes of idea generation-screening module*

In addition, as with the opportunity discovery module, phased sub-processes make up the entire spiral structure: the phased composition-modules for systematic ideation were equipped in each sub-module, built in a spiral form (Attribute 4). Besides, in conducting the formalised composition-modules, specific performance methods for ideation can be flexibly selected by performers. Thus, both the formalised and flexible attributes were well-harmonised in the structure of the ideation module (Attribute 4).

5.5 Module 3 and 4
– Requirement Lists Task
– Mission Statement Task

5.5.1 Module Building Mechanism

Main Modules 3 and 4 were structured, physically and functionally embodying the requirements list and mission statement task of the representative FFE scenario (*pp. 232-236 or 261*).

Main Modules 3 and 4 are the third and fourth parts of the model structure for the requirements list and mission statement tasks (Tasks 3 and 4). The fundamental concept of the requirements list (Main Module 3) is to systematically draw up the parameters produced in the opportunity identification-screening module (Main Module 1) and the idea generation-screening module (Main Module 2). The concept of the mission statement (Main Module 4) is to establish a project definition and design brief by summarising the requirements list (Main Module 3). Therefore, as shown in the blocks coloured in red and blue in *Figure 5.19*, Main Module 3 was structured as an extension of the previous two modules by applying 'Mechanism 1.3: Contextual Performance between Main Modules'. Main Module 4 was built as essentially a condensed form of Main Module 3 by adopting the same mechanism.

To contextually connect the requirements list module with the opportunity discovery and ideation module (which was structured on a component basis), detailed requirements for each component of the target product (Sub-module 3.1) preceded the overall requirements for the whole product (Sub-module 3.2). Unlike sub-modules lying in parallel in the previous main modules, these two sub-modules have a phased relationship, as a result of applying 'Mechanism 2.2: Concurrent Collaboration within Modules'. It indicates that the second collaboration form was equipped in Main module 3, different to the previous modules in which the first collaboration form (where operation occurred between modules) was fostered. By applying 'Mechanism 1.1: Contextual performance between composition-modules', composition-modules that make up Main Module 3 were linked with each other in pursuit of an interlock between Main Modules 1 and 2.

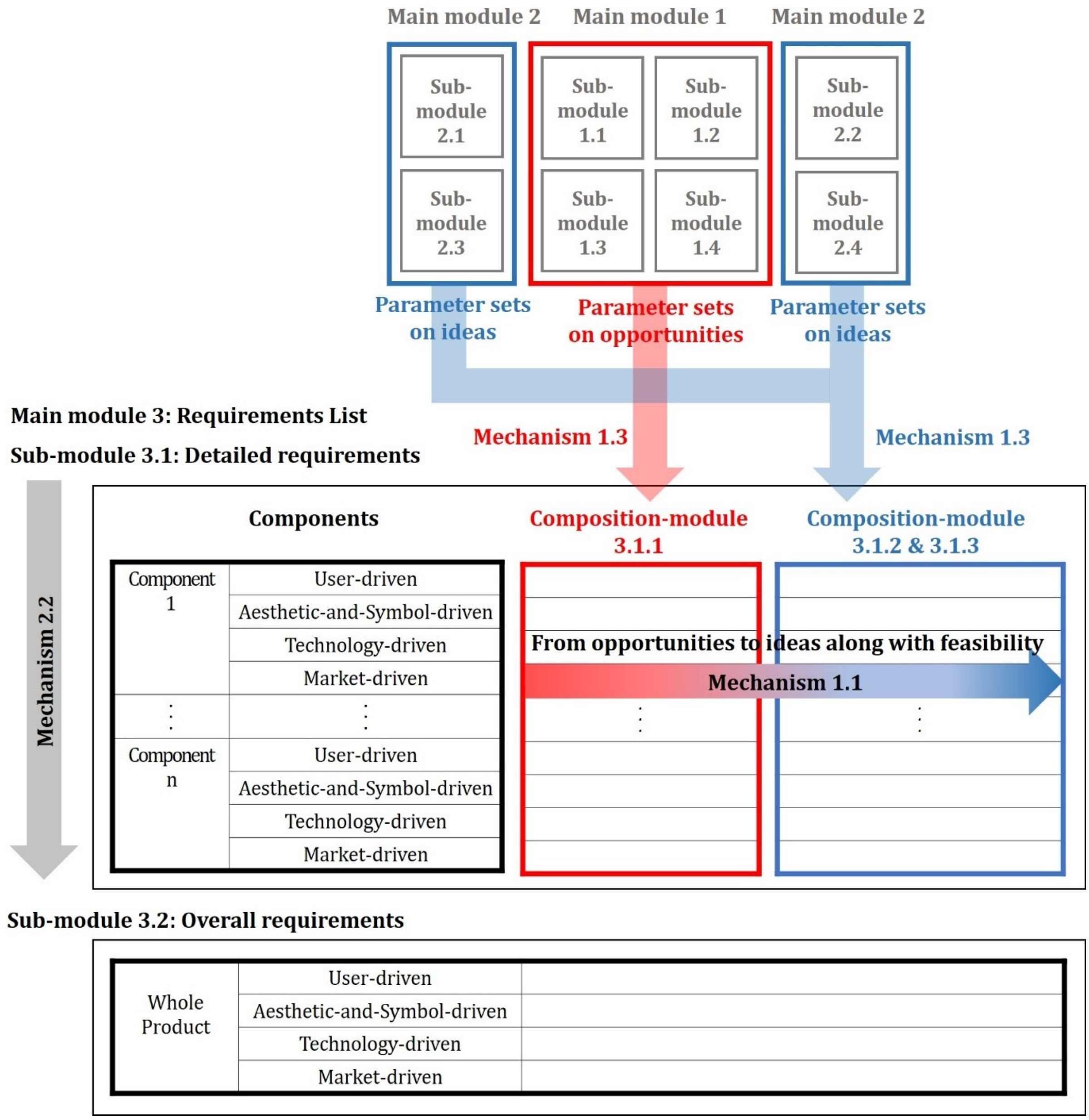

Figure 5.19. *Building mechanism for the requirements list module*

In the case of the mission statement module (Main Module 4), this is essentially a summarised form of Sub-module 3.2 which represents the overall requirements of the target product. Even though particular sub-modules and their composition-modules were not built into this main module, the main module was functionally divided according to what is required in the mission statement task.

5.5.2 Contextual Performance

By reflecting 'Mechanism 1.1: Contextual Performance between Composition-modules' into the embodiment of the requirements list and mission statement tasks which were defined in the representative FFE scenario, each sub-module was structured in a sequential arrangement of different composition-modules.

1) Module 3: Requirements List Module (*Figure 5.20*)

As shown in *Figure 5.20*, the requirements list module (Main Module 3) was structured with two sub-modules in a phased relationship.

The first sub-module (Sub-module 3.1) is for listing requirements, consisting of parameters from the opportunity discovery and ideation modules.

In the vertical axis, components defined in the user-driven and aesthetic-and-symbol-driven domains were constructed first in the main component format, e.g. Component 1, 2, 3 . . . n. As indicated in the previous section, 'Module 1: Opportunity identification-screening' (*pp. 296-297*), it is quite possible that the main-components are mostly identified in these two domains of research. Underneath that, components defined in the technology-driven domain were shared first with the main components of the previous two domains, and additionally structured in the sub-component format, e.g. Component 1.1, 1.2, 1.3. . . 2.1, 2.2, 2.3. . . n.1, n.2, n.3, etc., because there can be many sub-components for technical functions on the backs of those main components. In the case of components in the market-driven domain, the cost of developing the main components only is determined by adding up the total cost of the sub-components, calculated in the opportunity discovery module (Main module 1). Four domains in each component were further segmented with composition-modules representing each analysis category in the opportunity identification-screening module. For instance, in Component 1, the user-driven domain was structured as follows: 1) product usage process, 2) interaction system (Input and Output), 3) product usage function, 4) exposure environment, and 5) usability. In Component 1.1, the technology-driven domain was constructed thusly: 1) technical main-sub functions, 2) technical parameters (input and output), 3) operational mechanisms, 4) technical dimensions, and 5) required technologies.

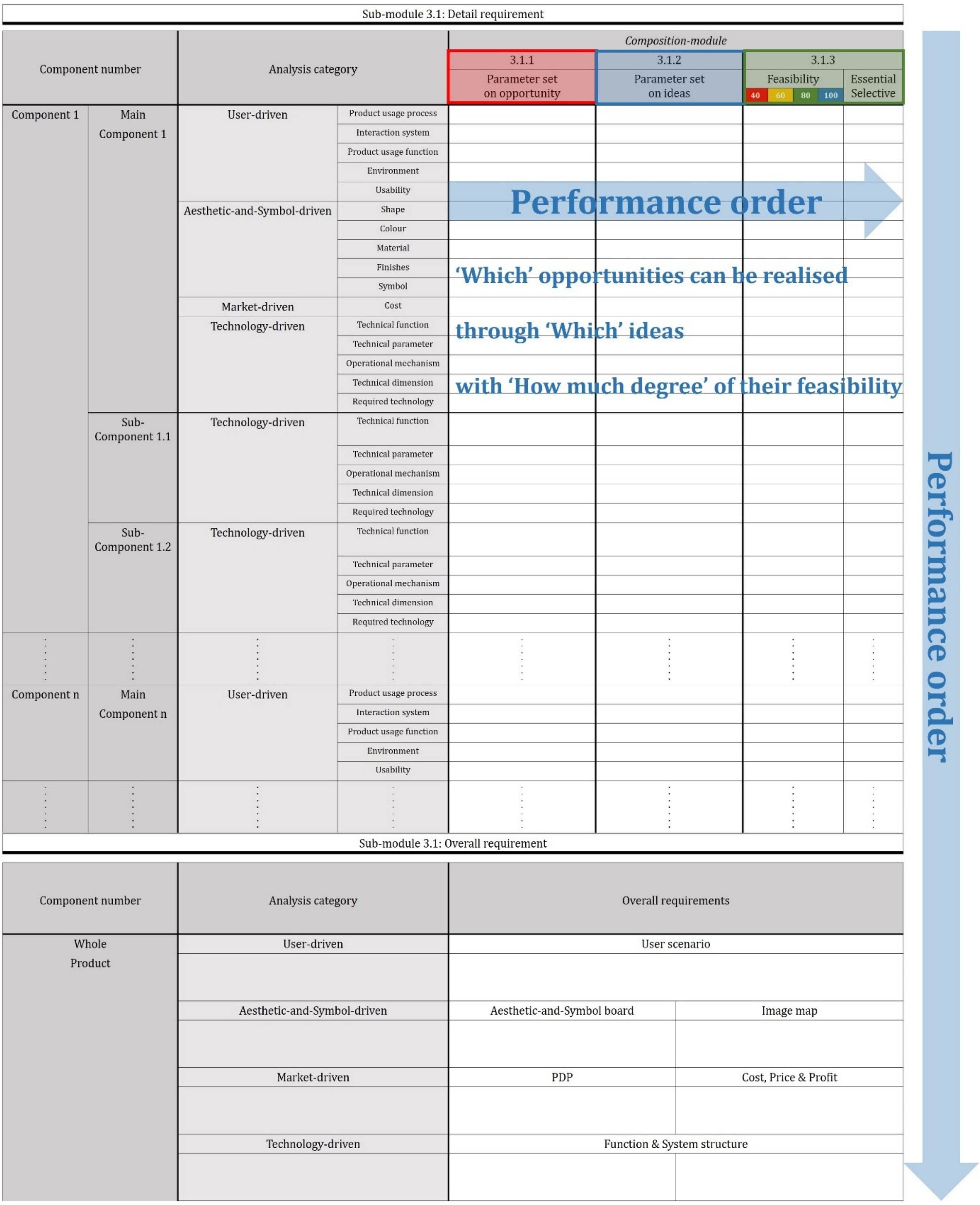

Figure 5.20. *Requirements list module*

The horizontal axis was divided into three composition-modules, in the following order: 1) Composition-module 3.1.1: parameters for opportunities obtained from Main Module 1, 2) Composition-module 3.1.2: parameters on ideas, supportive reasons, strengths and weaknesses gained from Main Module 2, and 3) Composition-module 3.1.3: classification with the essential/selective requirements along with a degree of feasibility obtained from

Main Module 2. The first and second composition-modules marked by the red and blue blocks were structured in an interlocking fashion, with the parameters drawn from Main modules 1 and 2. The third composition-module originated from the parameters from the feasibility check in Main Module 2 (shown in the green block).

Due to this structure consisting of a vertical and a horizontal axis, requirements for each component can be understood systematically, as follows. First of all, the opportunities in each analysis category of the four domains (the user-driven, aesthetic-driven, technology-driven, and market-driven domains) can be understood. Secondly, the ideas to realise those opportunities and the supportive reasons for these ideas can be identified. Through these two analyses, the contextual relationship between opportunities and ideas which lie on the same horizontal line can be grasped. Thirdly, the importance and the feasibility of those requirements which will be applied to the target product are studied. If it is imperative for a certain requirement to be reflected in the target product but the feasibility is relatively low, armed with this knowledge, the focus can shift to addressing this feasibility. Thus, both at individual component but also among different components, we can explore how these parameters interlock with each other, in terms of the three points above.

The second requirements sub-module (Sub-module 3.2), which summarises the entire target product, was structured with the four functional domains, the same as in the first sub-module (Sub-module 3.1). In each division for those functional domains, relevant contents which can reflect the condensed set of requirements were included. As shown in *Figures 5.12a to 5.12d* in the previous section, '5.3 Module 1: Opportunity identification-screening' (*pp. 228-294*), each particular composition-module, which encompassed most of the parameters produced in each sub-module, was equipped. These composition-modules are as follows:

1) Market-driven (Sub-module 1.1): market positioning-distribution-promotion (Composition-module 1.1.4) and overall development cost, product price and profits (Composition-module 1.1.7)
2) User-driven (Sub-module 1.2): user scenario (Composition-module 1.2.7)

3) Aesthetic-and-symbol-driven (Sub-module 1.3): aesthetic-and-semantic board and image map (Composition-module 1.3.6)
4) Technology-driven (Sub-module 1.4): function and system structure (Composition-modules 1.4.2 and 1.4.3).

Most of the contents of these parts are expressed primarily with images in the form of schematics, accompanied by brief explanations.

Consequently, requirements obtained in the opportunity discovery and ideation modules, be they from product component units or the overall product unit, can be understood systematically. Through a requirements list about, the opportunities and associated actionable methods required in the target product development can be grasped at a glance. In addition, how these individual requirements are infused into the entire product can also be viewed without difficulty. Ultimately, the requirements list can serve as a detailed mini-map of the target project.

2) Module 4: Mission Statement Module

The mission statement module (Main Module 4) was not structured in a hierarchy. Instead, it was organised with key contents required for establishing the project definition and design brief. The project title, aims and objectives serve as the main contents, alongside key contents from the four functional domains in the requirements list (Main Module 3), e.g. 1) target users/market and product price in the market-driven domain, 2) overall user behaviours and relevant product usage functions in the user-driven domain, 3) overall shape, colour and material of the product exterior in the aesthetic-and-symbol-driven domain, and 4) technical features and related-technologies in the technology-driven domain.

Consequently, the result of this module can play a role as an overall mini-map of the target project while the requirements list module can serve as a more detailed mini-map. These maps can be very useful tools to generate momentum to progress into the actual NPD phase once a direction has been established.

5.5.3 Concurrent Collaboration (*Figure 5.21*)

The collaborative work form identified in the representative FFE scenario was considered in order to foster concurrent collaboration in Modules 3 and 4.

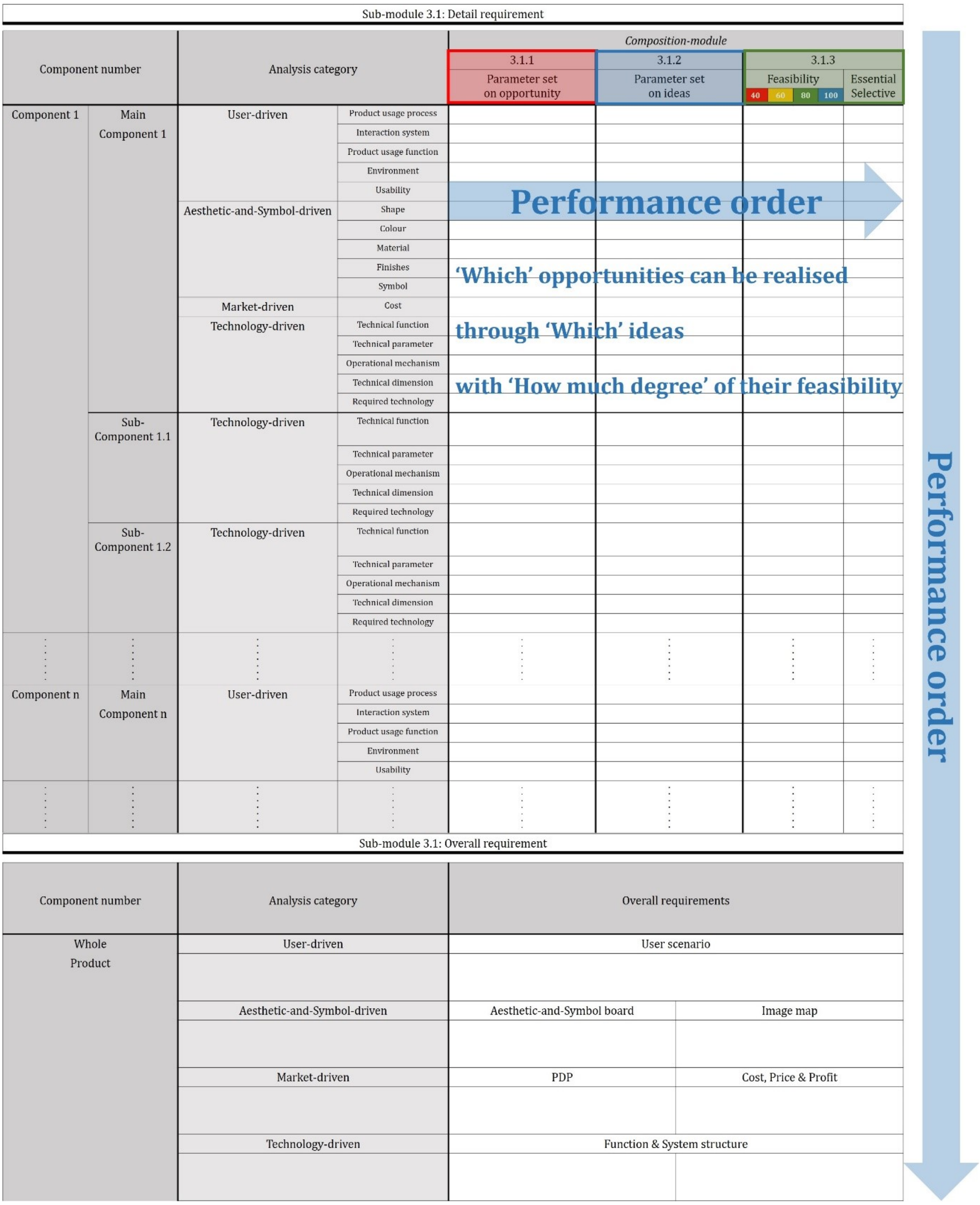

Figure 5.21. *Requirements list module, for concurrent collaboration*

Unlike the previous module (Main Modules 1 and 2) arranged in quadrants and in parallel, a different form of concurrent collaborative work was equipped in the requirements list module (Main Module 3), by applying 'Mechanism 2.2: Concurrent Collaboration within Modules', which places sub-modules in a phased relationship. By arranging requirements in the order that the relevant product components come into play, the relationship between the requirements of adjacent components can be achieved more functionally and with greater ease (shown in the red block). Furthermore, by dividing each component division into four functional domains, it is possible to concurrently inter-check as well as cross-check requirements from the viewpoint of those domains (shown in the blue block). Likewise, in the mission statement module (Main module 4), each section containing the key contents of the four domains can be filled by cross-checking.

5.5.4 Overall Attributes

To make the requirements list module (Main Module 3) and the previous two modules (Main Modules 1 and 2) interlock, the requirements list module also had to be structured with the performative type (Attribute 5). As with previous modules, the performative type can positively affect the embodiment of the data-driven platform (Attribute 1). A data-led requirements list that interlocks directly with the opportunity discovery and ideation modules can help prevent not only the omission of key requirements but also generate high-quality requirements considered from the viewpoint of contextual performance and concurrent collaboration. By means of a chain reaction, a data-centric platform can reduce not only the repetitive work caused by such low quality or omitted requirements (which might only be detected in the actual NPD phase) but also unnecessary meetings to explain requirements and their descriptive evidential interpretations, and thus ultimately effect more agile FFE practices (Attribute 2). Since accuracy for an abundance of requirements is important based on the nature and concept of the requirements list, its structure is more formalised than flexible (Attribute 4). The mission statement module (Main module 3) has the same context for the overall attributes as the requirements list module above.

5.6 Module 5
– Conceptual Design Task

5.6.1 Module Building Mechanism

Main Module 5 was developed, physically and functionally structuring the conceptual design task of the representative FFE scenario (*pp. 237-246 or 262-263*).

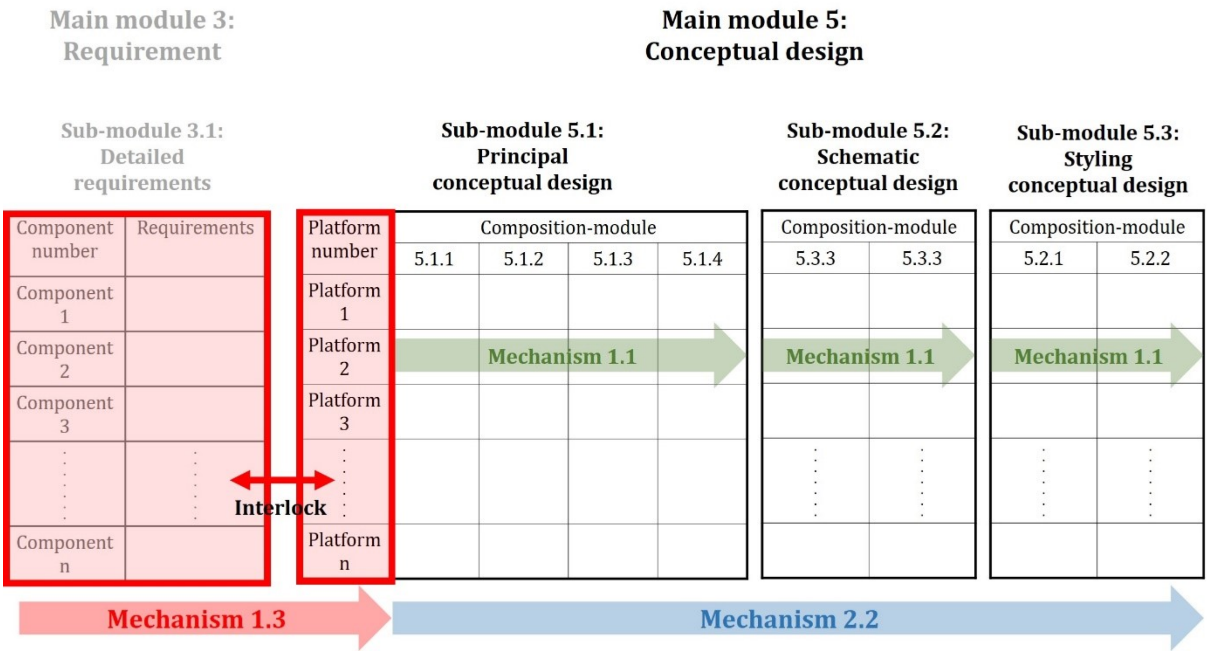

Figure 5.22. *Building mechanism for the conceptual design module*

Main Module 5 is the fifth part of the model structure for the conceptual design task (Task 5). The underlying concept of this module is to embody the target product visually by reflecting the product's requirements. Therefore, as shown in the block coloured in red in *Figure 5.22*, this module was designed to be initiated from requirements arranged on a component basis, by adopting 'Mechanism 1.3: Contextual Performance between Main Modules'. However, generating a conceptual design for each main component and sub-component can be complex and each component-based conceptual design work does not indeed represent much in the FFE phase. Hence, each group, consisting of the main component and the sub-components, was substituted for each product platform in the product architecture. By applying 'Mechanism 2.2: Concurrent Collaboration within Modules', Sub-modules 5.1 to 5.3 were structured in a phased relationship to foster the second form of concurrent collaboration. In each sub-module, relevant composition-modules were sequentially organised by reflecting 'Mechanism 1.1: Contextual Performance between Composition-modules'.

5.6.2 Contextual Performance

By reflecting 'Mechanism 1.1: Contextual Performance between Composition-modules' into the embodiment of the conceptual design task's relevant activities and performance methods, which were defined in the representative FFE scenario, each sub-module was structured in a sequential arrangement of different composition-modules.

Three phased sub-modules and their composition-modules (Figures 5.23a and 5.23b)

As shown in *Figures 5.23a* and *5.23b*, three sub-modules consisting of relevant composition-modules for contextual performance were sequentially structured for the systematic conceptual design task. Due to this structure, the initial composition-module in the first sub-module was consequently linked with the final composition-module in the third sub-module, via several composition-modules between the first and last composition-modules.

1) The First Sub-module and Its Composition-modules : Principal Conceptual Design

Sub-module 5.1 is to allow the principal conceptual design activity to devise possible concepts in an initial simple form. To carry out this activity systematically, the sub-module was structured with the following four composition-modules arranged in consecutive order.

Composition-module 5.1.1 devises the initial simple form using basic figures such as circles, triangles, rectangles, and parallelograms, for each product platform. Each simple form is devised by reflecting the requirements captured with each platform. Through these forms, a variety of initial principal concepts for each platform can be achieved.

Composition-module 5.1.2 determines which of the initial simple forms are optimal for each platform, considering their features, strengths, and weaknesses. In this work, a 'traffic light' marking scheme along with 100-point scoring system (also utilised back in the feasibility check in the ideation module) (Main module 2) were introduced.

Composition-module 5.1.3 interjoins those optimal forms by applying the basic frame of the target product. This can lead to the creation of many variations of initial concepts for the entire product by analysing different optimal combinations.

Composition-module 5.1.4 selects optimum principal concepts among the outcomes in the previous composition-module, depending on their features, and their strong and weak points.

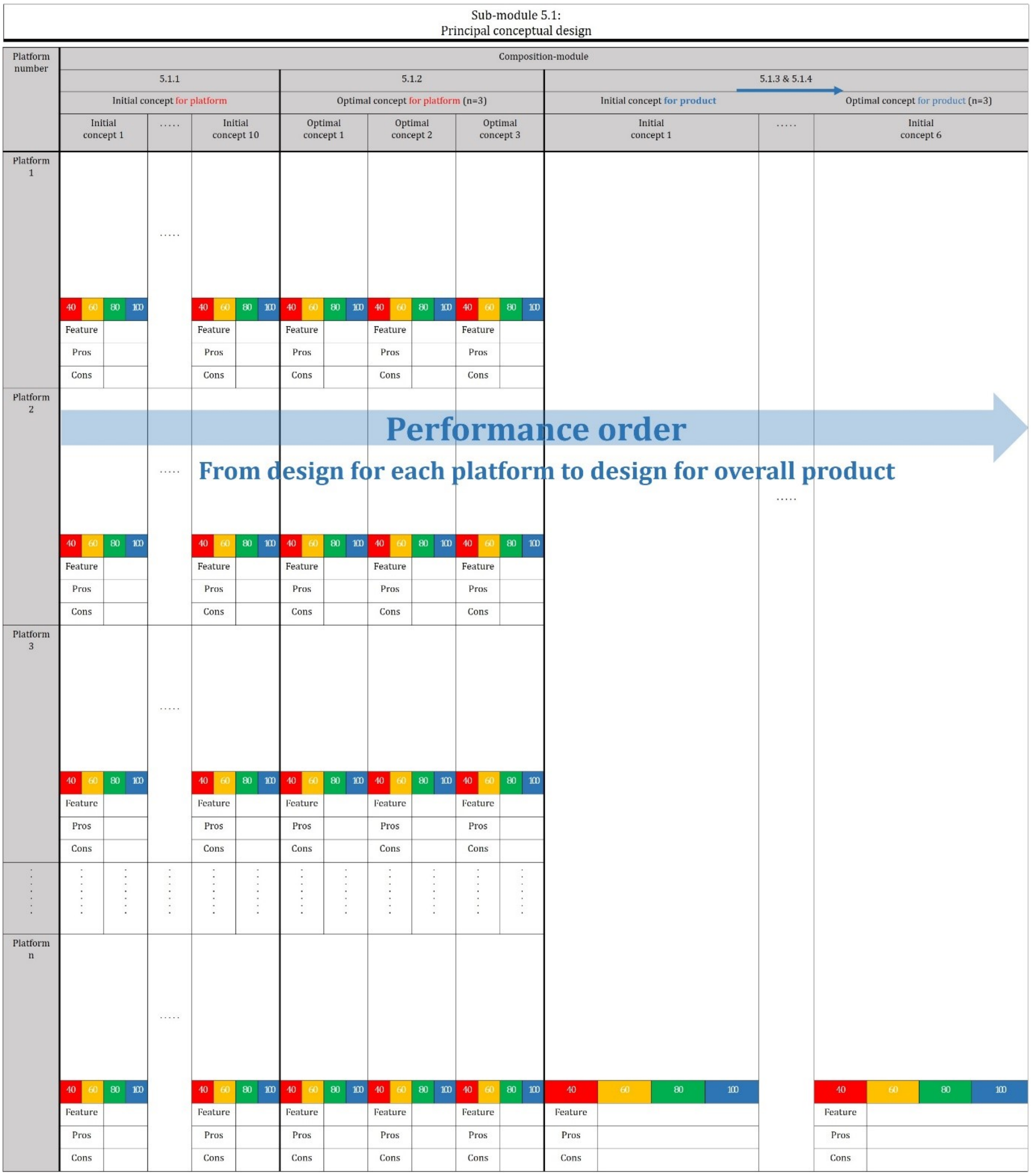

Figure 5.23a. *The first sub-modules and their composition-modules for conceptual design*

2) The Second Sub-module and Its Composition-modules
: Schematic Conceptual Design

Sub-module 5.2, structured with a sequential arrangement of two composition modules, is for the schematic conceptual design activity to devise conceptual forms that are more advanced than the principal conceptual designs.

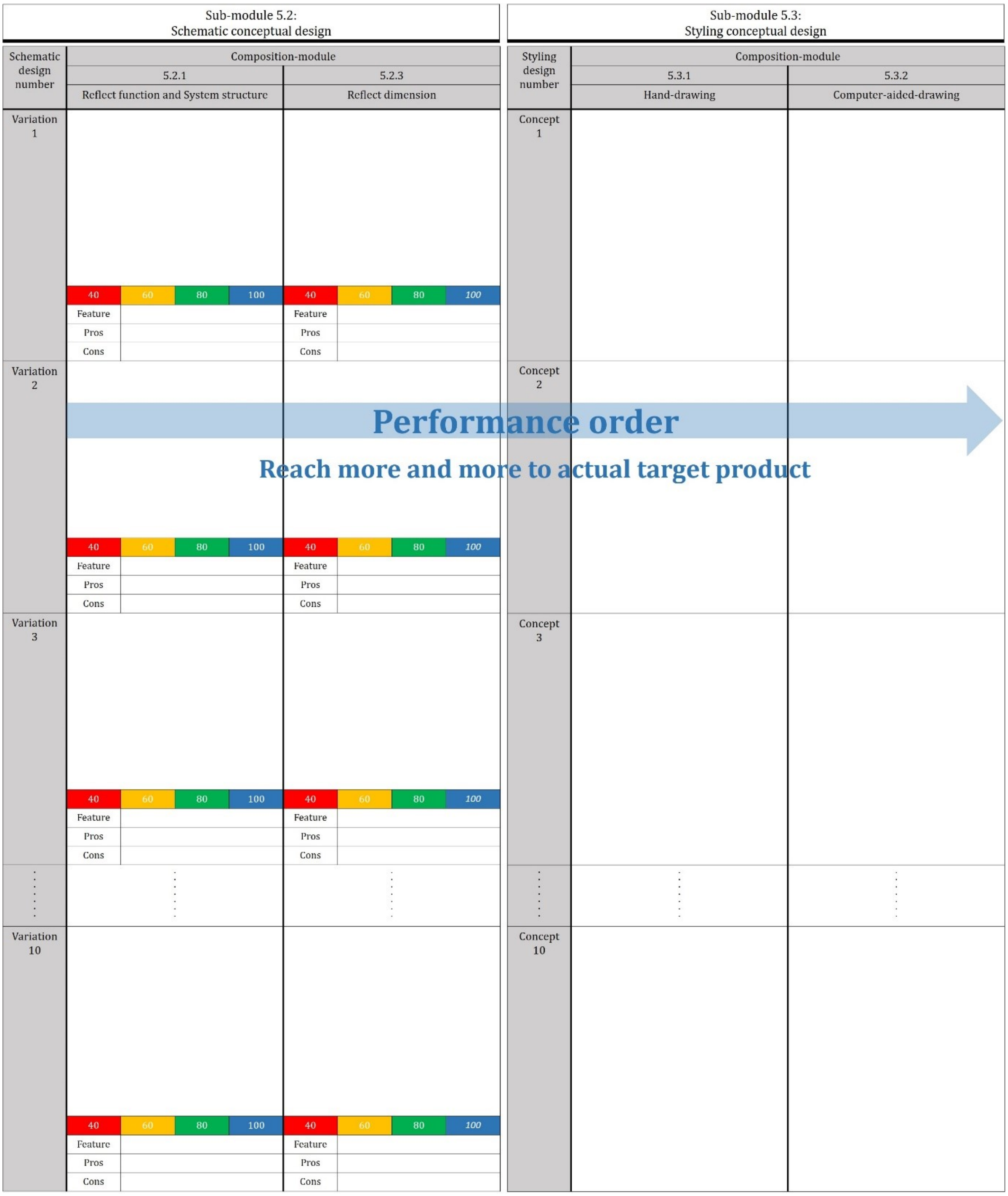

Figure 5.23b. *The second and third sub-modules, and their composition-modules for conceptual design*

Composition-module 5.2.1 modifies principal conceptual designs chosen in the last composition-module (Composition-module 5.1.4) of the first sub-module (Sub-module 5.1), according to the function and system structure. Even if the principal concepts for each platform are diverse, the outcomes of the principal concepts for the entire product can be simple since they are based on the basic structure of the product only. On the other hand, by assembling and disassembling principal concepts in different combinations for each platform, in compliance with the function and system structure (which can vary from the baseline), more diverse conceptual designs can be created. Of all these variations, around three or five are chosen to proceed into the next composition-module, based on their features, and strengths, and weaknesses.

Composition-module 5.2.2 reflects the technical dimensions and proportions in the previously selected variations, resulting in product concepts closer to the actual form of the target product. Suppose that three designs are selected in the previous composition-module. In this composition-module, the blank spaces that can be used for drawing, linked to the selected three in the previous composition-module, can be filled, leaving other spaces connecting to the seven unselected designs empty. After reflecting these dimensions and proportions, if the features, strengths and weaknesses of the three designs are altered, the modified contents can be filled in in this composition-module. Otherwise, the spaces remain identical.

When determining the optimal schematic designs in the composition-modules of this sub-module, the traffic light and scoring systems were also used in the selection.

3) The Third Sub-module and Its Composition-modules
: Styling Conceptual Design

Sub-module 5.3, the styling activity, is for exquisitely refining the schematic designs selected in the composition-module above. This work includes not only elaborating on the outlines of conceptual designs but also applying colours and materials. The styling activity is divided into two phased sub-works.

The first work carried out in Composition-module 5.3.1 is producing hand drawings of the conceptual designs. Then, in the next composition-module (Composition-module 5.3.2), more elaborate concepts are produced using CAD software such as 2D-sketching programs (e.g. Adobe Illustration) and 3D modelling and rendering programs (e.g. Rhino and 3DS Max). This sub-module makes it possible to generate possible conceptual designs which are much closer to the actual target product.

In this phased systematic way, once initial simple forms for each product platform have been devised in Composition-module 5.1.1, the remaining composition-modules can be conducted in serial order. This results in the acquisition of conceptual designs clarified in styling work activity, and constitutes the final results of Main module 5.

5.6.3 Concurrent Collaboration

With ‘Mechanism 2.1: Concurrent Collaboration between Modules’, Sub-modules 5.1 to 5.3 were placed in serial order, considering the sequential relationship between each FFE activity defined in the representative FFE scenario (*p. 245*).

As with the requirements list and mission statement module (Main modules 3 and 4), the second form of concurrent collaboration (which occurs within modules) was fostered in the conceptual design module (Main module 5), by applying ‘Mechanism 2.2: Concurrent Collaboration within Modules’. As mentioned in the section introduction, this module was designed to start in product platforms in which requirements produced from the four functional domains (market-driven, user-driven, aesthetic-and-symbol-driven, and technology-driven domains) are reflected. Therefore, using conceptual designs of the product platforms as well as designs for the product overall, performers can regularly confirm whether requirements are being met in each composition module, from the viewpoint of the four functional domains. For instance, a certain conceptual design more inclined to applying requirements from one domain only can be moderated and modified to include the viewpoints of the other three domains.

5.6.4 Overall Attributes

In order to interlock between the conceptual design module and the requirements list module, the conceptual design module had to be of the performative type (Attribute 5). As with previous modules, through the cluster networking reaction, the toolkit type for the module can lead to the embodiment of the data-driven conceptual design task (Attribute 1), facilitating the confirmation of parameter flows in terms of the reflection of requirements. This can contribute to agile conceptual design work (Attribute 2) by decreasing the repetition that arises from missed applications of requirements in conceptual designs and also from less accurate applications. In addition, this can lead to rapid conceptual design work (Attribute 2) by reducing unnecessary meetings to discuss which and how requirements have been reflected in the devised conceptual designs from the viewpoint of the four functional domains. Furthermore, by providing sufficient room to choose specific methods (including intuitive conceptual design methods such as brain-drawing and round-robin which were identified in various FFE practices, *pp. 244-245*) in each composition-module, it can be regarded as the formalised structures which foster flexible performance behaviours (Attribute 4).

5.7 Module 6
– Prototyping Task

5.7.1 Module Building Mechanism

Main Module 6 was developed, physically and functionally structuring the prototyping task of the representative FFE scenario (*pp. 247-250 or 264*).

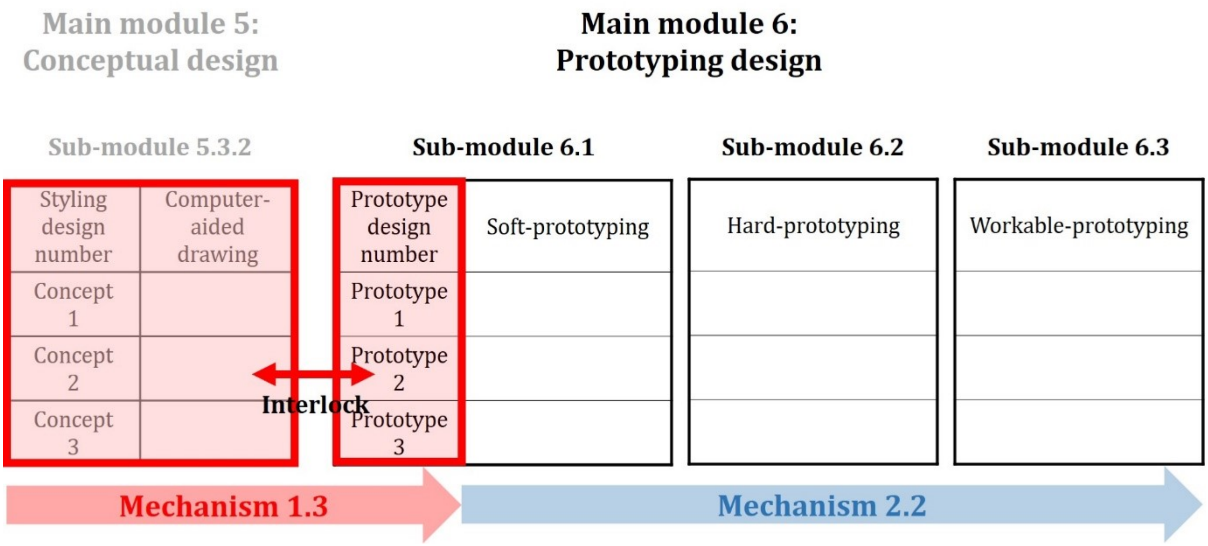

Figure 5.24. *Building mechanism for the prototyping module*

Main Module 6 is the final part of the model structure for manufacturing prototypes (Task 6) based on the conceptual designs. By applying 'Mechanism 1.3: Contextual Performance between Main Modules', the beginning of this module was designed to interlock with the final composition-module (for styling conceptual design) in the previous module. Also, while the fundamental concept of the conceptual design module (Main Module 5) is to visually embody and confirm the target product which will be developed in the actual NPD phase in terms of what requirements are reflected, the concept of this module (Main module 6) is to physically embody and verify it before it passes to the actual NPD phase. Therefore, since the main difference between the two modules is visual or physical embodiment of the target product, the overall structure of the module is nearly the same as that of the conceptual design module. Sub-modules were arranged in consecutive order, with ‘Mechanism 1.2: Contextual Performance between Sub-modules’ and ‘Mechanism 2.2: Concurrent Collaboration within Modules’. However, one difference from the conceptual design module is that particular composition-modules were not formally equipped into each sub-module since analysis of the real-world FFE scenarios indicated that related performance methods were used selectively depending on the preferences of individual performers.

5.7.2 Contextual Performance

By reflecting 'Mechanism 1.1: Contextual Performance between Composition-modules' into the embodiment of the conceptual design task's relevant activities, which were defined in the representative FFE scenario, each sub-module was structured in a sequential arrangement.

Phased three sub-modules (*Figure 5.25*)

Three sub-modules, representing relevant prototyping activities, were built in a phased-structure. Owing to this structure, initial outcomes generated in the first sub-module were consequently connected with final outcomes produced in the third sub-module via outcomes generated in the second sub-module.

1) The First Sub-module
: Soft-prototyping

Sub-module 6.1 is for soft-prototyping, to develop rough mock-ups which consider only the outlines and proportions of the chosen conceptual designs. In this activity, colours and materials are not reflected in mock-ups. Instead, only a sense of the product's form is confirmed in this sub-module.

2) The Second Sub-module
: Hard-prototyping

Sub-module 6.2 is for manufacturing hard-prototypes wherein not only the shape but also the colours and materials of the conceptual designs are reflected. In terms of product appearance only, these prototypes will be nearly the same as the target product (which is produced in the actual NPD phase).

3) The Third Sub-module
: Workable-prototyping

Sub-module 6.3 is for developing prototypes which can operate functionally and technically. Along with the shells or exteriors of those prototypes manufactured in the previous sub-module (to test the product's appearance), a prototype of the product's inner workings can allow performers to see if the product operates as intended.

Sometimes, separate from the hard-prototypes, only the functional and technical structure is physically developed in the form of a workable prototype, wherein there is no integration with the exteriors developed in the hard prototype. In this module, how the target product operates can be checked to see what will actually be developed in the NPD phase.

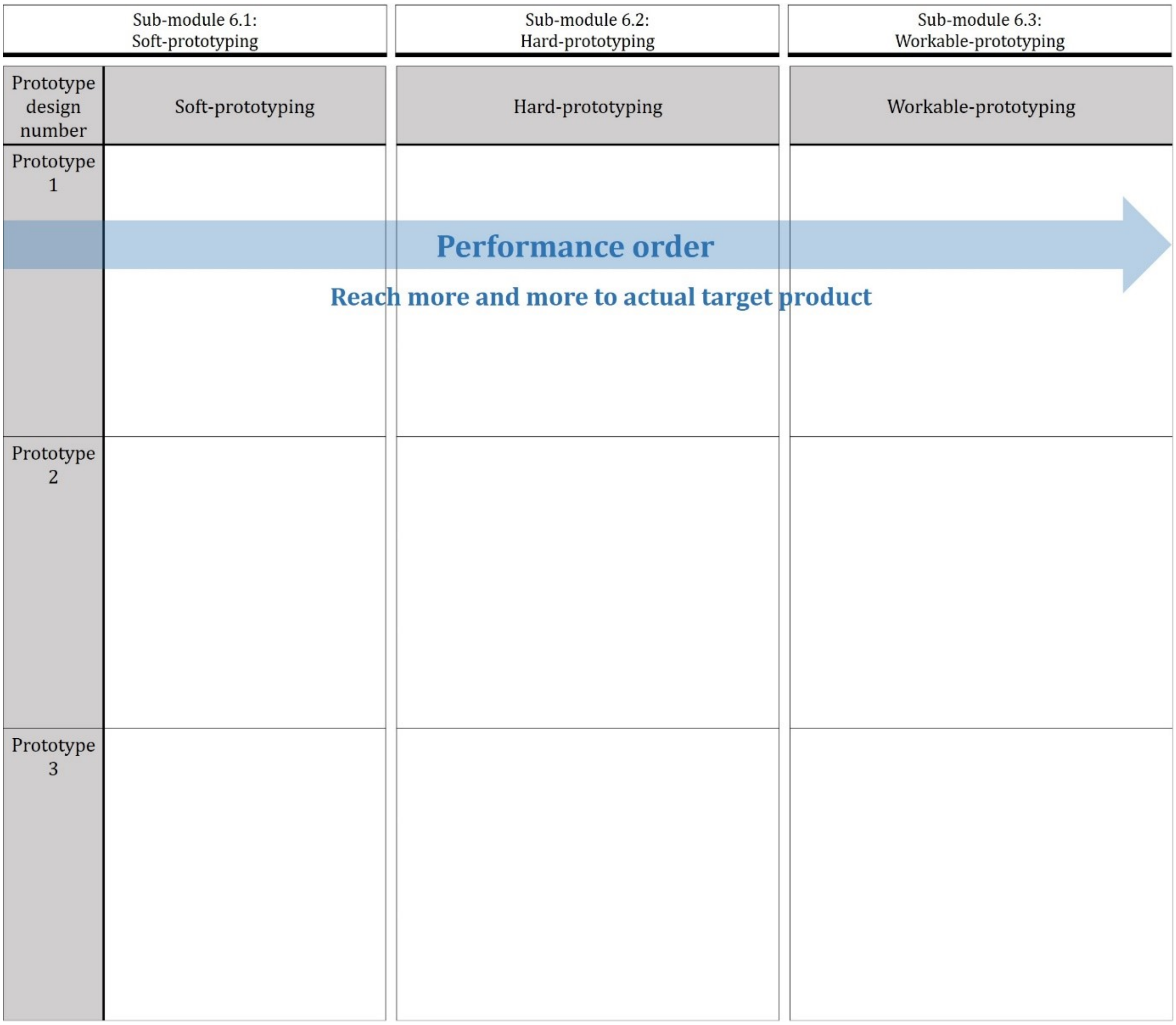

Figure 5.25. *Sub-modules for prototyping module*

The first and second sub-modules can include photographs of the soft and hard prototypes. The third module can include videos as well as photos. These materials can document not only the product as a whole but also its components.

Consequently, if the requirements theoretically generated through the opportunity discovery and ideation work is actually applied to the target product, we can confirm not only how the target product looks but also how it is works, functionally and technically, through these physical prototypes. Identified problems can be tackled by considering the deviations between the theoretical requirements and the practical embodiment. These modifications to the prototype are compared and evaluated, and only the one which survives to the end can go on to the actual NPD stage.

5.7.3 Concurrent Collaboration

With 'Mechanism 2.1: Concurrent Collaboration between Modules', Sub-modules 6.1 to 6.3 were placed in consecutive order, considering the phased-relationship between each FFE activity defined in the representative FFE scenario (*p. 250 or 264*).

As with the conceptual design module (Main Module 5), the second form of concurrent collaboration, operating within modules, was built into this module by adopting 'Mechanism 2.2: Concurrent Collaboration within Modules'. In the same context as with the conceptual design module, the degree to which requirements have been effectively applied to prototypes can be concurrently confirmed from the viewpoint of the four functional domains. In the first and second sub-modules aimed at developing soft- and hard-prototypes, the aesthetic-and-symbol-driven work leads in any collaboration. The third sub-module, manufacturing workable prototypes, can be conducted with the user-driven and technology-driven works as the centre. In the process of implementing those sub-modules, adjustments to the development cost led by the market-driven work can occur according to whatever is modified.

5.7.4 Overall Attributes

As with most of the previous modules, overall attributes 1, 2, 4 and 5 were fostered in this module by means of a chain-reaction. The prototyping module was realised with a performative platform (Attribute 5), which affects the data-driven type (Attribute 1) in which the flow of data (on whether numerous parameters on opportunities and ideas are properly reflected in the prototypes, physically) can be grasped. This encourages the agile manufacturing of prototypes (Attribute 2) by reducing iterative prototyping works caused by missed parameters and by parameters incorrectly applied. It can also encourage agile prototype manufacturing by decreasing unnecessary meetings about which and how requirements are applied to the prototypes. In addition, by offering discretion to select prototyping methods when conducting each sub-module that has a phased structure, the structure in which the flexible characteristics are built can be considered formalised (Attribute 4).

5.8 Chapter Conclusion

– Pragmatic-Prescriptive FFE Model Development

This chapter has described the progress and outcomes of Study 2.2's effort to build a pragmatic-prescriptive FFE model for large corporations and SMEs (e.g. design speciality firms and NPD consultancies) which target consumer products such as electronics, medical devices, vehicles, and furniture.

The model development strategies previously established in the literature (Study 1.0) and real-world FFE practices obtained from the interviews (Study 2.1) were reflected in the new FFE model's development.

By applying model building mechanisms to allow for contextual performance and concurrent collaboration, presented in the chapter introduction, the model was structured with specific module constituents. Main modules representing FFE tasks identified in the literature and in actual FFE practices were constructed first as the basic frame of the model structure. Then, in each main module, sub-modules indicating FFE activities revealed in the real-world FFE scenarios were structured in a parallel or phased arrangement, to promote concurrent collaboration. Lastly, composition-modules, in which performance methods and toolkits analysed in the real-world FFE practices were embodied in the form of toolkits, were structured and interlocked with each other for contextual performance.

With this structure built for contextual performance and concurrent collaboration, the overall attributes regarding: 1) the data-driven type, 2) agility, 3) both incremental and radical NPD, 4) a balance between the explicitness and responsiveness characteristics, and 5) a balance between the procedural and performative structures, were realised in the new FFE model by way of the chain-reaction effect.

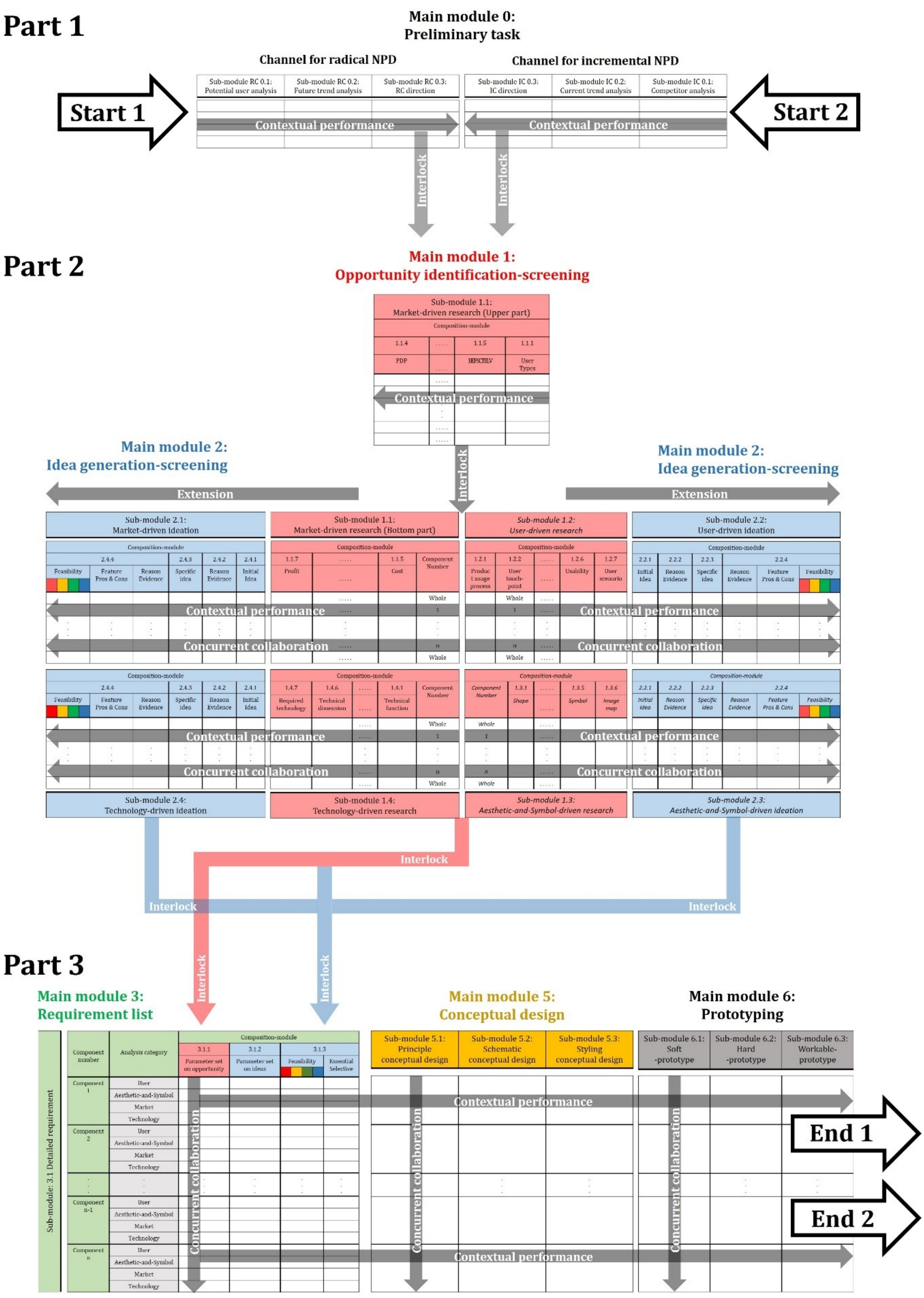

Figure 5.27. *Pragmatic-Prescriptive FFE model for contextual performance and concurrent collaboration*

The pragmatic-prescriptive FFE model developed in this research (shown in *Figure 5.27*) is outlined below, divided into three sections corresponding to the three viewpoints: contextual performance, concurrent collaboration (regarding the FFE performance structure and its operating mechanism), and overall attributes (regarding current and future trends of FFE model improvement).

1) FFE Performance Structure and Its Operating Mechanism : Contextual Performance

As shown in *Figure 5.26*, the main modules, sub-modules, and composition-modules were structured in the form of toolkits. Each composition-module can be regarded as an individual toolkit designed to execute a relevant performance method. Each sub-module can be considered a combined toolkit for conducting a related-activity. Each main-module can be regarded as a single integrated toolkit for a relevant task. Thus, the whole model can play a role as a consolidated toolkit for the entire FFE.

With the model building mechanism devised in this research, which is presented in the chapter introduction (*pp. 270-277*), the contextual performances analysed in the real-world FFE scenarios (Study 2.1) were systematically embodied between composition-modules, between sub-modules, and between main-modules. This makes it possible to interlock parameters produced in each composition-module, sub-module, and main-module. Once the initial module (Sub-module IC 0.1 or Sub-module RC 0.1) is conducted in one of the channels for an incremental or radical NPD project, all remaining modules, from the second module (Sub-module IC 0.2 or Sub-module RC 0.2) to the final module (Sub-module 6.3), can be contextually conducted in succession. Namely, all of the FFE performances, from determining the improvement or development direction to the manufacturing of workable prototypes, can be executed through an interlocking of parameters.

Overall, the structure of the FFE model for contextual performance is divided into three parts (shown in *Figure 5.26*): Part 1: Main Module 0 for the preliminary task, Part 2: Main Modules 1 and 2 for the opportunity identification-screening and idea generation-screening tasks, and Part 3: Main Modules 3, 4, 5, and 6 for the requirements list and mission statement tasks, and the conceptual design and prototyping tasks.

In the first part, the improvement or development directions were formulated via contextually connected sub-modules.

In the second part, in Main Module 1, the target product, in which those improvement or development directions are reflected, are scrutinised by means of those sub- and composition-modules interlocked for contextual performance. The investigation of the target product proceeds on a component basis, from the four functional domains: 1) market-driven domain, 2) user-driven domain, 3) aesthetic-and-symbol-driven domain, and 4) technology-driven domain. As an extension to this investigation, each idea (in the form of an actionable method for materialising the parameter sets produced in Main Module 1) is devised on a component basis, again from the four functional domains, in Main Module 2. The sub- and composition-modules interlocked for contextual performance in these two modules enable more exquisitely research and ideation works on the target product. *Figure 5.27* shows the magnified scene of Module 1 and 2 wherein contextual performance occurs.

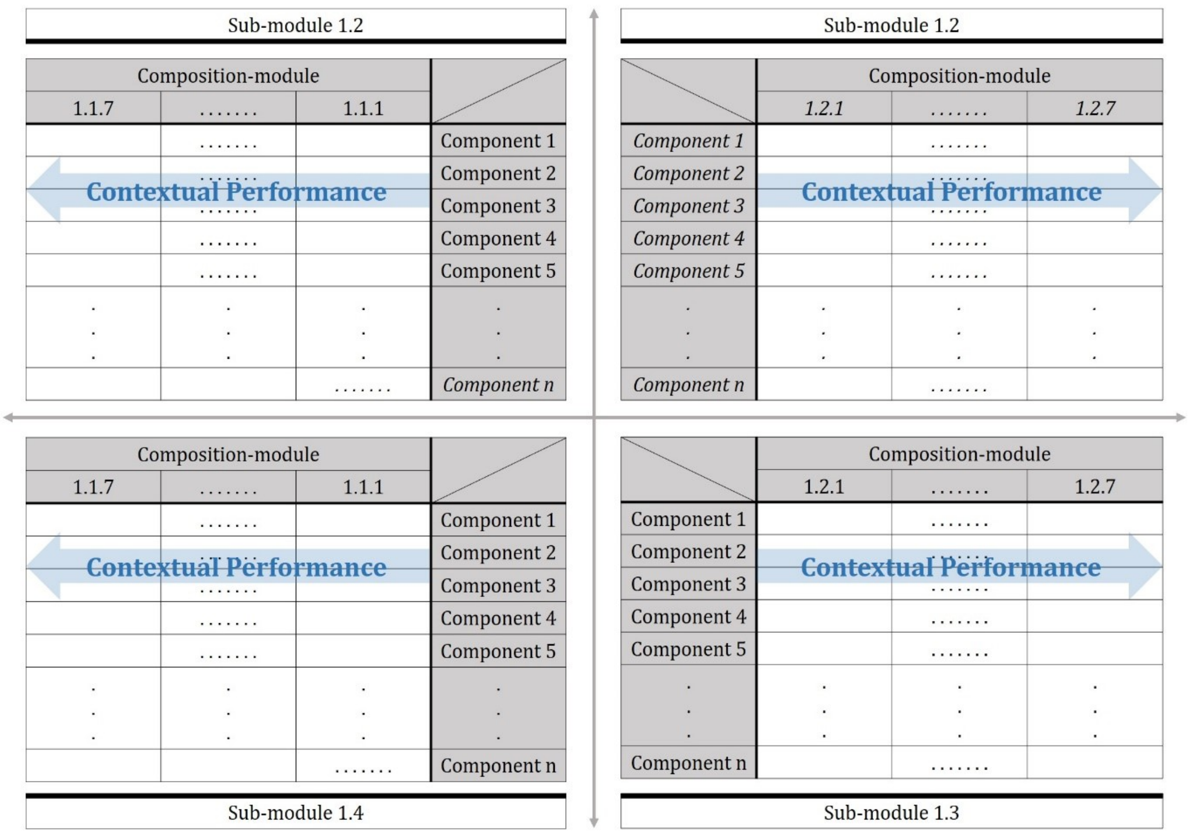

Figure 5.27. *Contextual performance mechanism in Module 1 and 2*

In the third part, structured with Main Modules 3 to 6 in a bundle, firstly, the requirements list was arranged also on a component basis, interlocking with parameters produced in Main Modules 1 and 2. Hence, the requirements consist of a combination of opportunity parameters gained in Main Module 1 and idea-and-feasibility parameters produced in Main Module 2. Secondly, considering the components' requirements, the creation of conceptual designs for individual components can proceed, eventually allowing a conceptual design for the target product, in its entirely, to be produced using the sub- and composition-modules connected for contextual performance. Lastly, on each possible conceptual design of the target product, three different types of prototypes, soft-, hard-, and workable-prototypes, are manufactured in sequence using the sub-modules interlinked for contextual performance.

As a result, through use of a series of composition-modules and sub-modules interlocked for contextual performance, the parameters required in the FFE phase can be contextually produced in Main Modules 0, 1, and 2, and integrated into the form of a parameters list in Main Modules 3 and 4, and finally transformed into visual, functional, and physical form in Main Modules 5 and 6.

2) FFE Performance Structure and Its Operating Mechanism : Concurrent Collaboration

As with the structure of the FFE model for contextual performance, the structure of the FFE model for concurrent collaboration is divided into three parts.

In the first part, as shown in *Figure 5.26* (*p. 338*), the two channels (Main Module 0) for incremental and radical NPDs, sequentially consisting of relevant three sub-modules, fosters concurrent collaboration of the different functional domains *within* the modules.

In the second part, the sub-modules that make up Main Module 1 for the opportunity identification-screening task were arranged in a clockwise direction in quadrants, for fostering concurrent collaboration *between* modules. Sub-modules which make up Main Module 2 for the idea generation-screening task were placed as an extension to each sub-module of Main Module 1. This makes it possible to arrange the sub-modules of Main Module 2 in a clockwise direction, enabling Modules 1 and 2 to exist in a single quadrant.

The two sub-modules of Main Modules 1 and 2 in quadrant 1 are for the market-driven research and ideation activity. The two sub-modules in quadrant 2 are for the user-driven research and ideation activity. The sub-modules in quadrants 3 and 4 are for aesthetic-and-symbol-driven research and ideation activity and the technology-driven research and ideation activity, respectively. With this structure, in which the research and ideation activities for these four functional domains occur in a single quadrant, parameters in each composition-module of a certain sub-module can be produced by concurrently considering other parameters generated by other composition-modules of the three remaining sub-modules. Namely, all of the parameters in the composition-modules of these four sub-modules can be produced by simultaneously considering the viewpoints of the four functional domains. *Figure 5.28* shows a magnified depiction of Modules 1 and 2 wherein concurrent collaboration is occurring.

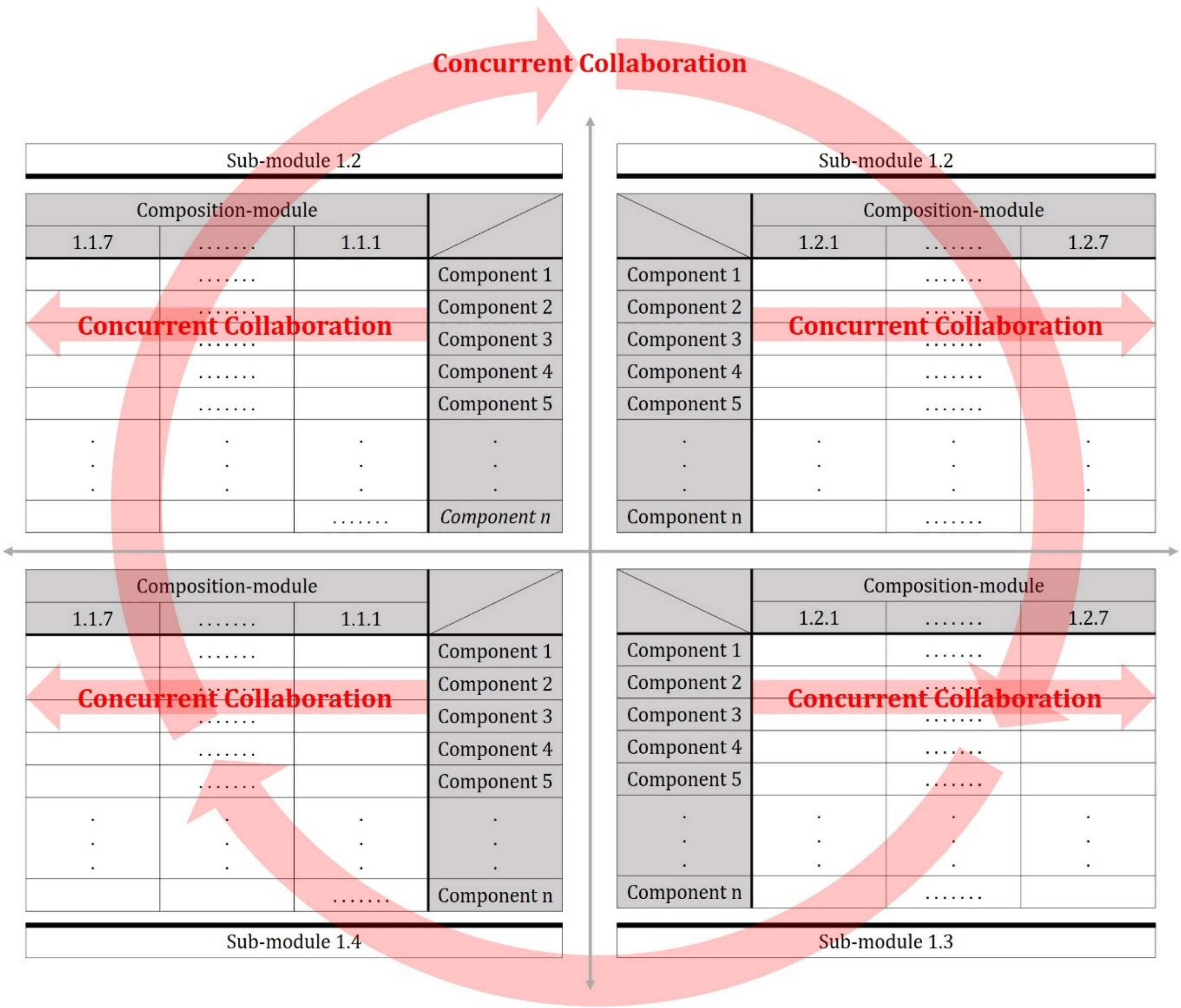

Figure 5.28. *Concurrent collaboration mechanism in Module 1 and 2*

In the third part, Main Modules 3, 4, 5, and 6 were built in a phase structure, to foster other forms of concurrent collaboration which do not occur *between* modules but *within* the modules themselves. This form of concurrent collaboration makes it possible to inter-check as well as cross-check requirements, conceptual designs, and prototypes produced in each sub- and composition-module, from the viewpoints of the four functional domains.

Consequently, through operation of the sub- and composition-modules interlocked for concurrent collaboration, the parameters demanded in the FFE stage can be multidimensionally produced not only in Main Modules 1 and 2 which foster concurrent collaboration *between* modules using the quadrant structure but also in Main Modules 0, 3, 4, 5, and 6 which facilitate concurrent collaboration *within* modules using the phase-structure.

3) Overall Attributes
: The Current and Future Trends of FFE Model Improvement

Contextual performance and concurrent collaboration, presented in the two sections above (*pp. 339-343*), lead to the infusing of expected overall attributes in the pragmatic-prescriptive FFE model by way of the chain-reaction effect.

As shown in *Figure 5.29*, all sub- and composition-modules were designed with toolkits, and these modules were built into the main modules, forming seven phased steps (shown in the arrow and descriptions coloured in grey and blue). This can be regarded as building specific structures of the performative type in the overall procedural structure (Attribute 5).

In addition, the performative type of all the sub- and composition-modules can facilitate data-centric FFE performance, which produces high-quality outcomes by interlocking input and output parameters not only in each single functional domain (from the contextual performance perspective) but also in the four functional domains (from the concurrent collaboration perspective) (Attribute 1). As shown in the part coloured in purple, these high-quality outcomes can be accumulated in a form of a FFE library dataset for every cycle of the FFE's execution. Each library dataset, essentially the knowledge and experience gained from the FFE, can take the form of an encyclopaedia for each target product. The applicable datasets can be extracted and selectively applied to later NPD projects. This is the ultimate goal of the data-driven type of FFE model, to build up this base of knowledge (Attribute 1).

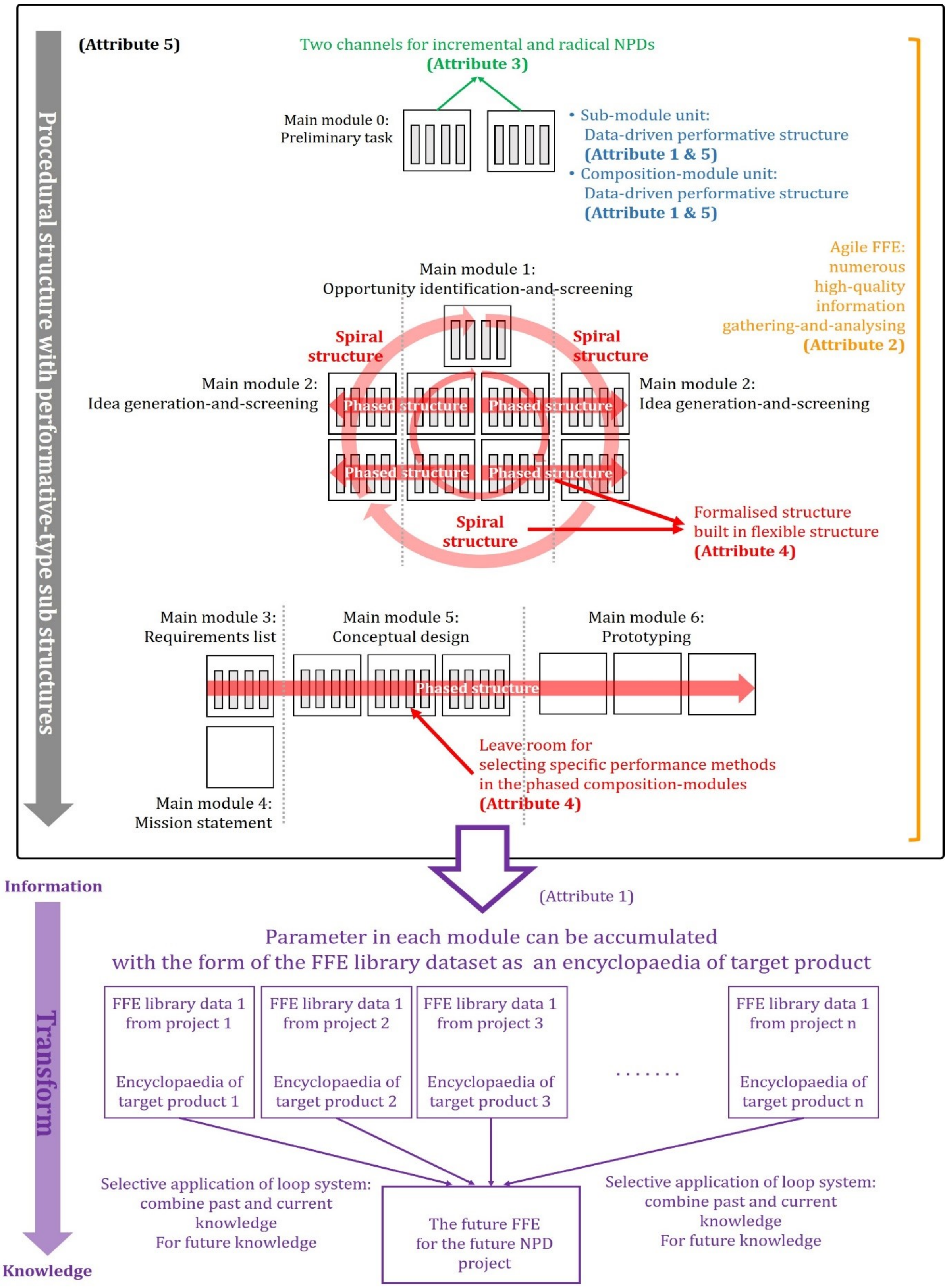

Figure 5.29. *Overall Attributes of the pragmatic-prescriptive FFE model*

Furthermore, as shown in the part coloured in orange, this data-led FFE model, which produces high-quality parameters that are exquisitely explored not just from a single functional domain but also multidimensionally from the other three domains, can contribute to agile FFE execution, by reducing repetitive works aimed at compensating for defective parameters (Attribute 3) as well as decreasing unnecessary meetings whose purpose is to describe parameters and their descriptive evidential interpretations.

As shown in the part coloured in red, Main modules 1 and 2 were built so that the composition-modules were not only sequentially arranged in a formalised structure but also such that the sub-modules were placed in a spiral process to foster flexible consideration of other sub- and composition-modules' progress and outcomes. Hence, the model structure can be considered balanced between explicitness and responsiveness (Attribute 4). Furthermore, by providing discretion to select specific performance methods in each composition-module, diverse FFE performances by performers can be fostered in the formalised composition-modules. Therefore, it can contribute to increasing creativity when the direction and guidelines are 'explicit', which many experts pursue in their NPD implementations. This can be regarded as harmonised between explicitness and responsiveness (Attribute 4).

In the case of Attribute 3, two different channels coloured in green were equipped in the initial part of the model structure to facilitate establishment of the improvement or development directions for incremental and radical NPDs.

In conclusion, the new pragmatic-prescriptive FFE model developed in this project fulfilled the development strategies established in the literature (Study 1.0) and in real-world FFE practices obtained from the interviews (Study 2.1). It is expected that research problems related to deficiencies in previous FFE models, defined in Chapter One (Introduction), can be effectively solved by embodying the development strategies in the Literature Review chapter and the representative FFE scenario derived from the analysis of real-world FFE scenarios. However, the model cannot be regarded as validated even if the model was developed using a method that fulfilled all internal validity criteria referred to in the research method section of Chapter Four (*pp. 146-149*). Thus, in the next chapters (Studies 3.1 and 3.2), the process and outcomes of an external validation of the new pragmatic-prescriptive FFE model are presented, and a new theoretical-descriptive FFE model is built, based on the results of said validation.

Chapter 6. Study 3.1

– Pragmatic-Prescriptive FFE Model Validation

6.1 Chapter Introduction

This chapter, Chapter Six, describes the progress and key findings of Study 3.1, fulfilling Objective 4 (shown in *Figure 6.1*).

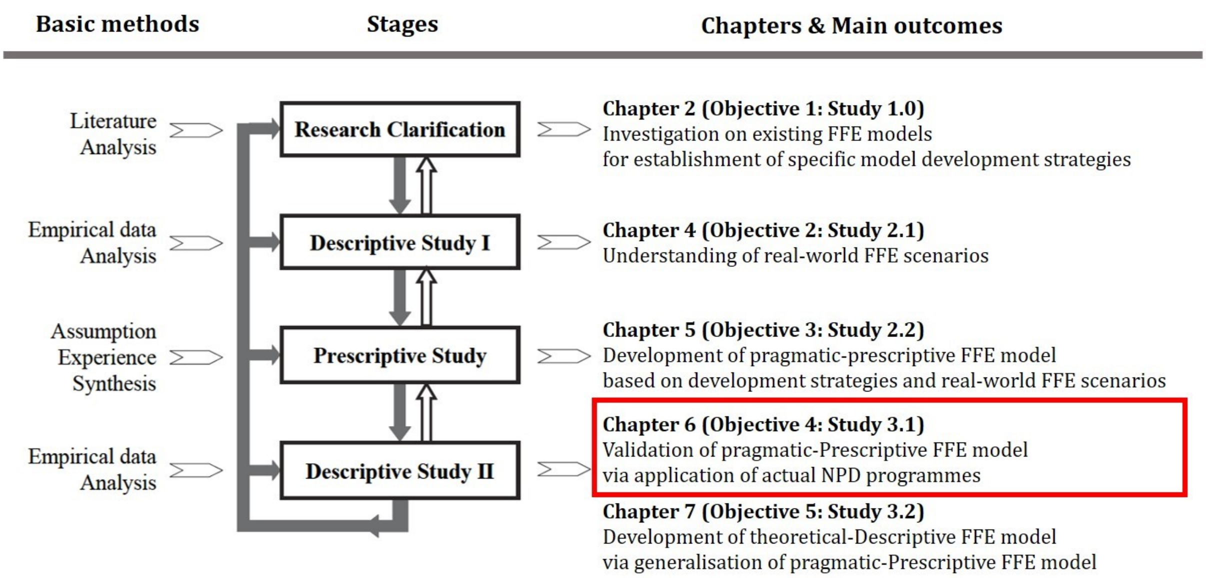

Figure 6.1. *Mini-map of Study 3.1 (Own depiction, adapted from Blessing & Chakrabarti, 2009)*

This chapter introduction starts by describing the research objective of this chapter, followed by the research method used to achieve the objective, before finishing with a summary of the chapter introduction.

4) Research Objective
5) Research Method
6) Research Summary

6.1.1 Research Objective

The purpose of Study 3.1 is to fulfil Objective 4; validating the pragmatic-prescriptive FFE model developed in Chapter Five (Study 2.2) through field tests which apply the FFE model into actual NPD programmes in consumer product sectors.

The validation proceeded from the following two perspectives: 1) performance structure and its operating mechanism (regarding contextual performance and concurrent collaboration) and 2) overall attributes (with respect to current and future trends in FFE model improvement).

In the first perspective, whether the structure of the pragmatic-prescriptive FFE model is well-constructed for contextual performance and concurrent collaboration was examined in terms of parameter processing and determination.

In the second perspective, whether current and future trends of FFE model improvement are well-fostered in the pragmatic-prescriptive FFE model were investigated from the viewpoints of the overall attributes in terms of the data-driven type, agile development, both incremental and radical NPDs, a balance between the explicitness and responsiveness characteristics, and a balance between the procedural and performative structures.

Thus, the pragmatic-prescriptive FFE model was validated from those aspects which come from the main direction of the FFE model development based on not only the development strategies to complement the limitations of the previous FFE model, established in Chapter Two (Study 1.0, Literature Review), but also based on analysis of real-world FFE scenarios studied in Chapter Four (Study 2.1).

6.1.2 Research Methods

1) Section Introduction

An outline of the research method for Study 3.1, conducted in this chapter, is shown in the block coloured in red in *Figure 6.2*. Fundamentally, the comprehensive direction of the research method was designed based on the collection and analysis of quantitative data, approached using deductive reasoning under the positivist paradigm.[43]

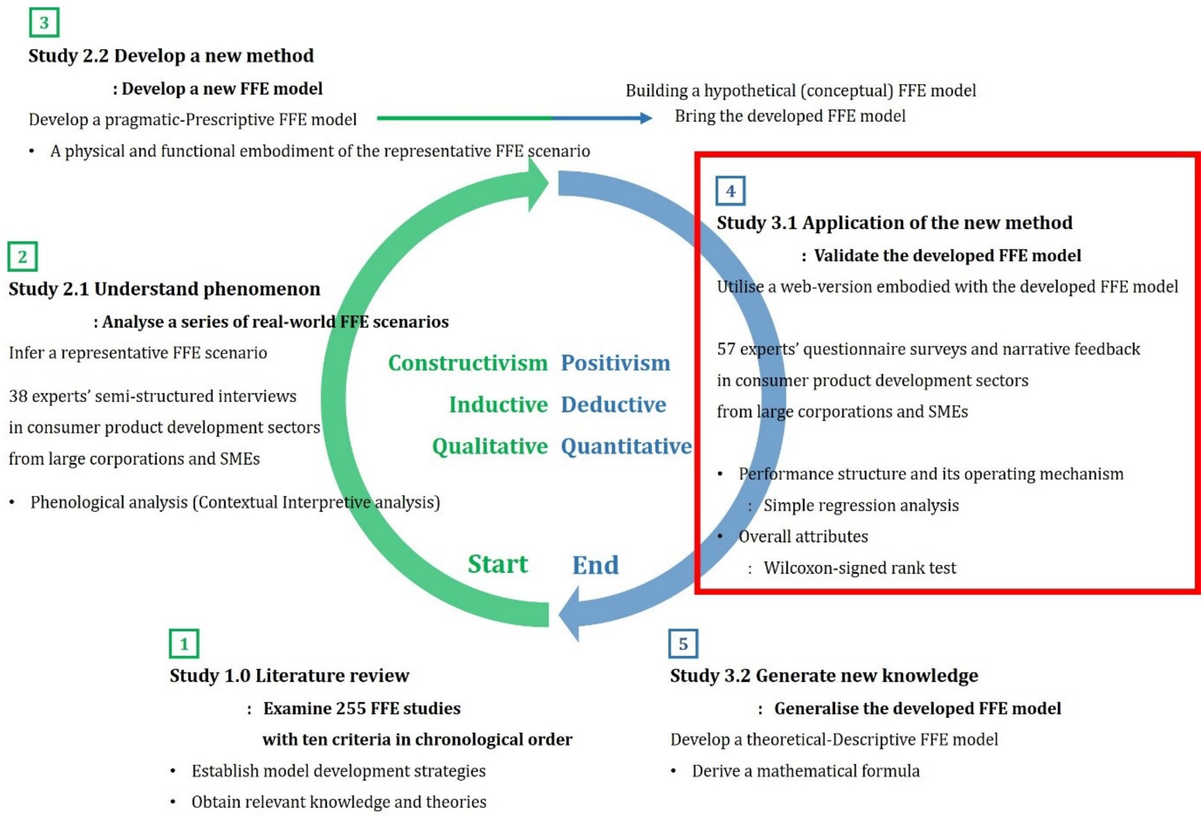

Figure 6.2. *Research method of Study 3.1*

More details of the research method are illustrated below, divided into the following sub-sections:

1) Prerequisites for Fostering an Experimental Environment
2) Participants and NPD Programmes Selection
3) Data Collection Method
    3.1) Questionnaire Survey

[43] More details of the deductive reasoning process under the positivists' research worldview can be found in Chapter Three (Research Methodology, *pp. 112-113*).

3.2) Self-observational Diary

4) Data Analysis Method

4.1) Simple Regression Analysis

4.2) Wilcoxon Signed-rank Test

4.3) Descriptive Feedback Analysis

2) Prerequisite for Fostering Experiment Environment

The first section presents the development of a web-version embodied from the pragmatic-prescriptive FFE model (shown in *Figure 6.3*). The web-version aims to foster an experimental environment which is close to an actual FFE performance environment in many NPD organisations.[44] In the embodiment of the web-version, various computer programming techniques, such as 'HTML', 'CSS' and 'JavaScript', were utilised.

There were merits and limitations in involving the web-version in the field-tests.

In the case of the merits, users were able to conduct experiments more functionally and interactively on the web-version itself only, without any supporting tools. In particular, one benefit obtained by using the web-version was that the parameters in the requirement list (Module 3) can be filled automatically once the parameters in the opportunity identification-screening (Module 1) and the idea generation-screening (Module 2) are produced. The other advantage was that image type parameters, as well as text-and-numeric parameters, was able to be uploaded, downloaded and previewed. These features of the web-version aided to reduce unplanned variables affecting the progress and outcomes of the experiment.

However, in the case of limitations, since the back-end part related to a server for networking and storing data was not built, there were two limitations in the experiment. Firstly, participants were not able to shut down web-pages during conducting the experiment, so that they needed to make PCs or laptops maintain with the sleeping mode. Secondly, for sharing their work in real time, they needed a large screen that could

[44] Many corporations, including Nortel (Montoya-Weiss & O'Driscoll, 2001), Samsung (Lee, 2017), LG, GE, Toyota (Jung, 2017), have established their own intranet-based NPD platforms.

provide a split-screen view or each additional screen which show the status of the progress and outcomes, placing in the centre of their workstations.

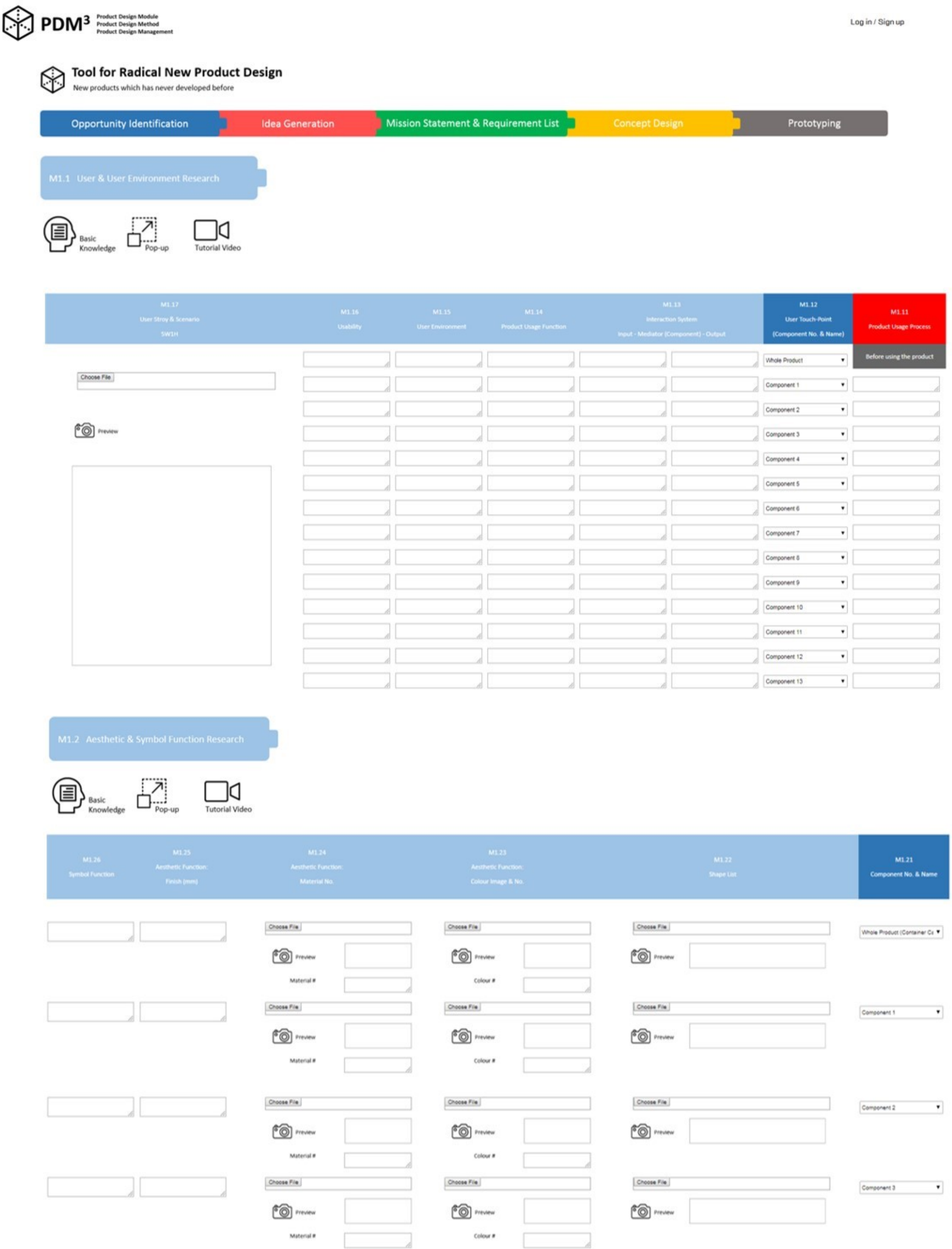

Figure 6.3. *Screen-captured image of web-version of pragmatic-prescriptive FFE model*

Comprehensively, the web-version was a prototype developed to a level where there were no critical problems in conducting a practical experiment, occurring the various merits. Use of the web-version enabled not only a reduction of unexpected variables but also the obtaining of a more realistic and reliable assessment.

3) Participants and NPD Programmes Selection

The process, method and criteria for selecting expert participants engaged in field tests was the same as that used in the interviews of Study 2.1 analysing real-world FFE scenarios (*p. 135).* However, the participants of the field tests were different to those of interviews to reduce any possibility of falling into a logical fallacy[45] in circular reasoning adapted in this research methodology. This led to the obtaining of different data resources from the field tests to that of the interview data used to develop the pragmatic-prescriptive FFE model.

As a result, 57 participants were selected for the field tests; the rate of participants from SMEs and the government were higher than that of participants from large corporations in the proposition of 4:1. This finding was because field tests that operate the pragmatic-prescriptive model developed in this study for actual NPD projects were not permitted in many large corporations, due to the nature of their bureaucracy and less flexible operation of organisations. The number of participants used here is not generally considered to be enough when conducting quantitative data research. However, in the case of expert participants, it can be regarded as a reasonable number, since each can represent the majority of opinions.

In the case of selecting projects, 12 projects were chosen for the field-tests. Six projects were from the electronics domain and four came from medical devices; the remaining two projects related to vehicle interior design, including a control joystick and cockpit panel. In particular, there were several trials to evenly distribute those projects into the radical and incremental NPD groups. Among the 12 projects, five - including the design of a vehicle interior - were for radical NPDs.

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[45] More detailed descriptions of the logical fallacy are shown in *p. 117*.

4) Data Collection Methods
– Questionnaire Survey and Self-observational Diary

4.1) Data Collection Method Selection

Firstly, participants were mainly involved in the field tests with a 7-point Likert-scale questionnaire survey when they conducted their actual projects by using the web-version of the model. Although there is no "Golden Rule" regarding the required maximum number of levels in the Likert-scale, if the number of scales is more than 10, participants cannot logically categorise and understand the meaning which each scale is indicating, struggling with recognising each of them by verbal labels (Kline, 2008; Prager et al., 2011). Hence, a minimum of a three-point scale, and a maximum of a ten-point scale is recommended; most should be five- to seven-point scales (Kline, 2008; Prager et al., 2011).

Secondly, when the participants responded to the survey, they wrote a self-observational diary[46] as a form of short-answer question to support questionnaire survey data. The study implemented by Kagioglou et al. (2000) shows the significance of the short-answer question method. Its main purpose is to grasp what statistical data which come from the survey implies in more detail by narrative evidential descriptions, which contributes to more explicit understanding improvement points and the direction for future research.

[46] Study 3.1 was designed to be conducted by deductive reasoning, mainly involving quantitative data. Nonetheless, the reason why the self-observational diary method - which can be regarded as the qualitative data method - was utilised in the study is that descriptive feedback can help the additional and more specific understanding of what statistical data indicates. The narrative feedback was utilised as the supportive material, and thus the overall research methodology for Study 3.1 did not follow a mixed-methods approach under the pragmatism paradigm; instead, it still followed the deductive reasoning approach under the positivism paradigm.

4.2) Use of Selected Methods

Before actually conducting the questionnaire survey and observational diary, participants were pre-trained for a period of a week at least to be skilled enough in using the web-version of the model; this resulted in more reliable survey data. The researcher also provided an operation manual to the participants. Additionally, via online-communication and remote control, the researcher trained them in person. Ester and Daniel (2007), Khurana and Rosenthal (1998), Stevens and Berley (2003), and Talk et al. (2006) have also stressed the importance of providing a training period and supportive instruction materials prior to the practical use of a new model in NPD areas.

Simultaneously, pre-tests with the method borrowed from studies by Miles, Huberman and Saldana (1984, 2013, 2014) were implemented by three participants to verify whether the questionnaire survey and self-observational diary were built appropriately.

After prior approvals through the consent pack, the actual survey started. When participants conducted their FFE projects with the given web-version of the model, they marked upon the given questionnaire and filled in the short-answer questions. Surveys continued over two to three months, depending upon their scheduled FFF periods.

5) Data Analysis Method

– Simple Regression Analysis

– Wilcoxon Singed-rank Analysis

– Descriptive Feedback Analysis

This sub-section is divided into three parts. The first part is the verification method for the FFE performance structure and its operating mechanism (regarding contextual performance and concurrent collaboration). The next is for the overall attributes (with respect to current and future trends in FFE model improvement), The last is for interpreting the descriptive feedback.

5.2) Simple Regression Analysis

for the FFE Performance Structure and Its Operating Mechanism

regarding Contextual Performance and Concurrent Collaboration

: Parameter Process and Decision

This section presents the validation method for the FFE performance structure and its operating mechanism in terms of concurrent collaboration and concurrent collaboration operation in the pragmatic-prescriptive FFE model. It begins by introducing building mechanisms for hypothesises and for a questionnaire, followed by describing the process to select an appropriate analysis method (simple regression analysis) for the survey data gathered by those questionnaires, before ending with how to interpret the validation results on the data.

5.2.1) Hypothesis and Questionnaire Building Mechanism

A method to build hypothesises was mainly adapted from the study presented by Antonsson (1987). Survey questions aimed at demonstrating hypothesises were established based on the studies of questionnaire design, such as Bradburn et al. (2004), Belson (1981), Oppenheim (2000) and Sudman and Bradburn (1982). Then, hypothesises and questions were elaborated, those that fit with the purpose of this study.

Therefore, the hypothesis and questionnaire design were iteratively confirmed, since the effectiveness and reliability of gathered data can differ depending upon whether the questionnaire and hypothesises are built appropriately. Unless these are not designed reasonably, the gathered data cannot be useful to the study's purpose.

- **Hypothesis Building**

  In the same context, the FFE performance structure and its operating mechanism is considered from the two perspectives: contextual performance and concurrent collaboration. A total two of hypothesises were established in the validation of the pragmatic-prescriptive FFE model, as follows.

H_1

If outcome parameters of the previous modules positively affect outcome parameters of the subsequent modules as input parameters in the 'contextual performance' structures of the pragmatic-prescriptive FFE model,

then the FFE model may be regarded as an FFE model structure wherein contextual performance is well-fostered.

H_2

If outcome parameters of the previous modules positively affect outcome parameters of the subsequent modules as input parameters in the 'concurrent collaboration' structures of the pragmatic-prescriptive FFE model,

then the FFE model may be regarded as an FFE model structure wherein concurrent collaboration is well-fostered.

- **Questionnaire Building**

  Based on the established hypotheses, in order to see how the outcome parameters of previous modules positively affect outcome parameters of subsequent modules as input parameters in the structure of a pragmatic-prescriptive FFE model for contextual performance and concurrent collaboration, the following questionnaire building mechanism is considered.

  Firstly, in the case of validating the model structure from the contextual performance perspective, the following questionnaire building mechanism was used. Suppose that suppose that Module A and B have the relationship of contextual performance, in which the outcome parameters of Module A serve as input parameters for Module B. Hence, the validation was designed in a sense that if the quality of outcomes of Module A increases, the usefulness of performing Module B increases. In other words, if the quality of outcomes of Module A is satisfactory with criteria, Module B can be performed more easily. In this regard, independent variables relate to the quality of outcomes in Module A, which affects Module B. Dependent variables related to the usefulness of performing Module B, which is influenced by Module A.

Secondly, in the case of verifying the model structure from the concurrent collaboration perspective, the identical verification mechanism used above was selected. Suppose that Module A, B and C have the relationship of concurrent collaboration: the quality of outcomes in Module A affects the usefulness of conducting Module B, and the quality of outcomes in Module B influence the usefulness of performing Module C. In this collaboration form, each independent variable relates to each previous module assigned to verifying the quality of outcomes, while each dependent variable relates to each subsequent module assigned to verify the usefulness of performance.

The following is an example set of questions for the independent and dependent variables:

I_v
To some extent are the quality of outcomes in Module A is fulfilled with the criteria?

D_v
To some extent are the usefulness in conducting Module B is fulfilled with the criteria?

5.2.2) Analysis Method Selection Process

To analysis data collected by the questionnaire survey questions, the statistical analysis method using 'SPSS' was involved. There are various statistical analysis methods, such as 'Nominal or Ordinal Regression Analysis' in non-parametric statistics and 'Factor Analysis', 'Correlational Analysis' and 'Simple or Multiple Regression Analysis' in parametric statistics. Of these analysis methods, it is important to select the most adequate method for this validation. Kline (2008) and Norman (2010) highlighted the following four prerequisites to consider, with respect to choosing the most reasonable statistical analytic method: 1) the sample size, 2) the type of the independent and dependent variable, whether data is parametric or non-parametric, 3) the number of independent and dependent variables, and 4) whether independent and dependent variables have a linear relationship.

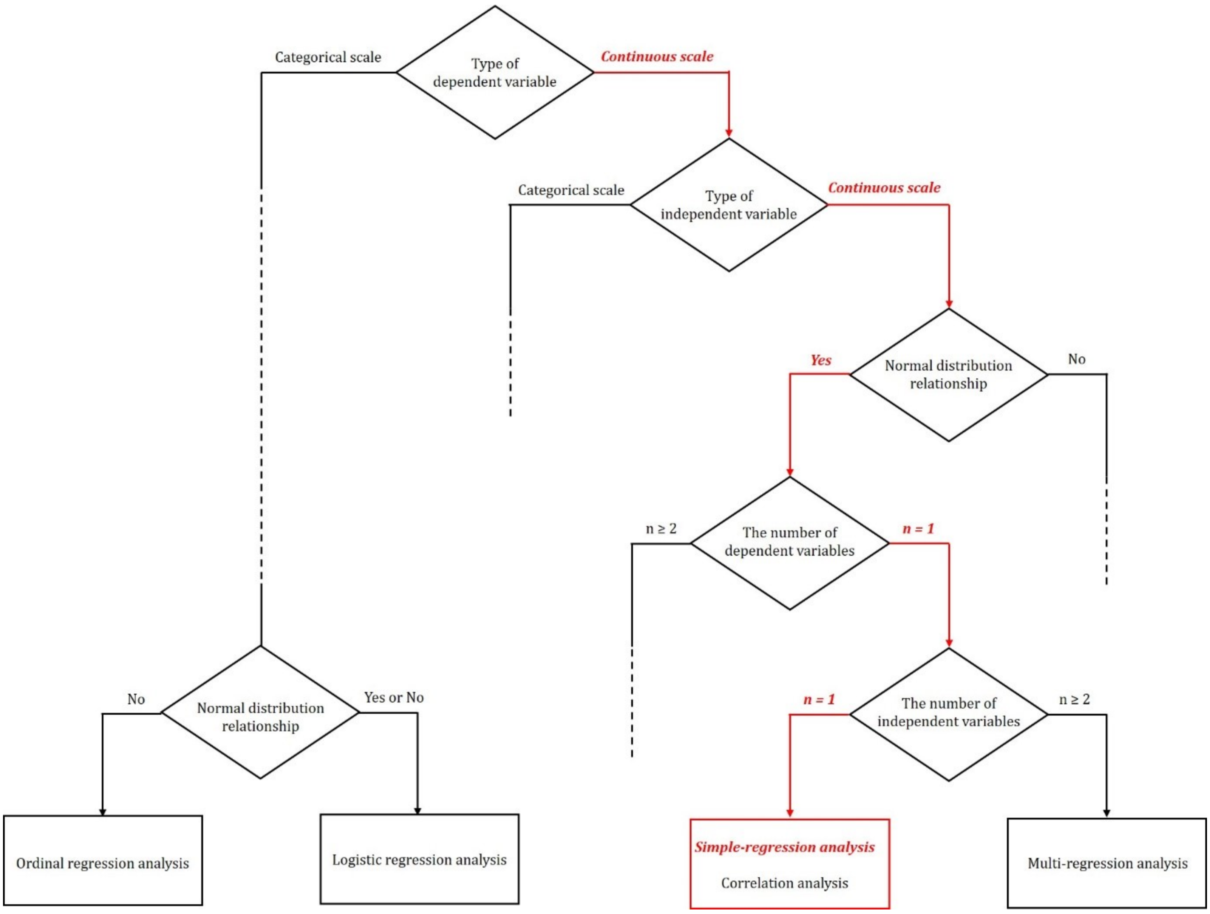

Figure 6.4. *Process of selecting an appropriate analysis method 1 (Simple Regression Analysis)*

Considering different preconditions of each statistical method and their cardinal principles, as well as the validation direction in this research, the 'Simple Regression Analysis' was selected, excluding all the remaining methods. This method's rationale and process (shown in *Figure 6.4*) are as follows:

In the first step, the number of samples, 57 experts participated in the field tests, may not be sufficient for the statistical analysis. However, as mentioned previously, each expert's validation data contains a representativeness which can substitute for the majority. Therefore, methods in both parametric and non-parametric statistics were regarded as all reasonable methods.

In the second step, the number of dependent and independent variable are one respectively, meaning that the multiple regression analysis – where the number of independent variables is more than one – was not acceptable under this condition. In the case of the factor analysis, this method is suitable for analysing the relationship of several variables and generalising them into one variable; by interpreting 'Cronbach' value to find out which variables (questions/Likert items) are relevant or not, without a distinction between the independent and dependent variable. Therefore, factor analysis was also not adequate for this research.

In the third step, the independent and dependent variables in the survey questions were measured with a 7-point Likert scale. According to Awang et al. (2016), Baggaley and Hull (1983), Carifio and Perla (2007), Knapp (1990), Maurer and Pierce (1998), Subedi (2016) and Vickers (1999), the type of variables evaluated with a Likert scale can be included in the continuous scale category. They argue that individual 'Likert Items' and 'Likert Scales' can be treated differently. The Likert scales can generally be averaged of responses to the multiple Likert items. Hence, in general, a study conducted with a questionnaire survey involving the Likert scale provides specific criteria as the Likert items. For instance, for the question in this research, 'The quality of outcomes in Module X (or the usefulness of performing Module Y) are satisfied with criteria', the criteria may consist of several evaluation items, such as reliability, concreteness, usefulness and creativity. Participants generally answer the question by considering those items on the quality of their outcomes (or usefulness of performance), meaning that their responses to the question are based on the average of each assessment on those items. Hence, Likert scales are made up of individual Likert items and, thus, gathered data has a continuous characteristic.

One fact we must notice here is that this research did not provide any particular validation criteria (Likert items). Instead, quality and usefulness were measured with their own criteria that was established in participants' organisations. The aim of the experiment in Study 3.1 was less related to whether the model can well-produce outcomes fulfilling particular standard; e.g. can the model generate creative as well as novelty outcomes. Instead, the experiment focused on whether the model is well-operated for actual NPD projects from the viewpoints of contextual performance and concurrent collaboration. Thus, providing those kinds of fixed criteria was able to be less reliable as well as realistic. Considering different companies conduct different FFE projects with different success criteria, permitting them to assess the model with their own criteria is more reasonable to obtain more reliable validation data from experimental conditions closer to the reality. This can be supported by the reasonable rationale on providing discretion on establishing own criteria (Likert items) through many experts' studies (e.g. Cropley and Kaufman, 2019). They contend that if criteria are set up by experts rather than the public, the criteria can be more effective as "Consensual Assessment Techniques" or "Golden Standards".

In this regard, the fact that the Likert scale (for measuring quality and usefulness) were evaluated by averages of responses to specific Likert items (established by participants' organisations) still remains unchanged. Namely, the Likert scale used in this research was considered to be the continuous scale and, thus, non-parametric statistical analysis methods were not acceptable in this research. Of the remaining parametric statistical analysis methods – 'Correlation Analysis' and 'Simple Regression Analysis' – considering the validation direction and survey question (if the quality of outcomes of Module A increases, the usefulness of performing Module B increases), the simple regression analysis was the most reasonable method, setting aside all the nominated methods. In the case of the correlation analysis, the method is useful when we want to confirm the correlation between Module A and B, regardless of the direction of influence between the two modules. Indeed, when analysing data gathered from the survey by the simple regression analysis in the SPSS, the values by the correlation analysis can be obtained together.

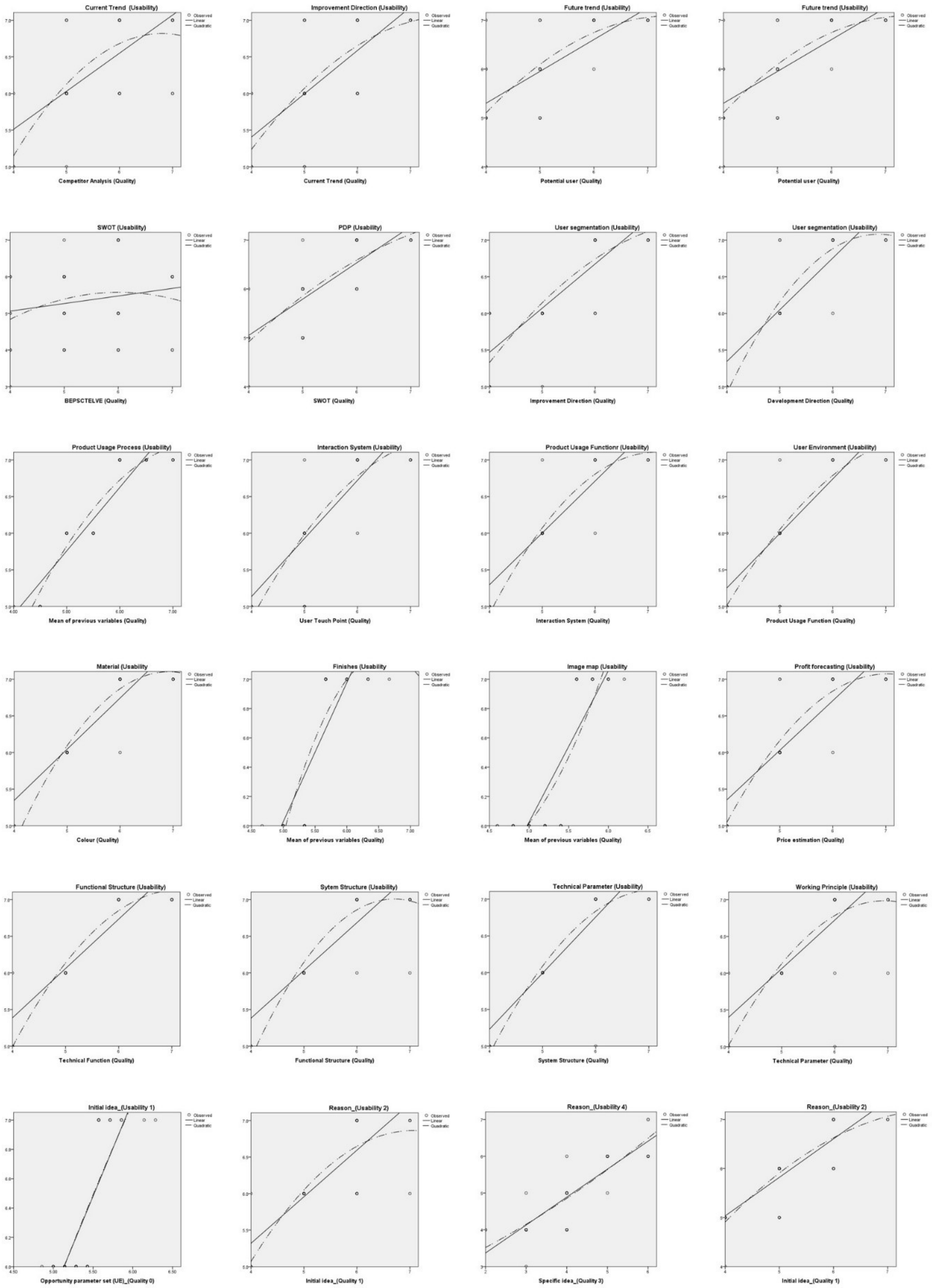

Figure 6.5. *Plots of raw data gathered in the linear relationship of each module*

In the last step, to ensure whether the simple regression analysis was able to be used, we need to check one remaining precondition: whether the independent and dependent variables lie on a linear relationship. The independent and dependent variables gathered in this experiment, showed linearity: as the independent variables increased, the dependent variables increased more or less constant. The linearity was checked by plots of raw data (shown in *Figure 6.5* above)[47]. On top of that, to use the simple regression analysis, we needed to assess whether the normality (Gaussian Distribution/Normal Distribution) were within the range: all the values of a skewness and kurtosis were also within the recommended range (±1.95). Furthermore, we also needed to see autocorrelation of residuals. All the vales of the autocorrelation of residuals were within in the recommended range ($1.5 \leq DW \leq 2.5$).

Consequently, considering the four steps for selecting the most appropriate statistical analysis method, the four preconditions derived from the four steps to use the simple regression analysis was met by this research.[48]

5.2.3) Validation Result Interpretation Method

The SPSS provided results that are divided into two parts: 1) a regression model summary and ANOVA that shows the suitability of the model structure for contextual performance and concurrent collaboration by a specific statistical explanation power (R^2, F and P values); and 2) a specific description of the regression model in terms of the degree of positive or negative effects of independent variables to dependent variables, with B, β and P values. The following illustrates those values in detail.

- **Model Summary and ANOVA Table**
  - ✓ ***R (Correlation coefficient)*** represents a statistical relationship between an independent and dependent variable.

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[47] As shown in *Figure 6.5*, all the plots, overall, show the linear relationship of each module. Some plots might seem to be regarded as a polynomial fit from specific viewpoints. The division on whether the relationships are a linear fit or a polynomial fit might be an effective approach to find out "to [what] extent are the dependent variables increas[ing]/decreas[ing] according to the increase/decrease of the independent variables?". However, we judged that an interpretation of each value of the statistical analysis ($R^2 or\ \beta$) is sufficient to grasp it to fulfil this research objective, so that the plots of raw data were, comprehensively, regarded as a linear fit.

[48] Exceptionally, in the case of the validation for the concurrent collaboration, there was a case in which the simple regression analysis was not acceptable to be used. Of collaboration forms fostered by the developed pragmatic-prescriptive FFE model, collaboration which does not be generated between modules but be activated within the modules themselves existed. In this case, a simple descriptive statistical method (using the mean and standard deviation value) was utilised.

- ✓ ***R^2 (Coefficient of determination)*** defines a statistical explanation power of a regression equation in terms of how differences in a dependent variable can be explained by differences in an independent variable. This means a statistical analysis that validates how a model explains and predicts future outcomes. Namely, $'R^2$represents the degree of the validity of the regression model; the degree of the validity of the model structure for contextual performance and concurrent collaboration. The following presents the grade of the explanation power, as referred to by Dancey and Reidy (2011):
  - $'R^2 = 1'$ indicates '*Perfect*'
  - $'0.7 \leq R^2 \leq 0.9'$ indicates '*Strong*'
  - $'0.4 \leq R^2 \leq 0.6'$ indicates '*Moderate*'
  - $'0.1 \leq R^2 \leq 0.3'$ indicates '*Weak*'
  - $'R^2 = 0'$ indicates '*Zero*'

  Therefore, when the value of $'R^2$ is more than 0.4, we can argue that the regression equation seems to have the fulfilled explanation power. However, most experts argue that this grade is not an explicit standard. Even if a value of $'R^2$ is relatively low (e.g., less than 0.4), a regression equation can also have sufficient validity if a reasonable reason for the low value is explained.
- ✓ ***P (p-value)*** of ***F*** is the probability that the null hypothesis for the full model is true; i.e., that all of the regression coefficients are zero. A lower value (P < 0.05) implies that at least some of the regression parameters are nonzero and the regression equation does have validity fitting with the data. This indicates that the independent variables are not purely random with respect to the dependent variable. Namely, F is so large that contextual performance or concurrent collaboration is unlikely to have occurred by chance (P < 0.05).
- ✓ ***DW (Durbin-Watson)*** is a statistical test that identifies he presence of autocorrelation in residuals. The following shows the grade of autocorrelation referenced by both Durbin and Watson (1951), and Field (2009):
  - $'DW \fallingdotseq 0'$ indicates there is '*Positive autocorrelation'.*

- $'DW \fallingdotseq 2'$ indicates there is no 'autocorrelation'.
- $'DW \fallingdotseq 4'$ indicates there is '*Negative autocorrelation*'.

Therefore, when the value is close to 2 ($1.5 \leq DW \leq 2.5$), we can argue that the analysis seems to have validity. All the values obtained from the field-tests were satisfied with the recommended range.

- **Coefficient Table**
  - ✓ ***P (p-value) of t*** is a probability value (asymptotic significance) A value less than the recommended 0.05 means that the independent variables affect the dependent variables by the regression model.
  - ✓ ***β (Standardised coefficients beta)*** is the relative strength (influence; leverage; effect size; amount) of the effect of each independent variable to a dependent variable:
    - $'\beta \fallingdotseq 0'$ indicates 'A*n independent variable weakly affects a dependent variable*'.
    - $'\beta \fallingdotseq 1'$ indicates '*An independent variable strongly affects a dependent variable*'.

    In this, β has a negative or positive value. The positive value indicates a positive influence, whereas the negative value indicates a negative influence.
  - ✓ ***B (Unstandardised coefficients b)*** represents the absolute amount of change in a dependent variable (y) when an independent variable (x) changes. The values of B given in constant (a) and coefficient (b) in the chart are constituents of the regression equation:

$$y = a + b \times x$$

In the case of the method to report the interpretation of the validation results in this thesis, studies by the American Psychological Association (2005) and Field and Hole (2003) were adopted.

In conclusion, to validate the pragmatic-prescriptive FFE model from the viewpoints of the FFE performance structure and its operating mechanism (regarding contextual performance and concurrent collaboration), the simple regression analysis method was used in SPSS.

5.3) Wilcoxon Singed-rank Analysis

for Overall Attributes

: The current and Future Trends of FFE Model Improvement

This section presents the verification method for overall attributes of the pragmatic-prescriptive FFE model in terms of 'Data-driven', 'Agile Development', 'Incremental and Radical NPDs', 'Explicitness and Responsiveness Characteristics' and 'Procedure and Performative Structures'. It begins by introducing building mechanisms for the hypotheses and the questionnaire, followed by a description of the process to select an appropriate analysis method (Wilcoxon signed-rank test) for the survey data gathered by those questionnaires, before concluding with how to interpret the validation results on the data.

5.3.1) Hypothesis and Questionnaire Building Mechanism

The verification for the overall attributes aimed at comparing the participants' own models used in their organisations with the model developed in this research. Considering this, the hypotheses and questionnaire questions for the independent and dependent variables were established as follows[49]:

- **Hypothesis building**

H_3

If the pragmatic-prescriptive FFE model developed in this research is better than the model used in participants' organisations in terms of the five overall attributes,

then the developed FFE model may be regarded as an FFE model in which the overall attributes are well-fostered.

** Five Overall Attributes*

- *Data-driven Type*
- *Agile Development*
- *Both Radical and Incremental NPDs*
- *A Balance between the Explicitness and Responsiveness Characteristics*
- *A Balance between the Procedural and Performative Structures*

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[49] In building the hypothesis and questionnaire questions, studies by Antonsson (1987) Bradburn et al. (2004), Belson (1981), Oppenheim (2000) and Sudman and Bradburn (1982) were referenced as with building hypothesises and questions for validating the pragmatic-prescriptive FFE model from the viewpoints of the FFE performance structure and its operating mechanism

- **Questionnaire Building**

I_v
To some extent is your model close to five overall attributes?

D_v
To some extent is the given model close to five overall attributes?

5.3.2) Analysis Method Selection Process

As mentioned above, the overall attributes were validated by comparing the participants' own models with the model developed in this research. This section presents an experimental condition for the validation of the overall attributes first before describing the process to choose the most appropriate statistical analysis method for this validation.

Experimental Condition for Validation of Overall Attributes

While the field-tests on using the given model were executed, the assessment on their own models was not progressed. The assessment on their models was dependant on participants' retrospective experience. This experiment condition might be considered to cause unreliable test results from the viewpoint of involving different projects implemented with their own models and the given models, as well as incorrect retrospective experiences.

However, since the validation aimed at verifying the 'overall model attributes' in comparison with two models, we judged that the experimental condition established in this research would be possible. Besides, conducting new projects twice simultaneously (or sequentially) with their models and the given model was realistically impossible, because it was highly probable to hinder their existing NPD schedules and working systems. In this regard, the experimental condition fostered in this research was a maximal trial to enable them to conduct their actual projects with the given model. There would be unexpected risks from their side, in that the given model developed in this research was not yet thoroughly demonstrated at that time. Also, even if the given model had already been evaluated robustly, performing their actual projects with the given model was a risk-able challenge from their perspective.

Thus, the experimental environment established in this validation was the optimal alternative.

Analysis Method Selection Process

Under the condition presented above, the overall model attribute was validated by the 'Wilcoxon Signed-rank Test' method. *Figure 6.6* describes the process of how to select the analytic method.

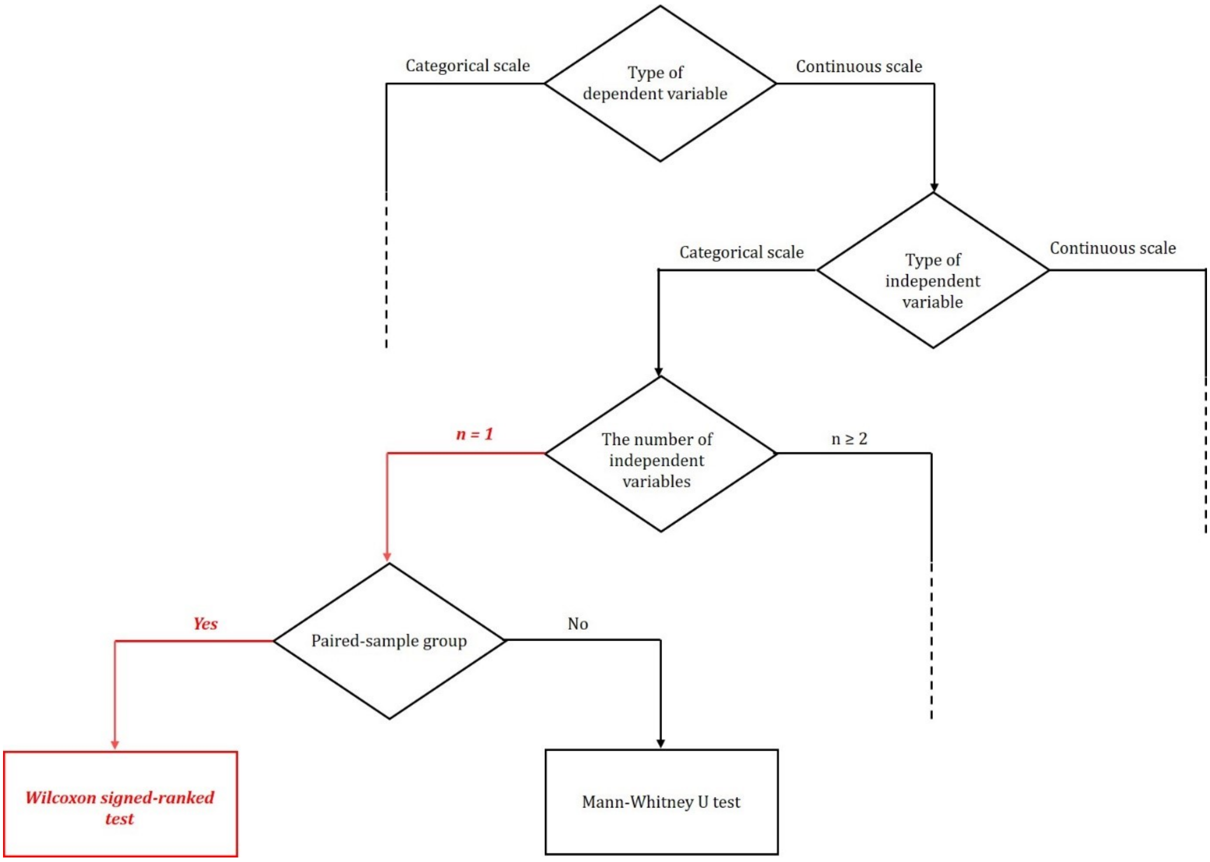

Figure 6.6 *Process of selecting an appropriate analysis method 2 (Wilcoxon Signed-rank Test)*

The process has the same context as selecting the simple regression analysis method mentioned above, strictly considering preconditions and their principles. For the study comparing the model developed in this research with their own models in participants' organisations, there were two possible representative methods[50]: 1) 'Mann-Whitney U

50 This validation test excludes a '2 sample t-test' and 'Paired-t-test'. The precondition to using these statistical methods is that independent and dependent variables have the normal distribution relationship. However, variables obtained from the field-tests did not show the normality.

Test'; and 2) 'Wilcoxon Signed-rank Test'. However, based on their prerequisite conditions and principles, one was not accepted by this study, and its rationale and process are as follows:

In the first step, the two methods can involve any dependent and independent variable types (either ordinal or continuous scale). The survey was conducted using a 7-point Likert scale that produces continuous scale variables, which shows that both analysis methods nominated above was able to be utilised.

In the next step, the number of participants was 57, fulfilling the precondition of both methods which can be used for the experiments involving even the small number of participants, e.g. fewer than 10.

In the last step, the verification was conducted on the same participant group consisting of 57 experts, involving different experiments. In this study, the identical group participated by comparing the new model with their own model. Besides, the field test involved two experiments: 1) one experiment using their own models based on a retrospective record; and 2) the other experiment actually conducting their FFE projects with the given model. Hence, the Mann-Whitney U test was not ideal, since an assumption of this method targets two different participant groups. Some researchers may consider this same group as two different groups, since the group is involved in two different conditions that use their own models as a 'Control Group' and the given model as an 'Experimental Group': a study by Han et al. (2017) was conducted under this condition. However, in favour of the cardinal principle, we regarded the Mann-Whitney U test as less valid to some extent.

Consequently, by these steps to select the most appropriate statistical analysis method, the Wilcoxon signed-rank test was finally selected for the validation of the model from the viewpoint of overall attributes.

5.3.3) Validation Result Interpretation Method

A result by the Wilcoxon signed-ranks test of the SPSS is derived mainly from differences of mean values evaluated between the control and experimental group. Aside from the mean values, other values that indicate more detailed information by describing the differences can additionally be generated in the statistical analysis test. Definitions of those values and their interpretation methods used in SPSS are presented below.

- ✓ ***P (p-value)*** is the probability of whether the difference exists between the mean values evaluated from the control and experimental group. A value less than the recommended 0.05 means the existence of the difference.
- ✓ $\pm\boldsymbol{W}$ means a positive and negative test statistic respectively. If the null hypothesis is true and there are no differences between the mean values evaluated from the control and experimental group, $+W$ and $-W(Z)$ would be similar. On the other hand, if the alternative hypothesis is true and there are large differences between the mean values evaluated between those two groups, and the result of the experimental group is better, $+W$ is greater than $-W(Z)$.
- ✓ $\boldsymbol{d}$ (Cohen's d) and $\boldsymbol{r}$ (Effect size) mean the degree of the standardised difference between the mean values evaluated from the control and experimental group, expressed by the standard deviation units. A difference between d (Cohen's d) and r (Effect size) is between calculation methods, but the meaning of these two values are the same as mentioned above. The following presents the grade of indicating the degree of difference.
  - d (Cohen's d): 0.20=Small, 0.50=Medium, 0.80=Large
  - r (Effect size): 0.10=Small, 0.30=Medium, 0.50=Large
- ✓ Under the precondition in conducting the Wilcoxon signed-ranks test, the number of participants (n=57) is enough (generally small number of participants, even fewer than 10, is fine) and thus there is less probability of the chance to estimate effects that have incorrect directions (Type S error) or to over-estimate effect sizes (Type M error) (Gelman & Carlin, 2014).

In conclusion, to validate the pragmatic-prescriptive FFE model from the viewpoints of the five overall attributes (the data-driven type, agile development, both incremental and radical NPDs, a balance between the explicitness and responsiveness characteristics, and a balance between the procedural and performative structures), the Wilcoxon signed-rank test method was used in SPSS.

5.4) Descriptive Feedback Analysis

The survey data obtained from the self-observational diary helped to provide further descriptive feedback for the two aforementioned validations. Since this narrative feedback was not for understanding phenomena or for developing conceptual models, certain methods useful for that objective were not employed to analyse these data . Meanwhile, unlike the analysis method used in the interview scripts, conducted in Chapter Four (Study 2.1), since the narrative feedback consisted of supportive data to show descriptive evidential interpretations of the statistical value, certain methods were not selected. Thus, each piece of feedback was simply referenced for an additional understanding of what each value was by indicating a score on a Likert scale .

6) Section Conclusion

This section has introduced the research methods used to validate the pragmatic-prescriptive FFE model. The validation proceeded using deductive reasoning under the positivism research worldview. By using a web-version of the pragmatic-prescriptive FFE model in the field tests, a questionnaire survey and self-observational diaries, which involved 57 expert participants, were utilised. Also, a total of three hypotheses were established concerning concurrent contextual performance and concurrent collaboration (regarding the FFE performance structure and its operating mechanism) and the overall attributes of the FFE model. In order to demonstrate the hypotheses, data gathered from those two research methods were analysed using simple regression analysis, the Wilcoxon signed-rank test, and descriptive feedback analysis.

One fact we must notice in this validation is that the pragmatic-prescriptive FFE model developed in this research cannot be regarded as a completely validated model, even if the validation result is strongly positive. This is because the validation was conducted based on statistical analysis, so that the validation result is literally based on probability. However, if the results indicate positive validity of the developed model, at least we can argue that the model seems to have validity from the target experiment perspective.

6.1.3 Research Summary

This chapter validates the pragmatic-prescriptive FFE model using the research methods presented above.

This chapter is divided into the following two sections in the same context as with the two dimensions which lead this research in terms of the limitations of previous FFE models and established FFE development strategies.

The first dimension (the FFE performance structure and its operating mechanism with respect to parameter processing from the contextual performance and concurrent collaboration perspectives) is divided into six sub-sections for presenting the key findings of the validation data on each module of the pragmatic-prescriptive FFE model. Furthermore, each sub-section is again divided into two parts: 1) contextual performance and 2) concurrent collaboration.

In the second dimension (overall attributes regarding current and future trends in FFE model improvement), the section is not divided into sub-sections. Instead, in terms of the validation data of the five overall attributes, key findings are described comprehensively.

1) Validation 1: The FFE Performance Structure and Its Operating Mechanism
– Parameter Process and Decision

- 1.1) Preliminary Task (Module 0)
- 1.2) Opportunity Identification-Screening (Module 1)
- 1.3) Idea Generation-Screening (Module 2)
- 1.4) Requirements List and Mission Statement (Modules 3 and 4)
- 1.5) Conceptual Design (Module 5)
- 1.6) Prototyping (Module 6)

2) Validation 2: Overall Attributes
– Current and Future Trends in FFE Model Improvement

6.2 Validation 1

– Performance Structure and Operating Mechanism

: Parameter Process and Decision

This section illustrates the validation of the pragmatic-prescriptive FFE model from the viewpoint of the performance structure and its operating mechanism which regard to contextual performance and concurrent collaboration. The validation aimed to substantiate H_1 and H_2 presented below.

H_1

If outcome parameters of the previous modules positively affect outcome parameters of the subsequent modules as input parameters in the 'contextual performance' structures of the pragmatic-prescriptive FFE model,

then the FFE model may be regarded as an FFE model structure wherein contextual performance is well-fostered.

H_2

If outcome parameters of the previous modules positively affect outcome parameters of the subsequent modules as input parameters in the 'concurrent collaboration' structures of the pragmatic-prescriptive FFE model,

then the FFE model may be regarded as an FFE model structure wherein concurrent collaboration is well-fostered.

Therefore, each sub-section (describing the validation results and their key findings of each main module) is divided into two parts: 1) contextual performance and 2) concurrent collaboration. Each part begins by illustrating the statistical analysis, followed by the descriptive feedback which indicates what the statistical data imply, ending with a section conclusion. Details are described below.

In the validation, as mentioned previously, simple regression analysis to grasp the linear relationship between previous and subsequent modules was utilised and the method of interpreting each value in the analysis charts can be found on the page.

6.3.1 Preliminary Task – Module 0

1) Contextual Performance

Tables 6.1 and *6.2* show the validation results and their key findings on whether Module 0 – considering two channels for incremental and radical NPDs – is well-structured for contextual performance. The validation results indicate that the structure of the two channels is well-constructed for contextual performance.

Table 6.1. *Main module IC 0: channel for incremental NPD*

Structure

Module	Sub-module IC 0.1	Sub-module IC 0.2	Sub-module IC 0.3
	Competitor analysis	Current trend	Improvement direction
Contextual performance	→ 1		
		→ 2	

Result

→1	**Model summary & ANOVA**					
		R	**R²**	**DW**	**F**	**P**
		0.693	0.481	2.012	50.879	0.000
	Coefficients					
	Competitor analysis	**B**	**SE**	**β**	**t**	**P**
		0.520	0.073	0.693	7.133	0.000
	Constant	3.434	0.416		8.244	0.000
	Regression equation					
	$y = 3.434 + 0.530 \times x$					

→2	**Model summary & ANOVA**					
		R	**R²**	**DW**	**F**	**P**
		0.749	0.560	2.330	70.879	0.000
	Coefficients					
	Current trend	**B**	**SE**	**β**	**t**	**P**
		0.591	0.071	0.749	8.375	0.000
	Constant	3.044	0.387		7.855	0.000
	Regression equation					
	$y = 3.044 + 0.591 \times x$					

Table 6.2. *Main module RC 0: channel for radical NPD*

Structure

Module	Sub-module RC 0.1	Sub-module RC 0.2	Sub-module RC 0.3
	Potential user	Future trend	Development direction
Contextual performance	→ 1		
	→ 2		

Result

Model summary & ANOVA					
	R	**R²**	**DW**	**F**	**P**
	0.779	0.608	1.706	85.130	0.000

→1		Coefficients				
	Potential user	B	SE	β	t	P
		0.652	0.071	0.779	9.227	0.000
	Constant	2.692	0.386		6.968	0.000
		Regression equation				
		$y = 2.692 + 0.652 \times x$				

→2		Model summary & ANOVA				
		R	R^2	DW	F	P
		0.790	0.624	1.901	91.243	0.000
		Coefficients				
	Future trend	B	SE	β	t	P
		0.608	0.064	0.790	9.552	0.000
	Constant	3.032	0.358		8.471	0.000
		Regression equation				
		$y = 3.032 + 0.608 \times x$				

To be specific, in the statistical analysis, the R^2-values are 0.481, 0.560, 0.608 and 0.624, suggesting that around half of the variation in a usefulness of the subsequent module can be accounted for by the quality of outcomes in the previous module. The *ANOVA* shows that contextual performance in this module is unlikely to occur by chance and is highly available by F=50.879, 70.879, 85.130 and 91.243, and $P < 0.05$. Besides, the β-values, 0.693, 0.749, 0.779, and 0.790 ($P < 0.05$) in *Coefficients*, implies that the usefulness of the subsequent module increases at the rate of around 72.5% when the quality of outcomes in the previous module increases by one unit. Therefore, Module 0 seems to be well-structured for contextual performance, meaning that the outcome parameters of each previous module seems to flow well into the following module as input parameters.

In addition, descriptive feedback was also strongly positive. In particular, 84% of the participants (48/57) highly rated the structure of Sub-module RC 0.1 and Sub-module RC 0.2. By applying the relationship between the current general users and trendsetters to the trendsetters, near future users were able to be expected systematically. By applying the relationship between the current trendsetter and the near future users to the near future users, users far into the future were scientifically predictable. Based on the anticipated near and distant future users, by projecting the flow between the past and present trends onto the present trends, future trends were able to be envisaged methodologically.

To conclude, based on the validation results of Module 0 in which Sub-Modules 0.1 and 0.2 are built separately, the two sub-modules of Module 0 seem to be well-structured for contextual performance.

2) Concurrent Collaboration

This section describes the validation data and the key findings on whether concurrent collaboration can be well-operated in the structure of Module 0.

Module 0 includes concurrent collaboration by a phased-structure. Concurrent collaboration occurs *within* each sub-module itself, instead of being formed *between* sub-modules. Therefore, the validation was not conducted by the regression analysis which is adequate to validating collaboration which occurs between sub- or composition-modules. Instead, the validation data was obtained from a descriptive statistic and narrative feedback to confirm whether concurrent collaboration is well operated within sub-module themselves.

Table 6.3. *Collaboration in incremental and Radical NPD channel of Module 0*

	Participants (N)	Maximum (Max)	Minimum (Min)	Mean (M)	Standard Deviation (SD)
Incremental NPD	32	7	4	5.38	0.660
Radical NPD	25	7	5	6.04	0.676

As shown in *Table 6.3*, considering validated values (M=5.38 and 6.04, SD=0.660 and 676), simultaneous collaboration seems to be operated well in both channels.

According to 72% of participants (41/57), the biggest benefit in using Sub-module IC 0.1 for incremental NPD projects was that experts who come from diverse functional domains (e.g., engineering, design, and marketing) were able to not only concurrently define features and specifications in their own product and competitors', but they also simultaneously understand the relationship between the defined features and specifications. Hence, the channel structure led to reducing intensive discussions regarding why certain features and specifications are compared. Also, 75% of participants (43/57), when estimating the future trends by the extrapolation approach in Sub-module RC 0.2, the relationship between each future trend related to different NPD-related functional domains can be apprehended with less discussions.

To conclude, considering the statistical analysis data and narrative feedback, concurrent collaboration seems to be well operated within the sub-modules themselves.

3) Section Conclusion

Two alternative hypotheses seem to be strongly selected, rejecting the null hypothesis; this implies the strong possibility of Module 0 being well-structured for contextual performance and concurrent collaboration.

6.3.2 Opportunity Identification-Screening Task – Module 1

1) Contextual Performance

This section describes the validation results and the key findings of the opportunity identification-screening module (Module 1) from the contextual performance viewpoint. Through the validation of the subordinated four sub-modules for the market-driven, user-driven, aesthetic-and-symbol-driven and technology-driven research, whether the main module is acceptable for contextual performance was examined. Therefore, this section is divided into the following four sub-sections:

1.1) Sub-module 1.1: Market-driven Research Activity Module
1.2) Sub-module 1.2: User-driven Research Activity Module
1.3) Sub-module 1.3: Aesthetic-and-Symbol-driven Research Activity Module
1.4) Sub-module 1.4: Technology-driven Research Activity Module.

In the same context as with the analysis method applied to the previous module (Module 0), validation was conducted on Module 1.

1.1) Sub-Module 1.1 : Market-driven Research Activity Module

The validation concentrated on whether Sub-module 1.1 for the market-driven research activity was well-structured for contextual performance. As shown in *Figure 5.12a* (*p. 289*), presented in Study 2.2 for developing the pragmatic-prescriptive FFE model, this sub-module was divided into two parts: 1) the first part related to estimations about the target users and markets, and 2) the second part related to cost and price estimations and price forecasting.

Table 6.4 shows the validation results and the key findings on the first part mentioned above (target users and markets).

Table 6.4. *Sub-module 1.1: market-driven research (part 1)*

Structure

Module	Sub-module IC or RC 0.3	Composition-module 1.1.1	Composition-module 1.1.2	Composition-module 1.1.3	Composition-module 1.1.4
	Improvement or Development direction	User segmentation	BEPSCTELVE	SWOT	PDP
	→ 1.1				
Contextual performance	→ 1.2				
		→ 2			
			→ 3		
				→ 4	

Result

		Model summary & ANOVA				
		R	R^2	DW	F	P
		0.838	0.701	2.211	129.246	0.000
		Coefficients				
→1.1	Improvement direction	B	SE	β	t	P
		0.603	0.053	0.838	11.369	0.000
	Constant	3.055	0.300		10.175	0.000
		Regression equation				
		$y = 3.055 + 0.603 \times x$				

		Model summary & ANOVA				
		R	R^2	DW	F	P
		0.879	0.773	2.211	187.176	0.000
		Coefficients				
→1.2	Development direction	B	SE	β	t	P
		0.705	0.052	0.879	13.681	0.000
	Constant	2.522	0.288		8.750	0.000
		Regression equation				
		$y = 2.522 + 0.705 \times x$				

		Model summary & ANOVA				
		R	R^2	DW	F	P
		0.224	0.050	2.317	2.893	0.095
		Coefficients				
→2	User segmentation	B	SE	β	t	P
		0.249	0.146	0.224	1.701	0.095
	Constant	4.450	0.830		5.362	0.000
		Regression equation				
		$y = 4.450 + 0.249 \times x$				

		Model summary & ANOVA				
		R	R^2	DW	F	P
		0.182	0.033	1.943	1.879	0.176
		Coefficients				
	BEPSCTELVE	B	SE	β	t	P
→3		0.207	0.151	0.182	1.371	0.176
	Constant	4.233	0.815		5.196	0.000
		Regression equation				
		$y = 4.233 + 0.207 \times x$				

		Model summary & ANOVA				
		R	R^2	DW	F	P
		0.818	0.669	2.251	111.290	0.000
		Coefficients				
→4	SWOT	B	SE	β	t	P
		0.744	0.071	0.818	10.549	0.000
	Constant	2.072	0.383		5.416	0.000

Regression equation
$y = 2.072 + 0.744 \times x$

Outcome parameters on improvement or development directions seems to positively influence segmenting specific user types (R^2=0.701 and 0.773, F=129.246 and 187.176 P<0.05, and β= 0.838 and 0.879).

However, in the subsequent contextual performance between the user segmentation, BEPSCTELVE identification and SWOT analysis (as shown in the labels '→2' and '→3'), R^2-values 0.050 and 0.033 represent an explanation power that are closer to 0 than 1 (F =2.893 and 1.879, P =0.095 and 0.176 > 0.05). These values indicate that the investigation of indirect factors affecting possible markets seems to be less effected by outcomes of the user segmenting work. Also, the examination of direct factors influencing possible markets does not seem to be affected by the investigation of indirect factors. In this regard, 89% of participants (51/57) left feedback to recommend structuring the three composition-modules in parallel, enabling them to be conducted independently.

Values indicating the degree of contextual performance between the previous composition-module for the SWOT analysis and the final module regarding the target market positioning-distribution-promotion are fulfilled with the recommended statistical standard (R^2 =0.669, F =111.290, P =0.000, and β =0.818). Therefore, two composition-modules can be regarded as well-structured from the contextual performance aspect.

Consequently, the structure of the first part can be improved as follows. The user segmentation composition-module and the subsequent two modules for examining indirect and direct factors for possible markets can be reconstructed by a single set. Based on previous parameters, strategies of the target market regarding the positioning, distribution and promotion way can be derived without modifying the current contextual performance structure.

Table 6.5 illustrates validation results and key findings for the second part of the market-driven research that conduct cost and price estimating and price forecasting.

Table 6.5. *Sub-module 1.1: market-driven research (part 2)*

Structure

Module	Composition-module 1.1.5	Composition-module 1.1.6	Composition-module 1.1.7
	Cost estimation	Price estimation	Profit forecasting
Contextual performance	→ 1	→ 2	

Result

→1	**Model summary & ANOVA**					
		R	**R²**	**DW**	**F**	**P**
		0.890	0.792	2.217	209.101	0.000
	Coefficients					
	Cost estimation	**B**	**SE**	**β**	**t**	**P**
		0.717	0.050	0.890	14.460	0.000
	Constant	2.390	0.265		9.004	0.000
	Regression equation					
	$y = 2.390 + 0.717 \times x$					

→2	**Model summary & ANOVA**					
		R	**R²**	**DW**	**F**	**P**
		0.880	0.775	2.003	189.514	0.000
	Coefficients					
	Price estimation	**B**	**SE**	**β**	**t**	**P**
		0.677	0.049	0.880	13.766	0.000
	Constant	2.646	0.270		9.788	0.000
	Regression equation					
	$y = 2.646 + 0.677 \times x$					

Significant validity of contextual performance among the three modules was found (F=209.101 and 189.514, P=0.000) with R^2-values of 0.792 and 0.775. Specifically, β-value, 890 and 880 (P=0.000) represents the usefulness of each subsequent module increasing at the ratio of around 90% when the quality of outcome parameters in each previous module increased by one unit. These values conclude that the price estimation can be conducted in consideration of the results of the investment costs and that the profit forecasting can be implemented based on the estimated product price, in which the costs are reflected.

Consequently, the second part seems to be well-developed for contextual performance, without critical points for improvement.

1.2) Sub-Module 1.2
: User-driven Research Activity Module

The verification focused on whether Sub-module 1.2 for the user-driven research activity is well-built for contextual performance. *Table 6.6* describes results of the verification.

Table 6.6. *Sub-module 1.2: user-driven research Structure*

Structure

Module	Composition -module 1.1.1&1.1.4	Composition -module 1.2.1	Composition -module 1.2.2	Composition -module 1.2.3	Composition -module 1.2.4	Composition -module 1.2.5	Composition -module 1.2.6	Composition -module 1.2.7
	User segment & PDP	Product usage process	User touch point	Interaction system	Product usage function	User environment	Usability	User scenario
Contextual performance	→ 1	→ 2	→ 3	→ 4	→ 5	→ 6	(→2 → 3 → 4 → 5 → 6)→ 7	

Result

→1	Model summary & ANOVA					
		R	R^2	DW	F	P
		0.916	0.840	2.012	288.104	0.000
	Coefficients					
	User segment & PDP	B	SE	β	t	P
		0.867	0.051	0.916	16.974	0.000
	Constant	1.421	0.290		4.899	0.000
	Regression equation					
	$y = 1.421 + 0.867 \times x$					

→2	Model summary & ANOVA					
		R	R^2	DW	F	P
		0.874	0.764	2.047	178.016	0.000
	Coefficients					
	Product usage process	B	SE	β	t	P
		0.675	0.051	0.874	13.342	0.000
	Constant	2.634	0.280		9.421	0.000
	Regression equation					
	$y = 2.634 + 0.675 \times x$					

→3	Model summary & ANOVA					
		R	R^2	DW	F	P
		0.848	0.718	2.320	140.297	0.000
	Coefficients					
	User touch point	B	SE	β	t	P
		0.793	0.067	0.848	11.845	0.000
	Constant	1.961	0.361		5.438	0.000
	Regression equation					
	$y = 1.961 + 0.793 \times x$					

	Model summary & ANOVA					
		R	R^2	DW	F	P
		0.900	0.810	2.472	233.851	0.176
	Coefficients					
	Interaction system	B	SE	β	t	P

→4		0.708	0.046	0.900	15.292	0.000
	Constant	2.462	0.249		9.898	0.000
	Regression equation					
	$y = 2.462 + 0.708 \times x$					
→5	**Model summary & ANOVA**					
		R	**R²**	**DW**	**F**	**P**
		0.867	0.751	2.155	166.315	0.000
	Coefficients					
	Product usage function	**B**	**SE**	**β**	**t**	**P**
		0.744	0.058	0.867	12.896	0.000
	Constant	2.277	0.307		7.425	0.000
	Regression equation					
	$y = 2.277 + 0.744 \times x$					
→6	**Model summary & ANOVA**					
		R	**R²**	**DW**	**F**	**P**
		0.944	0.891	2.217	447.333	0.000
	Coefficients					
	User environment	**B**	**SE**	**β**	**t**	**P**
		0.880	0.042	0.944	21.150	0.000
	Constant	1.582	0.222		7.116	0.000
	Regression equation					
	$y = 1.582 + 0.880 \times x$					
→7	**Model summary & ANOVA**					
		R	**R²**	**DW**	**F**	**P**
		0.824	0.679	1.789	116.559	0.000
	Coefficients					
	Usability	**B**	**SE**	**β**	**t**	**P**
		1.210	0.112	0.824	10.796	0.000
	Constant	- 0.117	0.602		- 0.194	0.847
	Regression equation					
	$y = -0.117 + 1.210 \times x$					

In the statistical analysis, most R^2-values are around 0.750 (P=0.000), therefore nearly 75% of the variation in a usefulness of conducting each subsequent module can be explained by the quality of outcomes in each previous module; this means contextual performance structure has strong validity by the rate of 75%. Also, all values of R showing are also near to 0.850, representing a very strong correlation between each module. Besides, β-values are larger than 0.880 (P=0.000), indicating a strong influence of each previous module affecting each subsequent module.

In the descriptive feedback, around 91% of participants (52/57) appreciated highly the first composition-module for defining the product usage process. In particular, 74% of participants (42/57) illustrated that the function of considering what users are doing before and after using the target product can support the producing of unexpected product usage functions. Moreover, the contextual connection among investigating product usage functions, user touch-points and interaction systems can remarkably contribute to the systematic understanding of the grounded user-behaviour patterns that draw more accurate ergonomic data. Also, they stressed that user scenario was envisaged more specifically and scientifically than an outcome from using their own models since parameters of the previous composition-modules were considered contextually.

Consequently, all these values, along with narrative feedback, indicates that the contextual performance structure for the user-driven research activity is strongly possible. Specifically, according to the defined specific user types and the target market in the market-driven research module (Sub-module 1.1), the product usage process of the target product can be examined with ease. In each step of the product usage process, user touch-points and associated interaction systems can be analysed, which can lead to more explicit definitions of product usage functions in each user touch-point. Examining how these functions are used in a particular environment can aid in proposing the scope of ergonomic data from the perspective of usability. Considering all parameters produced from all the implementations, the user scenario can be depicted easily. Consequently, this sub-module does not seem to have room for a critical point of improvement in terms of contextual performance.

1.3) Sub-Module 1.3
: Aesthetic-and-Symbol-driven Research Activity Module

The field-test investigated whether Sub-module 1.3 for the aesthetic-and-symbol-driven research activity is well-constructed for contextual performance. *Table 6.7* addresses the validation results of the test.

Table 6.7. *Sub-module 1.3: aesthetic-and-symbol-driven research*

Structure

Module	Composition-module 1.3.1	Composition-module 1.3.2	Composition-module 1.3.3	Composition-module 1.3.4	Composition-module 1.3.5	Composition-module 1.3.6
	Shape	Colour	Material	Finishes	Symbolic function	Image map & Semantic board
Contextual performance	→ 1	→ 2	(1 → 2) → 3	(1 → 2 → 3) → 4	(1 → 2 → 3 → 4) → 5	

Result

		R	**R²**	**DW**	**F**	**P**
→1	**Model summary & ANOVA**	0.242	0.059	2.183	3.421	0.070
	Coefficients	**B**	**SE**	**β**	**t**	**P**
	Shape	0.311	0.168	0.242	1.849	0.070
	Constant	4.251	0.915		4.643	0.000
	Regression equation	y = 4.251 + 0.311 × x				
		R	**R²**	**DW**	**F**	**P**
→2	**Model summary & ANOVA**	0.900	0.810	2.183	234.450	0.000
	Coefficients	**B**	**SE**	**β**	**t**	**P**
	Colour	0.699	0.046	0.900	15.312	0.000
	Constant	2.550	0.259		9.858	0.000
	Regression equation	y = 2.550 + 0.699 × x				
		R	**R²**	**DW**	**F**	**P**
(1→2) →3	**Model summary & ANOVA**	0.837	0.701	2.459	129.057	0.000
	Coefficients	**B**	**SE**	**β**	**t**	**P**
	Material	0.949	0.084	0.837	11.360	0.000
	Constant	1.283	0.466		2.752	0.008
	Regression equation	y = 1.283 + 0.949 × x				
		R	**R²**	**DW**	**F**	**P**
(1→2→3) →4	**Model summary & ANOVA**	0.869	0.755	2.087	169.645	0.000
	Coefficients	**B**	**SE**	**β**	**t**	**P**
	Finishes	1.027	0.079	0.869	13.025	0.000

	Constant	1.009	0.429		2.367	0.022
	Regression equation					
	$y = 1.009 + 1.027 \times x$					

(1→2→3→4) →5	Model summary & ANOVA					
		R	R^2	DW	F	P
		0.858	0.736	2.087	153.376	0.000
	Coefficients					
	Symbolic function	B	SE	β	t	P
		1.033	0.083	0.858	12.384	0.000
	Constant	0.860	0.452		1.904	0.062
	Regression equation					
	$y = 0.860 + 1.033 \times x$					

In the validation of contextual performance between proposing the possible scope of shape and colour (as indicated in the label '→1'), R^2-value 0.059 is not considerably close to 1, even though P-value 0.070 is just slightly greater than the recommended 0.050. This finding indicates that only 0.05% of the variation in the usefulness of proposing colour can be explained by outcomes of the shape scope, although the contextual performance nearly seems to be available in the given model by P-value 0.070. Moreover, β-value 0.242 (P=0.070) represents the weak influence by the module for shape affecting colour. This finding means there is rarely leverage of each outcome parameter of the shape range in nominating each colour range. Participants 1, 27 and 39 recommended conducting these two composition-modules in parallel in a bundle; they illustrated that outcomes of the two modules sometimes affect each other and are sometimes utilised independently.

In this structure, the possibility of contextual performance, in which different colours strongly affect selecting different acceptable materials, was confirmed in the subsequent structure (R^2=0.810, F=234.450, P<0.05, and β= 0.900).

The validation of the remaining composition-modules shows that all R^2-values are greater than 0.700 and all β-values are larger than 0.850 (P< 0.05). Consequently, outcomes of product exterior elements such as shape, colour and material can strongly influence defining the scope of finishing specification. The scope of these exterior elements including finishes can also greatly affect the designating of relevant symbolic functions. As a result, all these parameters can lead up to the image map and semantic board.

In summary, through the analysis, an opportunity to rebuild the contextual performance structure of the aesthetic-and-symbol-driven research module was identified. The scope of shape and colour can be handled first in a bundle and the following composition-modules can be left as it is. However, except for this, Sub-module 1.3 seems to be well-built for contextual performance, without a large modification of the existing structure.

1.4) Sub-Module 1.4
: Technology-driven Research Activity Module

The validation was conducted on whether Sub-module 1.4 for the technology-driven research activity is well-devised from the contextual performance perspective. *Table 6.8* presents results of the validation.

Table 6.8. *Sub-module 1.4: technology-driven research*

Structure

Module	Composition-module 1.4.1	Composition-module 1.4.2	Composition-module 1.2.3	Composition-module 1.2.4	Composition-module 1.2.5	Composition-module 1.2.6	Composition-module 1.2.7
	Technical function	Function structure	System structure	Technical parameter	Working principle	Technical dimension	Required technology
Contextual performance	→ 1						
		→ 2					
			→ 3				
				→ 4			
					→ 5		
					(1 → 2 → 3 → 4 → 5) → 6		

Result

→1	Model summary & ANOVA					
		R	**R^2**	**DW**	**F**	**P**
		0.908	0.824	2.286	257.889	0.000
	Coefficients					
	Technical function	**B**	**SE**	**β**	**t**	**P**
		0.674	0.042	0.908	16.059	0.000
	Constant	2.693	0.236		11.416	0.000
	Regression equation					
	$y = 2.693 + 0.674 \times x$					
→2	Model summary & ANOVA					
		R	**R^2**	**DW**	**F**	**P**
		0.858	0.736	2.523	153.211	0.000
	Coefficients					
	Function structure	**B**	**SE**	**β**	**t**	**P**
		0.652	0.053	0.858	12.378	0.000
	Constant	2.772	0.304		9.123	0.000
	Regression equation					
	$y = 2.772 + 0.652 \times x$					
→3	Model summary & ANOVA					
		R	**R^2**	**DW**	**F**	**P**
		0.881	0.776	2.068	190.088	0.000
	Coefficients					
	System structure	**B**	**SE**	**β**	**t**	**P**
		0.764	0.055	0.881	13.787	0.000
	Constant	2.174	0.307		7.073	0.000
	Regression equation					
	$y = 2.174 + 0.764 \times x$					
	Model summary & ANOVA					
		R	**R^2**	**DW**	**F**	**P**
		0.777	0.603	2.074	83.523	0.000
	Coefficients					
	Technical parameter	**B**	**SE**	**β**	**t**	**P**

→4		0.662	0.072	0.777	9.139	0.000
	Constant	2.752	0.405		6.797	0.000
	Regression equation					
	$y = 2.752 + 0.662 \times x$					

→5	**Model summary & ANOVA**					
		R	**R^2**	**DW**	**F**	**P**
		0.799	0.639	1.420	97.236	0.000
	Coefficients					
	Working principle	**B**	**SE**	**β**	**t**	**P**
		0.640	0.065	0.799	9.861	0.000
	Constant	2.834	0.365		7.757	0.000
	Regression equation					
	$y = 2.834 + 0.640 \times x$					

(1→2→3→4→5) →6	**Model summary & ANOVA**					
		R	**R^2**	**DW**	**F**	**P**
		0.763	0.582	2.019	76.487	0.000
	Coefficients					
	Technical dimension	**B**	**SE**	**β**	**t**	**P**
		0.993	0.114	0.763	8.746	0.000
	Constant	1.139	0.631		1.804	0.077
	Regression equation					
	$y = 1.139 + 0.993 \times x$					

As with the user-driven research module (Sub-module 1.2), all composition-modules in this module are well-structured for contextual performance. Most R^2s are greater than 0.700 (P<0.05), which indicates around 70% explanation power regarding the suitability of operating this contextual performance structure in the given model. All β-values are around 0.800 (P< 0.05), representing the strong leverage of each previous module affecting each subsequent module. These values indicate that the physical embodiment of technology-driven research scenarios analysed in the finding chapter seems to be proved overall from the contextual performance aspect.

This module was highly rated by 93% of participants (53/57). According to their descriptive feedbacks, first, the module is satisfied with the main purpose of the technology-driven research from the viewpoint of scrutinising how to technically operate the target product. Moreover, they described that the essential implementations required in the technology-driven research can be systematically conducted step by step. In particular, the structure designing the function and system structure based on defining technical functions of each component and the structure proposing working principals by understanding input and output technical parameters processed in components were highly regarded in the contextual performance aspect. Also, they praised the final composition-module for the required technologies defined in consideration of all other parameters obtained from the previous modules enabling R&D performers to recognise what technologies are more explicitly demanded and require developed. Consequently, this sub-module does not seem to have room for any critical points for improvement.

Consequently, the strong possibility of Sub-module 1.4 being well-structured from the contextual performance viewpoints was identified.

2) Concurrent Collaboration

This section presents the verification results of whether concurrent collaboration forms (the eight main forms) identified in Study 2.1 which analysed real-world FFE scenarios (*pp. 196-217 or 256-258*) can operate well in the developed structure of Module 1 (Opportunity Identification-Screening Task).

In the structure, there are four sub-modules representing the market-driven, user-driven, aesthetic-and-symbol-driven research. These four sub-modules consist of relevant composition-modules representing various performance methods involved in each research activity. The arrangement of those four sub-modules in a quadrant facilitates simultaneously considering parameters produced in each composition-module of the four sub-modules representing each different research activity.

According to Study 2.1, there are eight comprehensive forms of concurrent collaboration which generally occur in the opportunity identification-screening task. Details of the verification data and their key findings are described below.

Tables 6.9 to *6.11* handle the first to third concurrent collaboration forms initiated by segmenting different user types and defining target markets accordingly. Depending on what the second composition-module follows the modules for user segmentation and target market analysis, different subsequent collaboration can occur. Full details of validation results and key findings in those three collaboration structures are presented below.

2.1) The First Form of Concurrent Collaboration

The first form of the concurrent collaboration shown in *Table 6.9* regards whether product usage functions can be different according to different user types and target markets, generating different technical functions on the back of those usage functions and different technologies embodying these technical functions.

R^2-values 0.691, 0.809 and 0.599 (F=123.202, 233.691 and 82.146, P=0.000) means the outcomes of each previous composition-module strongly affect the implementation of each subsequent module at a rate of around 70%, at least in the collaboration structure. β-values 0.831, 0.900 and 0.774 (P=0.000) represent that the usefulness of conducting each subsequent module increases at a ratio of around 85% when one unit increases in the quality of outcomes in the previous module.

Consequently, this first collaboration form, which can be operated in Module 1, seems to work well in the given model.

Table 6.9. **The first form of concurrent collaboration in module 1**

Structure

Module	Composition-module 1.1.1&1.1.4 in MK	Composition-module 1.2.4 in UE	Composition-module 1.4.1 in TC	Composition-module 1.4.7 in TC
	User segment & PDP	Product usage function	Technical function	Required tech
Concurrent Collaboration	→ 1			
		→ 2		
			(→ 2) → 3	

MK= Market-driven research, UE=User-driven research, AS=Aesthetic-and-Symbol-driven research, and TC=Technology-driven research

Result

→1		**Model summary & ANOVA**				
		R	**R^2**	**DW**	**F**	**P**
		0.831	0.691	2.407	123.202	0.000
		Coefficients				
	User segment & PDP	**B**	**SE**	**β**	**t**	**P**
		0.574	0.294	0.831	11.100	0.000
	Constant	3.422	0.290		11.654	0.000
		Regression equation				
		y = 3.422 + 0.574 × x				

→2		**Model summary & ANOVA**				
		R	**R^2**	**DW**	**F**	**P**
		0.900	0.809	1.976	233.691	0.000
		Coefficients				
	Product usage function	**B**	**SE**	**β**	**t**	**P**
		0.677	0.044	0.900	15.287	0.000
	Constant	2.658	0.245		10.861	0.000
		Regression equation				
		y = 2.658 + 0.677 × x				

(→2) →3		**Model summary & ANOVA**				
		R	**R^2**	**DW**	**F**	**P**
		0.774	0.599	1.835	82.146	0.000
		Coefficients				
	Technical function	**B**	**SE**	**β**	**t**	**P**
		0.710	0.078	0.774	9.063	0.000
	Constant	1.961	0.361		5.438	0.000
		Regression equation				
		y = 2.719 + 0.710 × x				

2.2) The Second Form of Concurrent Collaboration

The second concurrent collaboration form illustrated in *Table 6.10* regards that product exterior elements can be different according to user types and target markets, producing different inherent technical parameters in those elements and different technologies accordingly.

R^2-values greater than around 0.650 (F=121.353, 97.070 and 96.515, P<0.05) explain the strong suitability of the model structure to operate this collaboration structure. β-values 0.830, 0.799 and 0.798 (P<0.05) support the suitability of presenting a large amount of increment in the usefulness of performing each subsequent module to the quality of outcomes in each previous module.

To sum up, all these values represent that this collaboration structure seems to be operated adequately in the given model.

Table 6.10. *The second form of concurrent collaboration in module 1*

Structure

Module	Composition-module 1.1.1&1.1.4 in MK	Composition-module 1.3.1 to 1.3.3 in AS	Composition-module 1.4.4 in TC	Composition-module 1.4.7 in TC
	User segment & PDP	Shape, Colour & Material	Technical parameters	Required tech
Concurrent Collaboration	→ 1			
		→ 2		
			(→ 2) → 3	

MK= Market-driven research, UE=User-driven research, AS=Aesthetic-and-Symbol-driven research, and TC=Technology-driven research

Result

→1	Model summary & ANOVA					
		R	R²	DW	F	P
		0.830	0.688	2.178	121.353	0.000
	Coefficients					
	User segment & PDP	B	SE	β	t	P
		0.623	0.057	0.830	11.016	0.000
	Constant	2.824	0.321		8.792	0.000
	Regression equation					
	y = 2.824 + 0.623 × x					

→2	Model summary & ANOVA					
		R	R²	DW	F	P
		0.799	0.638	2.093	97.070	0.000
	Coefficients					
	Shape, Colour & Material	B	SE	β	t	P
		0.909	0.092	0.799	9.852	0.000
	Constant	1.489	0.515		2.892	0.005
	Regression equation					
	y = 1.489 + 0.909 × x					

	Model summary & ANOVA					
		R	R²	DW	F	P

		0.798	0.637	2.221	96.515	0.000
		Coefficients				
(→2) →3	Technical parameters	**B**	**SE**	**β**	**t**	**P**
		1.064	0.108	0.798	9.824	0.000
	Constant	0.754	0.603		1.250	0.216
		Regression equation				
		$y = 0.754 + 1.064 \times x$				

2.3) The Third Form of Concurrent Collaboration

The third collaboration shown in *Table 6.11* is the other form initiated by defining user types and target markets. This collaboration notices that different users and markets can expose the target product and its component to different environments, leading to the consideration of different ergonomic data and relevant technical dimensions accordingly.

As with the previous collaboration forms, this collaboration also seems to be well-conducted. In particular, collaborative works among the second to fourth composition-modules for investigating appropriate ergonomic data and working principals according to different environments seemed to work well in the given model (R^2=0.640 and 0.658, F=97.875 and 105.995, P<0.05, and β=0.800 and 0.811).

However, in the initial collaboration between examining user-and-market types and relevant user environments, the explanation power of the regression model tends to be somewhat weak, as indicated in R^2-value 0.471 being less than 0.600 (F=49.061, P<0.05). 67% of participants (38/57) provided evidence explaining this result, agreeing that many products (e.g., smart watches and wheel chairs) and their components can have a high possibility of being exposed to different environments. On the other hand, other products (e.g., furniture) are generally situated in one place, surrounded by the same environment nearly every day. In this case, they have trouble defining different environments per component. Therefore, in developing this type of product, the usefulness of examining the environment is not strongly affected by the quality of outcomes in the previous module; instead, they are influenced by the type of product. However, they strongly highlighted the importance of researching environments on a component basis in the sense that the research generally affects usability and the working principal data of each component.

To conclude, considering all these values along with the narrative feedback, this concurrent collaboration form seems to have overall validity.

Table 6.11. The third form of concurrent collaboration in module 1

Structure

Module	Composition-module 1.1.1&1.1.4 in MK	Composition-module 1.3.1 & 1.3.3 in UE	Composition-module 1.4.5 in TC	Composition-module 1.4.6 in TC
	User segment & PDP	User-environment & Usability	Working mechanism	Technical dimension
Concurrent Collaboration	→ 1			
		→ 2		
			→ 2 → 3	

MK= Market-driven research, UE=Use-driven research, AS=Aesthetic-and-Symbol-driven research, and TC=Technology-driven research

Result

→1	**Model summary & ANOVA**					
		R	**R^2**	**DW**	**F**	**P**
		0.687	0.471	1.869	49.061	0.000
	Coefficients					
	User segment & PDP	**B**	**SE**	**β**	**t**	**P**
		0.568	0.081	0.687	7.004	0.000
	Constant	3.049	0.460		6.625	0.000
	Regression equation					
	$y = 3.049 + 0.568 \times x$					

→2	**Model summary & ANOVA**					
		R	**R^2**	**DW**	**F**	**P**
		0.800	0.640	1.560	97.875	0.000
	Coefficients					
	User-environment & Usability	**B**	**SE**	**β**	**t**	**P**
		0.720	0.073	0.800	9.893	0.000
	Constant	2.746	0.395		6.957	0.000
	Regression equation					
	$y = 2.746 + 0.720 \times x$					

(→2) →3	**Model summary & ANOVA**					
		R	**R^2**	**DW**	**F**	**P**
		0.811	0.658	2.125	105.995	0.000
	Coefficients					
	Working mechanism	**B**	**SE**	**β**	**t**	**P**
		0.964	0.094	0.811	10.295	0.000
	Constant	1.107	0.513		2.160	0.035
	Regression equation					
	$y = 1.107 + 0.964 \times x$					

2.4) The Fourth Form of Concurrent Collaboration

The fourth collaboration concurrent form results from researching user touch-points activated by the product usage process and thus developing the function structure of the target product.

A considerably high value of R^2 0.729 (F=148.174, P<0.05) is presented in *Table 6.12* and indicates that this collaborative work seems to be strongly operated in the given model. Moreover, β-value 0.854 (P<0.05) greatly supports the suitability of the structure for this collaborative work, with an 85% influencing power regarding the quality of outcomes in researching user touch-points to the usefulness of devising the function structure.

According to descriptive feedbacks from 91% of participants (52/57) when using their own models, the function structure was devised mainly based on the engineering viewpoint. Hence, subsequent iterative improvement works frequently occurred when fitting the structure into user-behaviour patterns. However, when using the given model, they were able to concurrently consider user-behaviour patterns, such as the product usage process and user touch-point, which particularly affect the function structure. Therefore, they confirmed that repeated works were considerably reduced.

Thus, this concurrent collaboration form also seems to be well-operated in the given structure of Module 1.

Table 6.12. *The forth form of concurrent collaboration in module 1*

Structure

Module	Composition-module 1.2.1&1.2.2 in UE	Composition-module 1.4.2 in TC
	Product usage process & User touch-point	Function structure
Concurrent Collaboration	→ 1	

MK= Market-driven research, UE=User-driven research, AS=Aesthetic-and-Symbol-driven research, and TC=Technology-driven research

Result

		Model summary & ANOVA				
		R	R^2	DW	F	P
		0.854	0.729	1.820	148.174	0.000
		Coefficients				
→1	Product usage process & User touch-point	B	SE	β	t	P
		0.749	0.062	0.854	12.173	0.000
	Constant	2.502	0.334		7.492	0.000
		Regression equation				
		$y = 2.502 + 0.749 \times x$				

Tables 8.13 to *8.15* address the fifth to seventh concurrent collaboration form initiated by interaction systems between users and products. According to the second composition-module following to the module studying the interaction systems, different collaboration can be required. Full details of validation results and key findings in these three collaboration structures are presented below.

2.5) The Fifth Form of Concurrent Collaboration

The validation of the fifth collaboration form, in which each technical parameter can be generated in the interaction system of each component, producing an appropriate working principal of each component is handled in *Table 6.13*. R^2-values representing an explanation power of this collaboration structure at 0.712 and 0.653 (F=135.996 and 103.694, P<0.05), indicating the strong suitability of operating the collaborative work in the given model structure. β-values 0.844 and 0.808 (P<0.05) strongly back up the suitability of the structure with leverage, in which the usefulness of implementing each subsequent module increases at a ratio of around 80% when one unit increases in the quality of outcomes in each previous module.

Table 6.13. *The fifth form of concurrent collaboration in module 1*

Structure

Module	Composition-module 1.2.3 in UE	Composition-module 1.4.4 in TC	Composition-module 1.4.5 in TC
	Interaction system	Technical parameter	Working principle
Concurrent Collaboration	→ 1		
		(→ 1) → 2	

MK= Market-driven research, UE=User-driven research, AS=Aesthetic-and-Symbol-driven research, and TC=Technology-driven research

Result

→1	**Model summary & ANOVA**					
		R	**R²**	**DW**	**F**	**P**
		0.844	0.712	1.840	135.996	0.000
	Coefficients					
	Interaction system	**B**	**SE**	**β**	**t**	**P**
		0.749	0.064	0.844	11.662	0.000
	Constant	2.228	0.345		6.460	0.000
	Regression equation					
	$y = 2.228 + 0.749 \times x$					

Model summary & ANOVA

		R	R^2	DW	F	P
		0.808	0.653	1.773	103.694	0.000
		Coefficients				
(→1) →2	Technical parameter	**B**	**SE**	**β**	**t**	**P**
		0.823	0.081	0.808	10.183	0.000
	Constant	2.125	0.441		4.821	0.000
		Regression equation				
		$y = 2.125 + 0.823 \times x$				

2.6) The Sixth Form of Concurrent Collaboration

Results below come from validating concurrent collaborative works in which product exterior elements can be proposed differently according to each interaction system in components, involving the considering of different inherent technical parameters in those elements and relevant technologies embodying these elements.

Relatively higher values of R^2 shown in *Table 6.14* represent that this concurrent collaboration can be well-implemented overall in the given structure of *Module 1*. However, in collaboration between the second and third composition-module for nominating the scope of product appearance elements and calculating inherent technical parameters respectively, R^2-value 0.537 (F=63.878, P<0.05) is somewhat less than other values (R^2=0.732 and 0.666, F=150.375 and 109.474, P<0.05) revealed in collaboration between the first and second and third and fourth module.

This result can be explained by descriptive feedbacks from 68% of participants (39/57), who agreed that the more accurate embodiment of different shape, colour and material theoretically must consider different inherent technical parameters in each exterior element. However, in reality, performers had difficulty considering the parameters for shape and colour, although they were familiar with calculating the parameters originating from inherent properties of materials. Even if they assented to the implementation of three product appearance elements in a bundle, they recommended focusing on the material element when working with calculating inherent technical parameters.

Consequently, collaboration between the first, second, third, and fourth composition-modules seem to be effective in the given structure, while collaboration between the second and third composition-modules seems to be comparatively weaker due to outcomes of the shape and colour scope estimation slightly affecting the calculation of technical properties.

Table 6.14. *The sixth form of concurrent collaboration in module 1*

Structure

Module	Composition-module 1.2.3 in UE	Composition-module 1.3.1 to 1.3.3 in AS	Composition-module 1.4.4 in TC	Composition-module 1.4.7 in TC
	Interaction system	Shape, Colour & Material	Technical parameters	Required tech
Concurrent Collaboration	→ 1			
		→ 2		
			→ 2 → 3	

MK= Market-driven research, UE=User-driven research, AS=Aesthetic-and-Symbol-driven research, and TC=Technology-driven research

Result

→1	**Model summary & ANOVA**					
		R	**R^2**	**DW**	**F**	**P**
		0.856	0.732	1.560	150.375	0.000
	Coefficients					
	Interaction system	**B**	**SE**	**β**	**t**	**P**
		0.563	0.046	0.856	12.263	0.000
	Constant	3.200	0.246		12.984	0.000
	Regression equation					
	$y = 3.200 + 0.563 \times x$					

→2	**Model summary & ANOVA**					
		R	**R^2**	**DW**	**F**	**P**
		0.733	0.537	2.270	63.878	0.000
	Coefficients					
	Shape, Colour & Material	**B**	**SE**	**β**	**t**	**P**
		0.888	0.111	0.733	7.992	0.000
	Constant	1.622	0.620		2.617	0.011
	Regression equation					
	$y = 1.622 + 0.888 \times x$					

(→2) →3	**Model summary & ANOVA**					
		R	**R^2**	**DW**	**F**	**P**
		0.816	0.666	2.345	109.474	0.000
	Coefficients					
	Technical parameters	**B**	**SE**	**β**	**t**	**P**
		1.152	0.110	0.816	10.463	0.000
	Constant	0.072	0.613		0.117	0.907
	Regression equation					
	$y = 0.072 + 1.152 \times x$					

2.7) The Seventh Form of Concurrent Collaboration

This section regards the other collaboration form initiated by studying interaction systems between users and target products. As referred to in the previous section, the interaction systems influence examining the appropriate scope of product appearance elements per component. The nominated shape, colour and material of each component provided semantic messages to users. According to the different symbolic functions, this affected the considering of usability aspects and the proper working principal of each component accordingly, which further leads to calculating their proper dimensions.

With regard to this flow of collaboration, a significant suitability of the model structure was found with R^2 -values at around 0.800 ($P< 0.05$). In detail, the usefulness of conducting each subsequent module increases at a rate of 75% when the quality of outcomes in each previous module increases by one unit.

According to around 86% of participants (49/57), using the given model they were able to produce parameters from usability aspects in consideration of aesthetic-and-symbolic function, whereas they had considered the usability aspects by focusing only user-behaviour aspects when using their own model. Consequently, they highly appraised the model structure in the sense that more user-friendly working principals and dimensions of components were then grasped more accurately.

In summary, considering the statistical analysis data along with the descriptive feedback, the strong possibility in which this collaboration form can be well-operated in the given structure was identified.

Table 6.15. *The seventh form of concurrent collaboration in module 1*

Structure

Module	Composition-module 1.2.3 in UE	Composition-module 1.3.1 to 1.3.3 & 1.3.4 in AS	Composition-module 1.2.6 in UE	Composition-module 1.2.5 in TC	Composition-module 1.2.6 in TC
	Interaction system	Symbolic function from Shape, Colour & Material	Usability	Working principle	Technical dimension
Concurrent Collaboration		→ 1			
			→ 2		
				→ 3	
					(→ 2 →3) → 4

MK= Market-driven research, UE=User-driven research, AS=Aesthetic-and-Symbol-driven research, and TC=Technology-driven research

Result

→1		**Model summary & ANOVA**				
		R	**R^2**	**DW**	**F**	**P**
		0.856	0.732	1.560	150.375	0.000
		Coefficients				
	Interaction system	**B**	**SE**	**β**	**t**	**P**
		0.563	0.046	0.856	12.263	0.000
	Constant	3.200	0.246		12.984	0.000
		Regression equation				
		$y = 3.200 + 0.563 \times x$				

→2		**Model summary & ANOVA**				
		R	**R^2**	**DW**	**F**	**P**
		0.839	0.704	2.346	130.524	0.000
		Coefficients				
	Symbolic function	**B**	**SE**	**β**	**t**	**P**
	from Shape, Colour & Material	1.064	0.093	0.839	11.425	0.000
	Constant	0.538	0.516		1.042	0.302
		Regression equation				
		$y = 0.538 + 1.064 \times x$				

→3		**Model summary & ANOVA**				
		R	**R^2**	**DW**	**F**	**P**
		0.899	0.809	2.664	233.054	0.000
		Coefficients				
	Usability	**B**	**SE**	**β**	**t**	**P**
		0.646	0.042	0.899	15.266	0.000
	Constant	2.875	0.235		12.163	0.000
		Regression equation				
		$y = 2.875 + 0.646 \times x$				

(→2→3) →4		**Model summary & ANOVA**				
		R	**R^2**	**DW**	**F**	**P**
		0.697	0.485	2.157	51.889	0.000
		Coefficients				
	Working principle	**B**	**SE**	**β**	**t**	**P**
		0.753	0.105	0.697	7.203	0.000
	Constant	2.269	0.581		3.903	0.000
		Regression equation				
		$y = 2.269 + 0.753 \times x$				

2.8) The Eight Form of Concurrent Collaboration

The final concurrent collaboration validated in Module 1 regards how different product exterior elements are considered according to different environments, which influences different inherent technical properties of the elements and different technologies for materialising them.

Table 6.16. *The eighth form of concurrent collaboration in module 1*

Structure

Module	Composition-module 1.2.5 in UE	Composition-module 1.3.1 to 1.3.3 in AS	Composition-module 1.4.4 in TC	Composition-module 1.4.7 in TC
	User environment	Shape, Colour & Material	Technical parameters	Required tech
Concurrent Collaboration	→ 1			
		→ 2		
			→ 2 → 3	

MK= Market-driven research, UE=User-driven research, AS=Aesthetic-and-Symbol-driven research, and TC=Technology-driven research

Result

→1	Model summary & ANOVA					
		R	R^2	DW	F	P
		0.950	0.902	2.187	508.923	0.000
	Coefficients					
	User environment	B	SE	β	t	P
		0.674	0.030	0.950	22.599	0.000
	Constant	2.557	0.160		16.022	0.000
	Regression equation					
	$y = 1.421 + 0.867 \times x$					

→2	Model summary & ANOVA					
		R	R^2	DW	F	P
		0.723	0.523	2.333	60.221	0.000
	Coefficients					
	Shape, Colour & Material	B	SE	β	t	P
		0.872	0.112	0.723	7.760	0.000
	Constant	1.571	0.672		2.506	0.015
	Regression equation					
	$y = 1.571 + 0.872 \times x$					

(→2) →3	Model summary & ANOVA					
		R	R^2	DW	F	P
		0.798	0.637	2.221	96.515	0.000
	Coefficients					
	Technical parameters	B	SE	β	t	P
		1.064	0.108	0.798	9.824	0.000
	Constant	0.754	0.603		1.250	0.216
	Regression equation					
	$y = 0.754 + 1.064 \times x$					

R^2-values in collaboration between initial two modules are 0.902 (F=508.923, P<0.05), indicating that 90% of the variation in the usefulness of examining product exterior elements can be explained by a quality of outcomes in user-environment research. This finding means that the product exterior elements study is very strongly affected by user environment research (β=0.950, P<0.05).

However, the following collaboration between studying product exterior elements and calculating their inherent properties seems to be somewhat less valid when operating in the given model than the collaborative work above (R^2=0.523, F=60.221, P<0.05, β=0.723). The reason described in 68% of descriptive feedback (39/57), was that the calculation of the properties was influenced mostly by the material element among three exterior elements handled in a bundle; this is in the same context mentioned in the sixth collaboration form (*pp. 396-397*).

However, the subsequent collaboration seems to be strongly acceptable when working in the model structure by the following statistical values: R^2=0.637, F=96.515, P<0.05, β=0.798.

Consequently, collaboration between the first and second composition-modules, in which strong collaboration occurs, seems to have relatively less effect on the final composition modules for the calculation of technical properties which are influenced by the third and fourth modules (which in turn are affected by the second module), since outcomes of the shape and colour scope estimation slightly affects calculation of the technical properties.

3) Section Conclusion

Module 1 for the opportunity identification-screening task has been validated from the contextual performance and concurrent collaboration perspectives.

The module consisting of four major NPD-related research sub-modules seems to be well-structured overall for contextual performance. Most of the composition-modules subordinated into each sub-module can be regarded as a well-interlocked structure, as indicated in most R^2 and β being greater than 0.750 once rounded up (P<0.05).

However, some of the use of the composition-modules have revealed points for improvement. For instance, in the first part of the market-driven research module, the examination of user types and indirect-and-direct factors affecting possible markets have been recommended conducted in parallel, instead of in phases (R^2=0.050 and 0.033, F=2.893 and 1.879, P=0.095 and 0.176, β=0.224 and 0.182). Also, in the aesthetic-and-symbol-driven research, the statistical validation result has indicated that the composition-module for proposing the scope of each shape and colour has been recommended implemented in the bundle instead of in contextual sequence, with an R^2 of 0.059 (F=3.421, P<0.070, β=0.242).

The structure in which the four sub-modules consisting of relevant composition-modules are arranged in the quadrant seems to strongly foster simultaneous collaborative works between the composition-modules involved in collaboration forms of four research fields (R^2=around 0.700, β=0.800, P<0.050).

One noticeable indication in the validation results has been exposed when collaborating with the final composition-module. R^2-values representing the suitability of the model structure to operate the final composition-module in a series of each collaboration form, and β-values indicating the strength of influence of affecting to the final module were reduced overall. This finding implies that the greater number of different functional aspects to be considered in processing a single module, the more difficult it is to conduct the module.

To conclude, considering all the validation results, including descriptive feedback, the possibility of Module 1 being acceptable for contextual performance and concurrent collaboration operations in the given structure appears to be substantiated.

6.3.3 Idea Generation-Screening Task – Module 2

1) Contextual Performance

This section addresses the verification results regarding whether Module 2 for idea generation-screening task is well-structured for contextual performance. Through the verification of the subordinated four sub-modules, whether the main module is suitable for contextual performance was analysed. In Module 2, there are four ideation sub-modules arranged as an extension to four research sub-modules in Module 1. Therefore, the validation of contextual performance from Module 1 to 2, as well as contextual performance within Module 2, were dealt with together in this section. *Tables 6.17* to *6.20* illustrate the validation results.

Table 6.17. *Sub-module 2.1: market-driven ideation activity*

Structure

Module	Sub-module 1.1	Composition-module 2.1.1	Composition-module 2.1.2	Composition-module 2.1.3	Composition-module 2.1.4
	Market-driven research	Initial idea	Supportive reason for initial idea	Specific idea	Supportive reason for specific idea
Contextual performance	→ 1				
		→ 2			
			(→2) → 3		
				→ 4	

Result

→1		**Model summary & ANOVA**				
		R	**R^2**	**DW**	**F**	**P**
		0.901	0.812	2.218	237.834	0.000
		Coefficients				
	Market-driven research	**B**	**SE**	**β**	**t**	**P**
		0.970	0.063	0.901	15.422	0.000
	Constant	1.139	0.342		3.333	0.002
		Regression equation				
		y = 1.139 + 0.970 × x				
→2		**Model summary & ANOVA**				
		R	**R^2**	**DW**	**F**	**P**
		0.891	0.794	2.023	212.262	0.000
		Coefficients				
	Initial idea	**B**	**SE**	**β**	**t**	**P**
		0.795	0.055	0.891	14.569	0.000
	Constant	2.037	0.274		7.431	0.002
		Regression equation				
		y = 2.037 + 0.795 × x				
		Model summary & ANOVA				
		R	**R^2**	**DW**	**F**	**P**

		R	R²	DW	F	P
		0.693	0.481	2.471	50.891	0.000
				Coefficients		
(→2) →3	Supportive reason for initial idea	**B**	**SE**	**β**	**t**	**P**
		- 1.145	0.160	- 0.693	-7.134	0.000
	Constant	9.797	0.821		11.935	0.000
				Regression equation		
				y = 9.797 − 1.145 × x		

				Model summary & ANOVA		
		R	**R²**	**DW**	**F**	**P**
		0.727	0.528	1.617	61.584	0.000
				Coefficients		
→4	Specific idea	**B**	**SE**	**β**	**t**	**P**
		0.604	0.077	0.727	7.848	0.000
	Constant	2.215	0.279		7.927	0.000
				Regression equation		
				y = 2.215 + 0.604 × x		

As shown in *Table 6.17*, contextual performance from producing the opportunity parameter set in the market-driven research module (Sub-module 1.1) to devising initial ideas as actionable methods for the opportunity in this ideation module (Sub-module 2.1) seems to be effectively operated in the given model structure.

R^2-value 0.812 (F=237,834, P=0.000) suggests that approximately 80% of the variation in the usefulness of devising initial ideas can be accounted for by the relationship with the quality of the set opportunity parameter. This indicates that the contextual performance structure is strongly valid. Besides, β-value 0.901 (P=0.000) implied that the usefulness of generating initial ideas can increase at a rate of 90% when the opportunity parameter quality increases by one unit, indicating the strong influence of the quality affecting the usefulness.

Between composition-modules for generating the initial ideas and providing supportive reasons and rationale evidence, the statistical result (R^2=0.794, F=212.262, P<0.05, and β= 0.891) also implies strong validity for the contextual performance.

However, contextual performance from the devising of the initial notions to coming up with more concrete ideas (as shown in the label '(→2)→3') does not seem to be operated well in the given structure. R^2-value 0.481 (F=50.891, P=0.000) is in the moderate range of suitability for a contextual performance. On the other hand, β-value –0.693 (P=0.000) is a negative decimal, indicating that the usefulness of devising specific ideas decreases at a ratio of around 70% when one unit increases in the quality of the initial ideas and their rationale evidence. Namely, it means that the higher quality of initial ideas, the more difficulty there is in devising specific ideas. One interesting result was also revealed in the subsequent contextual performance in providing their supportive reasons for the specific ideas. Once the specific ideas were generated somehow, their supportive reasons can be offered (R^2=0.528, F=61.584, P<0.05, and β= 0.727).

In this regard, 82% of participants (47/57) expressed their concern for a lack of room for their initial ideas to be defined more in-depth when the initial notions were too specific. Hence, they highly recommended integrating the initial idea and specific idea generation modules. Some of them suggested removing the composition-modules generating specific ideas and their supportive reasons, since in the FFE phase there were few chances to deeply investigate specific realisation methods to that extent.

Consequently, the market-driven ideation module (Sub-module 2.1) revealed room for improvement. The module can be contextually structured, with two composition-modules generating actionable realisation methods for opportunity parameter sets and providing supportive rationale and evidential reasons, including respective feasibility checks. Also, by providing discretion regarding the degree of concreteness in generating the actionable methods in a single composition-module, it is expected that performers can generate ideas at the flexible level according to their FFE projects.

Table 6.18. *Sub-module 2.2: user-driven ideation activity*

Structure

Module	Sub-module 1.1	Composition-module 2.1.1	Composition-module 2.1.2	Composition-module 2.1.3	Composition-module 2.1.4
	User-driven research	Initial idea	Supportive reason for initial idea	Specific idea	Supportive reason for specific idea
Contextual performance	→ 1				
		→ 2			
			→ 3		
				→ 4	

Result

		Model summary & ANOVA				
		R	**R²**	**DW**	**F**	**P**
		0.800	0.640	2.601	97.925	0.000
		Coefficients				
→1	User-driven research	**B**	**SE**	**β**	**t**	**P**
		1.310	0.132	0.800	9.896	0.000
	Constant	- 0.727	0.714		- 1.017	0.313
		Regression equation				
		$y = -0.727 + 1.310 \times x$				

Model summary & ANOVA

		R	R^2	DW	F	P
→2		0.827	0.684	2.184	119.239	0.000
	Coefficients					
	Initial idea	**B**	**SE**	**β**	**t**	**P**
		0.638	0.058	0.827	10.920	0.000
	Constant	2.768	0.314		8.818	0.000
	Regression equation					
	$y = 2.768 + 0.638 \times x$					

→3	**Model summary & ANOVA**					
		R	**R^2**	**DW**	**F**	**P**
		0.549	0.302	2.288	23.784	0.000
	Coefficients					
	Supportive reason for initial idea	**B**	**SE**	**β**	**t**	**P**
		- 1.010	0.207	- 0.549	- 4.887	0.000
	Constant	9.202	1.103		8.345	0.000
	Regression equation					
	$y = 9.202 - 1.010 \times x$					

→4	**Model summary & ANOVA**					
		R	**R^2**	**DW**	**F**	**P**
		0.856	0.733	2.072	151.330	0.000
	Coefficients					
	Specific idea	**B**	**SE**	**β**	**t**	**P**
		0.761	0.062	0.856	12.302	0.000
	Constant	1.846	0.258		7.164	0.000
	Regression equation					
	$y = 1.846 + 0.761 \times x$					

Table 6.19. *Sub-module 2.3: aesthetic-and-symbol-driven ideation activity*

Structure

Module	Sub-module 1.1	Composition-module 2.1.1	Composition-module 2.1.2	Composition-module 2.1.3	Composition-module 2.1.4
	aesthetic-and-symbol-driven research	Initial idea	Supportive reason for initial idea	Specific idea	Supportive reason for specific idea
Contextual performance	→ 1	→ 2	→ 3	→ 4	

Result

→1	**Model summary & ANOVA**					
		R	**R^2**	**DW**	**F**	**P**
		0.821	0.674	1.939	113.523	0.000
	Coefficients					
	aesthetic-and-symbol-driven research	**B**	**SE**	**β**	**t**	**P**
		1.073	0.101	0.821	10.655	0.000
	Constant	0.659	0.550		1.198	0.236
	Regression equation					
	$y = 0.659 + 1.073 \times x$					

→2	**Model summary & ANOVA**					
		R	**R^2**	**DW**	**F**	**P**
		0.870	0.757	1.980	171.715	0.000
	Coefficients					
	Initial idea	**B**	**SE**	**β**	**t**	**P**
		0.786	0.060	0.870	13.104	0.000

	Constant	1.889	0.312		6.048	0.000
	Regression equation					
	y = 1.889 + 0.786 × x					

→3	Model summary & ANOVA					
		R	R²	DW	F	P
		0.581	0.337	1.953	27.981	0.000
	Coefficients					
	Supportive reason for initial idea	B	SE	β	t	P
		- 0.903	0.171	- 0.581	- 5.290	0.000
	Constant	9.433	0.915		10.311	0.000
	Regression equation					
	y = 9.433 − 0.903 × x					

→4	Model summary & ANOVA					
		R	R²	DW	F	P
		0.778	0.606	2.132	84.512	0.000
	Coefficients					
	Specific idea	B	SE	β	t	P
		0.638	0.069	0.778	9.193	0.000
	Constant	2.513	0.343		7.324	0.000
	Regression equation					
	y = 2.513 + 0.638 × x					

The following validation results shown in *Tables 6.18* to *6.20* regard whether the user-driven, aesthetic-and-symbol-driven and technology-driven ideation activities operate well in the given structure from the contextual performance aspect. These three modules show the same context to the results of the market-driven ideation module mentioned above.

The contextual connection between producing opportunity parameter sets in three research modules and generating initial ideas in three ideation modules seems to be well structured in the given model.

R^2-values are 0.640, 0.674 and 0.709 (F=97.925, 113.523 and 133.744, P<0.05) in user-driven, aesthetic-and-symbol-driven and technology-driven ideation module respectively. This finding indicates that the initial structure in each module is strongly valid for contextual performance. β-values are 0.800, 0.821 and 0.865 (P<0.05), backing up this validity through a strong influence of the quality of opportunity parameters affecting the usefulness of devising initial ideas.

Between composition-modules for producing the initial ideas and offering their rationale evidence, all three ideation modules also show the strongly suitable structure from the contextual performance aspect (R^2=0.684, 0.757 and 0.709, F=119.239, 171.715 and 222.857, P<0.05, and β= 0.827, 0.870 and 0.896).

However, as with the market-driven ideation module, in the remaining three ideation modules, the negative results were also revealed in each composition-module, which are for devising more specific ideas in consideration of initial ideas and their supporting reasons (as indicated in the labels '(→2)→3').

In the user-driven and aesthetic-driven ideation module (shown in *Tables 8.18* and *8.19*), β-values - 0.549 and - 0.581 (P< 0.05) are negative decimals, representing that the usefulness of producing specific ideas decreases at a rate of around 60% when the quality of the initial ideas and their supportive reasons increases by one unit. This finding indicates that the higher quality of initial ideas, the more difficulty there is in devising specific ideas. Namely, performers had difficulty as there was no room for their initial ideas to be defined more in-depth when the initial ideas were too specific.

Table 6.20. *Sub-module 2.4: technology-driven ideation*

Structure

Module	Sub-module 1.1	Composition-module 2.1.1	Composition-module 2.1.2	Composition-module 2.1.3	Composition-module 2.1.4
	technology-driven research	Initial idea	Supportive reason for initial idea	Specific idea	Supportive reason for specific idea
Contextual performance	→ 1				
		→ 2			
			→ 3		
				→ 4	

Result

→1	**Model summary & ANOVA**					
		R	**R²**	**DW**	**F**	**P**
		0.842	0.709	1.829	133.744	0.000
	Coefficients					
	technology-driven research	**B**	**SE**	**β**	**t**	**P**
		1.267	0.110	0.865	11.565	0.000
	Constant	- 0.485	0.604		- 0.803	0.426
	Regression equation					
	$y = -0.485 + 1.267 \times x$					
→2	**Model summary & ANOVA**					
		R	**R²**	**DW**	**F**	**P**
		0.896	0.802	1.623	222.857	0.000
	Coefficients					
	Initial idea	**B**	**SE**	**β**	**t**	**P**
		0.731	0.049	0.896	14.928	0.000
	Constant	2.207	0.259		8.530	0.000
	Regression equation					
	$y = 2.207 + 0.731 \times x$					
	Model summary & ANOVA					
		R	**R²**	**DW**	**F**	**P**
		0.542	0.294	1.583	22.892	0.000

		Coefficients				
→3	Supportive reason for initial idea	**B**	**SE**	**β**	**t**	**P**
		0.608	0.127	0.542	4.785	0.000
	Constant	2.690	0.675		3.982	0.000
		Regression equation				
		y = 2.690 + 0.608 × x				

		Model summary & ANOVA				
		R	**R²**	**DW**	**F**	**P**
		0.744	0.553	2.438	68.048	0.000
		Coefficients				
→4	Specific idea	**B**	**SE**	**β**	**t**	**P**
		0.641	0.078	0.744	8.249	0.000
	Constant	2.506	0.394		6.355	0.000
		Regression equation				
		y = 2.506 + 0.641 × x				

For the same contextual performance structure (as shown in the label '(→2)→3') in the technology-driven ideation module (shown in *Table 8.20*), even though β-values are not negative (β=0.542, P<0.05), the R^2-value is in the weak range of suitability for contextual performance (R^2=0.294, F=22.892, P<0.05). This finding represents that only 20% of the variation in the usefulness of devising specific ideas can be explained by the relationship with the quality of initial ideas. Namely, although the reason is different, the structure for this contextual performance also seems to be less valid as with the user-driven and aesthetic-and-symbol-driven ideation module. In this regard, participants 17, 36, 45,46 and 51 provided understandable descriptive feedbacks. In the case of technology-intensive projects, they argued that works for several phased-digging up actionable methods occurred frequently. Therefore, as indicated in β-value, the initial ideas can moderately support the generation of more specific actionable methods, so long as projects require such a degree of concrete ideas. However, according to the R^2-value, we can recognise that such a case does not seem to occur frequently.

Consequently, Module 2 (the idea generation-screening task) can be contextually structured, with two composition-modules generating actionable realisation methods for opportunity parameter sets and providing supportive rationale and evidential reasons, including respective feasibility checks. The first and second composition-modules (related to initial ideation work) can remain, and the third and fourth composition-modules (related to specific ideation work) may be removed, leaving the part for checking the feasibility of ideas as it is. By leaving room for the degree of the concreteness in the initial idea generation in the first and second module, the idea generation-screening can be more or less explored according to different types of the FFE project.

2) Concurrent Collaboration

This section presents the validation results and key findings of whether concurrent collaboration forms demanded in the idea generation-screening task can operate well in the developed structure of Module 2 (*p. 309*). In this structure, there are four sub-modules for the market-driven, user-driven, aesthetic-and-symbol-driven and technology-driven ideation activities. These four sub-modules – comprised of relevant composition-modules – are an extension to the individual sub-module representing each four research activities in Module 1. Since sub-modules in Module 1 are arranged in the quadrant, sub-modules in Module 2 are naturally placed also in the quadrant.

The concurrent collaboration forms mainly worked in the given structure as follows. When one of the four ideation sub-modules are conducted, the parameter sets produced in the three remaining sub-modules can be considered simultaneously. For instance, when the user-driven ideation activity is being performed, the parameters being obtained from the market-driven, aesthetic-and-symbol-driven and technology-driven ideation activity can be considered concurrently. Therefore, as shown in *Table 6.21*, a total of four collaboration forms were validated by the field-tests.

Table 6.21. *Concurrent collaboration in ideation*

Structure

Module	Sub-module 2.2, 2.3 & 2.4					Sub-module 2.1
	User-driven ideation	+	Aesthetic-and-Symbol-driven ideation	+	Technology-driven ideation	Market-driven ideation
Concurrent collaboration 1					→ 1	

Module	Sub-module 2.1, 2.3 & 2.4					Sub-module 2.2
	Market-driven ideation	+	Aesthetic-and-Symbol-driven ideation	+	Technology-driven ideation	User-driven ideation
Concurrent collaboration 2					→ 2	

Module	Sub-module 2.1, 2.2 & 2.4					Sub-module 2.3
	Market-driven ideation	+	User-driven ideation	+	Technology-driven ideation	Aesthetic-and-Symbol-driven ideation
Concurrent collaboration 3					→ 3	

Module	Sub-module 2.2, 2.3 & 2.4	Sub-module 2.4

	Market-driven ideation	+	User-driven ideation	+	Aesthetic-and-Symbol-driven ideation	Technology-driven ideation
Concurrent collaboration 4					→ 4	

Result

		Model summary & ANOVA				
		R	R^2	DW	F	P
		0.761	0.579	1.638	75.714	0.000
		Coefficients				
→1	UE+AS+TC	B	SE	β	t	P
		1.097	0.126	0.761	8.701	0.000
	Constant	0.423	0.642		0.658	0.513
		Regression equation				
		y = 0.423 + 1.097 × x				

		Model summary & ANOVA				
		R	R^2	DW	F	P
		0.653	0.427	2.072	40.952	0.000
		Coefficients				
→2	MK+AS+TC	B	SE	β	t	P
		0.730	0.114	0.653	6.399	0.000
	Constant	2.376	0.578		4.110	0.513
		Regression equation				
		y = 2.376 + 0.730 × x				

		Model summary & ANOVA				
		R	R^2	DW	F	P
		0.677	0.458	2.459	46.519	0.000
		Coefficients				
→3	MK+UE+TC	B	SE	β	t	P
		0.858	0.126	0.677	6.820	0.000
	Constant	1.580	0.624		2.534	0.014
		Regression equation				
		y = 1.580 + 0.858 × x				

		Model summary & ANOVA				
		R	R^2	DW	F	P
		0.690	0.475	2.077	49.845	0.000
		Coefficients				
→4	MK+UE+AS	B	SE	β	t	P
		1.000	0.142	0.690	7.060	0.000
	Constant	0.930	0.694		1.340	0.186
		Regression equation				
		y = 0.930 + 1.000 × x				

In the statistical analysis, overall, the four collaboration forms seem to be moderately operated in the structure. Market-driven collaboration seems to most moderately work (R^2=0.579, F=75.714, P<0.05, and β= 0.761) when compared with the other three (R^2=0.427, 0.458 and 0.475, F=40.952, 46.519 and 49.845, P<0.05, and β= 0.653, 0.677 and 0.690).

In descriptive feedback, 79% of participants (45/57) had difficulty devising specific ideas and their supportive reasons when conducting the user-driven, aesthetic-and-symbol-driven and technology-driven collaborative works for ideation; this seems to affect the usefulness of performing the three-collaborative works, presenting relatively low statistical values. In market-driven collaboration even, performers had the same difficulty. However, since the development of actionable methods specifying and reducing the development costs in consideration of the ideas devised from the remaining three sub-modules being the main activity in market-driven ideation collaboration, the validation data seems to be comparatively higher.

3) Section Conclusion

Module 2 for the idea generation-screening task has been verified from contextual performance and concurrent collaboration viewpoints.

In each sub-module, the contextual performance that flows from producing opportunity parameter sets to devising initial ideas along with providing supportive reasons was effective in the developed structure phases (R^2=around 0.750, β= around 0.850, P<0.05).

However, in the contextual performance processing from the initial ideation-related work in the first and second composition-module to the specific ideation-related work in the third composition-module, β-values showed a negative decimal value, although P-values were within the recommended 0.05. This finding indicated that the higher the quality of initial ideas, the more difficulty there is in devising specific ideas. Therefore, the third and fourth composition-modules for the specific ideation-related work needed to be removed, leaving a part for the feasibility check. Instead, by providing discretion regarding the degree of the concreteness in the initial ideation-related work, it was expected that performers can produce ideas and supportive reasons in the flexible level according to different project cases.

Consequently, each ideation sub-module consisted of two composition-modules which come up with actionable methods to realise opportunity parameter sets and offer their rationale evidence, including the work for the idea-screening respectively.

The four collaboration forms led by each ideation sub-module could be moderately operated in the given model structure (R^2=around 0.500, β= around 0.700, P<0.05). This result seemed to be caused by a difficulty in handling the third and fourth composition-modules related to the specific ideation work in the same context mentioned above. Therefore, after each sub-module is modified with the suggested improvement direction, it was expected that collaboration can strongly work in the improved structure.

In conclusion, considering all the verification results along with the narrative feedback, the possibility of Module 2 being well-built for contextual performance and concurrent collaboration seemed to be confirmed.

6.3.4 Requirements List and Mission Statement Task – Modules 3 and 4

This section presents the validation of the requirements list and mission statement module (Module 3 and 4). As mentioned in Section 6.1, experimental environment control – web-version of FFE model embodiment (*pp. 349-350*), all parameters required in these two modules can be filled automatically from the two previous modules (Module 1 and 2), so that performers do not need any physical and functional implementation. Hence, the actual test involving the regression analysis method used in the validation of the previous modules was not conducted. Instead, a descriptive statistic and narrative feedback were utilised for confirming whether the system of the requirements list module enabling automatically filling parameters aid in contextual performance and concurrent collaboration.

As shown in *Table 6.22*, mean values indicates that the requirement lists module seems to be well developed overall for contextual performance and concurrent collaboration; the module structure and its operating system for contextual performance seems to be slightly better than that for concurrent collaboration (M: 6.33 > 5.98).

Table 6.22. *Contextual performance and concurrent collaboration in Module 3 and 4*

	Participant (N)	Maximum (Max)	Minimum (Min)	Mean (M)	Standard Deviation (SD)
Contextual Performance	57	5	7	6.33	0.607
Contextual Collaboration	57	4	7	5.98	0.813

When participants (88%; 50/57) used their own model, project managers had to make a requirements list by receiving the outcomes of each NPD-related functional team. Even they had to have intensive discussions to understand meanings of critical outcomes originated from each parameter. According to 89% of participants (51/57), project managers had difficulty following up the outcomes of each progress in those functional teams when seeking to write up the list and because they did not have several meetings for FFF progress reports. In addition, 93% of participants (53/57) illustrated that each team member had trouble understanding purposes and meanings of each requirement, despite project managers well organising the list. Hence, a meeting explaining requirements in detail had to be demanded every time.

However, when using the given web-version of the model developed in this research, first, project managers did not need to make any high dedication to making out the list due to the system automatically enabling filling requirements. Also, all team members – including the project managers – were able to monitor the parameters and generation of their progress while conducting previous Module 1 and 2. Hence, although they had less intensive discussions (and less of them), they can more explicitly apprehend requirements that are automatically organised with parameters from Module 1 and 2. They were also able to understand the relationship of those parameters from the contextual performance and concurrent collaboration aspects. Even though, owing to the structure built on a component basis, the relationship of requirements involved in adjacent components generally interconnected with each other in the product architecture, which can be grasped more clearly from those two aspects.

Consequently, considering all the descriptive statistics and narrative feedback, the possibility of Module 3 being well-structured for contextual performance and concurrent collaboration was confirmed.

6.3.5 Conceptual Design Task – Module 5

1) Contextual Performance

This section describes the verification of whether Module 5 for the conceptual design task is well-structured for contextual performance. This module interlocks the requirements list module (Module 3) by a product platform unit consisting of the main component and sub-component units. All eight composition-modules in this module are contextually linked overall since the final composition-module in each previous sub-module interlocked with the first composition-module in each subsequent sub-module. Therefore, the verification is executed on contextual performance between those eight composition-modules, including the contextual performance started by Module 3. The detailed verification data and the key findings are shown in *Table 6.23*.

Table 6.23. *Main module 5: conceptual design*

Structure

Module	Main Module 3	Sub-module 5.1				Sub-module 5.2		Sub-module 5.3	
		Principal design				Schematic design		Styling design	
		Composition -module 5.1.1	Composition -module 5.1.2	Composition -module 5.1.3	Composition -module 5.1.4	Composition -module 5.2.1	Composition -module 5.2.2	Composition -module 5.3.1	Composition -module 5.3.2
	Requirement list	Principal design for platform	Optimal principal design for platform	Principal design for product	Optimal principal design for product	Schematic design with function & system structure	Schematic design with dimension	Styling design with hand-drawing	Styling design with CAD-drawing
Contextual performance		→ 1							
			→ 2						
				→ 3					
					→ 4				
						→ 5.1			
				(→3) ········	········	→ 5.2			
							→ 6		
								→ 7	
									→ 8

Result

		Model summary & ANOVA				
→1		R	R^2	DW	F	P
		0.836	0.699	2.027	127.645	0.000
		Coefficients				
	Requirement list	**B**	**SE**	**β**	**t**	**P**
		0.613	0.054	0.836	11.298	0.000
	Constant	3.069	0.306		10.039	0.000
		Regression equation				
		$y = 3.069 + 0.613 \times x$				

Model summary & ANOVA

→2		R	R^2	DW	F	P
		0.854	0.730	2.015	148.543	0.000
		Coefficients				
	Principal design for platform	**B**	**SE**	**β**	**t**	**P**
		0.680	0.056	0.854	12.188	0.000
	Constant	2.656	0.311		8.552	0.000
		Regression equation				
		$y = 2.656 + 0.680 \times x$				

→3		**Model summary & ANOVA**				
		R	**R^2**	**DW**	**F**	**P**
		0.231	0.053	2.007	3.104	0.084
		Coefficients				
	Optimal principal design for platform	**B**	**SE**	**β**	**t**	**P**
		4.025	0.992		4.056	0.000
	Constant	0.321	0.182	0.231	1.762	0.084
		Regression equation				
		$y = 4.025 + 0.321 \times x$				

→4		**Model summary & ANOVA**				
		R	**R^2**	**DW**	**F**	**P**
		0.879	0.772	2.340	186.278	0.176
		Coefficients				
	Principal design for product	**B**	**SE**	**β**	**t**	**P**
		0.653	0.048	0.879	13.648	0.000
	Constant	2.790	0.269		10.383	0.000
		Regression equation				
		$y = 2.790 + 0.653 \times x$				

→5.1		**Model summary & ANOVA**				
		R	**R^2**	**DW**	**F**	**P**
		0.884	0.781	2.798	195.960	0.000
		Coefficients				
	Optimal principal design for product	**B**	**SE**	**β**	**t**	**P**
		0.637	0.045	0.884	13.999	0.000
	Constant	2.894	0.260		11.142	0.000
		Regression equation				
		$y = 2.894 + 0.637 \times x$				

→5.2		**Model summary & ANOVA**				
		R	**R^2**	**DW**	**F**	**P**
		0.941	0.886	2.583	427.585	0.000
		Coefficients				
	Optimal principal design for platform	**B**	**SE**	**β**	**t**	**P**
		0.773	0.037	0.941	20.678	0.000
	Constant	2.136	0.203		10.502	0.000
		Regression equation				
		$y = 2.136 + 0.773 \times x$				

→6		**Model summary & ANOVA**				
		R	**R^2**	**DW**	**F**	**P**
		0.867	0.752	2.440	166.764	0.000
		Coefficients				
	Schematic design with function & system structure	**B**	**SE**	**β**	**t**	**P**
		0.669	0.052	0.867	12.914	0.000
	Constant	2.703	0.295		9.165	0.000
		Regression equation				
		$y = 2.703 + 0.669 \times x$				

		Model summary & ANOVA				
		R	**R^2**	**DW**	**F**	**P**

		0.885	0.784	2.722	199.644	0.000
		Coefficients				
→7	Schematic design with dimension	**B**	**SE**	**β**	**t**	**P**
		2.718	0.274		9.935	0.000
	Constant	0.673	0.048	0.885	14.130	0.000
		Regression equation				
		$y = 2.718 + 0.673 \times x$				

		Model summary & ANOVA				
		R	**R^2**	**DW**	**F**	**P**
		0.903	0.815	2.229	241.940	0.000
		Coefficients				
→8	Styling design with hand-drawing	**B**	**SE**	**β**	**t**	**P**
		0.799	0.051	0.903	15.554	0.000
	Constant	1.992	0.270		7.383	0.000
		Regression equation				
		$y = -0.117 + 1.210 \times x$				

Output parameters on requirements organised with the main and sub-component unit seem to strongly flow into input parameters for the principal conceptual design in each product platform. R^2-value 0.700 – once rounded up (F=127.645, P=0.000) – represents around 70% of the suitability of this contextual performance. β-value 0.836 (P=0.000) indicates that the usefulness of the principal conceptual design conducted on a platform basis increases at the ratio of 84% when one unit increases in the quality of requirements.

In the next contextual performance, the quality of the principal conceptual design conducted by the platform unit also seems to strongly affect the usefulness of selecting optimal ones among them (R^2=0.730, F=148.543, P<0.05, β= 0.854).

The subsequent contextual performance (as shown in the label '→3') is to integrate the principal conceptual design of each platform by reflecting the basic frame of the target product and producing principal conceptual designs of the entire product. This contextual performance does not seem to work appropriately in the given structure, as indicated by an R^2 of 0.053, F of 3.104, β of 0.231, and P of 0.085 being greater than 0.050.

On the other hand (as shown in the label '→5.2'), after skipping the reflection of the basic frame, based on the principal conceptual design of each platform, when conceptual designs of the whole product were devised by directly reflecting various functions and system structures, the suitability of contextual performance was much better (R^2=0.886, F=427.585, P<0.05, β= 0.941). Namely, contextual performance between the second and fifth composition-modules (as shown in the label '→5.2') seems to be more valid than that between the second and third composition-modules (as shown in the label '→3).

Even so, contextual performance between the second and fifth composition-modules (as shown in the label '→5.2'), R^2=0.886, F=427.585, P<0.05 and β= 0.941 seems to have more validity than that seen between the fourth and fifth composition-module (as shown in the label '→5.1') (R^2=0.781, F=195.960, P< 0.05, β = 0.884). That is, when the schematic conceptual design work reflecting the function and system structures is conducted directly based on the initial conceptual design work devising principal concepts for each platform, the schematic conceptual design work seems to be performed more effectively.

In this respect, 68% of participants (39/57) described that they did not strongly need to conduct the third and fourth composition-modules. Of course, they agreed that when they execute the schematic conceptual design work by applying function and system structures via understanding the basic frame of the conceptual design first, the schematic design was able to be more systematically performed. However, they argued that the implementation of the third and fourth composition-modules seemed to be the somewhat repeated work, since they conduct the reflection of the function and system structures based on the basic structure intuitively. Therefore, the third and fourth composition-module seems to need to be removed, directly connecting the second and fifth composition-modules.

The remaining sixth to eighth composition-modules seems to be significantly well-structured for contextual performance, as indicated by R^2=around 0.800, β=around 0.900 and P<0.05.

In conclusion, contextual performance from the first to the second and from the fifth to the final composition-modules seems to be effective in the given structure of the conceptual design module (Module 5). However, the third and fourth composition-modules do not seem to be strongly required, so they could be removed, thus connecting to the second and fifth composition-modules directly. This can lead to one principal conceptual design for each platform being produced, alongside various conceptual designs in which different function and system structures are reflected and generated directly by assembling each principal platform design accordingly.

2) Concurrent Collaboration

Distinct from the opportunity identification-screening module (Module 1) and the idea generation-screening module (Module 2), which facilitates concurrent collaboration by the quadrant structure, this module (Module 5 for the conceptual design task) induces the different collaboration form by a phased-structure. The concurrent collaboration in Module 1 and 2 is formed *between* composition-modules involved in four sub-modules, which represent the market-driven, user-driven, aesthetic-and-symbol-driven and technology-driven research and ideation areas. On the other hand, concurrent collaboration in this module (Module 5) occurs *within* each composition-module itself. In the process of applying each requirement considered from those four functional areas to the conceptual designs of each platform and assembling these platforms, the collaboration of the four functional areas occur in each composition-module itself. Therefore, the validation for collaboration in this module was not conducted by the regression analysis used in the previous validation which is adequate to verifying collaboration generated between the composition-modules. Instead, the validation data was obtained from a descriptive statistics and narrative feedback, to confirm whether collaboration is performed well within composition-modules themselves.

As shown in *Table 6.24*, concurrent collaboration in cross-checking conceptual designs by four functional domains seems to be fostered well in the given structure, as indicated in M-value 5.86 (SD=0.667).

Table 6.24. *Concurrent collaboration in Module 5*

	Participant (N)	Maximum (Max)	Minimum (Min)	Mean (M)	Standard Deviation (SD)
Concurrent collaboration	57	7	5	5.86	0.667

According to 88% of participants (50/57) when using their own model, the conceptual design work was mainly progressed dependent on the ability of an individual industrial designer. Then, other team members from different functional fields confirmed outcomes, along with the industrial designers. This led to conceptual designs in which requirements were frequently reflected in an incorrect way or were not reflected at all. Hence, based on feedback from the project members, iterative revision work occurred continuously.

However, when utilising the given model, they simultaneously checked and reflected the requirements from those four functional aspects, so that conceptual designs were devised together. This collaboration was specifically implemented platform by platform, enabling the more functional grasping of the relationship between adjacent platforms being closely linked with each other, which led to the previous iterative modification (caused by the ill-reflection of the requirements and ill-understanding of the relationship between the adjacent platforms) being remarkably reduced.

Consequently, more elaborate conceptual designs considered multidimensionally can be developed from individual platforms to the entire product in the given structure of Module 5, by reinforcing both the reflection of the requirements and understanding of the relationship between adjacent platforms.

3) Section Conclusion

Module 5 for the conceptual design task has been validated from contextual performance and concurrent collaboration perspectives.

Overall, all parameters largely seem to be well-interlocked for contextual collaboration, as indicated in all R^2-values around 0.750 and β-values larger than 0.850 (P<0.05). However, the necessity of the third and fourth composition-modules seems to be low, so those might be removed, thus linking to the second and fifth module directly. This can result in one principal conceptual design for each platform being generated, diverse conceptual designs in which different functions and system structure are reflected and produced directly by assembling each principal platform design accordingly.

With the descriptive statistics and narrative feedback, the structure also strongly seems to be well-structured for the concurrent collaborative conceptual design work.

Consequently, through the statistical analysis data and narrative feedback on the validation results, Module 5 can be regarded as being well-constructed for contextual performance and concurrent collaboration.

6.3.6 Prototyping Task – Module 6

1) Contextual Performance

This section addresses the validation of whether Module 6 for the prototyping task is well-structured for contextual performance. This module arranged as an extension to the final module of the conceptual design module (Module 5) consists of three sub-modules without relevant composition-modules. Hence, the validation was conducted on contextual performance between those three sub-modules, including contextual performance initiated from the final sub-module of Module 5. In addition, the final outcomes of this module convey to the first task of conducting a detailed design in the actual NPD phase. Therefore, the validation is also involved in the contextual performance between the final sub-module of this module and the beginning of the actual NPD phase. *Table 6.25* shows the validation data.

Table 6.25. *Main module 6: prototyping*

Structure

Module	Composition-module 5.1.8	Sub-module 6.1	Sub-module 6.2	Sub-module 6.3	Actual NPD phase
	Styling design with CAD-drawing	Soft -prototyping	Hard -prototyping	Workable -prototyping	Detail design
Contextual performance	→ 1	→ 2	→ 3	→ 4	

Result

→1		**Model summary & ANOVA**				
		R	**R^2**	**DW**	**F**	**P**
		0.821	0.674	2.297	113.683	0.000
		Coefficients				
	Styling design with CAD-drawing	**B**	**SE**	**β**	**t**	**P**
		0.597	0.056	0.821	10.662	0.000
	Constant	3.067	0.323		9.492	0.000
	Regression equation					
	$y = 3.067 + 0.597 \times x$					

→2		**Model summary & ANOVA**				
		R	**R^2**	**DW**	**F**	**P**
		0.925	0.885	2.220	324.671	0.000
		Coefficients				
	Soft -prototyping	**B**	**SE**	**β**	**t**	**P**
		0.799	0.044	0.925	18.019	0.000
	Constant	1.924	0.230		8.370	0.000
	Regression equation					

		y = .924 + 0.799 × x				

→3	Model summary & ANOVA					
		R	R²	DW	F	P
		0.881	0.777	1.837	191.363	0.000
	Coefficients					
	Hard -prototyping	B	SE	β	t	P
		0.678	0.049	0.881	13.833	0.000
	Constant	2.642	0.267		9.883	0.000
	Regression equation					
	y = 22.642 + 0.678 × x					

→4	Model summary & ANOVA					
		R	R²	DW	F	P
		0.774	0.599	1.835	82.146	0.000
	Coefficients					
	Workable -prototyping	B	SE	β	t	P
		0.710	0.078	0.774	9.063	0.000
	Constant	1.961	0.361		5.438	0.000
	Regression equation					
	y = 2.719 + 0.710 × x					

Conceptual designs produced from the styling design work in the final composition-module of Module 5 seems to strongly serve as input resources for the first sub-module that represents the soft-prototyping activity in Module 6. R^2-value is 0.674 (F=113.683, P =0.000), indicating that approximately 70% of the variation in the usefulness of manufacturing the soft-prototypes can be explained by the relationship with the quality of the final conceptual designs. Also, β -value 0.821 (P =0.000) represents that the usefulness of developing the soft-prototypes increases at a rate of 82% when the quality of the final concepts increases by one unit.

Between the main three sub-modules for soft-hard-and-workable prototyping making up this module, contextual performance also seems to work strongly in the given structure result (R^2=0.885 and 0.777, F=324.671 and 191.363, P<0.05, β= 0.925 and 0.881).

Above all, the outcomes of the prototyping module seem to strongly serve as input resources for the actual NPD phase, with R^2 of 0.600 once rounded up (F= 82.146, P=0.000) and β of 0.774 (P=0.000).

To conclude, considering the validation results above, contextual performance seems to well work in the given structure of Module 6 for the prototyping task.

2) Concurrent Collaboration

In a similar manner to the validation of the conceptual design module (Module 5), in terms of concurrent collaboration, this module (Module 6) was verified based on the descriptive statistics and narrative feedback from participants. In the module inducing concurrent collaboration by the phased-structure, collaboration is not generated between sub-modules by the quadrant structure, but this does occur within each sub-module itself with the reflecting viewpoint of four NPD-related functional areas in the process of prototyping. Hence, instead of using the regression analysis suitable for collaboration generated between sub-modules, the descriptive statistics and narrative feedback were used for the verification on whether collaboration is operated well within sub-modules themselves.

Table 6.26. *Collaboration in Module 6*

	Participant (N)	Maximum (Max)	Minimum (Min)	Mean (M)	Standard Deviation (SD)
Concurrent collaboration	57	7	4	5.81	0.107

As indicated in *Table 6.26*, collaboration to cross-check prototypes by four functional domains seems to be facilitated well in sub-modules themselves (M=5.81, SD=0.107).

Most of the participants provided positive feedback (93%, 53/57). Before using the given model, the soft-and-hard prototyping was led by industrial designers and the workable prototyping was led by experts in a R&D team; this led that requirements and conceptual designs applied in an incorrect way, or those which were not applied to prototypes, were identified frequently. Hence, they needed to modify the prototypes repeatedly after several separated meetings. However, when using the given model, these problems were remarkably reduced. By concurrently confirming and reflecting the conceptual designs originated from the requirements from the four NPD-related functional perspectives, the several meetings and iterative revision work was decreased considerably.

Consequently, based on the interpretation of the statistical analysis data along with the descriptive feedback, Module 6 (the prototyping module) seems to be well-structured for concurrent collaboration, involving the viewpoints of the four functional domains in the cross-check prototypes.

3) Section Conclusion

Module 6 for the prototyping task has been verified from contextual performance and concurrent collaboration perspectives.

The given structure strongly seems to be well-constructed for contextual performance. All R^2 and β values show to be at around 0.700 and 0.850 respectively. Through the descriptive statistics and narrative feedbacks, the structure also seems to largely foster concurrent collaboration. In the case of concurrent collaboration, the structure of Module 6 also seems to be effective for cross-check prototyping (M=5.81, SD=0.107).

Given the statistical results and narrative feedback, Module 6 appeared to be well constructed for contextual performance and concurrent collaboration.

6.3 Validation 2

– Overall Attributes

: The Current and Future Trends of FFE Model

This section describes the progress and outcomes of the validation of the pragmatic-prescriptive FFE model from the viewpoint of five overall attributes: 1) data-driven, 2) agile development, 3) incremental and radical NPDs, 4) explicitness and responsiveness and 5) procedural and performative structures. The validation aimed to demonstrate H_3 presented below.

H_3

If the pragmatic-prescriptive FFE model developed in this research is better than the model used in participants' organisations in terms of the five overall attributes,

then the developed FFE model may be regarded as an FFE model in which the overall attributes are well-fostered.

** Five Overall Attributes*

- *Data-driven Type*
- *Agile Development*
- *Both Radical and Incremental NPDs*
- *A Balance between the Explicitness and Responsiveness Characteristics*
  A Balance between the Procedural and Performative Structures

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In the validation, as mentioned before, the Wilcoxon signed-rank test used. The test is useful for validating two different targets of an experiment using the same participant group, whose results is derived mainly from differences of mean values evaluated between the control and experimental target. The same participant group was divided into two parts: 1) a control group using their own FFE models based on a retrospective record and 2) an experimental group using the given model developed in this research, based on an implementation of their actual FFE projects. The method of how to interpret each value in the analysis chart can be referenced from the page (*p. 368*). Details of the validation results and the key findings are illustrated below.

Table 6.27. Overall attribute

Wilcoxon signed-ranks test

Overall attribute	+W (Sum of positive mean rank)	(-W) Z (Sum of negative rank)	Significant Difference (P-value)
Data-driven	29.00	-6.627	0.000
Agile development	26.50	-6.362	0.000
Incremental & Radical NPD	25.00	-6.385	0.000
Explicitness & Responsiveness	22.59	-1.860	0.063
Procedure & Performative	29.00	-6.658	0.000

Cohen's d & Effect size

Overall attribute	Their own model participants (N=57)		The given model participants (N=57)		Cohen's d	Effect sizes
	M	SD	M	SD		
Data-driven	2.61	0.750	5.89	0.699	d=4.52 (large)	r=0.91 (large)
Agile development	3.88	0.734	5.74	0.745	d=2.52 (large)	r=0.78 (large)
Incremental & Radical NPD	4.77	0.756	6.08	0.583	d=1.94 (large)	r=0.69 (large)
Explicitness & Responsiveness	4.02	0.641	4.25	0.689	d=0.35 (small)	r=0.18 (small)
Procedure & Performative	2.19	0.718	5.28	0.818	d=4.01 (large)	r=0.89 (large)

Cohen's d value: 0.20=small, 0.50=medium, 0.80=large

Effect size: 0.10=small, 0.30=medium, 0.50=large

Table 6.27 shows the validation results of the pragmatic-prescriptive FFE model from the viewpoint of the five overall attributes.

When comparing means between given model and their own models, the given model received higher-rated scores in terms of all attributes; besides, a $+W$-value greater than $-W(Z)$-value strongly supports this result. P-values between the mean scores of 'Data-driven'[51], 'Agile development', 'Incremental and Radical NPD' and 'Procedure and Performative' are less than the recommended standard (0.050), while the value of 'Explicitness and Responsiveness' is greater than 0.050 ($P = 0.063$).

51 For this validation, we can say that the data-driven attribute for information processing was tested explicitly with actual field-tests. However, the knowledge accumulation aspect, the other key aspect in the data-driven attribute, was determined using the participants' reasonable judgements, based on their expertise with the FFE model; specifically whether the given model seems to have potential or capacity to accumulate knowledge and apply this knowledge to future projects.

This finding appears to demonstrate that there are statistically significant differences between the given model and their own models in terms of 'Data-driven' (W=29.00, P=0.000), 'Agile development' (W=26.50, P=0.000), 'Incremental and Radical NPD' (W=25.00, P=0.000) and 'Procedure and Performative' (W=29.00, P=0.000), whereas there are less differences in terms of 'Explicitness and Responsiveness' (W=29.00, P=0.630).

Cohen's d values were also calculated to measure the degree of differences between the given model and their models. As shown in the table, the Cohen's d values of the four metrics for 'Data-driven', 'Agile development', 'Incremental and Radical NPD' and 'Procedure and Performative' are all greater than 0.80, representing that there are large differences with large effect sizes. On the other hand, the Cohen's d value of the remaining metric – 'Explicitness-and-Responsiveness' – is between 0.20 and 0.50, which indicates that there are small and medium differences with a small and medium effect size (r=0.18).

Consequently, the given model seems to be well-developed from the viewpoint of the data-driven type, agile development, both incremental and radical NPDs, and the balanced procedural and performative structures. However, from the viewpoint of balanced explicitness and responsiveness characteristics, even if the given model seems to be slightly better than their own models due to the slightly larger mean value, there seems to be minimal difference between the two models; the reason can be explained by descriptive feedback obtained from 86% of participants (49/57). Even though Module 1 and Module 2 have responsiveness characteristics by arranging their sub-modules in a clock-wise direction in the quadrant similar to the form of the spiral process, the overall characteristic tends to be closer to the explicitness due to composition-modules being contextually connected in the phased-structure. Besides, although discretion to select specific performance methods is provided for conducting each composition-module, the model tends to have somewhat more of an explicitness characteristic in considering the overall structure that consists of sequentially arranged the main module.

In conclusion, they comprehensively judged that the given model is much better than their own model from the viewpoint of the five overall attributes. Therefore, considering statistical data along with descriptive feedback, the five overall attributes seem to be well-fostered in the developed model.

6.4 Chapter Conclusion

– Pragmatic-Prescriptive FFE Model Validation

In this chapter, the pragmatic-prescriptive FFE model developed in Chapter Five (Study 2.2) has been validated through field tests involving a questionnaire survey and self-observational diaries. The summary of the validation results and the associated key findings are illustrated below, from the following three viewpoints.

Firstly, in terms of the FFE performance structures and their operating mechanisms (regarding contextual performance and concurrent collaboration), considering all the statistical analysis data and descriptive feedback, the two alternative hypotheses, 1 and 2, seem to be strongly selected, rejecting the null hypotheses: most of the R and R^2 values were around 0.750 and 0.700 respectively ($P \leq 0.050$), representing a very strong correlation between each module, and the β values were larger than 0.750 ($P \leq 0.050$), indicating the strong influence of each previous module on each subsequent module. Namely, the FFE model seemed to have strong validity across the board. However, the following opportunities to improve the model structure were also identified.

1) **Module 1: Opportunity Identification-Screening Task**
   - Composition modules 1.1.1 to 1.1.3 for examining user types and indirect-and-direct factors affecting the possible market needs to be arranged in parallel in the market-driven research module (Sub-module 1.1).
   - Composition modules 1.3.1 and 1.3.2 for estimating the scope of shapes and colours demand to be conducted in a bundle in the aesthetic-and-symbol-driven research module (Sub-module 1.3).
2) **Module 2: Idea Generation-Screening Task**
   - Composition modules 1.1.1 to 1.1.3 for examining user types and indirect-and-direct factors affecting the possible market needs to be arranged in parallel in the market-driven research module (Sub-module 1.1).

- Composition modules 1.3.1 and 1.3.2 for estimating the scope of shapes and colours demand to be conducted in a bundle in the aesthetic-and-symbol-driven research module (Sub-module 1.3).

3) **Module 5: Conceptual Design Task**

- The third and fourth composition-modules (for assembling conceptual designs for each platform by reflecting the basic structure of the target product) need to be removed. The conceptual designs for each platform (the outcomes of the first and second composition-modules) can be assembled by directly reflecting various functions and system structures, since the module structure has the first and second composition-modules directly connected to the fifth composition-module.

Secondly, the validation, in terms of the five overall attributes, also indicated positive results: +W values were larger than the -W(Z) values in the validation data for all five attributes. The *P* values on the mean scores between the control and experimental models were less than the recommended standard (0.050), and Cohen's *d* values were greater than 0.800, meaning that there are large differences with large effect sizes. Namely, the FFE model seemed to be well-developed from the viewpoints of the data-driven type, agile development, both incremental and radical NPDs, balanced explicitness and responsiveness characteristics, and balanced procedural and performative structures. However, in terms of balanced explicitness and responsiveness characteristics, room for improvement for reinforcing the responsiveness characteristic was observed to some extent.

Thirdly, a point for improvement we need to consider in terms of concreteness was additionally found for a few modules. *Figure 6.7* shows an example graph which presents the relationship between the quality of outcomes in one module and the usefulness of performing another module. The x-axis indicates the quality of outcomes in one module, while the y-axis indicates the usefulness of conducting the other module. Until the quality of outcomes in one module reaches a certain level (around 5), the usefulness of conducting the other module increases gradually. However, after the quality of outcomes exceeds a certain level (around 6), the usefulness decreases somewhat radically. This implies that when the outcome parameters of the previous module are too specific (even if they are less defective), performers have difficulties in fulfilling achieving the same level of precision for outcomes in subsequent modules. According to feedback from participants, this phenomenon does not seem to be caused by the structure itself (which promotes contextual performance and concurrent collaboration). Therefore, downgrading the concreteness of these modules yet maintaining the current structure may be effective.

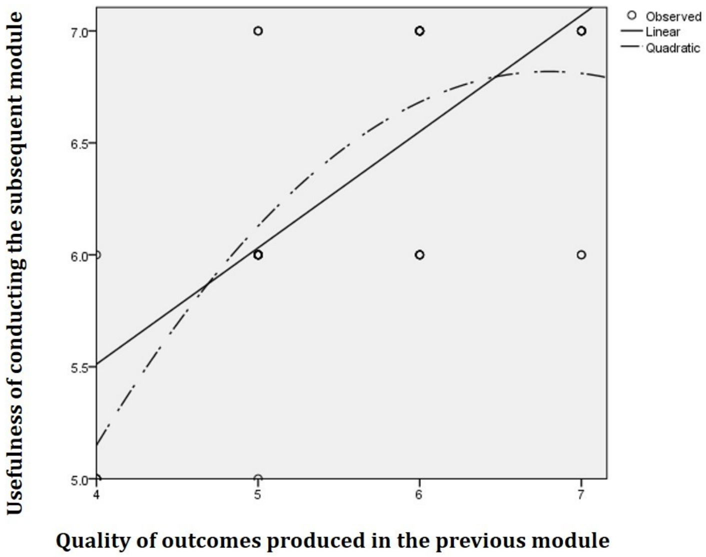

Figure 6.7. *Example graph presenting the relationship between the quality of outcomes in previous module and the usefulness of performing subsequent module*

In conclusion, the pragmatic-prescriptive FEE model developed in this research has been strongly substantiated. The validation results indicate that the FFE model has the strong possibility of being effective for contextual performance and concurrent collaboration. Also, the data implies that the five overall attributes (with respect to current and future trends in the FFE model improvement) are well fostered in the FFE model. However, we need to consider a few improvement points: a few composition-modules need to be removed or integrated into the previous composition-modules and the overall structure needs to decrease its concreteness but maintain the current structure-building mechanism.

Chapter 7. Study 3.2

– Pragmatic-Prescriptive FFE Model Generalisation

– Theoretical-Descriptive FFE Model Development

7.1 Chapter Introduction

This chapter illustrates the progress and key findings of Study 3.2, which fulfils Objective 5 (shown in *Figure 7.1*).

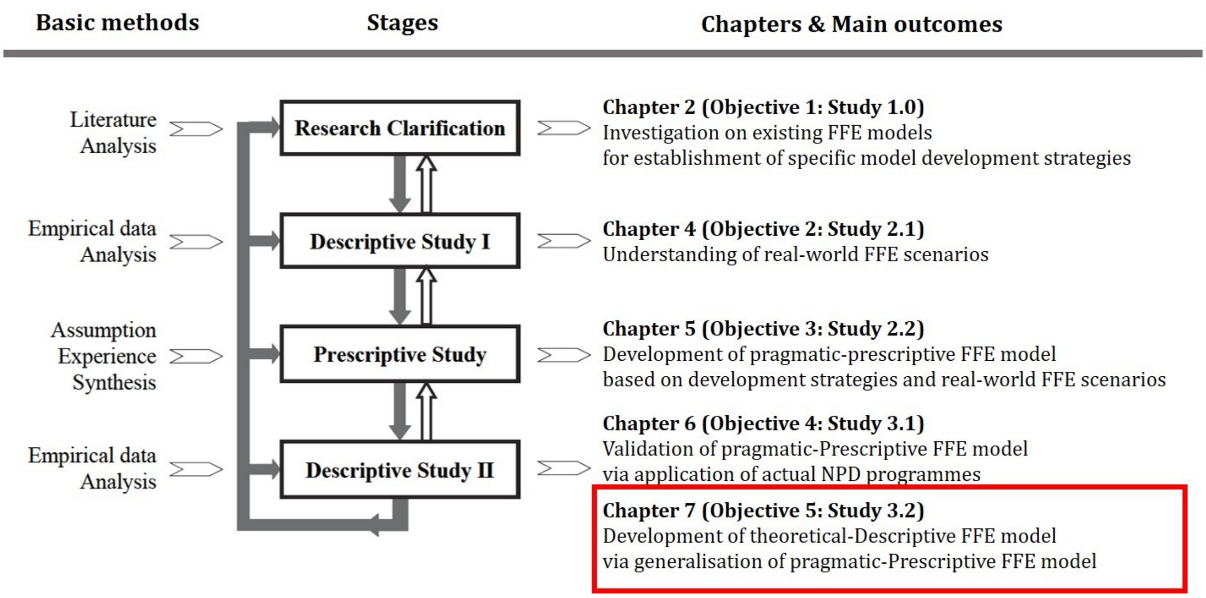

Figure 7.1. *Mini-map of Study 3.2 (Own depiction, adapted from Blessing & Chakrabarti, 2009)*

The research objective of this chapter is first introduced, followed by the research method to accomplish the objective, before concluding with a chapter summary.

1) Research Objective
2) Research Method
3) Research Summary

7.1.1 Research Objective

The goal of Study 3.2 is to fulfil Objective 5: generalising the pragmatic-prescriptive FFE model developed in Chapter Five (Study 2.2), based on the validation results presented in Chapter Six (Study 3.1), to produce a theoretical-descriptive FFE model.

The generalisation considered the following two viewpoints on the validation results: 1) performance structure and its operating mechanism and 2) overall attributes.

Firstly, the majority of the field-test results addressed in the previous sections have indicated the strong validity of the pragmatic-prescriptive model in terms of the FFE performance structure and its operating mechanism and with regard to contextual performance and concurrent collaboration, except for a few minor areas in need of improvement. These areas for improvement did not seem to significantly affect the FFE performance structure since a few of the composition-modules could be removed or integrated into other modules within the same structure of contextual performance and concurrent collaboration. The number of removed and integrated composition modules was less than five, from among a total of 62. Therefore, the strong possibility of the generalisation of the model can be considered.

Secondly, the five overall attributes also seemed to be well integrated into the model. Even though the balanced explicitness and responsiveness characteristics were not remarkably different between the model developed in this research and the models used in participants' organisations, this also does not seem to influence the model's generalisation. This is because the evaluated *Mean* and *W* values of the developed model were larger than that of their own models.

Thus, the pragmatic-prescriptive FFE model can be generalised, with the result that a theoretical-descriptive FFE model. The theoretical-descriptive FFE model took a form of a mathematical formula since a particular pattern which can be handled mathematically in the progress of the pragmatic-prescriptive FFE model's generalisation was observed.

7.1.2 Research Method

An outline of the research method for Study 3.2 conducted in this chapter is shown in the block coloured with red in *Figure 7.2*. Fundamentally, the overall direction of the research method was approached using deductive reasoning under the positivism paradigm.[52] More details of the research method are described below.

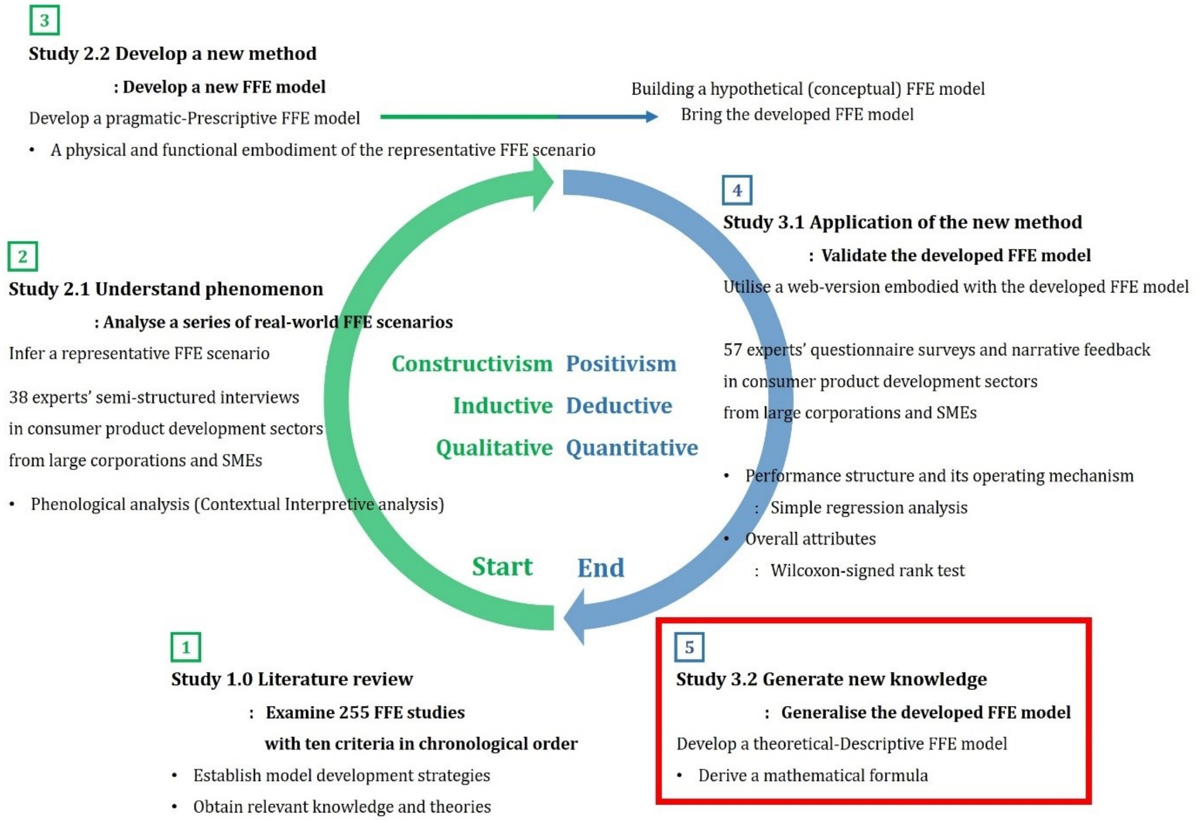

Figure 7.2. *Research method of Study 3.2*

The concepts and methods for generalising the pragmatic-prescriptive FFE model were referenced from studies on 'Axiomatic Design Theory', as conducted by Suh (1988; 1990; 2001). These studies are regarded as the genesis of mathematical models for design activities. Suh's model provides mathematical theories for four different sequential steps of design activities when generating design concepts: 1) Consumer Attributes (CAs), 2) Functional Requirements (FRs), 3) Design Parameters (DPs), and 4) Process Variables

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[52] More details of the deductive reasoning process under the positivists' research worldview can be found in Chapter Three (Research Methodology, *pp. 112-113*).

(PVs). Based on an understanding of the purpose, roles, and parameters of each step, theories for each step, in the form of mathematical formulas, were developed.

By referencing this concept and direction, the purpose, roles, and parameters of each FFE task in the pragmatic-prescriptive FFE model developed in this research and a particular pattern which can be treated mathematically when using the FFE model were grasped. Consequently, mathematical theories representing a fundamental theoretical concept for implementing each FFE task were derived. The theoretical concepts behind the FFE tasks came down to a single mathematical theory, an underlying theoretical concept for the entire FFE execution, in the same context as with the pragmatic-prescriptive model structure in which all parameters interlock from beginning to end.

Since the validation of the pragmatic-prescriptive FFE model proceeded based on statistical probability, the generalised FFE model cannot be regarded as a kind of 'law'. However, if the developed pragmatic-prescriptive FFE model is tested consistently over a long period of time under various experimental conditions, we can, at least, estimate that a generalised FFE model will be derived in the form of the mathematical formula, as presented in this chapter (Study 3.2).

7.1.3 Research Summary

This chapter produces a theoretical-descriptive FFE model by generalising the pragmatic-prescriptive FFE model and its validation results, using the research method presented above. The theoretical-descriptive FFE model indicates an underlying theoretical concept for performing the entire FFE phase with a mathematical theory wherein the basic concepts for implementing the main modules (FFE tasks) are reduced to a single theory.

This chapter is, overall, divided into the following seven sections for producing each mathematical theory, representing a fundamental theoretical concept for conducting the seven modules (FFE task). In the chapter conclusion, those mathematical theories are summed up with a single mathematical theory for executing the whole FFE stage.

0) Preliminary Task (Module 0)
1) Opportunity Identification-Screening Task (Module 1)
2) Idea Generation-Screening Task (Module 2)
3) Requirements List and Mission Statement Tasks (Modules 3 and 4)
4) Conceptual Design and Prototyping Tasks (Modules 5 and 6)

7.2 Preliminary Task – Module 0

The purpose of Module 0 in the preliminary task is to define improvement or development directions respectively for increment or radical NPDs. For this module, a particular mathematical theory is not derived for the following two reasons.

Firstly, as shown in the nature and concept of this task, presented in Chapter Four (Study 2.1, *p. 151*), once the improvement or development directions are defined in this Module 0, the target product in which these directions are reflected is scrutinised in Module 1 (Opportunity Identification-Screening Task). Therefore, parameters produced in Module 1 can be considered to already have the directional nature in terms of incremental or radical NPDs, and thus Module 0, as a preparation module, can be regarded as being included in Module 1.

Secondly, the aim of this task is not to produce specific parameters for NPDs in the FFE but about providing abstract improvement or development directions, e.g. the development of a reddish-metallic-and-slim mobile phone for young users below the age of 30. This leads to difficulties in detecting a particular pattern which can be dealt with mathematically when establishing abstract improvement or development directions.

Thus, for these two reasons, the preliminary task does not deduce a mathematical formula.

7.3 Opportunity Identification-Screening – Module 1

This section illustrates a mathematical formula transformed from the structure of the opportunity identification-screening module (Module 1). The primary purpose of Module 1 is to scrutinise the target product on a component basis from the market-driven, user-driven, and aesthetic-and-symbol-driven, and technology-driven domains, based on the improvement or development directions established in the preliminary task (Module 0). *Table 7.1* is a chart in which the structure of Module 1 for the opportunity identification-screening task is schematised.

Table 7.1. *Schematic chart of opportunity identification-screening task (Module 1)*

$\boldsymbol{o_k^m}$ = Market-driven Research		
o_1^m	Parameter set 1	Component 1
o_2^m	Parameter set 2	Component 2
o_3^m	Parameter set 3	Component 3
o_4^m	Parameter set 4	Component 4
o_5^m	Parameter set 5	Component 5
. . .	. . .	. . .
o_{n-1}^m	Parameter set n-1	Component n-1
o_n^m	Parameter set n	Component n

User-driven Research = $\boldsymbol{o_k^u}$		
Component 1	Parameter set 1	o_1^u
Component 2	Parameter set 2	o_2^u
Component 3	Parameter set 3	o_3^u
Component 4	Parameter set 4	o_4^u
Component 5	Parameter set 5	o_5^u
. . .	. . .	. . .
Component n-1	Parameter set n-1	o_{n-1}^u
Component n	Parameter set n	o_n^u

$\boldsymbol{o_k^t}$ = Technology-driven Research		
o_1^t	Parameter set 1	Component 1
o_2^t	Parameter set 2	Component 2
o_3^t	Parameter set 3	Component 3
o_4^t	Parameter set 4	Component 4
o_5^t	Parameter set 5	Component 5
. . .	. . .	. . .
o_{n-1}^t	Parameter set n-1	Component n-1
o_n^t	Parameter set n	Component n

Aesthetic-and-Symbol-driven Research = $\boldsymbol{o_k^a}$		
Component 1	Parameter set 1	o_1^a
Component 2	Parameter set 2	o_2^a
Component 3	Parameter set 3	o_3^a
Component 4	Parameter set 4	o_4^a
Component 5	Parameter set 5	o_5^a
. . .	. . .	. . .
Component n-1	Parameter set n-1	o_{n-1}^a
Component n	Parameter set n	o_n^a

(k = Component No., $1 \leq k \leq n$)

As shown in *Table 7.1*, use of Module 1 can lead to each component being comprised of an opportunity parameter set produced by the market-driven, user-driven, aesthetic-and-symbol-driven and technology-driven research activity, which can be expressed as the following equation:

$$\boldsymbol{O_k} = o_k^m + o_k^u + o_k^a + o_k^t, \quad (k = Component\ No.,\ 1 \leq k \leq n)$$

$'O'$ represents 'Opportunity' and $'k'$ is each component number. In $'o_k^u'$, $'u'$ represents the user-driven research, so that $'o_k^u'$ means the opportunity parameter set produced from the user-driven research for the component k; this is identically applied to $'o_k^m'$, $'o_k^a'$ and $'o_k^t'$, representing that each opportunity parameter set obtained by the market-driven, aesthetic-and-symbol-driven and technology-driven research respectively.

Consequently, from component 1 to n, the overall opportunity parameters processed and determined in Module 1 can be expressed as follows:

$$\boldsymbol{O_k} = \begin{vmatrix} o_1^m + o_1^u + o_1^a + o_1^t \\ o_2^m + o_2^u + o_2^a + o_2^t \\ o_3^m + o_3^u + o_3^a + o_3^t \\ \vdots \\ o_n^m + o_n^u + o_n^a + o_n^t \end{vmatrix} = \begin{vmatrix} O_1 \\ O_2 \\ O_3 \\ \vdots \\ O_n \end{vmatrix} = \begin{vmatrix} Opportunity\ Parmeter\ set\ for\ component\ 1 \\ Opportunity\ Parmeter\ set\ for\ component\ 2 \\ Opportunity\ Parmeter\ set\ for\ component\ 3 \\ \vdots \\ Opportunity\ Parmeter\ set\ for\ component\ n \end{vmatrix}$$

$$\boldsymbol{O_k} = o_k^m + o_k^u + o_k^a + o_k^t, \quad (k = Component\ No.,\ 1 \leq k \leq n)$$

7.4 Idea Generation-Screening Task – Module 2

This section describes a mathematical formula derived from the structure of Module 2 (Idea Generation-Screening Module). The main purpose of Module 2 is to come up with ideas as actionable methods for materialising opportunities explored in Module 1 (Opportunity Identification-Screening Module) from the viewpoints of the market-driven, user-driven, and aesthetic-and-symbol-driven, and technology-driven domains. *Table 7.2* is a schematic chart wherein the structure of Module 2 for the idea generation-screening task is depicted.

Table 7.2. *Schematic chart of idea generation-screening task (Module 2)*

$\boldsymbol{i_k^m}$ = Market-driven Ideation		
i_1^m	Parameter set 1	Component 1
i_2^m	Parameter set 2	Component 2
i_3^m	Parameter set 3	Component 3
i_4^m	Parameter set 4	Component 4
i_5^m	Parameter set 5	Component 5
. . .	. . .	. . .
i_{n-1}^m	Parameter set n-1	Component n-1
i_n^m	Parameter set n	Component n

User-driven Ideation = $\boldsymbol{i_k^u}$		
Component 1	Parameter set 1	i_1^u
Component 2	Parameter set 2	i_2^u
Component 3	Parameter set 3	i_3^u
Component 4	Parameter set 4	i_4^u
Component 5	Parameter set 5	i_5^u
. . .	. . .	. . .
Component n-1	Parameter set n-1	i_{k-1}^u
Component n	Parameter set n	i_k^u

$\boldsymbol{i_k^t}$ = Technology-driven Ideation		
i_1^t	Parameter set 1	Component 1
i_2^t	Parameter set 2	Component 2
i_3^t	Parameter set 3	Component 3
i_4^t	Parameter set 4	Component 4
i_5^t	Parameter set 5	Component 5
. . .	. . .	. . .
i_{n-1}^t	Parameter set n-1	Component n-1
i_n^t	Parameter set n	Component n

Aesthetic-and-Symbol-driven Research = $\boldsymbol{i_k^a}$		
Component 1	Parameter set 1	i_1^a
Component 2	Parameter set 2	i_2^a
Component 3	Parameter set 3	i_3^a
Component 4	Parameter set 4	i_4^a
Component 5	Parameter set 5	i_5^a
. . .	. . .	. . .
Component n-1	Parameter set n-1	i_{n-1}^a
Component n	Parameter set n	i_n^a

(k = Component No., $1 \leq k \leq n$)

Using Module 2 can result in an individual component consisting of an actionable realisation method parameter set obtained from the market-driven, user-driven, aesthetic-and-symbol-driven and technology-driven ideation activity, which can be shown as the following equation:

$$\boldsymbol{I_k} = i_k^m + i_k^u + i_k^a + i_k^t, \quad (k = \text{Component No., } 1 \leq k \leq n)$$

$'I'$ represents 'Idea' and $'k'$ is each component number. In $'i_k^t'$, $'t'$ indicates the technology-driven ideation, so that $'i_k^t'$ represents the realisation method parameter set generated from the technology-driven ideation for the component k; this is identically reflected in $'i_k^m'$, $'i_k^u'$ and $'i_k^a'$, representing that each realisation method parameter set produced by the market-driven, user-driven research and aesthetic-and-symbol-driven ideation respectively.

Consequently, from component 1 to n, all ideation parameters processed and decided from Module 2 can be represented as follows:

$$\boldsymbol{I_k} = \begin{vmatrix} i_1^m + i_1^u + i_1^a + i_1^t \\ i_2^m + i_2^u + i_2^a + i_2^t \\ i_3^m + i_3^u + i_3^a + i_3^t \\ \vdots \\ i_n^m + i_n^u + i_n^a + i_n^t \end{vmatrix} = \begin{vmatrix} I_1 \\ I_2 \\ I_3 \\ \vdots \\ I_n \end{vmatrix} = \begin{vmatrix} Realisation\ Method\ Parameter\ set\ for\ Component\ 1 \\ Realisation\ Method\ Parameter\ set\ for\ Component\ 2 \\ Realisation\ Method\ Parameter\ set\ for\ Component\ 3 \\ \vdots \\ Realisation\ Method\ Parameter\ set\ for\ Component\ n \end{vmatrix}$$

$$\boldsymbol{I_k} = i_k^m + i_k^u + i_k^a + i_k^t, \quad (k = \text{Component No., } 1 \leq k \leq n)$$

7.5 Requirements List and Mission Statement – Modules 3 and 4

This section introduces a mathematical formula transformed from the structure of the requirements list module (Module 3). The core aim of Module 3 in the pragmatic-prescriptive FFE model is to enumerate product specification parameters. The operating mechanism for this rests in the requirements for each component, which consists of a combination of opportunity and idea parameters (shown in *Table 7.3*). The meaning of the term *combination*, presented in the sentence above, does not contain a simple physical integration but an inherent fusion for building a form of requirements. Therefore, an equation for the requirements of each component can be expressed as follows:

$$\boldsymbol{R_k} = O_k \times I_k \qquad (k = \text{Component No.},\ 1 \leq k \leq n)$$

$'R'$ represents 'Requirement' and $'k'$ is each component number. Hence, '$R_k = O_k \times I_k$' means requirements formed by the combination of opportunities and their actionable realisation methods for the component k.

Table 7.3. *Schematic chart of requirement list task (Module 3)*

Component	Opportunity $= \boldsymbol{O_k}$ *k = Component No.*	Idea $= \boldsymbol{I_k}$ *k = Component No.*	Requirement $= \boldsymbol{R_k}$ *k = Component No.*
Component 1	$o_1^m + o_1^u + o_1^a + o_1^t = O_1$	$i_1^m + i_1^u + i_1^a + i_1^t = I_1$	$O_1 \, x I_1 = R_1$
Component 2	$o_2^m + o_2^u + o_2^a + o_2^t = O_2$	$i_2^m + i_2^u + i_2^a + i_2^t = I_2$	$O_2 \, x I_2 = R_2$
Component 3	$o_3^m + o_3^t + o_3^a + o_3^t = O_3$	$i_3^m + i_3^u + i_3^a + i_3^t = I_3$	$O_3 \, x I_3 = R_3$
. . .	. . .	. . .	. . .
Component n	$o_n^m + o_n^u + o_n^a + o_n^t = O_n$	$i_n^m + i_n^u + i_n^a + i_n^t = I_n$	$O_n \, \text{x} \, I_n = R_n$

↓

Product			
Component 1 + Component 2 + Component 3 . . . Component n	$O_k = \begin{vmatrix} O_1 \\ O_2 \\ O_3 \\ \vdots \\ O_n \end{vmatrix}$ $O_k = \lvert O_1 \quad O_2 \quad O_3 \quad \cdots \quad O_n \rvert$	$I_k = \begin{vmatrix} I_1 \\ I_2 \\ I_3 \\ \vdots \\ I_n \end{vmatrix}$	(O_1 x I_1) + (O_2 x I_2) + (O_3 x I_3) . . . (O_n x I_n)

(k = Component No., $1 \leq k \leq n$)

In addition, the overall requirements list for the entire product can be formed by adding up the requirements of each component, which can be depicted with the following equation:

$$\boldsymbol{R_k} = O_k \times I_k \qquad (k = \textit{Component No.},\ 1 \leq k \leq n)$$

$$= \left| o_1^m + o_1^u + o_1^a + o_1^t \quad o_2^m + o_2^u + o_2^a + o_2^t \quad o_3^m + o_3^u + o_3^a + o_3^t \quad \cdots \quad o_n^m + o_n^u + o_n^a + o_n^t \right| \times \begin{vmatrix} i_1^m + i_1^u + i_1^a + i_1^t \\ i_2^m + i_2^u + i_2^a + i_2^t \\ i_3^m + i_3^u + i_3^a + i_3^t \\ \vdots \\ i_n^m + i_n^u + i_n^a + i_n^t \end{vmatrix}$$

$$= \left| O_1 \quad O_2 \quad O_3 \quad \cdots \quad O_k \right| \times \begin{vmatrix} I_1 \\ I_2 \\ I_3 \\ \vdots \\ I_n \end{vmatrix}$$

$$= (O_1 \times I_1) + (O_2 \times I_2) + (O_3 \times I_3) \ \ldots \ (O_n \times I_n) = \sum_{k=1}^{n} O_k \times I_k$$

$$= R_1 + R_2 + R_3 \ \ldots \ R_k = \sum_{k=1}^{n} R_k$$

In '$\sum_{k=1}^{n} O_k \times I_k$', '$R_k$' can be substituted for '$O_k \times I_k$' by the previous equation representing requirements of each component. Consequently, '$\sum_{k=1}^{n} R_k$' indicates that the overall requirements for the target product are to sum up requirements formed by the combination of the opportunity and realisation method parameters for the component from 1 to n.

And to conclude, from component 1 to n, all requirement parameters obtained from this module can be represented as follows:

$$\sum_{k=1}^{n} O_k \times I_k = \sum_{k=1}^{n} R_k \qquad (k = \textit{Component No.},\ 1 \leq k \leq n)$$

In the case of mission statement module – Module 4, its basic performance concept is to extract core requirements and arranged with the form of the project title, aim and objectives. Therefore, a particular formula was not built.

7.6 Conceptual Design and Prototyping – Modules 5 and 6

This section illustrates a mathematical formula derived from the structure of Module 5 (Conceptual Design Module). The primary goal of Module 5 is to embody visually the requirements. In the case of Module 6 (Prototyping Module), its fundamental concept relates to the physical, functional, and technical embodiment of the requirements. Therefore, articular equations of the prototyping task are in line with those of the conceptual design task.

The generalisation of Module 5 proceeds from the two perspectives:

1) On a Component Basis
2) On a Platform Basis

As shown in the initial composition-module in the conceptual design module (Module 5, *p. 322*), developed by considering analyses of real-world FFE scenarios, each component unit generally consists of the main component and relevant sub-components. The component unit is substituted with a platform unit when developing the conceptual design. Generally, in the FFE, sub-components are hardly ever defined, so the component unit can be replaced with the platform unit.

However, there is a case in which the platform unit consists of the main component and related sub-components. This case commonly occurs where the target product requires an embodiment of a more complex system from the viewpoint of the functional and technical operation of the product or aesthetic appearance.

Thus, we need to consider the two cases when generalising this module.

The following sections begin by introducing a mathematical formula on a component basis, followed by an introduction of the same formula but on a platform basis.

7.6.1 Conceptual Design on a Component Basis

Table 8.4 shows a schematic chart in which the structure of Module 5 for the conceptual design task, conducted on a component basis, is outlined.

Table 7.4. *Schematic chart 1 of conceptual design task (Module 5)*: on a component basis

Component = Platform	**Requirement** $\boldsymbol{R_k}$	**Various conceptual design for platform** $\boldsymbol{V_k(i)}$	**FIltering processing** $\boldsymbol{V_k(iCr) \rightarrow V_k(rC1)}$	**Best Conceptual design for platform** $\boldsymbol{C_k = R_k \times V_k(rC1)}$
	k = Component No., 1≤k ≤ n *i = Principal design No.* *r = The number of optimal principal designs*			
Component 1 = Platform 1	$O_1\ xI_1 = R_1$	$V_1(1)V_1(2)V_1(3)\ldots V_2(i)$	$V_1(rC1)$ **Step 1** $iCr\ (e.g.10C3)$ $= \frac{i\,P\,r}{r!}$ $= \frac{i\,(i-1)\times(i-2)\times(i-r+1)}{r!}$ $= \frac{i!}{r!(i-r)!}$ ↓ *Filtering* **Step 2** $rC1\ \ (e.g.3C1)$	$R_1 \times V_1(rC1) = C_1$
Component 2 = Platform 2	$O_2\ xI_2 = R_2$	$V_2(1)V_2(2)V_2(3)\ldots V_2(i)$	$V_2(rC1)$	$R_2 \times V_2(rC1) = C_2$
Component 3 = Platform 3	$O_3\ xI_3 = R_3$	$V_3(1)V_3(2)V_3(3)\ldots V_3(i)$	$V_3(rC1)$	$R_3 \times V_3(rC1) = C_3$
⋮	⋮	⋮	⋮	⋮
Component n = Platform n	$O_n\ xI_n = R_n$	$V_n(1)V_n(2)V_n(3)\ldots V_n(i)$	$V_n(rC1)$	$R_n \times V_n(rC1) = C_n$
Product				
Platform 1 + Platform 2 + Platform 3 + ⋮	$R_k = \begin{vmatrix} R_1 \\ R_2 \\ R_3 \\ \vdots \\ R_n \end{vmatrix}$	$V_k(i) = \begin{vmatrix} V_1(1)V_1(2)V_1(3)\ldots V_1(i) \\ V_2(1)V_2(2)V_2(3)\ldots V_2(i) \\ V_3(1)V_3(2)V_3(3)\ldots V_3(i) \\ \vdots \\ V_n(1)V_n(2)V_n(3)\ldots V_n(i) \end{vmatrix}$	$V_k(rC1) = \begin{vmatrix} V_1(rC1) \\ V_2(rC1) \\ V_3(rC1) \\ \vdots \\ V_n(rC1) \end{vmatrix}$	$\{R_1 \times V_1(rC1)\}$ + $\{R_2 \times V_2(rC1)\}$ + $\{R_2 \times V_3(rC1)\}$ ⋮

. . + Platform n				$\{R_n \times V_n(r\text{C}1)\}$ = $C_1 + C_2 + C_3 + \dots + C_n$

As mentioned before, a component unit consisting of the main component and sub-components are generally grouped and replaced by each platform unit. However, considering on the descriptive feedback from field tests, in most cases of the FFE execution in the conceptual design, the FFE phase does not generally define components minutely, unlike what is doing in the actual design phase, so that most of the component units are used to be replaced with the platform unit as it is. Therefore, the generalisation of this module proceeded based on the standard that each platform can be regarded as containing requirements of each component.

For each platform (component) containing requirements, conceptual designs are devised as many as the number of i. In '$V_k(i)$', $'V'$ indicates various conceptual designs, $'k'$ represents the platform (component) number and $'i'$ means the number of the various conceptual designs. Hence, '$V_k(i)$' means the i number of various conceptual designs for the platform (component) k.

Then, among the i number of various conceptual designs for platform (component) k, we need to choose an optimum design with the following two steps. In the first step, we can select optimal ones as many as the number of r among the i number of conceptual designs. In the second step, we can choose the best one among the r number of the optimal designs. These two steps can be represented with the following formula:

$$Step\ 1: V_k(i\text{C}r) \longrightarrow Step\ 2: V_k(r\text{C}1)$$

As a result, the optimum conceptual design for platform (component) k can be expressed as follows:

$$C_k = R_k \times V_k(r\text{C}1)$$

$'C'$ indicates 'Conceptual design', $'R'$ represents requirements and '$V_k(r\text{C}1)$' means the selected best design among the r number of optimal designs. Namely, the conceptual design for platform k can be regarded as choosing the best conceptual design among various alternatives, in which requirements for the platform (component) k are reflected.

Consequently, by using Module 5 in the pragmatic-prescriptive model, the conceptual design of the entire product is formed by assembling the best conceptual design of each platform (component) containing requirement parameters. This can be depicted by the equation as follows:

$$\sum_{k=1}^{n} R_k \times V_k(r\mathrm{C}1)'$$

$$= \sum_{k=1}^{n} C_k$$

More detailed reasoning processes of the equation are presented below:

$\boldsymbol{C_k}$ *(k = Component No., 1≤ k ≤ n, r = The number of optimal principal designs)*

$$= \begin{vmatrix} R_1 & R_2 & R_3 & \dots & R_n \end{vmatrix} \times \begin{vmatrix} V_1(r\mathrm{C}1) \\ V_2(r\mathrm{C}1) \\ V_3(r\mathrm{C}1) \\ \vdots \\ V_n(r\mathrm{C}1) \end{vmatrix}$$

$$= \{R_1 \times V_1(r\mathrm{C}1)\} + \{R_2 \times V_2(r\mathrm{C}1)\} + \{R_3 \times V_3(r\mathrm{C}1)\} + \dots\dots + \{R_n \times V_n(r\mathrm{C}1)\}$$

$$= \sum_{k=1}^{n} R_k \times V_k(r\mathrm{C}1)$$

$$= \sum_{k=1}^{n} C_k$$

7.6.2 Conceptual Design on a Platform Basis

On occasion, where the target product demands a more complex system, there is a case where the target product is largely scrutinised in the FFE, so that there are many component units, comprised of the main component and sub-components. In this case, the component unit might not be replaced with the platform unit. Instead, the platform unit can be formed by integrating the component units that have similar functions. By reflecting this case, an alternative mathematical theory to the one mentioned above for this module (Module 5) was generated, as follows.

Table 7.5. *Schematic chart of platform building*

Component	Requirement	Grouping	Platform
	$\boldsymbol{R_k}$ k = *Component No.,* $1 \leq k \leq n$	$\boldsymbol{G_j \rightarrow R_k \in G}$ $\boldsymbol{R_k = X,}$ $\boldsymbol{G = \{X \;/ X \text{ is an element of } G\}}$ $\boldsymbol{R = \begin{vmatrix} O_1 \text{ x } I_1 \\ \vdots \\ O_k \text{ x } I_k \end{vmatrix} = \begin{vmatrix} R_1 \\ \vdots \\ R_k \end{vmatrix}}$ j = *Grouping No.* k = *Component No.,* $1 \leq k \leq n$	$\boldsymbol{P_j = Sum\ of\ G_j{}'s\ elements}$ $\boldsymbol{P_j = \sum_{k=1}^{n} R_k}$ j = *Grouping No.= Platform No.* k = *Component No.,* $1 \leq k \leq n$
Component 1	$O_1 \text{ x } I_1 = R_1$	$G_1 = \begin{vmatrix} O_1 \text{ x } I_1 \\ O_2 \text{ x } I_2 \\ O_3 \text{ x } I_3 \end{vmatrix} = \begin{vmatrix} R_1 \\ R_2 \\ R_3 \end{vmatrix}$	$P_1 = Sum\ of\ G_1{}'s\ elements$ $= \sum_{k=1}^{3} R_k = R_1 + R_2 + R_3$
Component 2	$O_2 \text{ x } I_2 = R_2$		
Component 3	$O_3 \text{ x } I_3 = R_3$		
Component 4	$O_4 \text{ x } I_4 = R_4$	$G_2 = \begin{vmatrix} O_4 \text{ x } I_4 \\ O_5 \text{ x } I_5 \\ O_6 \text{ x } I_6 \\ O_7 \text{ x } I_7 \end{vmatrix} = \begin{vmatrix} R_4 \\ R_5 \\ R_6 \\ R_7 \end{vmatrix}$	$P_2 = Sum\ of\ G_2{}'s\ elements$ $= \sum_{k=4}^{7} R_k = R_4 + R_5 + R_6 + R_7$
Component 5	$O_5 \text{ x } I_5 = R_5$		
Component 6	$O_6 \text{ x } I_6 = R_6$		
Component 7	$O_7 \text{ x } I_7 = R_7$		
Component 8	$O_8 \text{ x } I_8 = R_8$	$G_3 = \begin{vmatrix} O_8 \text{ x } I_8 \\ O_9 \text{ x } I_9 \end{vmatrix} = \begin{vmatrix} R_8 \\ R_9 \end{vmatrix}$	$P_3 = Sum\ of\ G_3{}'s\ elements$ $= \sum_{k=8}^{9} R_k = R_8 + R_9$
Component 9	$O_9 \text{ x } I_9 = R_9$		
. . .	. . .	. . .	. . .
Component m	$O_m \text{ x } I_m = R_m$	$G_j = \begin{vmatrix} O_m \text{ x } I_m \\ \vdots \\ O_n \text{ x } I_n \end{vmatrix} = \begin{vmatrix} R_m \\ \vdots \\ R_n \end{vmatrix}$	$P_j = Sum\ of\ G_n{}'s\ elements$ $= \sum_{k=m}^{n} R_k = R_m + \ldots\ldots + R_n$
. . .	. . .		
Component n	$O_n \text{ x } I_n = R_n$		

Table 8.5 above describes the schematic chart of the platform units, with an example. The example shows that components 1 to 3 can be grouped under platform 1; components 4 to 7 can be integrated into platform 2; and platform 3 can consist of components 8 and 9. In this, each component contains each relevant requirement formed by the combination

of opportunities and their realisation methods. The grouping process can be expressed with the following formula:

$$G_j \rightarrow R_k \in G, \quad (j = \text{Grouping No., } k = \text{Component No., } 1 \leq k \leq n)$$

$$R_k = X, \qquad G = \{X \;/\; X \text{ is an element of } G\}$$

$$G_j = \begin{vmatrix} O_1 \; x \; I_1 \\ \vdots \\ O_k \; x \; I_k \end{vmatrix} = \begin{vmatrix} R_1 \\ \vdots \\ R_k \end{vmatrix}$$

Applying the example of group 1 that consists of components 1 to 3, the relevant formula can come into being as follows:

$$G_1 = \begin{vmatrix} O_1 \text{ x } I_1 \\ O_2 \text{ x } I_2 \\ O_3 \text{ x } I_3 \end{vmatrix} = \begin{vmatrix} R_1 \\ R_2 \\ R_3 \end{vmatrix}$$

$$(j = \text{Grouping No., } k = \text{Component No., } 1 \leq k \leq 3)$$

Since the platform in the product architecture is the form in which the involved components are coupled, the formula for each platform can be depicted as follows:

$$P_j = Sum \; of \; G_j{}'s \; elements$$

$$P_j = \sum_{k=1}^{n} R_k$$

$$(j = \text{Grouping No., } k = \text{Component No., } 1 \leq k \leq n)$$

Reflecting the same example of group 1 (comprised of components 1 to 3), the relevant formula can be shown as follows:

$$P_1 = Sum \; of \; G_j{}'s \; elements$$

$$P_1 = \sum_{k=1}^{3} R_k$$

$$P_1 = R_1 + R_2 + R_3$$

$$(j = \text{Grouping No., } k = \text{Component No., } 1 \leq k \leq 3)$$

This formula can replace the initial part of the schematic chart shown in *Table 8.4* (*pp. 446-447*). The replaced part is marked with the bold block in *Table 8.6*.

Table 7.6. *Schematic chart 2 of conceptual design task (Module 5):* on a platform basis

Component	Platform	Various Conceptual design for platform	FIltering processing	Optimal conceptual design for platform
	$\boldsymbol{P_j} = \boldsymbol{Sum\ of\ G_j's\ elements}$ $\boldsymbol{P_j = \sum_{k=1}^{n} R_k}$ j = *Platform No.* k = *Component No.*	$\boldsymbol{V_j(i)}$ j = *Platform No.* $1 \le j \le n$ i = *Principal design No.*	$\boldsymbol{V_j(iCr) \rightarrow V_j(rC1)}$ j = *Platform No.,* $1 \le j \le n$ i = *Principal design No.* r = *The number of optimal principal designs*	$\boldsymbol{C_j = P_j \times V_j(rC1)}$ j = *Platform No.,* $1 \le j \le n$
Component 1	P_1 $= Sum\ of\ G_1's\ elements$ $= \sum_{k=1}^{3} R_k = R_1 + \cdots R_3$	$V_1(1)V_1(2)V_1(3)\ldots V_1(i)$	$V_j(rC1)$ **Step 1** iCr $(e.g.\ 10C3)$ $= \frac{i\ P\ r}{r!}$ $= \frac{i\ (i-1) \times (i-2) \times (i-r+1)}{r!}$ $= \frac{i!}{r!(i-r)!}$ ↓ *Filtering by* **Step 2** $rC1$ $(e.g.\ 3C1)$	$P_1 \times V_1(rC1)$ $= C_1$
Component 2				
Component 3				
Component 4	P_2 $= Sum\ of\ G_2's\ elements$ $= \sum_{k=4}^{7} R_k = R_4 + \cdots R_7$	$V_2(1)V_2(2)V_2(3)\ldots V_2(i)$	$V_2(rC1)$	$P_2 \times V_2(rC1)$ $= C_2$
Component 5				
Component 6				
Component 7				
Component 8	P_3 $= Sum\ of\ G_3's\ elements$ $= \sum_{k=8}^{9} R_k = R_8 + R_9$	$V_3(1)V_3(2)V_3(3)\ldots V_3(i)$	$V_3(rC1)$	$P_3 \times V_3(rC1)$ $= C_3$
Component 9				
. . .	. . .	. . .	. . .	. . .
Component n	P_j $= Sum\ of\ G_n's\ elements$ $= \sum_{k=m}^{n} R_k = R_m + \cdots R_n$	$V_n(1)V_n(2)V_n(3)\ldots V_n(i)$	$V_n(rC1)$	$P_n \times V_n(rC1)$ $= C_n$

↓

Product				
Platform 1 + Platform 2 + Platform 3 + ... + Platform n	P_j $= \begin{vmatrix} P_1 \\ P_2 \\ P_3 \\ \vdots \\ P_n \end{vmatrix}$	$V_j(i)$ $= \begin{vmatrix} V_1(1)V_1(2)V_1(3)\ldots V_1(i) \\ V_2(1)V_2(2)V_2(3)\ldots V_2(i) \\ V_3(1)V_3(2)V_3(3)\ldots V_3(i) \\ \vdots \\ V_n(1)V_n(2)V_n(3)\ldots V_n(i) \end{vmatrix}$	$V_j(rC1)$ $= \begin{vmatrix} V_1(rC1) \\ V_2(rC1) \\ V_3(rC1) \\ \vdots \\ V_n(rC1) \end{vmatrix}$	$\{P_1 \times V_1(rC1)\}$ + $\{P_2 \times V_2(rC1)\}$ + $\{P_3 \times V_3(rC1)\}$ . . . $\{P_n \times V_n(rC1)\}$ = $C_1 + C_2 + C_3 + \ldots + C_n$

Also, the formula for the conceptual design can be modified accordingly as follows.

$$\boldsymbol{C_j} \quad (j = Platform\ No.,\ 1 \leq j \leq n,\ r = \text{The number of optimal principal designs})$$

$$= |P_1 \quad P_2 \quad P_3 \quad \cdots \quad P_n| \quad \times \quad \begin{vmatrix} V_1(r\mathrm{C}1) \\ V_2(r\mathrm{C}1) \\ V_3(r\mathrm{C}1) \\ \vdots \\ V_n(r\mathrm{C}1) \end{vmatrix}$$

$$= \{P_1 \times V_1(r\mathrm{C}1)\} \quad + \quad \{P_2 \times V_2(r\mathrm{C}1)\} \quad + \quad \{P_3 \times V_3(r\mathrm{C}1)\} \quad + \quad \ldots\ldots. \quad + \quad \{P_n \times V_n(r\mathrm{C}1)\}$$

$$= \sum_{j=1}^{n} P_j \times V_j(r\mathrm{C}1)$$

$$= \sum_{j=1}^{n} C_j$$

7.6.3 Section Conclusion

Consequently, no matter whether the conceptual design is conducted on a component basis (*pp. 446-448*) or on a platform basis (*p. 449-452*), the basic theoretical concept of the formula for this module (*Module 5*) is identical. In the case conducted as component-based, the conceptual design for the entire product can be formed by assembling all components that have optimally conceptualised requirements. On the other hand, when performing as platform-based, the conceptual design for the whole product can be derived by assembling all optimally conceptualised platforms architected with relevant components that consist of requirements.

7.8 Chapter Conclusion

– Theoretical-Descriptive FFE Model Development

In this chapter, the pragmatic-prescriptive FFE model developed in Chapter Five (Study 2.2.) has been generalised based on the validation results derived in Chapter Six (Study 3.1).

The pragmatic-prescriptive FFE model has been generalised using the main module unit, producing each mathematical formula that represents a fundamental theoretical concept for performing each FFE task. In the same context as with the structure of the pragmatic-prescriptive FFE model wherein all parameters interlock with each other from beginning to end, those theories have been concluded with a single mathematical theory indicating the underlying theoretical concept of the entire FFE execution.

0) **Preliminary Task:**
   Module 0
   The target product in which improvement or development directions established in the preliminary task are reflected is scrutinised in the opportunity identification-screening task present below. Therefore, parameters produced in Module 1 contains can be considered to have already the directional nature in terms of incremental or radical NPDs, and thus Module 0, as a preparation module, can be regarded as being included in Module 1. Consequently, for this module, a particular mathematical theory was not derived.[53]

1) **Opportunity Identification-Screening and Idea Generation-Screening Task:**
   Module 1 and 2
   $O_k = o_k^m + o_k^u + o_k^a + o_k^t$ and $I_k = i_k^m + i_k^u + i_k^a + i_k^t$, *k = component No.*
   - Opportunities are NPD-related parameter sets scrutinised on a component basis from the market-driven, user-driven, aesthetic-and-symbol-driven and technology-driven research activity;

[53] More details can be found in *p. 438*.

- Ideas are actionable realisation method parameter sets devised on a component basis from the market-driven, user-driven, aesthetic-and-symbol-driven and technology-driven ideation activity.

2) **Requirements List (Mission Statement) Task:**
   Module 3 and 4
   $R_k = O_k \times I_k$, k *= component No.*
   - Requirements are the combination of the parameter sets produced from the opportunities and ideas, on a component basis.

3) **Conceptual Design (and Prototyping) Task:**
   Module 5 and 6
   $\sum_{k=1}^{n} R_k \times V_k(rC1)$
   $$= \sum_{k=1}^{n} C_k$$
   k *= component No,* r = *The number of optimal principal designs*
   - Conceptual designs (and Prototypes) are the assembling of optimal visual, functional and technical conceptualisations (embodiment) of each requirement, on a component basis.

The final formula, '$\sum_{k=1}^{n} C_k$', represents an overall outcome of the FFE. In order to derive its inherent meaning, the formula can be dismantled by the reverse order of building the above formula.[54]

$$\sum_{k=1}^{n} C_k$$
$$= \sum_{k=1}^{n} R_k \times V_k(rC1)$$

[54] The formula built for conducting on a platform basis, presented in *pp. 449-452*, was not applied in the final generalisation, focusing on the case conducting on a component basis which occurs more frequently in the FFE phase.

$$= \sum_{k=1}^{n} (O_k \times I_k) \times V_k(rC1)$$

$$= \sum_{k=1}^{n} (o_k^m + o_k^u + o_k^a + o_k^t) \times (i_k^m + i_k^u + i_k^a + i_k^t) \times V_k(rC1)$$

The formula presented in the last line represents an underlying theoretical concept of executing an overall FFE phase.

$$\sum_{k=1}^{n} (o_k^m + o_k^u + o_k^a + o_k^t) \times (i_k^m + i_k^u + i_k^a + i_k^t) \times V_k(rC1)$$

k = *component No.*, r = *The number of optimal principal designs*

Consequently, the overall FFE execution can be regarded as a vision of a new product that can be embodied by assembling components in which requirements comprised of opportunities and their realisation methods derived from the market-driven, user-driven, aesthetic-and-symbol-driven and technology-driven study are optimally conceptualised from the visual, functional and technical perspective.

In summary, in this chapter, the structure of the pragmatic-prescriptive FFE model has been generalised into the theoretical-descriptive FFE model. The theoretical-descriptive FFE model shows the theoretical concept of processing and determining parameters when using the pragmatic-prescriptive FFE model. This, meanwhile, also represents the theoretical concept of the data-driven performative type of the FFE model for contextual performance and concurrent collaboration. Furthermore, the theoretical-descriptive FFE model indicates that the parameters processed and decided in the pragmatic-prescriptive FFE model inherently contain the nature of the directions for incremental and radical NPDs. Furthermore, the nature of the balance between the explicitness and responsiveness characteristics and the balance between the procedural and performative structures seem to be inherently embedded in the theoretical-descriptive FFE model. Thus, the theoretical-descriptive FFE model would appear to fulfil the development strategies (established in Chapter Two, Literature Review) needed to complement the limitations of previous FFE models.

Chapter 8. Discussion

8.1 Chapter Introduction

This chapter discusses key assertions and insights regarding the key findings produced in Studies 2.1 to 3.2, conducted in Chapters Four to Seven. These discussions cover the following areas: 1) the understanding of real-world FFE scenarios, 2) the developed pragmatic-prescriptive FFE model, 3) the application of the pragmatic-prescriptive FFE model, and 4) the generalised theoretical-descriptive FFE model. The first two areas relate to the pragmatic-prescriptive FFE model's development. The latter two relate to the theoretical-descriptive model.

Pragmatic-Prescriptive FFE model Development

1) Study 2.1: understanding actual NPD practices and proposing a representative real-world FFE scenario
2) Study 2.2: developing the pragmatic-prescriptive FFE model which can provide practical-functional FFE execution guidance

Theoretical-Descriptive FFE Model Development

3) Study 3.1: validating the pragmatic-prescriptive FFE model and suggesting applicable cases for practical-functional FFE execution guidance
4) Study 3.2: developing the theoretical-descriptive FFE model which can provide theoretical-conceptual FFE execution guidance

Through confirmation of the assertions and insights on the main findings obtained in each study, what each key finding mean can be grasped. Furthermore, how the key outcomes, assertions, and insights of this study differ from those of previous FFE studies can then be laid out.

In the following chapters, core assertions and insights on the primary findings obtained in Studies 2.1 to 3.2 are discussed, study by study. Then, in the chapter conclusion, the assertions and insights are summed up, divided into two groups, the pragmatic-prescriptive FFE model and theoretical-descriptive FFE model.

8.2 Study 2.1
– Understanding Actual FFE Practices

This section outlines major assertions and insights on the representative FFE scenario (see the chapter conclusion of Chapter Four, *pp. 251-264*) inferred from various actual FFE practices gathered and analysed in Chapter Four (Study 2.1).

The representative FFE scenario suggests the strong possibility of developing a physical and functional FFE model for contextual performance and concurrent collaboration. The following two insights are relevant:

1) The possibility of building a representative FFE scenario: there are gaps in that this has not been done before (previously, different FFE scenarios, including diverse FFE execution principles and approaches, were provided in different FFE models.
2) The possibility of connecting the progress and outcomes of each task, activity, performance method, and toolkit throughout the representative FFE scenario

Firstly, the work on determining linkages indicates that in FFE execution principles and approaches and in FFE practice examples scattered across different FFE practices, the possibility of linking together different purposes and roles of each disassembled units was confirmed from the viewpoint of contextual performance and concurrent collaboration, to infer a representative FFE scenario. This implies the potential of aiding in the comprehension of how to conduct the FFE by connecting different contextual FFE implementations.

Secondly, through the inferred representative FFE scenario, the possibility of connecting the progress and outcomes of each task, activity, performance method, and toolkit from the contextual performance and concurrent collaboration perspectives was confirmed. This implies the potential of fully understanding how the FFE can be conducted from beginning to end, with consideration of contextual performance and concurrent collaboration.

In summary, an analysis of FFE scenarios was conducted. It looked at ways in which FFE tasks, activities, performance methods, and toolkits can be linked together for contextual performance and concurrent collaboration. Until now, these FFE practices have been executed with different FFE principles and approaches. This hints at the strong possibility of reasoning a representative FFE scenario for developing an FFE model for contextual performance and concurrent collaboration. The representative FFE scenario was reasoned in Chapter Four (Study 2.1) and the FFE model was developed in Chapter Five (Study 2.2). The assertions and insights on the developed model are presented in the next section.

8.3 Study 2.2 – Pragmatic-Prescriptive FFE Model Development

8.3.1 Section Introduction

This section delineates the main assertions and insights on the pragmatic-prescriptive FFE model developed in Chapter Five (Study 2.2). The pragmatic-prescriptive FFE model was physically and functionally embodied with not only the representative FFE scenario (the key finding which was inferred in Chapter Four, Study 2.1) but also its assertions and insights. The entire model can be found in the chapter conclusion of Chapter Five (*pp. 337-345*), and details of each partial component can be identified in each relevant section of said chapter.

Considering three aspects of the key findings which come from the pragmatic-prescriptive FFE model, details of assertions and insights on the findings are described in the following three sub-sections:

1) Insights on Contextual Performance Operation in the Pragmatic-Prescriptive FFE Model
2) Insights on Concurrent Collaboration Operation in the Pragmatic-Prescriptive FFE Model
3) Insights on Overall Attributes in the Pragmatic-Prescriptive FFE Model

8.3.2 Insights on Contextual Performance Operation in the Pragmatic-Prescriptive FFE Model

This section discusses insights on the effects of using the pragmatic-prescriptive FFE model from the contextual performance perspective. The insights are described in the same context as with how limitations from the contextual performance perspective (see the introduction chapter, *pp. 23-25*) in existing FFE models are tackled.

By using the pragmatic-prescriptive FFE model developed in Study 2.2, performers can achieve the following:

- During the use of a given module as a toolkit for a certain activity or task, a performer can understand the purpose and roles of using the given module (toolkit) by considering the purpose and roles of other modules (toolkits) for activities or tasks.
- After using the given module (toolkit) for a certain activity or task, the performer can apprehend the purpose, roles, and meanings of parameters produced from the given module (toolkit), by considering the purpose, roles, and meanings of parameters of other toolkits.
- The performer can comprehend the relationship between the parameters of each module (toolkit) in terms of how to connect these parameters with each other. Specifically, the performer can understand how parameters produced from the previous module (toolkit) flows into parameters for the next module. They can grasp how output parameters obtained in the previous module (toolkit) becomes input parameters for the subsequent module (toolkit).
- As a result, after using a given module (toolkit), the performer can grasp which module (toolkit) should be utilised next from among the many module (toolkits) available. The performer can understand which of the next modules (toolkits) should be initiated, by considering output parameters produced from the previous module (toolkit).

- Consequently, the performer understands the system as a whole, and not just the constituent parts of the system; Previously, they would only understand separate toolkits, and even then, only the ones that they themselves use.

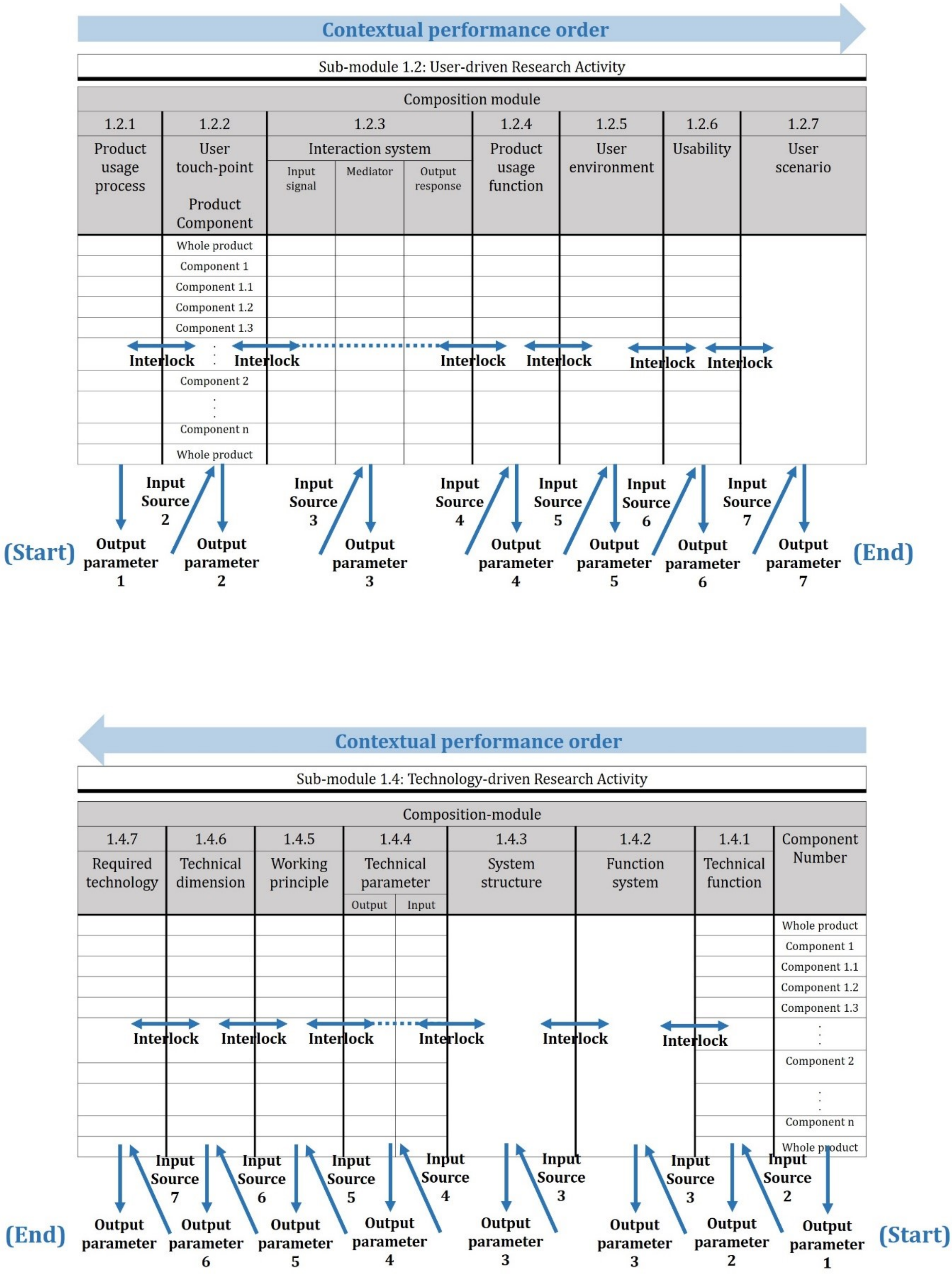


Figure 8.1. *Contextual Performance in pragmatic-prescriptive FFE model*

Suppose that performers scrutinise the target product with the aim of examining user behaviour patterns when users use the target product in a given environment, using Sub-module 1.2 (User-driven Research Activity Module). As shown in the upper part of *Figure 8.1*, seven composition-modules in the form of toolkits are arranged in the right direction in a structure in which input and output parameters related to user behaviours can interlock.

The order in which target users operate the product is investigated first (Composition-module 1.2.1). In each step of the product usage process, the user touch-points are generated (Composition-module 1.2.2), enabling understanding of each interaction system (Method 1.2.3) whose structure is designed with the following three units: 1) input signals from users, 2) mediators identical to the touch-points, and 3) output responses from these touch-points. With each interaction system, each product usage function can be explicitly identified (Composition-module 1.2.4). By apprehending how users employ those functions in the given environments (Composition-module 1.2.5), the usability of the target product can be grasped on a component basis from an ergonomics point of view (Composition-module 1.2.6). Encompassing all of the information produced by using the performance methods above – a user-scenario, an overall scene where target users display particular behaviour patterns in the given environment – can be envisaged (Composition-module 1.2.7).

Suppose that performers scrutinise the target product with the aim of investigating how the target product can be operated technically, using Sub-module 1.4 (Technology-driven Research Activity Module). As shown in the bottom part of *Figure 8.1*, seven composition-modules realised in toolkit form are built in the left direction, under a structure in which input and output parameters related to the technical operation of the target product can interlock.

Technical compositions and their main and sub-functions can be defined in the first performance (Composition-module 1.4.1). With those functions and their relationships in hand, each composition can be arranged, forming the functional structure of the product (Composition-module 1.4.2). By grasping the processing systems generated in each composition and their systemic relationships in the functional structure, the overall system structure can be devised, considering how the product can be operated technically (Composition-module 1.4.3). Then, the technical parameters can be estimated for those processing systems and their systemic connections (Composition-module 1.4.4). Based on these parameters, the operational mechanisms of not only the product as a whole but also its various compositions can be understood explicitly (Composition-module 1.4.5). These working mechanisms, along with the technical parameters, enable the performers to estimate the possible range of technical dimensions for the overall product and its various components (Composition-module 1.4.6). Considering all the information obtained in the previous implementations, the technologies which are required for the technical operation of both the product and its parts can be grasped (Composition-module 1.4.7).

To conclude, FFE model operation from the contextual performance perspective means that the purpose, roles, and outcomes of each module (toolkit) can be inferred from those of other modules (toolkits). The purpose, roles, and outcomes of each module (toolkit) have very few possibilities of existing independently. This leads to the reduction of uncertainty as the result of the performer being able to gather a sufficient quantity of parameters, as all the required modules (toolkits) are configured for contextual performance. This also decreases ambiguity by allowing for precise interpretations and decisions on parameters from the contextual performance perspective by making it possible to explicitly understand the purpose, roles, and parameters of each module (toolkit). Consequently, the FFE model aids in reducing the deviations in FFE progress and outcomes, deviations which are triggered by different backgrounds and specialities of performers.

8.3.3 Insights on Concurrent Collaboration Operation in the Pragmatic-Prescriptive FFE Model

This section describes insights on the efficacy of utilising the pragmatic-prescriptive FFE model from the viewpoint of concurrent collaboration. The insights are discussed in the same vein as how deficiencies from the concurrent collaboration perspective (see introduction chapter, *pp. 25-26*) of previous FFE models are improved.

By utilising the pragmatic-prescriptive FFE model developed in Study 2.2, performers can achieve the following:

- When performers who come from different NPD-related functional fields such as engineering, design, and management employ different (modules) toolkits from the viewpoint of their own fields of expertise, they can understand the purpose and roles of other modules (toolkits) used by other performers.
- After those who come from different sectors use different modules (toolkits), they can apprehend the purpose, roles, and meanings of parameters produced in their modules (toolkits), by considering those of parameters obtained in other modules (toolkits) conducted by other performers.
- They can comprehend the relationship between the purpose, roles, and parameters of the modules (toolkits) used by different performers with different backgrounds and areas of expertise.
- As a result, they can grasp how parameters produced by their modules (toolkits) affect or are influenced by other parameters obtained from other modules (toolkits) used by other performers. Ordinarily, they would not be able to understand how output parameters produced by their modules (toolkits) become input parameters for other modules used by other performers, a difficulty that arises when multiple, disparate toolkits are used together.

Suppose that four teams, specialised in the four functional domains, are involved in collaboration in the pragmatic-prescriptive FFE model described above. In an idealised scenario, each team can simultaneously fill the parameters in the matrix by following the contextual performance order of the composition-modules arranged in each sub-module. As a result of the processes carried out by each team, other parameters from other composition-modules conducted by other teams can be concurrently considered, allowing the practitioners to grasp the contextual relationships between parameters produced from the composition-modules configured for contextual performance. Each team member can understand the parameters produced by other team members, without the need for an in-depth explanation, since the descriptive, evidential interpretations of parameters can be grasped simply by considering the contextual performance and contextual collaboration relationships: this is because the flow of parameters which interlock sequentially (the phased composition-modules in each sub-module), and are connected multidimensionally (the sub-modules arranged in the quadrants), make it possible to understand not only how each parameter is calculated but also what the evidence for each calculation is.

For instance (shown in the blocks coloured in red in *Figure 8.2* displaying Module 1 for the opportunity identification-screening task), when developing a multi-functional electronic wheelchair, different usage functions were required for different environments, such as stairs, slanted ground, and the gates at mass transit railway stations. These different functions for diverse environments demand different technical operational mechanisms for the wheels (and the control panel). The parameters produced in these composition-modules are for users handicapped in their legs only. For users handicapped in both their legs and arms, the working mechanisms for the wheels and control panel must be modified. Reasonable shapes more appropriate for quadriplegics can be proposed. In this way, user touch-point identification, product usage function definition user environment examination, technical operation mechanism design, and the scope of the shape selection can be simultaneously conducted.

In another example (shown in shown in the blocks coloured in blue, *Figure 8.2*), in the development of a drone-type amphibious camera, the upper part of the body container is generally above the surface of the water, while the bottom part is submerged. These two environments will require different materials which have different technical properties; a material suitable for both cases will need to be used. This changes the investment cost. In this way, user environment examination, the scope of material selection, technical properties' calculation, budget adjustment can be concurrently implemented.

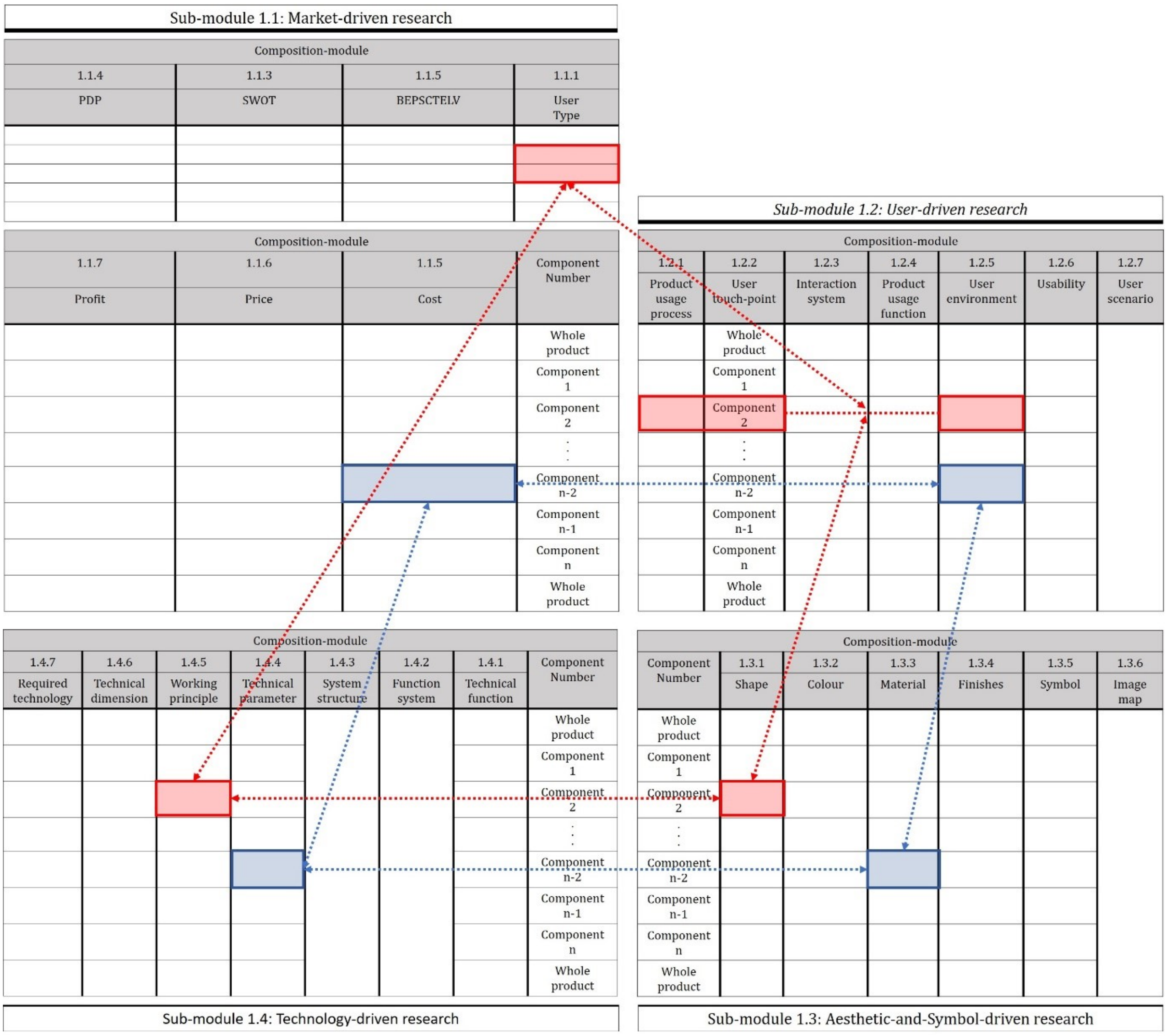


Figure 8.2. *Example scenes of concurrent collaboration in Module 1 for opportunity identification-screening*

Consequently, FFE model operation from the concurrent collaboration perspective means that the purpose, roles, and outcomes of each module (toolkit) used by different performers who come from diverse functional fields can be inferred by each of them. It is quite possible that parameters obtained from each module (toolkit) coexist through an interrelationship between parameters produced from different functional domains. This results in sufficient parameters where NPD-related information researched and analysed from the different functional domains is integrated, decreasing uncertainty. This also leads to more accurate interpretations and determinations of parameters gathered and analysed from the diverse functional domains, decreasing ambiguity. In conclusion, the pragmatic-prescriptive FFE model, structured for concurrent collaboration, has the same effect as involving ‘T’, ‘TT’, or even ‘TTT’ type performers who have expertise in more than two functional areas.

8.3.4 Insights of Overall Attributes in Pragmatic-Prescriptive FFE Model

This section illustrates insights on the effectiveness of using the pragmatic-prescriptive FFE model, looking specifically at the following five overall attributes:

1) Data-driven Type
2) Agile Development
3) Incremental and Radical NPDs
4) Explicitness and Responsiveness Characteristics
5) Procedural and Performative Structures

As mentioned previously (*pp. 101-103*), since these five attributes are fostered in the FFE model by the chain-reaction effect of each of them, the insights are derived through the form of a cluster network.

Firstly, fostering contextual performance and concurrent collaboration with the form of the toolkit exerted influence on building the performative structure. This structure leads to the production of parameters in the model itself, making it possible for performers to use the FFE model more functionally. The structure is definitely different to most previous FFE models whose structure is action-oriented, focusing more on providing the procedural structure.

Secondly, the performative structure for contextual performance and concurrent collaboration aids in embodying the data-driven type of the FFE model wherein all the parameters interlock each other not only intensively in a single functional domain but also multidimensionally in the four functional domains, from beginning to end. This means that parameters are processed consecutively in each structure of the model and not just generated. Moreover, the data-driven FFE model developed in this research is suitable for handling qualitative parameters rather than quantifiable parameters managed by most other FFE models. The distinctive features can be better explained by comparing it with other performative models using the matrix approach, e.g. QFD, DSM, etc., a comparison which yields the following three points:

1) Output parameters produced in the previous models have difficulty with qualitative parameters (text-and-images). Previous models have trouble in providing not only the status of the parameter processing but also the descriptive evidential interpretations and their contexts of the produced parameters. Instead, the models are only useful for ascertaining the status of parameters with the numerical or semantic type, '1 to 9' or 'O' and 'X'.
2) Parameters obtained in previous FFE models have trouble linking to each other for contextual performance and concurrent collaboration and thus tend to exist independently. The reason for this is that the target research and analysis elements presented in the *x*- and *y*-axes in the matrices appear to be selected and arranged based on what performers expect, instead of being configured in advance for contextual performance and concurrent collaboration. Therefore, output parameters are limited by the expectations of performers. If performers have expertise in FFE execution from the viewpoints of contextual performance and contextual collaboration, there would be no issue as parameters are processed precisely in a single domain as a well as multidimensionally in the four functional domains. However, when the performers do not specialise in contextual performance and concurrent collaboration in the FFE, the guaranteed inter-connectedness of parameters for contextual performance and concurrent collaboration cannot be infinite.
3) For the two reasons, even with the same matrix-type, the previous models can be more complex for performers, and thus they tend to be reluctant to use.

Consequently, the data-driven type for contextual performance and concurrent collaboration was hard to obtain in most of the previous FFE models. Thus, the effects of the data-driven type used by the FFE model developed in this research is difficult to replicate using other FFE models.

One of the ultimate aims of the data-driven type is to save parameter sets in each FFE project and extract applicable parameters for future projects. In using the FFE model developed in this research, it is expected that the parameter sets produced in the requirement list format, along with the conceptual designs (the final outcomes), can be utilised as knowledge assets in future FFE projects. As a result, it is possible that the parameter sets positively affect not only the actual NPD that follows the FFE but future FFE projects as well.

Thirdly, the data-driven type, which largely relates to data processing from the viewpoints of contextual performance and concurrent collaboration, leads to agility in NPDs by enhancing the '*Quality* of Parameter Processing' instead of increasing the '*Speed* of Parameter Processing' which is the most common approach used in previous FFE models. Higher quality parameter processing reduces the iterative work needed to correct defective parameters which arise from a lack of contextual performance and concurrent collaboration. Furthermore, by using an FFE model structured for contextual performance and concurrent collaboration, it is feasible that unnecessary meetings to explain parameters and their interpretations not only within a single functional domain but also in various functional domains will no longer be required. Consequently, without these time-consuming discussions, each individual parameter can contain the viewpoint of not only a single functional domain but also the viewpoint of the consolidated four functional domains.

Fourthly, the fixed model structure, which arranges the composition-modules in a linear form, known as the explicitness characteristic, is better for processing and determining parameters more accurately, by virtue of its stable management. Moreover, the flexible model structure not only arranges sub-modules in quadrants (similar to the spiral form) but also leaves room for specific methods for conducting the composition-modules, known as the responsive characteristic, and is suitable for encouraging creative parameter generation. This means that even if different performers are making use of the FFE model developed in this research, the produced parameters between these performers are different (giving rise to creativity) and accurate as well (giving rise to reliability). The characteristic of most previous FFE models either leaned towards explicitness or responsiveness but did not accommodate both.

Lastly, having two channels structured only in the initial part of the FFE model means that there are few possibilities for performers to become confused about what FFE activities should be conducted, in terms of the two different NPD directions: confusion over what FFE activities should be implemented throughout the process between the incremental and radical NPD directions was a chronic problem in most of the previous FFE models.

In conclusion, the pragmatic-prescriptive FFE model wherein the five overall attributes (the current and future trends in FFE model improvement) are applied produces various benefits:

1) **Data-driven Type:** exquisite and multidimensional processing of parameters for contextual performance and concurrent collaboration instead of just producing parameters which exist independently without context regarding the parameters' interrelationships. A positive impact will be felt in future projects as well as in the actual NPD stage which follows the FFE.
2) **Agile Development:** a decrease in wasted time by reducing not only iterative work to correct parameters which have not been handled exquisitely in a single functional domain as well as multidimensionally in the four functional domains but also unnecessary meetings discussing parameters and their descriptive evidential interpretations
3) **Incremental and Radical NPDs:** the provision of the direction for stable parameter processing, preventing confusion over what FFE activities should be conducted between the two NPD attributes throughout the FFE process.
4) **Explicitness and Responsiveness Characteristics:** the generation of reliable as well as creative parameters through not only the combination of the spiral and linear structures but also the provision of discretion regarding the selection of specific methods when conducting strictly configured composition-modules
5) **Procedural and Performative Structures:** the processing and deciding of parameters in the model itself, different from action-led models which concentrate more on providing the procedural structure

Consequently, the pragmatic-prescriptive FFE model in which the current and future trends of the FFE model improvement are reflected, which affects the overall attributes of the front-end, allows performers to conduct the FFE by effectively responding to essential considerations issued from the industrial circumstances of today and the future.

8.3.5 Section Conclusion

Section 8.3 has discussed the assertions and insights gained from the use of the pragmatic-prescriptive FFE model developed in Study 2.2. The assertions and insights have covered how the two dimensions of limitations in previous FFE models have been improved and what effects of using the model are:

1) **First Dimension**
   : Performance Structure and Operating Mechanism
   – Parameter Process and Decision
   1.1) Contextual Performance
   1.2) Concurrent Collaboration
2) **Second Dimension**
   : Overall Attributes
   – Current and Future Trends in FFE Models
   2.1) Data-driven Type
   2.2) Agile Development
   2.3) Incremental and Radical NPDs
   2.4) Explicitness and Responsiveness Characteristics
   2.5) Procedural and Performative Structures

All the assertions and insights gained from each category affect each other in the form of a cluster network.

The pragmatic-prescriptive FFE model makes all qualitative and quantitative parameters interlock with each other throughout the course of the FFE, by virtue of the data-driven performative structure built for contextual performance and concurrent collaboration. In this way, performers can understand/process the purpose, roles, and outcomes of parameters not only exquisitely in a single functional domain but also multidimensionally in the four functional domains, from the beginning to the end of the FFE.

Through the flexible spiral structure of the sub-modules with a fixed linear-type sub-structure of composition-modules, performers can produce reliable as well as creative parameters. By flexibly leaving room for selecting specific methods when operating strictly configured composition-modules, performers can maintain their creative behaviours within a stable system of management.

The parameters obtained from such an FFE model reduces wasted time by no longer requiring work to correct defective parameters (which have not treated from the contextual performance and concurrent collaboration perspectives) and eliminating the need to discuss evidential interpretations of parameters.

Along with all the above advantages, the two channels equipped in the initial part of the model aid in providing explicit FFE activities for both incremental and radical NPD, preventing confusion over what activities should be implemented between the two NPD attributes.

Consequently, by virtue of all the effects and merits mentioned, the pragmatic-prescriptive FFE model can be utilised as practical-functional performance guidance in the entire FFE's execution.

8.4 Study 3.1 – Pragmatic-Prescriptive FFE Model Validation

8.4.1 Section Introduction

This section comprehensively illustrates key assertions and insights on substantiating the validity of the pragmatic-prescriptive FFE model which was conducted in Chapter Six (Study 3.1). The overall validation results can be found in the chapter conclusion of Chapter Six (*pp. 430-432*), and each detailed result of the model can be identified in each relevant section of the chapter. The assertions and insights focus on validating the pragmatic-prescriptive FFE model's effects when used and the merits of doing so. In the following section, the insights on the validation results of the pragmatic-prescriptive FFE model is addressed in earnest.

8.4.2 Insights of Pragmatic-Prescriptive FFE Model Validation

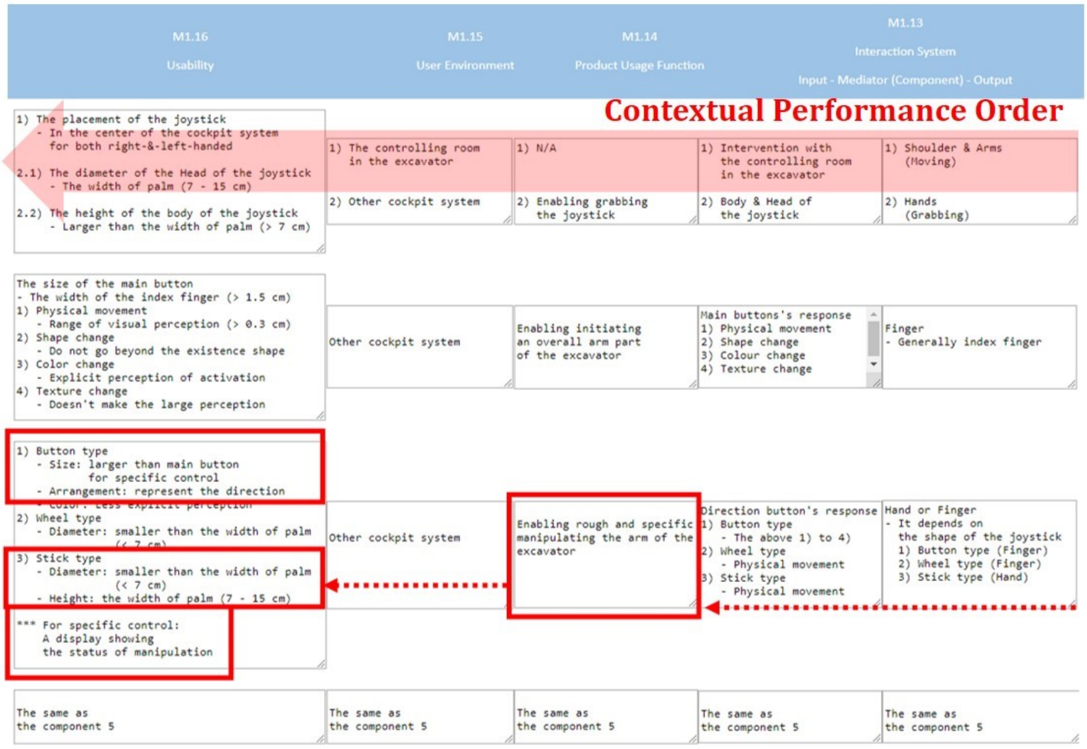
This section discusses the assertions and insights on what the pragmatic-prescriptive FFE model validation results represent. The section concentrates on the viewpoint of demonstrating the pragmatic-prescriptive FFE model's effects of use and the advantages thereof. To ease understanding, one of the field test cases is reviewed below.

Figure 8.3a and *8.3b* shows screen-captures[55] of an FFE project to develop a joystick for an excavator, obtained from the field test. Originally, the main role of the team was to design joysticks for various game consoles. Since the video games of today need more

[55] In order to foster an experimental environment which is close to an actual FFE performance environment in many NPD organisations, a web-version embodied with the pragmatic-prescriptive FFE model was utilised in the field tests. Screen captures of the web-version developed in this research can be found on *pp. 349-350*.

sophisticated control functions, one heavy equipment development firm commissioned the joystick development company to devise a new joystick for their excavators.

User-driven Research (Sub-Module 1.2 in Module 1)



Aesthetic-and-Symbol Research (Sub-Module 1.2 in Module 1)

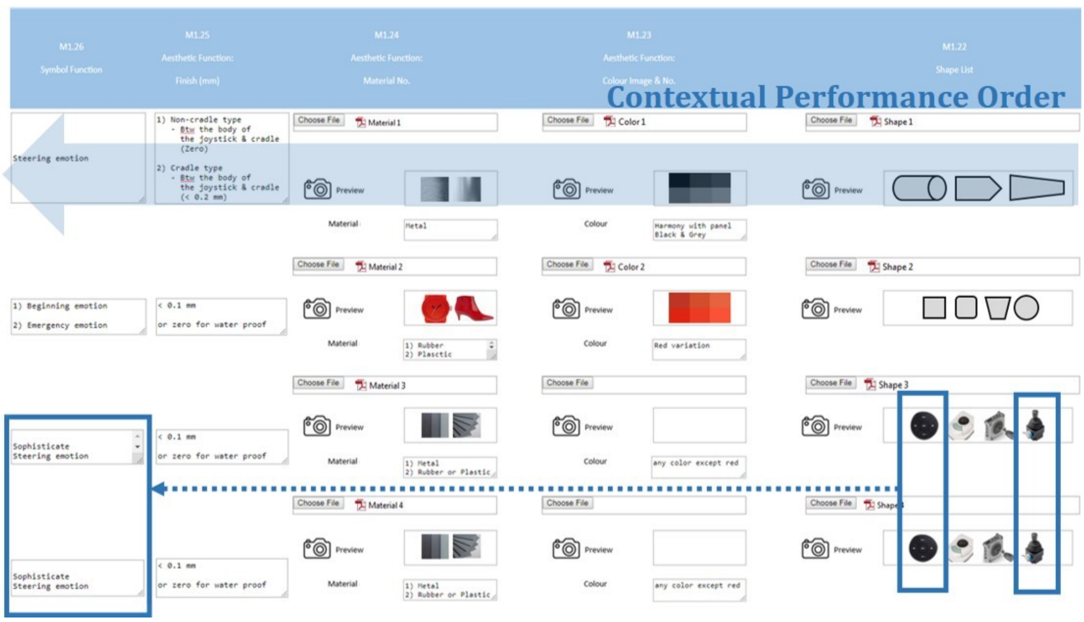
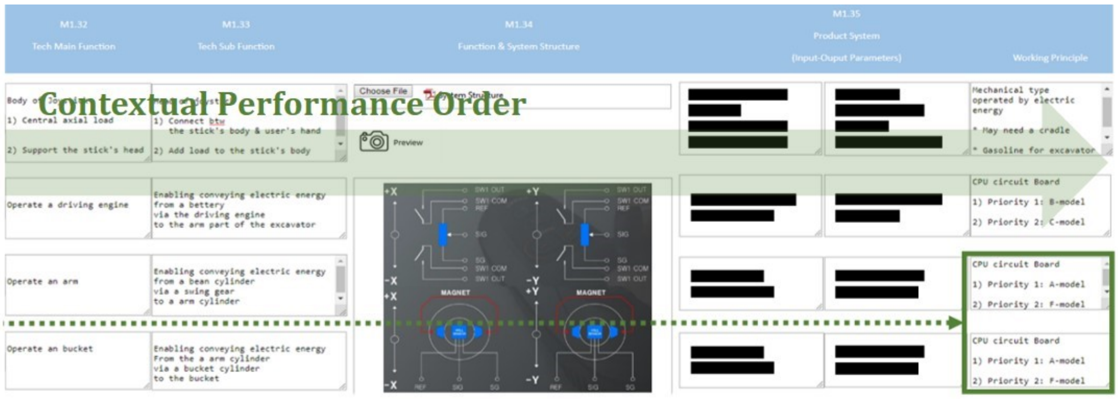
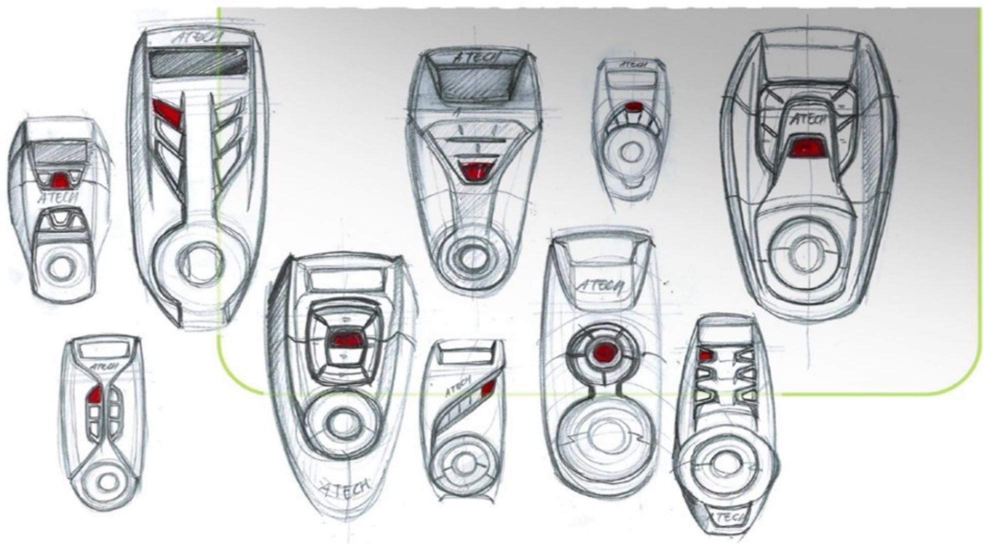


Figure 8.3a. Example scene of using pragmatic-prescriptive FFE model in actual NPD programme



Conceptual Design of Ordinary Joysticks

Conceptual Design of This Research



- **Screen for checking details of X, Y & Z-coordinate in manipulating**
- **Stick type for a overall manipulating**
- **Directional button type for a sophisticated manipulation**

Figure 8.3b. *Example scene of using pragmatic-prescriptive FFE model in actual NPD programme*

As shown in the section displaying the outcome of the conceptual design (See *Figure 8.3a* and *8.3b*), when using their own model, the joystick design was very similar to many other ordinary joysticks derived from studies that looked at general ergonomics.

On the other hand, when using the model developed in this research, a different performance process and outcomes were revealed from the following two viewpoints:

1) Performance Structure and Operating Mechanism (regarding contextual performance and concurrent collaboration).
2) Overall Attributes (with respect to the data-driven type, agile development, both incremental and radical NPDs, a balanced explicitness and responsiveness characteristics, and balanced procedural and performative structures)

1) Performance Structure and Operating Mechanism
: Parameter Process and Decision
– Contextual Performance
– Concurrent Collaboration

Firstly, in terms of contextual performance (shown in the box coloured in red in *Figure 8.3a*), in the user-driven research activity, the examination of the product usage process and interaction system generated in each step of the process encouraged a more specific understanding of user behaviours. This resulted in the demand for new functions for not only checking the status of a manipulation but also to allow for different levels of precision when manipulating the excavator's arm and bucket. As a result, these new functions required a stick type control system for rough manipulation and a series of directional buttons for precise manipulations, as well as a display to enable status checks. Also, the ergonomic data that would satisfy each of these provisions were calculated accordingly.

Secondly, from the view point of concurrent collaboration, those parameters generated in the user-driven research activity affected the study of the shape, colour, material, finishes, and symbolic functions accordingly in the aesthetic-and-symbol-driven research (shown in the blue box in *Figure 8.3a*). Furthermore, considering these parameters, the technology-driven research module (shown in the green box in *Figure 8.3b*) allowed a proper function and system structure and relevant working principles to be drawn up.

Consequently, as seen in the final two graphics of *Figure 8.3b*, those parameters led to the production of conceptual designs different to many other ordinary joysticks. Moreover, the parameters were archived in the form of an FFE library dataset from which applicable parameter sets could be extracted and applied to future projects. Furthermore, those parameters made a positive impact on the execution of the actual NPD stage to be executed after the FFE.

2) Overall Attributes
: Current and Future Trends in FFE Models

With the progress and outcomes of the field test, in terms of the five overall attributes, we confirmed that this data-driven performative type developed for contextual performance and concurrent collaboration encouraged production of more exquisite as well as creative parameters. As a result, as shown in *Figure 8.3b* above (*p. 476*), parameters considered with contextual performance and concurrent in mind led to more precise as well as more creative conceptual designs (as the output of the FFE). This accorded with one of the strategies for new FFE model development; a balance between the explicitness characteristic for producing reliable outcomes under formalised control and the responsiveness characteristic for generating creative outcomes under flexible control. We demonstrated that more reliable and creative parameters aided in considerably reducing the iterative works needed to compensate for poor-quality parameters. It also helped reduce the need for meetings to discuss the roles and meanings of each parameter and their relationships, from the viewpoints of the four NPD functional fields. As a result, whereas most previous models realised agile development by fostering rapid iterations of works, this model pursues a new form of agility by reducing the actual amount of works and eliminating things that are unnecessary, e.g. meetings to bring everybody up to speed. The descriptive feedback obtained from the field test showed that participants generated the parameters and conceptual designs (shown in *Figure 8.3a* and *8.3b, pp. 475-476*) at once without any meetings for explaining descriptive evidential interpretations of those parameters and conceptual designs. Moreover, through continuously accumulating parameters from each FFE case in the form of a library dataset, it is strongly expected that performers can extract applicable parameters and apply them in future FFE projects. This accorded with the aims of a data-driven FFE model which is to collect, process, and generate parameters and transform them into usable knowledge.

Consequently, the insights viewed from applying the pragmatic-prescriptive model to real-world FFE projects seem to be strongly validated. Also, we were able to positively confirm that the FFE model can strongly contribute to facilitating quality in the actual NPD phase's execution.

8.4.3 Section Conclusion

The outcomes of the pragmatic-prescriptive FFE model validation strongly indicate that the effects of using the FFE model and their merits were strongly substantiated from the viewpoints of contextual performance, concurrent collaboration, and the five overall attributes. This demonstrates that the FFE model can largely be utilised as practical-functional performance guidance in the FFE. The validation outcomes strongly showed that the FFE model enables performers to effectively process parameters from the contextual performance and concurrent collaboration perspectives. It also strongly confirmed that the various expected benefits produced from fostering the five overall attributes in the FFE model can be indeed be achieved in the actual use of the model in the consumer product industries. Since this validation was implemented based on statistical probabilities, we cannot say that the effects of using the model and their insights were demonstrated at a rate of 100%, but we can at least assume that it is strongly valid.

8.5 Study 3.2 – Theoretical-Descriptive FFE Model Development

This section describes assertions and insights on the theoretical-descriptive FFE model development, which originated from the generalisation of the pragmatic-prescriptive FFE model, based on its validation data which was conducted in Chapter Seven (Study 3.2). The comprehensive generalisation results can be found in the chapter conclusion of Chapter Seven (*pp. 453-455*), and each detailed result of the generalisation can be identified in each relevant section of the chapter.

The majority of the field-test results and their insights presented in Chapter Six (Study 3.1), addressed in the section above (*pp. 474-479*), indicated the strong possibility of generalising the pragmatic-prescriptive FFE model. The pragmatic-prescriptive FFE model was generalised first based on what the implementations of the main modules (representing each FFE task) mean, to produce each mathematical formula. Each mathematical theory was then interlocked, concluded by a single mathematical theory, analogous to the pragmatic-prescriptive FFE model wherein all parameters interlock from beginning to end. The generalised theoretical-descriptive FFE model is described in detail below:

1) **Preliminary Task:**
   The target product (in which the improvement or development directions established in the preliminary task are reflected) is scrutinised in the opportunity identification-screening task. Therefore, parameters produced in Module 1 can be considered to already have a directional nature in terms of incremental or radical NPDs, and thus Module 0, as a preparation module, can be regarded as being included in Module 1. Consequently, for this module, a particular mathematical theory was not derived.[56]

[56] More details can be found in *p. 438*.

2) Opportunity Identification-Screening and Idea Generation-Screening Task:

$O_k = o_k^m + o_k^u + o_k^a + o_k^t$ and $I_k = i_k^m + i_k^u + i_k^a + i_k^t$, *k = component No.*

- Opportunities are NPD-related parameter sets scrutinised on a component basis from the market-driven, user-driven, aesthetic-and-symbol-driven and technology-driven research activity;
- Ideas are actionable realisation method parameter sets devised on a component basis from the market-driven, user-driven, aesthetic-and-symbol-driven, and technology-driven ideation activities.

3) Requirements List (Mission Statement) Task:

$R_k = O_k \times I_k$, *k = component No.*

- Requirements are the combination of the parameter sets produced from the opportunities and ideas, on a component basis.

4) Conceptual Design (and Prototyping) Task:

$\sum_{k=1}^{n} R_k \times V_k(r\text{C}1)$

$$= \sum_{k=1}^{n} C_k$$

k = component No, r = The number of optimal principal designs

- Conceptual designs (and prototypes) refer to the assembling of optimal visual, functional, and technical conceptualisations (embodiments) of each requirement, on a component basis.

The final formula, '$\sum_{k=1}^{n} C_k$', represents the overall outcome of the FFE. In order to derive its inherent meaning, the formula can be dismantled by simply reversing the order in which the formula was built above.

$$\sum_{k=1}^{n} C_k$$

$$= \sum_{k=1}^{n} R_k \times V_k(r\text{C}1)$$

$$= \sum_{k=1}^{n} (O_k \times I_k) \times V_k(r\text{C}1)$$

$$= \sum_{k=1}^{n} (o_k^m + o_k^u + o_k^a + o_k^t) \times (i_k^m + i_k^u + i_k^a + i_k^t) \times V_k(rC1)$$

The formula presented in the last line represents the underlying concept of the overall FFE execution.

$$\sum_{k=1}^{n} (o_k^m + o_k^u + o_k^a + o_k^t) \times (i_k^m + i_k^u + i_k^a + i_k^t) \times V_k(rC1)$$

k = *component No.*, r = *The number of optimal principal designs*

This theoretical-descriptive FFE model represents the underlying concept of executing the overall FFE phase. Performers can better understand the fundamental purpose, roles, and meanings of NPDs in the entire FFE. To be specific, the overall FFE execution can be regarded as a vision of a new product that can be embodied by assembling components in which requirements comprised of opportunities and their means of realisation derived from the market-driven, user-driven, aesthetic-and-symbol-driven and technology-driven studies, which were conceptualised from a visual, functional, and technical perspective.

Consequently, the theoretical-descriptive FFE model, consisting of a mathematical theory for each FFE task, can be utilised as theoretical-conceptual guidance for the entire FFE.

8.6 Chapter Conclusion

This chapter has discussed the key assertions and insights on the key findings obtained from each study (Studies 2.1 to 3.2). As mentioned in the chapter introduction (*p. 456*), the key assertions and insights can naturally be divided once again into two groups, just as the key findings were categorised into two divisions.

1) Pragmatic-Prescriptive FFE model (Study 2.1 and 2.2)

1.1) Performance Structure and Operating Mechanism : Parameter Process and Decision

1.1.1) Contextual Performance

The pragmatic-prescriptive FFE model, wherein the performance structure and its operating mechanism for contextual performance is incorporated via toolkits, has the following effects:

- The performers can exquisitely understand the purpose, roles, and meanings of toolkits, their outcomes, and their relationships, accurately processing and deciding all the required parameters in each functional domain, reducing uncertainty and ambiguity.
- The performers can comprehend the execution of toolkits from the viewpoint of the system as a whole and not just the constituent parts of the system.
- As a result, the pragmatic-prescriptive FFE model can help to produce better, more abundant and precise parameters by reducing issues as a result of deviations in the backgrounds and specialities of the performers.

1.1.2) Concurrent Collaboration

The pragmatic-prescriptive FFE model in which the performance structure and its operating mechanism devised with concurrent collaboration in mind is consolidated via toolkits has the following effects:

- The performers can multidimensionally apprehend the purpose, roles, and meanings of toolkits, outcomes, and their relationships, collaboratively processing and determining parameters in the representative four functional domains, decreasing uncertainty and ambiguity.

- The performers can understand the implementation of toolkits from the viewpoint of the complete system and not just its pieces.
- As a consequence, the pragmatic-prescriptive FFE model can support the production of more abundant and exquisite parameters, with the same effect as employing 'T', 'TT', and even 'TTT' type experts.

1.2) Overall Attributes
: Current and Future Trends of the FFE Model

The pragmatic-prescriptive FFE model in which current and future trends of FFE model improvement are reflected, which affects the overall attributes of the front-end, allows performers to operate the FFE by efficiently responding to essential considerations issued from the industrial circumstances of today and the future:

- **Data-driven Type:** the exquisite and multidimensional processing of parameters from the contextual performance and concurrent collaboration perspectives instead of just generating parameters which exist independently without the contexts of the parameters' interrelationships. There will be positive effects on future projects as well as the subsequent actual NPD stage.
- **Agile Development:** time savings by reducing not only iterative works needed to correct parameters improperly handled in a single functional domain as well as multidimensionally in the four functional domains but also unnecessary meetings for discussing parameters and their descriptive evidential interpretations.
- **Incremental and Radical NPDs:** provision for the direction in producing the stable parameter processing, preventing confusion over what FFE activities should be conducted between the two NPD attributes throughout the FFE process.

- **Explicitness and Responsiveness Characteristics:** the generation of reliable as well as creative parameters through not only the flexible spiral structure consisting of sub-modules with fixed linear type sub-structures consisting of composition-modules but also a provision for discretion when selecting specific methods in the composition-modules
- **Procedural and Performative Structures:** the processing of parameters in the model itself, different from the action-led models concentrating more on providing the procedural structure

As a result, the pragmatic-prescriptive FFE model can be utilised as practical-functional performance guidance in the FFE.

2) Theoretical-Descriptive FFE model (Study 3.1 and 3.2)

2.1) The theoretical-descriptive FFE model allows performers to theoretically understand the underlying concept of the FFE in the NPD.

2.2) As a result, the performers can better comprehend the fundamental purpose, roles, and meanings of the FFE in the NPD when using the pragmatic-prescriptive FFE model.

Consequently, the theoretical-descriptive FFE model can serve as theoretical-conceptual performance guidance when using the pragmatic-prescriptive FFE model as practical-functional performance guidance in the FFE.

In conclusion, the assertion that the pragmatic-prescriptive and theoretical-descriptive FFE models, developed in this research, have improved limitations identified in previous models has been substantiated. We can also confirm that the potential contributions laid out in Chapter One (Introduction, *pp. 32-33*) do lead to actual contributions, through the key findings produced from each study (Study 2.1 to 3.2) and the insights thereof.

The following chapter, the Conclusion, provides a final summary and review of this thesis and its key findings, insights, and contributions.

Chapter 9. Conclusion

This closing chapter presents the final conclusions of this doctorate. It begins by addressing the key outcomes of this research, followed by a review of what contributions these outcomes make to both industry and to academia, before concluding with a discussion of limitations and potential future research directions.

9.1 Research Overview

This research has explored the development of a new model for the early design stage in new product development (NPD) programs, a stage known as the 'Fuzzy Front End' (FFE). The primary goals of this research were to produce the following two outcomes: 1) a pragmatic-prescriptive FFE model developed with knowledge-and-theories and cues-and-resources obtained from examining existing FFE models and understanding actual FFE practices, which complements the deficiencies of previous FFE models, and 2) a theoretical-descriptive FFE model produced by generalising the pragmatic-prescriptive FFE model based on validation results of the developed model. Consequently, this research aims to contribute to pragmatic as well as theoretical NPDs in the FFE through these two research outcomes.

The FFE model developed in this research targeted consumer product development sectors (electronics, medical devices, furniture, vehicles, etc.), but excludes pharmaceuticals, apparel, microchips, and software as the attributes, characteristics, and features of these product categories are sufficiently different such that the principles for the product categories being studied do not apply. In this NPD sector, the model is aimed at both large corporations and SMEs. SMEs here are typically specialty design firms and NPD consultancies that are engaged in practical design activities throughout the FFE. Other types of SMEs not only focusing on production activities more in the later stage of the NPD process but also deal with distribution and promotion activities in the commercialisation stages; these are excluded as such activities do not pertain to the FFE.

A salient point should be made here: today, companies require a similar NPD model regardless of their size in the sense that these companies are dedicated to fostering effective communication systems in their NPD environments by employing both types of employees, specialists, i.e. specialised in a single area, and generalists, i.e. specialised in multidimensional areas.

In the following section, a research overview describes the objectives (from Chapter One) that have been achieved thus far. Objectives 1, 2, and 3 (Studies 1.0, 2.1, and 2.2) relate to the development of the pragmatic-prescriptive FFE model, and Objectives 4 and 5 (Studies 3.1 and 3.2) relate to the generation of the theoretical-prescriptive FFE model.

9.1.1 Objective 1 (Study 1.0)

To examine existing FFE models and related studies to understand the features of each model and trends in FFE model development

Study 1.0 examined 255 FFE studies to understand the features of each FFE model and trends in FFE model development. Based on this examination, a total of nine strategies were established, as shown in *Table 9.1*. Those nine strategies were categorised into two dimensions of development directions: 1) to foster overall attributes regarding the reflection of current and future trends in FFE model improvement and 2) to improve the performance structure and operating mechanism with respect to contextual performance and concurrent collaboration.

Table 9.1 *Nine strategies for pragmatic-prescriptive FFE model development*

Dimension	#	Area	Strategy
The First Dimension: **Overall Attribute**	1	Model Type	A data-driven type can be created by augmenting information processing and knowledge accumulation.
	2	NPD Speed	Agile development can be realised by concentrating on quality of information processing capabilities.
	3	NPD Attribute	A model aims at balancing both incremental and radical NPDs can be developed through different arrangements of FFE activities in the front or back sections of the FFE.

	4	Model Characteristic		An overall characteristic can be designed based on explicitness in the pursuit of stable operations, e.g. phased and formalised processes, while responsiveness can support the sub-structures in the pursuit of creative behaviour, e.g. modular and spiral processes. In addition, by leaving room for performers to select optional performance techniques (to foster creative behaviour) in each formalised performance structure (to control performance directions), the explicitness and responsiveness characteristics can be balanced.
	5	Model Structure		A model can be built with a procedural structure using performative-type sub-structures.
The Second Dimension: **FFE Performance Structure & Operating Mechanism**	6	Task		The six main FFE tasks are: opportunity identification-screening, idea generation-screening, requirements list, mission-statement, conceptual design, and prototyping.
	7	Activity		Essential FFE activities can involve diverse NPD-related functional domains.
	8	Performance Method		Performance methods can serve as underlying resources for the physical and functional embodiment of toolkits.
	9	Toolkit	9.1	Toolkits can be developed with consideration of the contextual performance and concurrent collaboration perspectives.
			9.2	Toolkits are more appropriate for dealing with qualitative (as opposed to quantitative) data.
			9.3	Toolkits following the above two considerations can be incorporated into the model structure.

9.1.2 Objective 2 (Study 2.1)

To research and analyse actual FFE practices in NPD industries to better understand real-world FFE scenarios

Study 2.1 gathered diverse real-world FFE scenarios with expert interviews and analysed those scenarios where different FFE execution principles and approaches and various FFE tasks, activities, and performance methods (hierarchical FFE performance units) are scattered. The analysis revealed the possibility of linking those principles, approaches, and hierarchical FFE performance units. As a result, a single representative FFE scenario was inferred as the final outcome of Study 2.1.

9.1.3 Objective 3 (Study 2.2)

To develop a new FFE model based on the outcomes of 'Study 1.0' and 'Study 2.1' listed above

Considering the nine development strategies established in Study 1.0, the representative FFE scenario inferred in Study 2.1 was physically and functionally embodied into the structure of the pragmatic-prescriptive FFE model by reflecting model building mechanisms built in this research. Those model building mechanisms were devised, with consideration of how to effectively apply the nine strategies and the representative FFE scenario physically and functionally into the model structure.

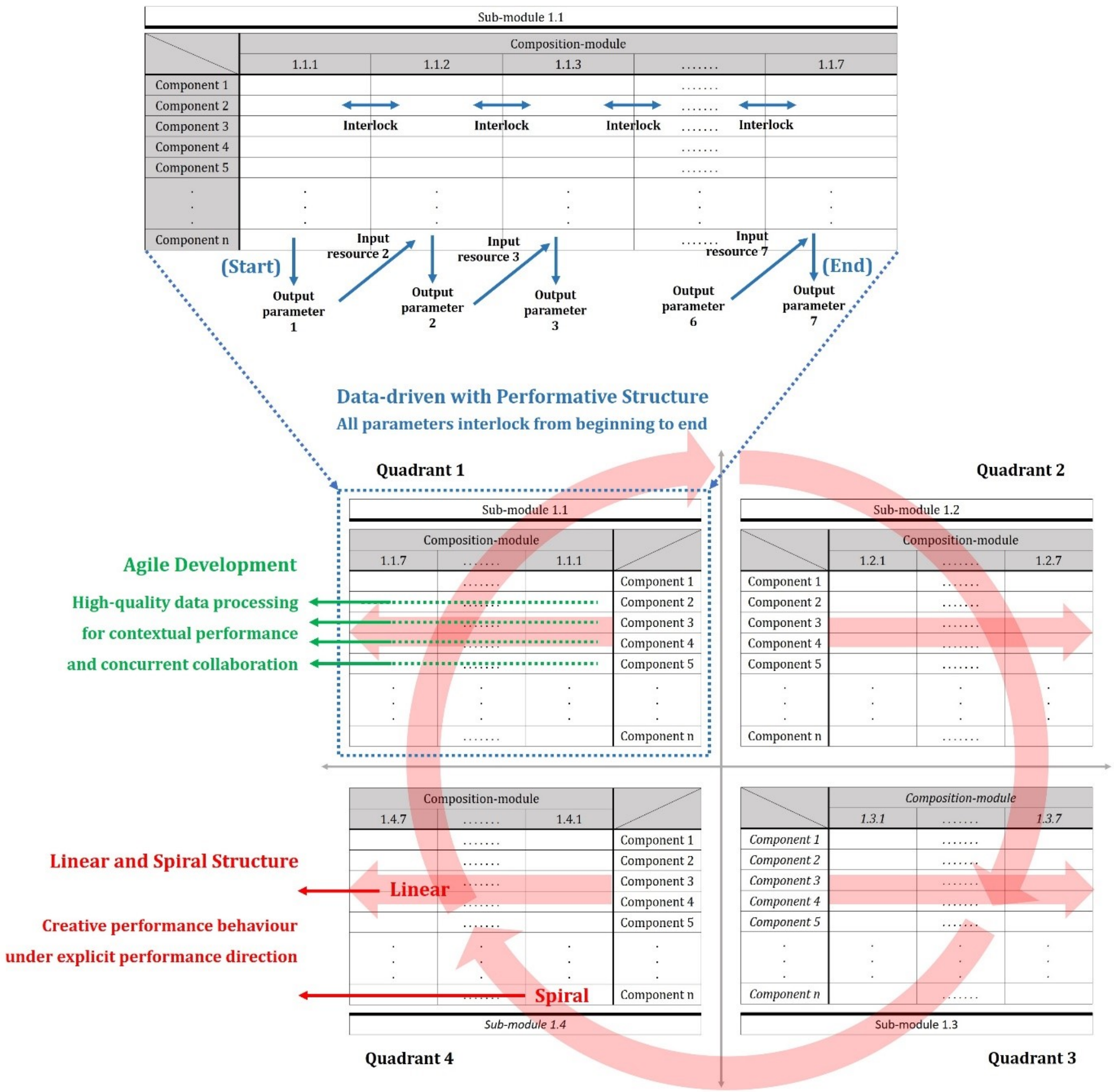


Figure 9.1 *Pragmatic-Prescriptive FFE model structure*

As a result, the pragmatic-prescriptive FFE model has a data-driven form with a performative structure wherein parameters can interlock for contextual performance and concurrent collaboration throughout the entire FFE process. With an interlocking structure, once an initial parameter is produced, all remaining parameters considered from the contextual performance and concurrent collaboration perspectives can be obtained successively in the model itself (shown in the upper part of *Figure 9.1*, coloured in blue). As shown in the bottom part of *Figure 9.1*, coloured in green and red, this facilitates agile FFE execution by reducing the iterative work needed to correct defective parameters which have not been handled with contextual performance and concurrent collaboration in mind but instead exist independently. Besides, the combination of linear and spiral structures in pursuit of balance between the explicitness and responsiveness characteristics facilitates flexible and creative performance behaviour under explicit and fixed performance directions. Lastly, two different channels incorporated into the initial part of the model make it possible to conduct incremental and radical NPDs.

9.1.4 Objective 4 (Study 3.1)

> *To validate the developed pragmatic-prescriptive FFE model in actual NPD fields in terms of correcting the identified limitations*

Study 3.1 validated the pragmatic-prescriptive FFE model developed in Study 2.2 by applying it to actual NPD programmes.

Firstly, in terms of the FFE performance structure and its operating mechanism, regarding contextual performance and concurrent collaboration, the FFE model seemed to have strong validity. In the simple regression analysis, most of the R- and R^2-values were around 0.750 and 0.700 respectively ($P \leq 0.050$), representing a very strong correlation between each module, while the β values were greater than 0.750 ($P \leq 0.050$), indicating the strong influence of each previous module on each subsequent module.

Secondly, the validation (in terms of the five overall attributes) also showed positive results. In the Wilcoxon signed-ranked test, the $+W$-values were greater than the $-W(Z)$-values in the validation results for all five attributes. The P-values of the mean scores between the control and experimental models were less than the recommended standard (0.050), and Cohen's *d* values were greater than 0.800, meaning that there are large differences with large effect sizes. Overall, the FFE model seemed to be well-developed from the viewpoints of the data-driven type, agile development, both incremental and radical NPDs, balanced explicitness and responsiveness characteristics, and balanced procedural and performative structures.

9.1.5 Objective 5 (Study 3.2)

> To generalise the pragmatic-prescriptive FFE model based on the outcomes of 'Study 3.1'

Study 3.2 produced the theoretical-descriptive FFE model by generalising the pragmatic-prescriptive FFE model based on the validation results obtained in Study 3.1. The majority of the validation results indicated the strong possibility of generalising the pragmatic-prescriptive FFE model. Furthermore, when schematising the main modules in the pragmatic-prescriptive FFE model (representing the task units in the FFE), particular patterns which can be dealt with mathematically were detected in the generalisation process.

As a result, the pragmatic-prescriptive FFE model was generalised first based on what the implementations of the main modules (representing each FFE task) mean, to produce each mathematical formula. Each mathematical theory was then interlocked, concluding with a single mathematical theory, analogous to the pragmatic-prescriptive FFE model wherein all parameters interlock from beginning to end.

In summary, this research was aimed at developing an FFE model for NPDs to address the shortcomings identified in existing FFE models. It generated the following two outcomes.

The first outcome (produced from Studies 1.0, 2.1, and 2.2) was the pragmatic-prescriptive FFE model developed with knowledge-and-theories and cues-and-resources obtained from examining existing FFE models and the understanding of actual FFE practices, which complements the deficiencies of previous FFE models.

Once the pragmatic-prescriptive FFE model was verified in actual NPD programmes, the second outcome (produced from Studies 3.1 and 3.2), a theoretical-descriptive FFE model, as a generalised output of the pragmatic-prescriptive FFE model, was produced based on the results of the verification. When a particular pattern (which can be handled mathematically in the pragmatic-prescriptive FFE model's generalisation) was observed, the theoretical-descriptive FFE model took the form of a mathematical theory.

9.2 Research Contributions

The research contributions come from key findings produced in this research and assertions and insights which the key findings mean. The research contributions can be considered in the following four parts:

1) Literature Review (Study 1.0)
2) Research Methodology
3) Pragmatic-Prescriptive FFE Model (Studies 2.1 and 2.2)
4) Theoretical-Descriptive FFE Model (Studies 3.1 and 3.2)

9.2.1 Literature Review
– Study 1.0 fulfilling Objective 1

The literature review chapter contains a chart depicting the analysis of 255 previous FFE studies conducted since 1910 in chronological order, using ten specific criteria concerning the five overall attributes and the FFE performance structure and its operating mechanism. This chart aids in the understanding of features of each FFE study and of the historical trends regarding model development.

The chart, essentially a database of the FFE studies, can be utilised in selecting FFE studies which need to be examined in different research, as well as for apprehending all previous FFE studies all at once. This chart can also be expanded by adding the results of future studies (after 2018) of the FFE.

9.2.2 Research Methodology
– Circular Reasoning Process

The research methodology chapter firstly contributes to a basic understanding of building an appropriate research methodology by considering the relationship between research directions and relevant research worldviews, approaches and specific research methods. A more explicit understanding of how to build a research methodology was promoted by providing both adequate and inadequate research methodology building cases.

This chapter also showed how research should be conducted by following a circular reasoning process from an inductive to a deductive approach, and its reverse. This leads to a comprehending of how research continuously evolves. This thesis itself can be an example of advancing the current body of research by using a circular reasoning process, from an inductive to a deductive approach.

9.2.3 Pragmatic-Prescriptive FFE Model – Studies 2.1 and 2.2 fulfilling Objectives 2 and 3

The pragmatic-prescriptive FFE model developed in Chapter Five (Study 2.2, *pp. 266-345*) reflected a representative FFE scenario inferred from various real-world FFE scenarios examined in Chapter Four (Study 2.1, *pp. 131-265*). The model also considered the model development strategies established in Literature Review (Study 1.0, *pp. 40-103*).

This section outlines the research contributions of the pragmatic-prescriptive FFE model's development and its operation. These contributions align with the following: 1) complementing the limitations identified in previous FFE models, presented in Chapter One (Introduction, *pp. 17-27*), 2) realising the expected contributions of using the pragmatic-prescriptive FFE model, presented in the introduction chapter (*pp. 32-33*), and 3) substantiating assertions and insights on the effects of using the pragmatic-prescriptive FFE model, addressed in the discussion chapter (*pp. 460-473*). The contributions treated in this section are the things which were strongly validated in Chapter Six (Study 3.1, *pp. 346-432*).

1) The pragmatic-prescriptive FFE model is **a data-driven model with a performative structure (toolkit-type)** wherein NPD-related parameters produced in each module can interlock for **contextual performance and concurrent collaboration** from beginning to end, unlike most of the previous models which are action-driven models at each step of the procedural structure.

- The model allows users, including scholars and practitioners, to use the model more functionally by processing and determining parameters in the model itself without any supportive toolkits.
- The model also enables users to more explicitly understand the purpose, roles, and meanings of parameters and their relationships with respect to contextual performance and concurrent collaboration. With this model, users can process and determine all of the required parameters not only more exquisitely in single functional domains with structures for contextual performance but also more multidimensionally in the four functional domains with the structures for concurrent collaboration. This greatly decreases uncertainty caused by insufficient parameters and ambiguity incurred by incorrect interpretations of parameters.
- The model permits users to understand the execution of each module (as an individual toolkit) from the viewpoint of the system as a whole and not just the constituent parts of the system.
- The model can help users to produce more abundant and exquisite parameters with the same effect as employing 'T', 'TT', and even 'TTT' type experts, regardless of the different backgrounds and specialities of the users.
- Consequently, those high-quality parameters, which reduce uncertainty and ambiguity, can have a positive effect on the execution of the actual NPD phase which will be implemented after the FFE, thus leading to an innovative (superior) final product[57]. Furthermore, the FFE model allows users to save those high-quality parameter sets as FFE library knowledge assets in each FFE project and extract applicable parameters for different FFE projects in the future.

  These features are appropriate for a data-driven FFE model which aims to collect, process, and determine parameters and *transform them into usable knowledge*, instead of just producing parameters.

[57] The definition of 'Innovative (Superior) Product' can be found in the introduction chapter (*p. 2*).

2) The pragmatic-prescriptive FFE model is constructed by the sub-modules flexibly structured in quadrants (in pursuit of **the responsiveness characteristic**) with the composition-modules formalised in linear structures (in pursuit of **the explicitness characteristic**). The main modules wherein the sub-modules are structured in quadrants are sequentially structured again (in pursuit of **the balance between explicitness and responsiveness characteristics**). In addition, the composition-modules formalised in the linear structures leave room to flexibly select specific performance techniques.

- Users can flexibly employ the composition-modules, maintaining their creative performance behaviours, under stable control. Namely, the model enables users to produce creative parameters under the explicit control of the performance direction.
- This leads to the production of reliable as well as creative parameters. Previously, parameters generated in existing toolkits developed for maximum creativity were indeed creative but unreliable, lacking any sort of standard and were too irregular, and thus less likely to be used in practical FFE projects.
- As a result, parameters obtained from the FFE model developed in this research are reliable as well as creative, and so can be used in practical FFE projects. Moreover, these parameters lead to reliable and creative conceptual designs, as the final outcomes of the early design stage, different from ordinary conceptual designs devised in most previous FFE models.

3) The pragmatic-prescriptive FFE model produces reliable and creative parameters which are processed and determined from the viewpoint of contextual performance and concurrent collaboration, which facilitates **agile development**.

- The need for iterative works to address defective parameters which were not handled from the contextual performance and concurrent collaboration perspective are remarkably reduced.
- Unnecessary meetings in which project participants who come from different functional domains have to explain not only the purpose, roles, and meanings of parameters and their relationships but who also must discuss descriptive evidential interpretations of each parameter and their relationships are considerably reduced.

4) The pragmatic-prescriptive FFE model wherein two channels for **incremental and radical NPDs** are established in the initial part of the model aids in providing two explicit NPD directions from the initial period, constantly producing parameters differently after that period, depending upon the two NPD directions initially set up.
    - Once the implementation of the modules involved in the two channels defining two different NPD directions, there can be fewer possibilities for users to become confused about what FFE activities should be conducted. The confusion about what FFE activities should be implemented throughout the FFE between the incremental and radical NPD directions was a chronic problem in most of the previous FFE models examined.

In summary, the pragmatic-prescriptive FFE model embodied with both the FFE model development strategies established in Study 1.0 (Literature Review) and the representative FFE scenario inferred from the analysis of various real-world FFE scenarios in Study 2.1 can be utilised as practical-functional performance guidance for FFEs in the future.

9.2.4 Theoretical-Descriptive FFE Model
– Studies 3.1 and 3.2 fulfilling Objectives 4 and 5

Through the validation studies conducted in Chapter Six (Study 3.1, *pp. 436–432*), the pragmatic-prescriptive FFE model was generalised, producing a theoretical-descriptive FFE model, described in Chapter Seven (Study 3.2, *pp. 433–455*). As shown in *Figure 9.2*, the theoretical-descriptive FFE model consists of mathematical formulas for each FFE task, adding up to a single mathematical formula for the entire FFE execution in the same context as with the pragmatic-prescriptive FFE model wherein all parameters interlock with each other from beginning to end.

The research contributions on the theoretical-descriptive FFE model is discussed below.

- Each theory, produced by generalising each main module (task) of the pragmatic-prescriptive FFE model, can be used as basic theoretical concept for performing each FFE task.
- An overall theory in which each theory for each main module (task) is integrated can be utilised as an underlying theoretical concept for the whole FFE.

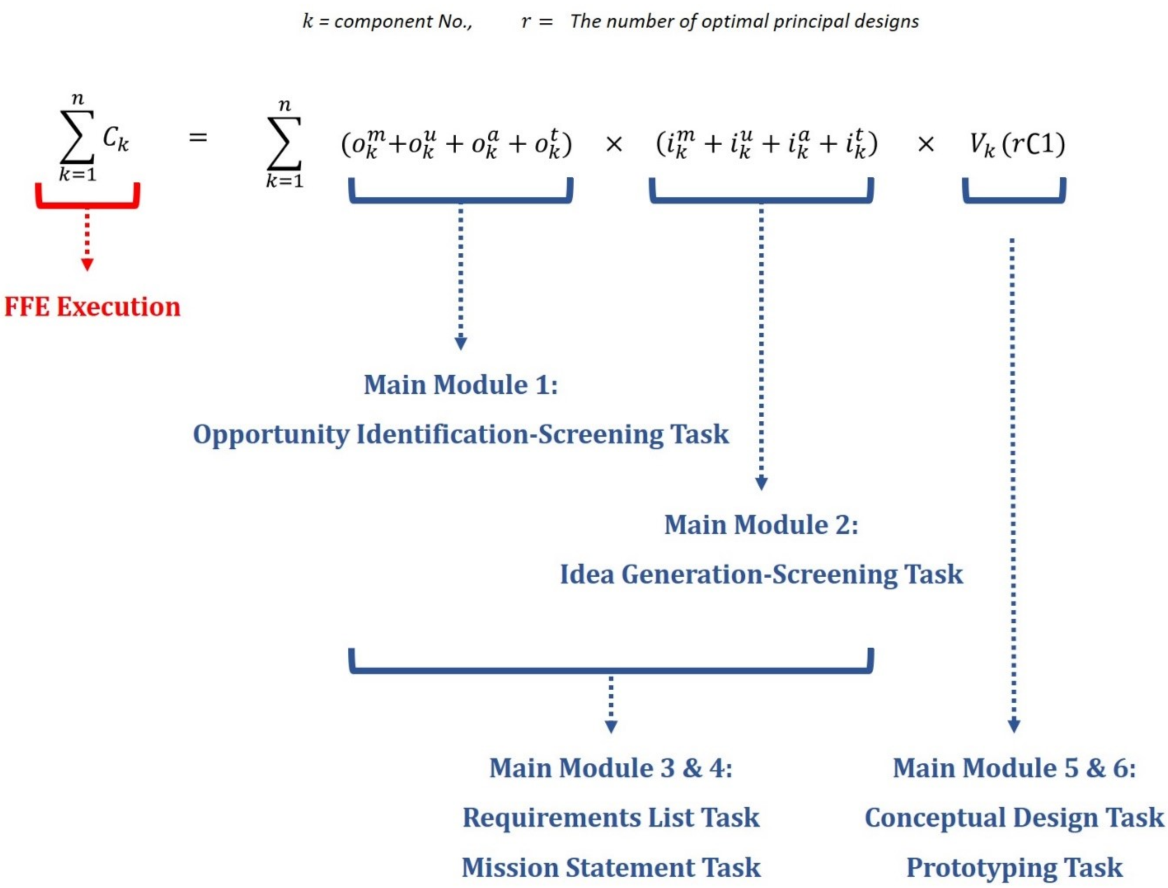


Figure 9.2. *Theoretical-Descriptive FFE model*

To conclude, the theoretical-descriptive FFE model can serve as theoretical-conceptual performance guidance for FFE execution when using the pragmatic-prescriptive FFE model is used as practical-functional performance guidance.

9.3 Research Limitations and Future Research Directions

Research limitations and future research directions can be considered in terms of the research methodology and outcomes.

1) Research Methodology
2) Research Outcomes

9.3.1 Research Methods

This section describes research limitations prospected in terms of research methodology. There are limitations viewed from four perspectives as follows.

First of all, the new pragmatic-prescriptive FFE model developed in this research targeted on large corporations and SMEs (e.g. design specialty companies and NPD consultancies) which develop consumer products. Hence, the real-world FFE scenarios utilised for practical resources for the model development were gathered within the scope of those firms. However, in the future research, theories on application conditions, approaches and methods to each different types of companies should be understood through literature, and those theories should also be reflected respectively on the model development.

Next, the number of experts (n=57) that participated in the validation is limited. Even though each value and piece of descriptive feedback from the experts contains some degree of representativeness which can describe the majority accurately, the number of participants, objectively speaking, seems to be small, by standards of statistical analysis. Therefore, future research involving a greater number of participants is necessary to further increase the validity of the developed model. If a large number of participants are gathered more than now, validation using 'Structural Equation Modelling' (SEM) method can be possible.

Then, in the validation, this research has not obtained data on how the developed model can be applied differently to the different types of consumer products such as electronics, medical devices, furniture. In future research, this application should be implemented to see how the model can be fine-tuned to these different types. Furthermore, the possibility of subdivided models leading up to a single, improved universal model, better than the current model, can also be identified from the results of this application. Indeed, with a continuous circular reasoning cycle, this future research can be executed using an inductive reasoning approach initiated again after the deductive reasoning research which was conducted in the latter half of this research.

Lastly, under the experimental condition fulfilling all the future research directions mentioned above, in-depth longitudinal case studies are required. Comparatively, a six-month period for field-testing was insufficient for tracking the validation results which may change periodically over a longer stretch of time. Therefore, a much longer period (more than 5 years at least) to validate results may be recommend for future research.

9.3.2 Research Outcomes

This section illustrates research limitations in terms of research outcomes. Besides the improvement points identified from the validation of the developed model (*pp. 430-431*), there are also further limitations from the following two viewpoints.

The first limitation considers how to downgrade the concreteness of the model structure. Ester and Daniel (2007), Khurana and Rosenthal (1998), Stevens and Berley (2003) and Talk et al. (2006) have stressed the importance of providing a training period prior to the use of a new model. Many NPD consultancies such as McKinsey and Booze and Allen have also highlighted the importance of this training period. This is because performers need time and effort to not only adapt themselves to using the new model but also to reconcile the new model with their own existing NPD systems, execution styles, and even organisation cultures. The larger the organisation and the more complex the existing NPD system, the more time and effort are required. Hence, in this research, participants were also pre-trained for a week at least, to ensure proficiency in using the developed model prior to validation. However, without any training and separate instruction manuals or resources, if performers can recognise intuitively how to use the new model with the model structure and interface only, and if they can consolidate the new model into their existing NPD systems with ease, the model can be regarded as a better one. Thus, in future research, we need to consider how to downgrade the concreteness of the model structure, and how to best maintain the currently fostered FFE performance structures and operating mechanisms which have received positive assessments.

The second limitation concerns the ultimate purpose of the data-driven model in the future. This model pursues the data-driven type in which parameters are not mere produced but be processed to interlock. With this structure, parameters can be produced and accumulated in each FFE project in the form of a library dataset, and performers can extract applicable parameters from the library and reflect them in future FFE projects. This process of the accumulation, extraction and application has so far been done manually. However, in future research, by incorporating machine learning technology and allowing it to handle this operation, the building and utilisation of the library dataset can be automated. Furthermore, after the library dataset has existed for some time, once performers put parameters in the initial module only, parameters from the beginning to the end of the process can be automatically produced by a system wherein the model can learn to process data by itself.

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Appendix 1:

The Examination of the 255 FFE models

1) Analysis Chart

Model #	Appraisal Criteria												
	1 Study Taxo-nomy	2 Model Attribute	3 NPD Speed	4 NPD Attribute	5 Model Autonomy	6 Model Type	7 FFE Task	8 FFE Activity	9 Performance Method	10 Toolkit			
										1	2	3	4
– 1970s													
M001	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
M002	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
M003	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
M004	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
M005	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
M006	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
M007	1.1	2.1	X	4.2	5.1	6.3	7.1, 7.2, 7.4	△	△	○	△	○	X
M008	1.1	2.1	X	4.2	5.1	6.1	7.1, 7.2, 7.4	○	△	X			
M009	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	△	X			
M010	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
M011	1.1	2.1	X	4.2	5.1	6.1	7.1, 7.2, 7.4	○	○	○	△	△	X
M012	1.1	2.1	X	4.2	5.2	6.1	7.1, 7.2, 7.4	△	△	△1	△	X	X
M013	1.1	2.1	X	4.2	5.1	6.3	7.1, 7.2, 7.4, 7.5, 7.6	○	○	○	△	△	X
M014	1.1	2.1	X	4.2	5.1	6.1	7.1, 7.2, 7.4, 7.5	○	○	X			
M015	1.1	2.1	X	4.2	5.1	6.1	7.1, 7.2, 7.4, 7.5	○	○	X			
M016	1.1	2.1	X	4.2	5.1	6.1	7.1, 7.2, 7.3, 7.4	△	X	X			
M017	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
1980s													
M018	1.1	2.1	X	4.2	5.6	6.1	7.1, 7.2, 7.4, 7.5, 7.6	△	△	X			
M019	1.1	2.1	X	4.2	5.1	6.1	7.1, 7.2, 7.4, 7.5, 7.6	△	△	○	△	△	X
M020	1.1	2.2	△	4.4	5.1	6.1	7.1, 7.2, 7.3, 7.5	○	△	△2	△	X	X
M021	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
M022	1.2	2.7	X	4.6	5.3	6.2	7.4, 7.5, 7.6	△	○	○	△	△	△
M023	1.2	2.1	X	4.6	5.6	6.6	7.5	△	△	○	△	○	X
M024	1.1	2.3	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.5	△	△	X			
M025	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
M026	1.1	2.1	X	4.2	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	○	○	△	△	X
M027	1.1	2.5	X	4.4	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	○	○	△	△	X
M028	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	△	X			
M029	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
M030	1.2	2.3	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	△	△2	○	X	X
M031	1.1	2.4	X	4.1	5.3	6.1	7.1, 7.2, 7.4, 7.5	X	X	X			
M032	1.4	N/A	N/A	N/A	5.6	6.2	N/A	N/A	△	○	△	△	X
M033	1.1	2.1	X	4.2	5.1	6.3	7.1, 7.2, 7.3, 7.4, 7.5	○	○	○	△	△	X
M034	1.1	2.4	X	4.6	5.3	6.3	7.1, 7.2, 7.4, 7.5	○	△	○	○	△	△
M035	1.2	2.1	X	4.6	5.1	6.2	7.5	△	○	○	△	○	X
M036	1.2	2.4	X	4.4	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	△	△2	○	X	X
M037	1.2	2.4	X	4.4	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	△	△2	○	X	X
M038	1.2	2.4	X	4.4	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	X	X			
M039	1.1	2.1	X	4.4	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	○	○	△	△	X
M040	1.2	2.3	X	4.2	5.2	6.1	7.1, 7.2, 7.4, 7.5, 7.6	X	X	X			
M041	1.1	2.7	X	4.2	5.1	6.1	7.1, 7.2, 7.3	○	X	△2	○	X	X
M042	1.1	2.7	X	4.6	5.2	6.1	7.1, 7.3, 7.4, 7.5, 7.6	△	△	○	○	△	X
M043	1.2	2.7	X	4.6	5.3	6.1	7.3, 7.5, 7.6	X	△	△2	○	X	X
M044	1.2	2.7	X	4.3	5.1	6.1	7.1, 7.2, 7.5	○	△	○	○	X	X
M045	1.2	2.7	X	4.2	5.1	6.1	7.1, 7.2, 7.5	○	△	○	○	X	X
M046	1.2	2.1	X	4.6	5.1	6.2	7.5	△	△	○	△	○	X
M047	1.1	2.1	X	4.2	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	△	X			
M048	1.1	2.1	X	4.2	5.1	6.1	7.1, 7.2, 7.4, 7.5	○	○	△2	△	△	X
1990s													
M049	1.4	2.3	X	4.2	5.3	6.6	7.7	X	X	X			
M050	1.2	2.4	X	4.6	5.3	6.1	7.1, 7.2, 7.3	X	X	X			
M051	1.1	2.4	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	○	X			
M052	1.1	2.3	X	4.4	5.3	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	○	○	△	X	X
M053	1.2	2.3	X	4.2	5.6	6.2	7.1, 7.2, 7.4, 7.5	△	△	○	○	△	X
M054	1.2	2.2	X	4.2	5.1	6.1	7.1, 7.2, 7.3	○	△	△2	○	X	X

M055	1.1	2.1	○	4.4	5.1	6.1	7.1, 7.2, 7.4, 7.5, 7.6	X	X	X			
M056	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	△	X			
M057	1.2	2.1	X	4.2	5.4	6.1	7.2, 7.4, 7.5	△	△	X			
M058	1.2	2.1	X	4.2	5.1	6.1	7.2	○	△	△2	△	△	X
M059	1.2	2.1	X	4.2	5.3	6.2	7.2, 7.5	○	○	○	△	○	X
M060	1.2	2.1	X	4.5	5.3	6.1	7.2, 7.5	○	△	○	△	○	X
M061	1.2	2.5	X	4.6	5.1	6.1	7.1, 7.2, 7.3	○	△	○	○	△	X
M062	1.2	2.1	X	4.6	5.1	6.3	7.2, 7.4, 7.5	○	○	○	△	○	X
M063	1.1	2.4	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	X	X	X			
M064	1.4	2.7	X	4.6	5.4	6.4	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	△	△	○	○	△	X
M065	1.1	2.1	X	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.5, 7.6	○	○	△2	△	X	X
M066	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
M067	1.2	2.4	X	4.6	5.3	6.1	7.1, 7.2, 7.4, 7.5	X	△	△2	○	△	△
M068	1.1	2.4	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	○	○ + △2	○	△	△
M069	1.4	N/A	N/A	N/A	5.1	6.2	N/A	N/A	X	X			
M070	1.2	2.1	X	4.6	5.1	6.2	7.4, 7.5	△	○	○	△	○	X
M071	1.2	2.1	X	4.6	5.1	6.2	7.4, 7.5	△	○	○	△	○	X
M072	1.4	2.4	X	4.6	5.6	6.6	7.7	X	X	X			
M073	1.2	2.1	X	4.6	5.1	6.2	7,4, 7.5, 7.6	○	○	○	○	○	△
M074	1.2	2.4	○	4.6	5.3	6.1	7.1, 7.3, 7.5	X	X	X			
M075	1.2	2.4	X	4.4	5.1	6.1	7.1, 7.4, 7.5, 7.6	○	△	△2	○	X	X
M076	1.3	2.7	X	4.6	5.6	6.6	7.7	X	X	X			
M077	1.2	2.4	X	4.1	5.3	6.1	7.1, 7.3, 7.4	○	X	X			
M078	1.1	2.1	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	△	○ + △2	△	△	X
M079	1.1	2.4	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	○	△2	○	△	X
M080	1.1	2.4	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	○	△2	○	X	X
M081	1.1	2.4	△	4.4	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	○	○ + △2	○	△	△
M082	1.2	2.7	X	4.2	5.3	6.1	7.5, 7.6	X	X	X			
M083	1.4	N/A	N/A	N/A	5.6	6.6	N/A	N/A	X	X			
M084	1.4	2.7	△	4.6	5.1	6.3	7.7	X	△	○	△	△	X
M085	1.2	2.4	X	4.6	5.3	6.3	7.4, 7.5	△	△	○	○	○	△
M086	1.2	2.5	△	4.5	5.3	6.1	7.1, 7.2, 7.3, 7.5	△	△	○ + △2	△	△	X
M087	1.2	2.4	○	4.6	5.3	6.2	7.4, 7.5	○	○	○	○	○	△
M088	1.1	2.4	○	4.6	5.3	6.4	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	○	○	○	○	△
M089	1.4	N/A	N/A	N/A	5.6	6.6	N/A	N/A	X	X			
M090	1.4	N/A	N/A	N/A	5.2	6.6	N/A	N/A	X	X			
M091	1.1	2.7	X	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	△	X	△2	○	X	X
M092	1.2	2.7	X	4.1	5.1	6.3	7.1, 7.2	△	△	○	△	△	X
M093	1.2	2.3	X	4.2	5.1	6.1	7.1	△	X	△2	○	X	X
M094	1.1	2.3	X	4.6	5.1	6.1	7.1, 7.3, 7.4, 7.5	○	△	△2	○	X	X
M095	1.2	2.4	△	4.2	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	X	△2	○	X	X
M096	1.2	2.4	X	4.6	5.1	6.2	7.1, 7.4	○	△	○	○	○	△
M097	1.1	2.4	X	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	○	○ + △2	○	△	△
M098	1.1	2.1	X	4.4	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	○	○ + △2	△	△	X
M099	1.1	2.4	△	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.5	△	△	X			
M100	1.1	2.4	△	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.5	△	△	X			
M101	1.1	2.3	△	4.4	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	△	X	X			
M102	1.2	2.1	○	4.4	5.3	6.1	7.2, 7.5, 7.6	X	X	X			
M103	1.2	2.4	X	4.1	5.1	6.1	7.1, 7.2, 7.4, 7.5, 7.6	△	△	X			
M104	1.1	2.7	X	4.6	5.1	6.1	7.3, 7.4, 7.5, 7.6	△	X	X			
M105	1.1	2.1	X	4.5	5.1	6.1	7.1, 7.2, 7.3, 7,4, 7.5, 7.6	△	X	X			
M106	1.2	2.7	X	4.6	5.3	6.2	7.2	○	△	△1	△	○	X
M107	1.4	2.7	△	4.3	5.3	6.1	7.1, 7.2, 7.5	○	△	X			
M108	1.3	2.5	X	4.5	5.6	6.6	7.1, 7.3, 7.5	X	X	△2	○	X	X
M109	1.2	2.5	X	4.5	5.1	6.1	7.5, 7.6	○	△	△2	○	X	X
2000s													
M110	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
M111	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
M112	1.2	2.1	○	4.2	5.3	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	X	X	X			
M113	1.2	2.5	X	4.6	5.1	6.4	7.1, 7.2, 7.3, 7.4, 7.5	○	△	○	○	△	X
M114	1.4	2.7	△	4.1	5.3	6.6	7.1, 7.2, 7.5	○	X	X			
M115	1.1	2.5	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	△	X			
M116	1.1	2.5	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	△	△2	○	X	X
M117	1.2	2.1	X	4.6	5.3	6.3	7.5	△	○	○	△	○	X
M118	1.2	2.4	X	4.5	5.1	6.3	7.1, 7.2, 7.4, 7.5	○	△	△2	○	△	X
M119	1.2	2.1	X	4.6	5.3	6.1	7.5	△	○	○	△	○	X
M120	1.4	N/A	N/A	N/A	5.3	6.1	N/A	N/A	X	X			
M121	1.2	2.7	○	4.6	5.1	6.1	7.5, 7.6	X	X	○ + △2	○	X	X
M122	1.2	2.7	○	4.6	5.3	6.1	7.5, 7.6	X	X	○	△	X	X
M123	1.2	2.3	X	4.1	5.1	6.1	7.1	△	X	X			
M124	1.2	2.5	○	4.5	5.4	6.1	7.1, 7.2, 7.3, 7.5	○	△	△2	○	X	X
M125	1.2	2.4	X	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	△	△	△2	○	X	X
M126	1.2	2.5	X	4.5	5.6	6.6	7.1, 7.3, 7.4, 7.5	△	X	X			

M127	1.2	2.7	X	4.6	5.1	6.2	7.4	○	△	○ + △2	○	△	X
M128	1.4	N/A	N/A	N/A	5.4	6.1	N/A	N/A	X	X			
M129	1.2	2.5	X	4.5	5.6	6.6	7.2	○	△	X			
M130	1.2	2.4	X	4.5	5.3	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	△	X	△2	△	X	X
M131	1.4	N/A	N/A	N/A	5.1	6.2	N/A	N/A	△	△1	△	○	X
M132	1.2	2.5	△	4.6	5.1	6.1	7.1, 7.2, 7.5	△	△	△2	○	X	X
M133	1.2	2.7	X	4.6	5.3	6.4	7.2, 7.5	○	X	○	○	○	△
M134	1.2	2.5	○	4.5	5.2	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	△	△2	○	X	X
M135	1.2	2.7	X	4.5	5.1	6.1	7.1, 7.3, 7.4	X	△	○	△	△	X
M136	1.2	2.5	○	4.3	5.3	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	X	X			
M137	1.2	2.5	△	4.6	5.2	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	△	△2	○	X	X
M138	1.2	2.7	△	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	X	X			
M139	1.2	2.4	△	4.5	5.1	6.1	7.1, 7.2, 7.4	△	△	X			
M140	1.2	2.7	△	4.5	5.3	6.1	7.1, 7.2, 7.5, 7.6	○	△	X			
M141	1.1	2.4	○	4.6	5.3	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	X	X			
M142	1.4	N/A	N/A	N/A	5.2	6.6	N/A	N/A	X	X			
M143	1.4	N/A	N/A	N/A	5.4	6.1	N/A	N/A	△	△2	△	○	X
M144	1.2	2.4	○	4.5	5.2	6.4	7.1, 7.3	△	X	△2	○	△	△
M145	1.2	2.5	○	4.1	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	△	X	△2	○	X	X
M146	1.2	2.5	X	4.5	5.1	6.1	7.1, 7.2, 7.3	△	X	X			
M147	1.1	2.5	△	4.5	5.3	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	△	△2	○	X	X
M148	1.4	N/A	N/A	N/A	5.2	6.3	N/A	N/A	△	○	△	○	X
M149	1.4	N/A	N/A	N/A	5.1	6.1	N/A	N/A	X	X			
M150	1.2	2.1	X	4.6	5.1	6.2	7.4, 7.5	△	○	○	○	○	△
M151	1.2	2.5	X	4.6	5.3	6.1	7.1, 7.3, 7.4, 7.5	○	X	X			
M152	1.2	2.4	X	4.6	5.1	6.1	7.1, 7.3, 7.4	△	△	○	○	○	△
M153	1.2	2.1	X	4.2	5.3	6.3	7.1, 7.2	○	△	○	△	○	X
M154	1.2	2.7	X	4.3	5.1	6.6	7.1, 7.2	△	△	X			
M155	1.4	2.7	△	4.5	5.3	6.1	7.7	X	X	X			
M156	1.2	2.7	X	4.6	5.1	6.1	7.2, 7.3, 7.5	X	X	X			
M157	1.4	N/A	N/A	N/A	5.6	6.6	N/A	N/A	X	X			
M158	1.1	2.4	△	4.5	5.1	6.1	7.1, 7.2, 7.3, 7,4, 7.5	○	○	△2	△	X	X
M159	1.1	2.1	X	4.5	5.1	6.1	7.1, 7.3, 7.4, 7.5	△	X	X			
M160	1.1	2.2	X	4.6	5.2	6.1	7.2, 7.5	△	X	X			
M161	1.4	N/A	N/A	N/A	5.3	6.1	N/A	N/A	△	△2	○	X	X
M162	1.4	N/A	N/A	N/A	5.6	6.6	N/A	N/A	△	○	○	△	X
M163	1.2	2.7	X	4.3	5.1	6.1	7.2, 7.5	△	△	X			
M164	1.2	2.7	X	4.1	5.3	6.1	7.5, 7.6	△	X	X			
M165	1.2	2.4	X	4.5	5.3	6.1	7.1, 7.2, 7.3, 7.4, 7.5	△	X	X			
M166	1.2	2.7	X	4.6	5.1	6.1	7.1, 7.2, 7.5	○	△	△2	○	X	X
M167	1.4	2.7	X	4.5	5.6	6.6	7.7	X	X	X			
M168	1.2	2.7	X	4.5	5.1	6.1	7.1, 7.3	△	△	△1	○	X	X
M169	1.2	2.7	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	X	X			
M170	1.4	2.7	○	4.6	5.3	6.1	7.7	X	X	X			
M171	1.1	2.5	△	4.5	5.4	6.1	7.1, 7.2, 7.3, 7,4, 7.5, 7.6	○	○	○ + △2	○	X	X
M172	1.1	2.5	△	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	○	○ + △2	○	△	△
M173	1.1	2.5	○	4.5	5.3	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	○	△2	○	X	X
M174	1.1	2.7	△	4.6	5.3	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	△	X	X			
M175	1.2	2.5	○	4.6	5.3	6.1	7.1, 7.3, 7.4, 7.5	○	○	○	○	○	△
M176	1.2	2.4	X	4.6	5.1	6.3	7.1, 7.4, 7.5	○	△	○	○	○	△
M177	1.2	2.4	△	4.5	5.3	6.1	7.1, 7.2	X	X	△2	○	X	X
M178	1.2	2.4	N/A	4.6	5.6	6.6	7.1, 7.2, 7.3, 7.4	○	X	X			
M179	1.1	2.5	△	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	△	△	△2	○	X	X
M180	1.4	N/A	N/A	N/A	5.6	6.6	N/A	N/A	△	○	△	△	X
M181	1.2	2.4	N/A	4.5	5.6	6.6	7.1, 7.2, 7.3, 7.4, 7.5	○	X	X			
M182	1.2	2.4	X	4.6	5.6	6.6	7.1, 7.2, 7.4, 7.5	X	X	X			
M183	1.2	2.7	N/A	4.6	5.6	6.6	7.7	X	X	X			
M184	1.2	2.5	X	4.1	5.6	6.6	7.1, 7.2	X	X	△1	○	X	X
M185	1.2	2.5	X	4.5	5.4	6.1	7.1, 7.2, 7.3, 7,4, 7.5, 7.6	○	○	△2	○	X	X
M186	1.2	2.5	△	4.6	5.3	6.1	7.5, 7.6	X	X	X			
M187	1.1	2.5	○	4.6	5.3	6.3	7.1, 7.2, 7.3, 7.4, 7.5	△	△	○ + △2	○	△	△
M188	1.1	2.4	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	X	○ + △2	○	X	X
M189	1.4	2.7	X	4.6	5.2	6.1	7.7	X	X	△2	△	△	X
M190	1.4	N/A	N/A	N/A	5.3	6.1	N/A	N/A	X	X			
M191	1.4	N/A	N/A	N/A	5.3	6.1	N/A	N/A	X	X			
M192	1.2	2.1	X	4.6	5.1	6.3	7.2	○	△	○	△	○	X
M193	1.2	2.1	X	4.6	5.1	6.1	7.2	○	△	X			
M194	1.2	2.1	X	4.6	5.2	6.6	7.2	○	△	X			
2010s													
M195	1.1	2.7	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	△	△2	○	X	X
M196	1.1	2.2	△	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.5	○	○	△2	△	X	X
M197	1.1	2.2	○	4.5	5.4	6.1	7.1, 7.2, 7.3, 7.5	○	○	○ + △2	△	X	X
M198	1.2	2.4	△	4.5	5.3	6.1	7.1, 7.3	○	△	○	○	△	△
M199	1.2	2.4	X	4.6	5.1	6.1	7.1, 7.3, 7.4, 7.5	○	△	△2	○	X	X
M200	1.4	2.7	N/A	4.6	5.6	6.6	N/A	N/A	○	○ +	○	X	X

										△2			
M201	1.1	2.5	N/A	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	○	○ + △2	○	X	X
M202	1.4	2.7	N/A	4.5	5.1	6.1	N/A	N/A	○	○ + △2	○	X	X
M203	1.1	2.5	N/A	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	○	○ + △2	○	X	X
M204	1.1	2.5	○	4.6	5.3	6.1	7.1, 7.2, 7.3, 7,4, 7.5	△	X	X			
M205	1.1	2.5	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7,4, 7.5	△	X	X			
M206	1.1	2.5	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	X	X			
M207	1.2	2.5	X	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	△	△	△2	○	X	X
M208	1.2	2.7	X	4.6	5.1	6.1	7.1, 7.3	X	○	○	△	△	X
M209	1.2	2.4	N/A	4.6	5.6	6.6	7.1, 7,2, 7.3, 7.4, 7.5	X	X	X			
M210	1.2	2.5	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	△	△	△2	△	X	X
M211	1.1	2.5	○	4.5	5.3	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	△	△2	○	X	X
M212	1.2	2.5	X	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	△	△2	○	X	X
M213	1.2	2.7	X	4.6	5.3	6.1	7.4, 7.5	△	X	○	○	○	△
M214	1.2	2.1	X	4.6	5.1	6.6	7.2, 7.4	○	○	○	△	○	X
M215	1.2	2.1	X	4.6	5.3	6.6	7.2, 7.4	○	○	X			
M216	1.2	2.1	X	4.6	5.6	6.6	7.2, 7.4	○	○	X			
M217	1.2	2.1	X	4.6	5.1	6.1	7.1, 7.2, 7.4	○	○	○	△	○	X
M218	1.2	2.1	X	4.6	5.1	6.1	7.1, 7.2, 7.5	○	○	△2	△	△	X
M219	1.2	2.1	X	4.6	5.1	6.1	7.1, 7.2, 7.4, 7.5	○	○	△2	△	△	X
M220	1.2	2.5	△	4.1	5.1	6.1	7.1, 7.2, 7.3, 7.5, 7.6	△	X	X			
M221	1.2	2.4	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4	X	X	X			
M222	1.2	2.4	X	4.6	5.6	6.6	7.1, 7.2, 7.3, 7.4, 7.5	X	X	X			
M223	1.2	2.5	X	4.2	5.6	6.6	7.2, 7.3, 7.5	X	X	X			
M224	1.2	2.5	X	4.3	5.1	6.1	7.2, 7.5	△	X	X			
M225	1.2	2.5	○	4.6	5.1	6.1	7.1, 7.2, 7.5	○	○	△2	○	△	△
M226	1.2	2.5	X	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	○	△2	○	X	X
M227	1.3	2.5	X	4.6	5.6	6.6	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	△	△	△2	○	X	X
M228	1.1	2.5	X	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	△	△2	○	X	X
M229	1.2	2.5	X	4.6	5.1	6.1	7.1, 7.2	X	X	X			
M230	1.2	2.5	○	4.1	5.1	6.1	7.1, 7.2	△	X	X			
M231	1.2	2.7	N/A	4.1	5.6	6.6	7.1, 7.2, 7.4, 7.5	△	X	X			
M232	1.2	2.5	X	4.5	5.6	6.6	7.1, 7.2, 7.4, 7.5	△	X	△2	○	X	X
M233	1.1	2.5	△	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	△	△	△2	○	X	X
M234	1.1	2.5	X	4.1	5.1	6.1	7.1, 7.2, 7.4, 7.5	△	X	△2	○	X	X
M235	1.4	2.5	X	4.3	5.6	6.6	7.1, 7.2, 7.5	△	△	△2	○	X	△
M236	1.2	2.5	X	4.5	5.1	6.1	7.1, 7.3, 7.4	△	○	○	○	○	△
M237	1.3	2.7	X	4.6	5.6	6.6	7.7	X	X	X			
M238	1.2	2.7	X	4.4	5.6	6.6	7.2, 7.3, 7.5	X	X	X			
M239	1.2	2.5	X	4.5	5.6	6.6	7.1, 7.2, 7.5	X	X	X			
M240	1.2	2.5	X	4.4	5.6	6.6	7.1, 7.2, 7.3, 7.5	X	X	X			
M241	1.1	2.5	X	4.5	5.3	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	△	X	X			
M242	1.2	2.5	△	4.4	5.6	6.6	7.1, 7.2, 7.3, 7.5	○	△	△2	○	X	X
M243	1.2	2.5	X	4.6	5.6	6.6	7.7	X	X	X			
M244	1.1	2.4	△	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5, 7.6	○	○	○ + △2	△	△	X
M245	1.2	2.5	X	4.4	5.6	6.6	7.1, 7.3	X	X	X			
M246	1.2	2.5	△	4.5	5.1	6.1	7.1, 7.2, 7.3, 7.4, 7.5	○	△	△2	○	X	X
M247	1.1	2.4	△	4.6	5.1	6.1	7.1, 7.2, 7.3, 7.5, 7.6	○	△	△2	○	X	X
M248	1.2	2.5	△	4.3	5.2	6.6	7.1, 7.2, 7.5	X	X	X			
M249	1.3	2.7	X	4.5	5.6	6.6	7.1, 7.2, 7.3, 7.5, 7.6	○	X	△2	○	X	X
M250	1.2	2.2	△	4.2	5.1	6.1	7.1, 7.2, 7.3	○	X	X			
M251	1.3	2.7	X	4.5	5.6	6.6	7.7	X	X	X			
M252	1.2	2.5	○	4.5	5.4	6.1	7.1, 7.2, 7.5, 7.6	△	X	△2	○	X	X
M253	1.3	2.7	X	4.6	5.6	6.6	7.2, 7.5	X	○	○ + △2	○	△	△
M254	1.2	2.1	X	4.1	5.1	6.1	7.2, 7.5	△	X	△2	△	X	X
M255	1.2	2.5	△	4.5	5.4	6.6	7.1, 7.2, 7.5, 7.6	○	X	△2	○	X	X

2) List of Models

Model Number	***Reference***
M001 (Dewey, 1910)	. Dewey, J. (1910). *How We Think, DC Heath & Co.* Boston, Mass 224.
M002 (Wallas, 1926)	. Wallas, G. (1926). *The Art of Thought, ed.* Jonathan Cape *(London: Jonathan Cape, 1926)*: 79-96. . Truman, S. (2011). A generative framework for creative learning: A tool for planning creative-collaborative tasks in the classroom. *Border Crossing 1*(1): 1-13. . Larsen, M. A. (2013). Possibilities of Courageous Creativity in Comparative and International Education Research. *Comparative and International Education 42*(1): 1.
M003 (Kris, 1952)	. Kris, E. (1952). *Psychoanalytic explorations in art.* International Universities Press, *New York*.
M004 (Polya, 1957)	. Polya, G. (1957). *How to solve it*: *A new aspect of mathematical method:* Princeton university press. . Polya, G. (2014). *How to solve it*: *A new aspect of mathematical method:* Princeton university press.
M005 (Guilford,1957)	. Guilford, J. P. (1957). *A Revised Structure of Intellect: Studies of Aptitudes of High-level Personnel:* University of Southern California.
M006 (Buhl, 1960)	. Buhl, H. R. (1960). *Creative engineering design:* Iowa State University Press. . Cropley, D. H. (2016). Creativity in engineering. *Multidisciplinary Contributions to the Science of Creative Thinking* (pp. 155-173): Springer.
M007 (Marples, 1960)	. The decisions of engineering design Inst. of Eng. *Designers, London*. . The decisions of engineering design. *IRE Transactions on Engineering Management* (2), 55-71. . Stauffer, L. A. (1987). *An empirical study on the process of mechanical design*. Thesis, Department of Mechanical Engineering, Oregon State University, Corvalhs, OR.
M008 (Asimow, 1962)	. Asimow, M. (1962). *Introduction to design* (Vol. 394): Prentice-Hall Englewood Cliffs, NJ.
M009 (Rogers, 1962)	. Howard, T. J., et al. (2008). Describing the creative design process by the integration of engineering design and cognitive psychology literature. *Design Studies 29*(2): 160-180. . Rogers, E. M. (2010). *Diffusion of innovations:* Simon and Schuster.
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M012 (Watts, 1966)	. Watts, R. D. (1966). The elements of design. *The design method* (pp. 85-95): Springer. . McCrory, R. (1963). The design method—A scientific approach to valid design. *Contributions to a Philosophy of Technology* (pp. 158-173): Springer. . Gregory, S. A. (2013). *The design method*: Springer.
M013 (Matchett & Briggs, 1966)	. Matchett, E., & Briggs, A. (1966). Practical design based on method (fundamental design method) *The design method* (pp. 183-199): Springer. . Gregory, S. A. (2013). *The design method*: Springer.
M014 (Krick, 1965)	. Krick, E. V. (1965). *An introduction to engineering and engineering design.* John Wiley, New York
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M016 (Utterback, 1971)	. Utterback, J. M. (1971). The process of technological innovation within the firm. *Academy of management Journal, 14*(1), 75-88. . Utterback, J. M. (1971). The process of innovation: A study of the origination and development of ideas for new scientific instruments. *IEEE Transactions on Engineering Management* (4), 124-131. . Utterback, J. M. (1994). *Mastering the Dynamics of Innovation*, Boston, MA: Harvard Business School Press.
M017 (Stein, 1974)	. Stein, M. I. (1974). *Stimulating creativity.* Academic Press, New York. . Stein, M. I. (2014). *Stimulating creativity: Individual procedures:* Academic Press, New York.
M018 (Harris, 1980)	. Harris, A. J. (1980). Can design be taught? Proc. Inst. *Civ. Engrs 68*(1), 409-416.
M019 (Wilson, 1980)	. Wilson, D. R. (1980). *An exploratory study of complexity in axiomatic design*, Massachusetts Institute of Technology.
M020 (Urban & Hauser, 1980)	. Urban, G. L., & Hauser, J. R. (1993). *Design and marketing of new products* (Vol. 2): Prentice hall Englewood Cliffs, NJ. . Hauser, J. R. (2008). *Note on Product Development*: Cambridge, MA: MIT Sloan Courseware.
M021 (Barron & Harrington, 1981)	. Barron, F., & Harrington, D. M. (1981). Creativity, intelligence, and personality. *Annual review of psychology, 32*(1), 439-476.
M022 (Steward, 1981)	. Steward, D. V. (1981). The design structure system: A method for managing the design of complex systems. *IEEE transactions on Engineering Management* (3), 71-74. . Eppinger, S. D., et al. (1994). A model-based method for organizing tasks in product development. *Research in engineering design 6*(1): 1-13. . Eppinger, S. D., Whitney, D. E., Smith, R. P., & Gebala, D. A. (1994). A model-based method for organizing tasks in product development. *Research in engineering design, 6*(1), 1-13. . Morelli, M. D., Eppinger, S. D., & Gulati, R. K. (1995). Predicting technical communication in product development organizations. *IEEE transactions on engineering management, 42*(3), 215-222.
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M024 (Booz & Company, 1982)	. From New Products Management for the 1980s by Booz & Company. Copyright © 1982 by Booz & Company. Reprinted by permission of Booz & Company.
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M029 (Crawford, 1984)	. Crawford, C. M. (1984). Protocol: new tool for product innovation. *Journal of Product Innovation Management, 1*(2), 85-91.
M030 (Fledman & Page, 1984)	. Feldman, L. P., & Page, A. L. (1984). Principles vs. practice in new product planning. *Journal of Product innovation management 1*(1): 43-55.
M031 (Kline & Rosenberg, 1986)	. Kline, S. J., & Rosenberg, N. (1986). An overview of innovation. The positive sum strategy: *Harnessing technology for economic growth, 14*, 640.
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M045 (Shocker & Srinivasan, 1979)	. Shocker, A. D., & Srinivasan, V. (1979). *Multiattribute approaches for product concept evaluation and generation: A critical review*. Journal of Marketing Research: 159-180.
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M048 (Cross, 1989)	. Cross, N., & Roy, R. (1989). *Engineering design methods* (Vol. 4): Wiley New York. . Cross, N. (1984). *Developments in design methodology:* John Wiley & Sons. . Roozenburg, N. F., & Cross, N. (1991). Models of the design process: integrating across the disciplines. *Design studies, 12*(4), 215-220.
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M247 (Moretti & Junior, 2017)	. Moretti, I. C., & Junior, A. B. (2017). Reference model for apparel product development. *Independent Journal of Management & Production, 8*(1), 232-262.
M248 (Andriopoulos et al., 2017)	. Andriopoulos, C., Gotsi, M., Lewis, M. W., & Ingram, A. E. (2017). Turning the Sword: How NPD Teams Cope with Front-End Tensions. *Journal of Product Innovation Management 35*(3), 427-445.
M249 (Parida et al., 2017)	. Parida, V., Patel, P. C., Frishammar, J., & Wincent, J. (2017). Managing the front-end phase of process innovation under conditions of high uncertainty. *Quality & Quantity, 51*(5), 1983-2000.
M250 (Rodrigues et al., 2017)	. Rodrigues, T., Braghini Junior, A., & Sola, A. V. H. (2017). Structuring front-end innovation activities throughout strategic product planning. *Production*, 27.
M251 (Yong, 2017)	. Yong, C., Islam, M. S., Sun Hilen, M., & Nizam, E. H. (2017). Front-End Activities Promote Front-End Performance? —The Moderating Effect of Front-End Uncertainty. *Global Journal of Management and Business Research*.
M252 (Tate et al., 2018)	. Tate, M., Bongiovanni, I., Kowalkiewicz, M., & Townson, P. (2018). Managing the "Fuzzy front end" of open digital service innovation in the public sector: A methodology. *International Journal of Information Management, 39*, 186-198.
M253 (Khastehdel et al., 2018)	. Khastehdel, M., & Mansour, S. (2018). Developing a Dynamic Model for Idea Selection during Fuzzy Front End of Innovation. World Academy of Science, Engineering and Technology, *International Journal of Economics and Management Engineering, 5*(3).
M254 (Cho et al., 2018)	. Cho, Y., Kirkewoog, S., & Daim, T. U. (2018). Managing strategic intellectual property assets in the fuzzy front end of new product development process. *R&D Management*, *48*(3), 354-374.
M255 (Marshall, 2018)	. Marshall, J. K. (2018). *Front-End Innovation and Craft Beer Breweries: Exploring Problem Framing and the Customer Experience through Design Thinking*. Doctoral Dissertation in School of Business and Technology, Capella University.

The following papers, which examine representative models, were also referenced:

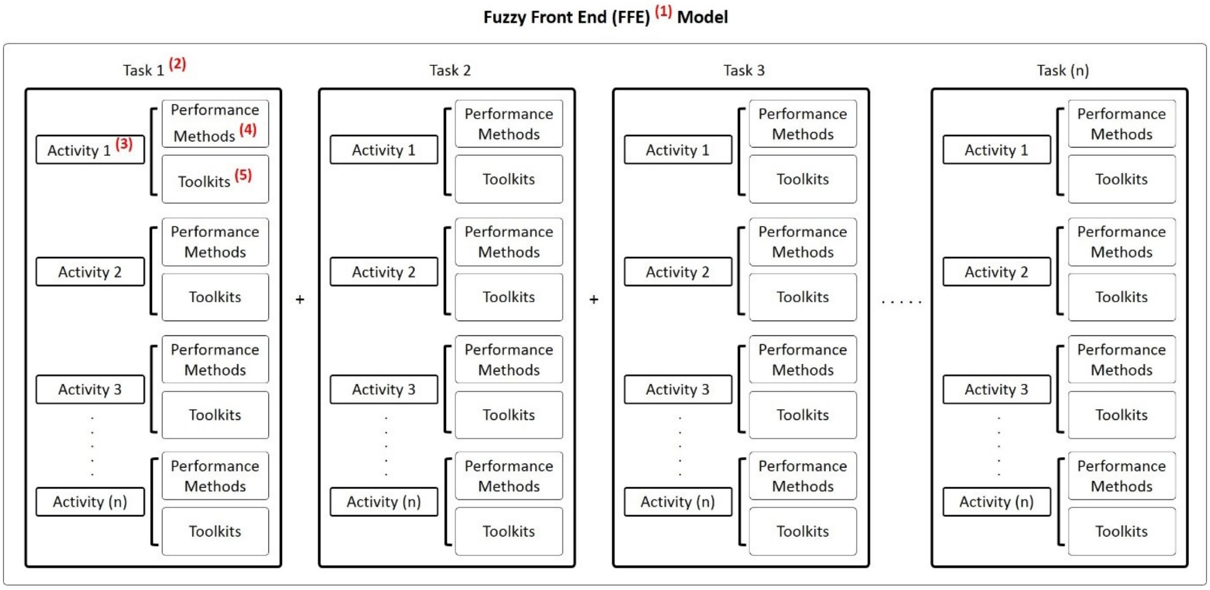
- Evbuomwan, N., Sivaloganathan, S., & Jebb, A. (1996). A survey of design philosophies, models, methods and systems. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 210*(4), 301-320.
- Eveleens, C. (2010). Innovation management; a literature review of innovation process models and their implications. *Science, 800*(2010), 900.
- Howard, T. J., et al. (2008). Describing the creative design process by the integration of engineering design and cognitive psychology literature. *Design Studies 29*(2), 160-180.
- McAdam, R., & McClelland, J. (2002). Individual and Team-based Idea Generation Within Innovation Management: Organisational and Research Agendas. *European Journal of Innovation Management, 5*(2), 86-97.
- Meredith, J. R. and S. M. Shafer (2009). *Operations management for MBAs,* John Wiley & Sons.
- Simms, C. D. (2012). *An analysis of the management of packaging within new product development: an investigation in the UK food and drinks sectors.* University of Portsmouth.
- Wynn, D., & Clarkson, J. (2005). Models of designing. *Design process improvement* (pp. 34-59): Springer.
- van Aken, J. E. (2005). Valid knowledge for the professional design of large and complex design processes. *Design Studies, 26*(4), 379-404.

In the table above describing the features of each model, some papers which have similar features and affect other models; these are not arranged in chronological order. Instead, they are grouped. However, when the historical trend analysis was conducted with SPSS, those models were arranged in chronological order.

Appendix 2:

Interview Sheet

1) Relevant Information



Fuzzy Front End (FFE) (1):

A Fuzzy Front End (FFE) describes an early design phase in a new product development (NPD) where an original idea is generated from the discovery of new opportunities, a potential product is defined and conceptualised, and its project is evaluated and approved for further development in the more formal and well-structured NPD stage.

Task (2):

The broadest unit making up the FFE phase.

Activity (3):

The subordinate unit to the task unit in that its actions aim to accomplish those tasks.

Performance Method (4):

The actual instructions describing how to conduct each activity.

Toolkit (5):

A physical and functional construct in which the Performance Method is structured. The toolkit has an explicit form and frameset in which input and outputs related to product development parameters, variables, and constraints are yielded. The Toolkit can help to increase effectiveness when executing performance methods from a usability standpoint.

- **Radical NPDs:** new products which have never been developed before
- **Incremental NPDs:** new products which will be improved based on new needs/problems identified from previous versions

2) Interview Questions

Main question

Please explain the tasks, activities, and their performance methods and toolkits involved in the FFE phase, in as much detail as you are willing to give.

The FFE phase can be regarded as covering the early design stage until the prototyping task.

Each of the following sub-questions is structured using a **'Top-Down' approach** in which the question begins with broad 'pieces' and then divides them into successively smaller pieces: **from 'Task' to 'Activity' to 'Performance Methods' and finally 'Toolkits'.** Each interview question concerns the attributes of new product developments, specifically radical and incremental NPDs.

Sub-question 1) Please explain **the first task**, relevant activities, and their performance methods and toolkits, in as much detail as you are willing to give.

If there is a difference between radical and incremental NPDs in conducting the first task, please describe the difference, in as much detail as you are willing to provide.

If there is no difference, you can just answer the given question.

Sub-question 2) Please explain **the second task**, relevant activities, and their performance methods and toolkits, in as much detail as you are willing to give.

If there is a difference between radical and incremental NPDs in conducting the second task, please describe the difference, in as much detail as you are willing to provide.

If there is no difference, you can just answer the given question.

Sub-question 3) Please explain **the third task**, relevant activities, and their performance methods and toolkits, in as much detail as you are willing to give.

If there is a difference between radical and incremental NPDs in conducting the third task, please describe the difference, in as much detail as you are willing to provide.

If there is no difference, you can just answer the given question.

.
.
.

Sub-question n) Please explain **the last task**, relevant activities, and their performance methods and toolkits, in as much detail as you are willing to give.

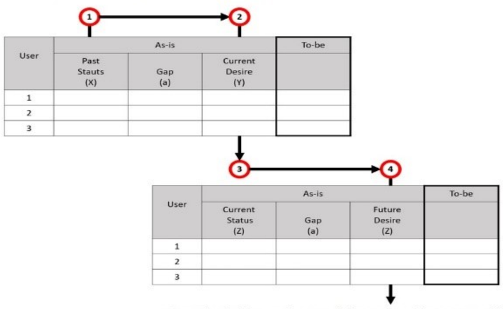
If there is a difference between radical and incremental NPDs in conducting the last task, please describe the difference, in as much detail as you are willing to provide.

If there is no difference, you can just answer the given question.

Appendix 3:

Raw Data from Analysis of Interview Script

1) Preliminary Task (Task 0)

Participants	Phase 1: Defining meaning units *P:* Participant's dialogue / *R:* Researcher's dialogue	Classification Interconnection	Phase 2: Transformation Phase 3: Structural Description
P02 Interview	In incremental NPDs, we more focus on the competitor analysis (01, Activity 0.1) because we compete with other companies in the same market. However, we cannot neglect the current and future trend analysis (01). If we put more weight on the future trend (01, Activity 0.2) rather than competitors or the trend of the day (02, Activity 0.2), we can say the (02) case where our project is more inclined to the radical development . . . . the competitor analysis (01, Activity 0.1) is conducted to extract gaps of specs and features between ours and others. According to the given schedule, the degree of depth in investigating competitors (03) are generally decided. We know it is not good. But, realistically, we cannot do the research more than defined period overdue. Sometimes, we minutely study competitors without the scheduled period when we developed "Killer Model" (04). The project, the killer model, intensively targets only one or two of the products of competitors . . . . when we research (05) the current trends (05, Activity 0.2), we utilise off-line and online (04) resources. Also, we closely collaborate with various universities and economic labs. We gather the current trends as much as possible no matter which fields are, e.g. industry, technology, economy, politics, environment, culture, art, entertainment, etc., and then we filtered it by the in-depth discussion within expert groups. For the future trend (02, Activity 0.2), we are doing similarly, too. But, we are (08) frequently using a particular method developed internally. I will send relevant (09) materials later (10). Anyway, tracking the current and future trends is conducted all the time to be in the ready state to apply them to our projects . . . . . . (11)	06 07	***Both Incremental and Radical NPDs:*** 01 02 03 04 05 06 • ***Purpose*** Finding gaps 01 1) Incremental NPD . Focus on the competitors' products and the present needs-and-trends . Users are tacitly defined as the nearly same as the existing ones. 2) Radical NPD . Focus on the future needs-and-trends . Potential users are defined along with their trends • ***Structure*** 1) Initial part of the process Two different routes consisting of different compositions 01 04 12 2) Remaining part of the process The same route consisting of the same compositions 02 05 13 Different outcomes depending on two NPD attributes 03 05
P04 Additional material	***Method for envisaging future trends*** (10)  ***Own depiction, referenced from the given material***		
P05 P12 P14	*R:* First of all, do you have any particular differences between the incremental and radical NPD in your process system? 01 ***Both NPD attributes*** *P:* According to demands of users, trends and techs, we judge and classify them into the two development on each occasion. Based on this, our next (2) activities are defined. More precisely, the activities may be same, but (3) outcomes can be, of course, different accordingly . . . . . When we improve the existing product, we more concentrate (Activity 0.2, 07) on the present users' feedbacks or needs, trends and technologies. But, in developing products which is totally different from the existing version, we more focus on (15) forecasting their potential needs (Activity 0.1, 03), trends and technologies (Activity 0.2, 04)	12 13 06 *Activity 0.1* 14	
⋮	⋮		

Incremental NPDs
Radical NPDs
Both NPD attributes
Contextual interconnection

Cont'd

P17, P21, P22 Interview

P: Activities are differently comprised in the early part of the process. For improving products, we find improvement points by other products in the market or customer feedbacks for previous versions. Based on this, we reflect the current or expected trends. The combination of two things determines the initial development direction. The radical NPD is more focused on expected user targets and their trends which lead their new lifestyles implying to demand new products. This case also determines the initial NPD direction by those activities. After this, we conduct activities to materialise the items with the same process, generating outcomes matched with two different development directions . . . . . .

Both NPD attributes

R: Can you tell me how to conduct each performance more in detail?

P: You mean each performance method? In the examination of other products which compete with us, we research product specifications and functions as many and detail as possible, and organise them into a comparative analysis chart. Its aim is to find gaps between our product and their products in the same market. After this we extract different items and determine the ranking. According to the priority, development items are decided. In the case of expected users and their trends, we generally utilised the persona analysis based on data come from contracted economic labs. They maximumly utilise professional manpower in each discipline. I expect they generate more detailed interpretations from multi-dimensional views even if they are also based on the same data, even from googling . . . . . .

(Margin labels: Activity 0.1; Activity 0.2; Activity 0.3)

P21 Additional material

Method for comparative analysis

Priority	Spec/ Feature	Our Product	Gap	Competitor 1	Competitor 2	Competitor 3	....
1	Spec						....
	Feature						....
2	Spec						....
	Feature						....
3	Spec						....
	Feature						....
4	Spec						....
	Feature						....
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Own depiction, referenced from the given material

P19, P32, P37 Interview

In the radical NPD, users serve as a trigger role in generating new trends. Again, users are centric agent to use our products. So, we highly focus on who can be users in the future and what trends can be generated from those users. Through different user groups defined by the persona analysis, potential trends can be detected. If user groups continue to be collected and accumulated, "Persona Library" dataset, a list form for the groups, can be attained so that "Trend Library" can be formed . . . . . the persona library can be divided into two parts, general user cases and trendsetter cases. In finding potential trends, trendsetters play a extremely important role because they serve as a kind of bridge between the present and future trends. Through the persona analysis, we can understand users' way of life, how they satisfy with their desire. So, in the progress mentioned above, we can know gaps among the current product, their potential desire and future trends . . . .

The example result of the development item is, "To develop a new device to enable for early adopter housewives to sterilise their lavette in daily-base."

Example statement of development item

(Margin labels: Activity 0.1; Activity 0.2)

⋮

Incremental NPDs:

Activity IC 0.1: Competitor analysis

- ***Target***

All products competing with our product in the same market

"Killer model": intensively target on one competitor's

1) ***Method 1: Customer feedback***

2) ***Method 2: Comparative analysis chart***

1) Examine specification and features of products

2) Extract gaps

3) Define priorities

Activity IC 0.2: Trend analysis

- ***Target***
  : The current trends > The future trends

- ***Research areas***
  Industry, Technology,
  Economy, Politics,
  Environment,
  Culture, Art, Entertainment

Conduct all the time to be in the ready state for applications

1) ***Method 1: Online and Off-line resources***

1) Online resources
: Reports, Publications, web-sites, etc.

2) Off-line resources
: Collaborate with economic labs and universities

2) ***Method 2: Expert group discussion***

Activity IC 0.3: Improvement item

Cont'd

P19 Additional material

Method for persona and trend library 32 33

Persona Library: General user cases						
User	Character Profiling (5W1H)	4 Factors in NPD . Physio-Product Characters . Socio-Product Characters . Phyco-Product Characters . Ideo-Product Characters				Trend Lifestyle . Way/Form of life . How to fulfil desires
		1	2	3	4	
1						
2						
3						
⋮	⋮	⋮	⋮	⋮	⋮	⋮

Persona Library: Trendsetter cases						
User	Character Profiling (5W1H)	4 Factors in NPD . Physio-Product Characters . Socio-Product Characters . Phyco-Product Characters . Ideo-Product Characters				Trend Lifestyle . Way/Form of life . How to fulfil desires
		1	2	3	4	
1						
2						
3						
⋮	⋮	⋮	⋮	⋮	⋮	⋮

39

Contextual Persona Library						
	G1	G2	G3	T1	T2	T3
G1						
G2						
G3						
T1						
T2						
T3						

Own depiction, referenced from the given material

P24 Interview

14 11 06

R: You are saying the trend analysis affects different degrees of changes in the NPD. In this, could you please tell me more how to conduct the analysis?

Activity 0.3 & 0.2 ***Both NPD attributes***

P: Trend analysis? Actually, we use this more in the radical NPD projects. We extrapolate 'Hard' and 'Soft' trends from mega trends. We call it 'Trend forecasting' or 'Trend projection'. The hard trend is clear trend which should occur near future. The soft trend is which might be occur in (a little bit) distant future. We use four steps of our own process. In the process, we can define those kinds of trends . . . . . .

40 41 42 12 ***Activity 0.2*** 43 44 45

R: could you please the four phased-process more in detail?

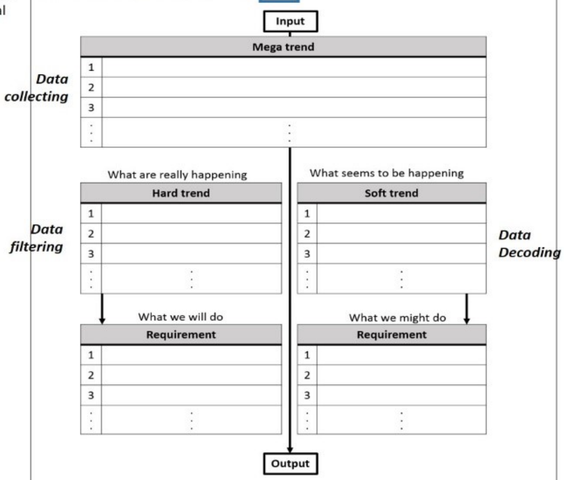
46

P: These four steps can be formed by each relevant questions as follows: 1) what seems to be happening?, 2) what is really happening?, 3) what and how will we do?, and 4) what and how might we need to do?. The initial two steps are to define the hard and soft trend, and the remaining steps are in terms of brief realising methods . . . .

47 48

P24 Additional material

Method for trend extrapolation 46



Own depiction, referenced from the given materials

P28 P30 P31

16 ***Activity 0.1*** 49 50

We examine products of competitors from the viewpoint of product functions, characteristics and specification, ... Based on the comparison, we can identify improvement items for the new project . . . . . .

17 ***Activity 0.3***

The example statement of the improvement item is, "To develop a wider but more slim display of the smart watch to enable for 20 to 40 aged men and women to check their various physical conditions when they are exercising." 51

Example statement of improvement item

⋮ ⋮

Radical NPDs:

Activity RC 0.1: Persona analysis 03 05 07 11

1) ***Method 1: Online and Off-line resources***

a) Online resources
: Reports, Publications, web-sites, etc. 25

b) Off-line resources
: Collaborate with economic labs and universities 26

2) ***Method 2: Persona and Trend library***

User serve as a trigger role in generating trends
27 28 29 30
Continue to be collected and accumulated
31

32 "Persona library"
a) General users 34
b) Trendsetters 34 35

39

33 "Trend library"
a) User desire 37
b) User lifestyle 18 38

36 ***Bridge role***

16 27 29 38

Activity RC 0.2: Trend analysis 04 06 08 12

- ***Target***
: The current trends < The future trends
02 14 15

- ***Research areas*** 09
Industry, Technology,
Economy, Politics,
Environment,
Culture, Art, Entertainment

11

Conduct all the time to be in the ready state for applications

1) ***Method 1: Online and Off-line resources*** 09

a) Online resources
: Reports, Publications, web-sites, etc.
b) Off-line resources
: Collaborate with economic labs and universities

2) ***Method 2: Expert group discussion*** 09

3) ***Method 3: Trend extrapolation*** 46

a) Mega trend
42
b) Hard trend (for the current time/near future) 40 43
36
c) Soft trend (for a distant future) 41 44

Four phased 46
Step 1) Hard trend: what are really happening
Step 2) Soft trend: what seems to be happening 47
Step 3) What and how will we do?
Step 4) What and how might we do? 48

4) ***Method 4: Envisage future trends*** 10

a) $Y^1 = a^1X^1$ (Y^1 = Current desire, a^1 = Gap, X^1 = Past trend)

b) $Z^2 = a^2\ Y^1$ (Z^2 = Future desire, a^2 = Gap, Y^1 = Current desire)

∴ Future desire

= (Gap) x (Flow from the past to current trend)

17

Activity RC 0.3: Development item 19

2) Six Main Tasks (Task 1 – 6)

Participants	Phase 1: Defining meaning units	Classification Interconnection
P03 P17 P26 P27	[01] After concept design (Task 5) [02] the mock-up task (Task 6) is in terms of making virtual 2D-3D drawings and realisation of them into physical designs	
P07	. . . . [03] We come up with methods to embody those items (Task 2) identified in the [04] new business discovering stage (Task 1). It is always challenge to us to [05] devise feasible ideas (Task 2)	
P14	The Stage [06] exploring new business venture and its opportunities (Task 1) is firstly implemented in the FFE. We regard this stage as the most important part	
P15	Finding something new for our design starts from the first stage named as [07] 'Search challenge items' (Task 1).	
P19	We are always faced with two troublesome phase. The first one is [08] a new development items searching (Task 1) and the next is a [09] proper methods/ideas developing for new items (Task 2). Depending on directions of projects, sometimes the first	
P22 P23 P27	. . . . [30] Organising all characteristics along with properties (Task 3) of the targeted product is very helpful in terms of efficiency in performing the [11] concept design (Task 5). [12] [13] Those are mostly brought from initial two stage (Task 1 & 2). After this work, we [10] defined one statement of project purpose . . . (Task 4)	
P25	Our company's main role is to consult others, so that the [14] idea generation and (Task 2) [15] opportunity identification task are sometimes combined (Task 1). [16] Specifications defined (Task 3) [redacted] in one sheet and those are reflected one by one in the concept design [17] (Task 5)	
P29	Always, we need to [18] explore new chances (Task 1) from various aspects, to apply our product lines. Sometimes, it generates a new product line which you generally term it as the radical NPD	
P30	. . . . I am actually working at a division which tries to find [19] new business environments and strategies (Task 1). . . . . . major role is to accumulate	
P31	As you know, the most difficult task is in the initial stage of the process. We call it [20] 'Adventure Phase' (Task 1). We sometimes discover in new trends and sometimes "Excavate" in old trends. We cannot neglect the latter one since it frequently support to come up with new opportunities	
P34	Our business directions normally concentrates on improving existing product. As you know, most of the business strategies in our company focus on prevent from risks rather than making a breakthrough by serving as a pioneer in the market . . . . . . Our main works aim at [21] finding workable solutions (Task 2). Solutions themselves can more specify new [22] opportunities. . . . . . (Task 1)	
P36	In our process, the [23] concept design (Task 5) includes [24] prototyping (Task 6). We generate product concepts through [25] hand drawings, 2D-Illustrates, 3D-Rhinos and mock-ups in (Task 6) sequence. The work is to confirm whether concept designs are feasible	
P01 P03 P06 . . P37	Data generated from [26] opportunity discovery (Task 1) and [27] ideation (Task 2) are filled into the [28] requirement list sheet (Task 3). It is better as much detail as possible. In a summary version of the sheet is [29] our project aim and objectives (Task 4)	
. . .	. . .	

Phase 2: Transformation / Phase 3: Structural Description	Codes	Contextual interconnection
Task 1: Opportunity identification-screening	11, 12, 14, 21, 25	
New business discovering stage	04	
New business venture and opportunities	06	
Search challenge items	07	
New development items searching	08	
Explore new chances	18	
New business environments and strategies	19	02, 03, 04, 05, 06, 12, 13
Adventure phase	20	09, 10
Task 2: Idea generation-screening	12, 13, 14, 27	
Come up with methods to embody methods	03	
Devise feasible ideas	05	
Proper methods/ideas developing for new items	09	
Finding workable solutions	21	08, 16, 17
Task 3: Requirement list	28, 30	
Organising characteristics/properties of each part	30	
Specifications defined for each component assembled in a sheet	16	18, 19
Task 4: Mission statement		
One statement of project purpose	10	
Project aim and objectives	29	07, 11
Task 5: Concept design	01, 11, 17, 23	01, 14, 15
Task 6: Prototyping	24	
2D, 3D Image & Mock-up task	02, 25	

Meaning unit

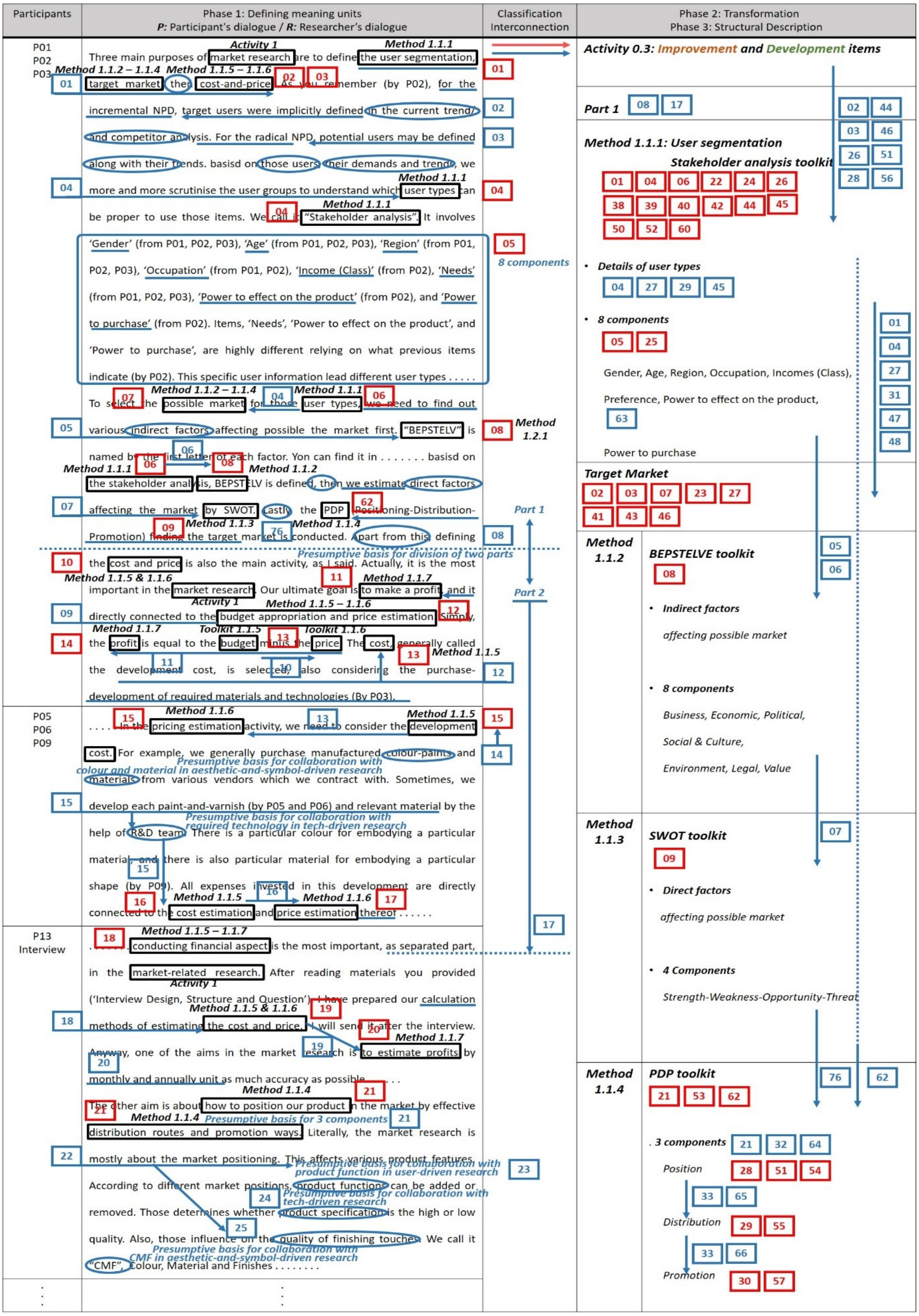
Contextual classification

Contextual interconnection

3) Four Activities of the Opportunity Identification-Screening Task (Task 1)

Participants	Phase 1: Defining meaning units *P:* Participant's dialogue / *R:* Researcher's dialogue	Classification Interconnection	Phase 2: Transformation Phase 3: Structural Description
P01 P05 P06 P13 P19 P32 P37 ⋮	• ***P:*** The user research (*Activity 1.2*) is the most important activity in the opportunity identification stage (*Task 1*) because the user is a principal agent to indicate everything including user behaviours (by P01). It involves an environment in which users use the product and the product is situated (by P37), apart from identifying who can be main users, which is also conducted in the market research (*Activity 1.1*). But the research purpose and direction are different between those two activities. • ***R:*** How those are different? Could you explain more about them? • ***P:*** I will explain later and now I will focus on the user research . . . . ⋮ • ***P:*** The research for design aspect (*Activity 1.3*) is also essential activity in this stage (*Task 1*). Customers are fascinated by more beautiful and sleek products at first. Overall research is in terms of how users feel on products from the aesthetic aspect (by P02). It also examined from semantic (symbolic function) aspect (by P05, P06 and P13). I will explain it later in detail		***Activity 1.1: Market-driven research*** 03 10 15 16 17 18 ***Activity 1.2: User-driven research*** 01 02 05 06 09 11 12 15 16 17 18
P14	There are two main streams of research in our lab to discover new business ventures (*Task 1*). The user and user environment research (*Activity 1.2*) and technology research (*Activity 1.4*). The user research is		
P19	New development items (*Task 1*) can brought from several research domains. As you know, first of all, consumers (*Activity 1.2*) imply everything. They are key to find new items . . . . Even, they give a direction how product looks like, appearance (*Activity 1.3*) . . .		***Activity 1.3: Aesthetic-and-symbol-driven research*** 04 07 11 13 15 16 17 18
P22 P25 P29	• ***P:*** New chances (by P29); opportunities (by P22 and 25) (*Task 1*) can be explored to the in-depth study on multi-dimensional areas. New technologies and their application methods (*Activity 1.4*) can be one of the areas. Users (*Activity 1.2*) who primarily use the product can be another. The other one is the market (*Activity 1.1*) where those technology are applied and target users are selected. The ideation activity is, so, closely related to these activities. • ***R:*** Before going to the ideation stage, could you explain those activities more in detail as much as possible? • ***P22 and 29:*** Can I start from the new technology research?		***Activity 1.4: Technology-driven research*** 05 08 11 14 15 16 17 18
P24	Opportunities (*Task 1*) can be generated from several domains. We cannot clearly divide them. The boarder between each domain is becoming blurred. But, main domains are the following three. Firstly, it is the user-driven domain (*Activity 1.2*), the second domain is about product itself including the inner structure-system and exterior (*Activity 1.3*). The final is required technologies and their application (*Activity 1.4*) to embody our product strategies.		***Collaborative activities*** • Market-driven + User-driven 01 02 09 • User-driven + Aesthetic-and-Symbol-driven 03 04
P30	. . . . We call them '4 Winning Team Players' (*Activity 1.1 – 1.4*). We also call them the acronym 'MUTD' (*Activity 1.1 – 1.4*) which stands for the first letter of the market, user and technology and design. As you can guess, the meaning of the team players indicates those four requires the collaboration. We operate a special research lab consisting of four relevant research departments involves experts in each area. We also notice the importance of the opportunity identification task (*Task 1*) . .		• Aesthetic-and-Symbol-driven + Technology-driven 06 • Market-driven + User-driven + Technology-driven 05 08 10
P31	The adventure phase (*Task 1*) is operated from the collaboration of three research perspectives. Users and their environments (*Activity 1.2*), markets (*Activity 1.1*) and technologies (*Activity 1.4*). Generally, we conduct the user research along with other research		• Market-driven + User-driven + Aesthetic-and-symbol-driven + Technology-driven 07 ▭ ***Meaning unit*** → ***Contextual classification*** → ***Contextual interconnection***
⋮	⋮		

3.1) Performance Methods of the Market-driven Research Activity in Task 1



Cont'd

P13 Additional material

Toolkit for cost-and-price, and profit 18 19 20

Selling Price

= Investment Cost + Profit
= (Direct Cost + Indirect Cost) + Profit

Profit Margin

$$M = \frac{(P - C)}{P}$$

. M = Profit margin
. P = Price
. C = Cost

$$C = P \prod_{i=1}^{n} (1 - M_i)$$

. C = Target cost
. P = Price to the end user
. Mi = The margin at the i^{th} stage

Forecasting Sales

Q = N x A x P

. Q = Sales (annual)
. N = Number of (annual) purchases
. A = Awareness X availability (fractions)
. P = Probability of Purchase (surveyed)

$$= C_{def} \times F_{def} + C_{prob} \times F_{prob}$$

"top box" "second box"

Own depiction, referenced from the given materials

P14 P16 P18 P19

Activity 1.1 26 *Method 1.1.1* 22

In the market-led research firstly we investigate user groups as much detail 27 as possible for expecting target markets, 23 basis on the briefly defined target users, *Method 1.1.2 – 1.1.4* 28 their desire and new trends which they will enjoy, we examine users 24 groups more in detail. We classify the user groups into particular segment 29 units showing singularity. The singularity is determined by 'Gender', 'Age', 25 'Job', 'Needs', 'Purchasing power' and so on. We generally envisage the user scenario when conducting the user-led research, in your word, the user-driven research, anyway, and the scenario encompasses such singularities (by P14 and P16) . . . . The 26 defined user segmentation leads which market is 27 proper for the product to be positioned. 28 According to the decided market 32 segment, the distribution method can be different and advertising methods 29 30 can also be decided accordingly 32 . . . . For 33 estimating the price of the product, 31 33 we consider total invested costs. 34 Those costs include R&D expenses first. The cost for developing new technologies and systems takes up much rate of . . . .

Method 1.1.1 · *5 components* · *Presumptive basis for collaboration with user scenario in user-driven research* 30 · *Method 1.1.1* · *Method 1.1.2 – 1.1.4* · *Method 1.1.4* 31 · *Presumptive basis for 3 components* · *Method 1.1.4* · *Method 1.1.4* · *Method 1.1.5* · *Method 1.1.6*

P22 P25

35 33 *Method 1.1.6*

P: the price estimation is actually much complex. Usually, we calculate 34 *Method 1.1.5* invested money by the product assembly unit. *Presumptive basis for division by component unit* 36

R: What is the meaning of the product assembly? 37

P: It means simply product component. Per product component, we can 35 *Method 1.1.5* calculate each invested cost. 38 Some components use a new material. Some 39 *Presumptive basis for collaboration with CMF in aesthetic-and-symbol-driven research* components need new technologies. In the calculation, we also consider 40 *Presumptive basis for collaboration with required technology in tech-driven research* various external factors such as the contract structure with vendors or OEMs, 42 international currency, international-and-domestic tax, politics affecting the 41 tax, etc . . . . . . I cannot explain it in detail without a specialist for accounting. 36 *Method 1.1.6* Anyway, based on these factors, the price of the product can be estimated. As 37 *Method 1.1.7* you know, to make a profit, the 43 price should be higher than the cost . . . . . .

P28

Different from the previously mentioned user research to identify trends, the 44 45 38 *Method 1.1.1* *Activity 1.1* user research in this activity is more and more specific. Also, the research is 45 not for user behaviours things but for users themselves. We research who *Method 1.1.1* 39 users are as much detail as possible in understanding which user groups can 46 be more acceptable to use the product in which their demands are reflected.

Example tools in user-driven research 46

The user behaviour things, e.g. how users are using the product, how they are recognising the product, how the product is operated in their life, are researched in the other activity, the user research . . . . Specifically defined

40 *Method 1.1.1* *Method 1.1.2 – 1.1.4* users also affects the market 41 which we can succeed with our product. Our 47 CEO prefer to generating new market through our products rather than going 48 into the existing market. He likes the challenge although we don't like . . . . . .

42 *Method 1.1.1* *Method 1.1.2 – 1.1.1* 43 Different users, different product features, different markets . . . .

Presumptive basis for collaboration with user-and-tech-driven research 49 50

. . .

Part 2 08 17 67

Cost and Price estimation 68 74

10 12 18

Method 1.1.5

Cost estimation

13 15 16 19 32 34 35 47 49 56 58 59 61

- ***Purchase and Development costs*** 12 34
- ***External factors*** 41

  Contract structure with vendors/OEMs, Currency Tax, Politics, etc.

- ***Calculation method toolkit*** 18 19 20

10 13 16 33 35 42 75

Method 1.1.6

Price estimation

13 15 17 19 31 33 48

- ***Calculation method toolkit*** 18 19 20

01 09 11 19 43

Method 1.1.7: Profit forecasting

11 14 20

- ***Calculation method toolkit*** 18 19 20

Cont'd

P29	As you know, we have already known who can be possible users and their trends. We have also known initial development directions basisd on those users and trends. But, the research of the more specific user segmentation is very important. Depend on different layers of users, many things can be decided. As you know, product functions and any other features cannot but be different in disables, elders or youth. Those are also changed by different genders, regions, jobs, and so on . Different users needs different products in which different functions and techs are equipped. Some functions may demand new technical systems . . . . . . According to the market status, our invested money and then product price is considered in order. . there is the standard price which is used in the market . . . Also, used techs and systems cannot help influencing the cost. New designs frequently require new materials and technologies	Tool 1.1
P31	I will tell you the reason why we should do the more specific user research in this activity, even if we did the user research for identifying their new desires and trends. Younger people and older people need different product functions. Office workers and housewives have different lifestyles in different environment. It makes the budget and price increase. For example, divers and firefighters requires different watches including different functions and materials. Different technologies may be required in this. Disables and elders also need different products. Have you heard the universal design and inclusive design? Main considerations of those designs are in different usability related to ergonomics and different user environments	
P33 P35	The market research is mainly about which market we position the product. According to user types and their preferences, some products should be developed for the high quality of specifications' market, and some products should be developed for the low-price high-volume market. For example, [redacted] series target on the former market whereas its [redacted] series aims at the market between the former and latter . . . . . . After defining the target market, the distribution routes can be determined. The product positioned in the former market is generally shipped by air and placed in official stores or more luxury stores. But, the product in the latter one is generally transported by ship and placed in less luxury stores or arcades. This is because different routes has different invested costs. We also importantly consider promotion ways. The product in the former market is promoted by the public TV, in particular, before and after popular TV programmes. It is also advertised in central undergrounds or huge electronic displays. But, the latter market's product is promoted in the cable TV, local news papers, hoardings of the suburb of cities. This also causes different invested costs.	Method 1.1.4 Presumptive basis for division of 3 components
P37 P38	. . . . . . There are no areas in which the costs does not affect. The defined users affect required functions from the usability perspective. Materials which determine how products' appearance looks like influence on the budget. If the budget is insufficient, we need to reduce the required functions or replace the required materials with others. Or, we can maintain the functions, by utilising technologies required less expenses. With less expenses, we can develop new technologies in developing new materials whose appearance looks the same as the original ones	Presumptive basis for collaboration with other 3 research areas Method 1.1.5
⋮	⋮	

Presumptive basis for conducting with component unit

36 37 38

Presumptive basis for collaboration

- Market-driven research (MK)
- User-driven research (UE)
- Aesthetic-and-Symbol-driven research (AS)
- Technology-driven research (TC)

1) Activity ↔ Activity

- MK ↔ UE: 49, 69
- MK ↔ AS: 69
- MK ↔ TC: 24, 50, 69

2) Method ↔ Method

- User segmentation (MK) — *Method 1.1.1*
  - → Product function (UE): 52, 57, 70
  - → User environment (UE): 58
  - → Usability (UE): 61, 70
  - → User scenario (UE): 30
  - → Material: 59
  - → Technical function (TC): 53
  - → Required technology (TC): 54, 60
- PDP (MK) — *Method 1.1.4*
  - → Product function (UE): 23
  - → CMF (AS): 25
  - → Technical function (TC): 53
- Development Cost (MK) — *Method 1.1.5*
  - → Product function (UE): 72
  - ← CM (AS): 14, 39, 71
  - ← System structure (TC): 54
  - ← Required technology (TC): 15, 40, 55, 73

3.2) Performance Methods of the User-driven Research Activity in Task 1)

Participants	Phase 1: Defining meaning units *P:* Participant's dialogue / *R:* Researcher's dialogue	Classification Interconnection	Phase 2: Transformation Phase 3: Structural Description
P01 P03 *Incremental NPDs* *Radical NPDs*	*Activity 1.2* *P:* As I said before, this activity is the most important because users are the main agent to use our target product. The nature of this activity is different from defining specific user types in market research. It is more focusing on how those users are using the product. But, we always keep in mind who users are, because, again, they are main subjects to use the product. When you think about the 'How', what aspect we will research firstly do you think? *R:* Operation method? Operation sequence? *P:* Yes, the order of the operation can be the starting point. In each step of the order, users show functions needed in the product. Each operation method you said is just right the way how users to use such functions. Simply put, these are to research "How" specifically defined users are using the product in which their needs and new trend are applied, under those defined trends (P03) . . . Through the specific examination on the operation sequence, hidden function which we have not known so far and the product newly requires can be exposed. Specially, what users do before and after using the product give many opportunities to add new functions. If new functions are added, the design of the product can be updated and changed physically. *R:* I think this is more related to the incremental NPD. How does this research work for the radical NPD? *P:* The examination on the product usage process is identically applied to the Radical NPD. basisd on the early development direction, we can imagine a certain kind of product, its brief form and each scene of its usage process (by P03). Even tough we have never experienced the product, we can imagine how the appearance of the product can become and which functions are needed by those scenes at least	01 *Presumptive basis for collaboration with user type in market-driven research* 02 *Method 1.2.1* 03 *Similar meaning of products usage function* 04 *From trend research analysis* 05, 06, 07, 08 *Method 1.2.1 / Method 1.2.4* 09 *Presumptive basis for collaboration with aesthetic-and-symbol-driven research* 10 *From trend research analysis* 11 *Presumptive basis for collaboration with shape in aesthetic-and-symbol-driven research* 12 *Presumptive basis for collaboration with aesthetic-and-symbol-driven research* 09, 10 *Method 1.2.4*	***Activity 0.3: Improvement and Development items*** ***Method 1.2.1: Product usage process*** 01 05 07 09 40 52 • A series of actions in using the product 66 • ***3 Division*** 07 1) What users do before using it 2) What user do in using it 3) What user do after using it 07 • ***Able to find hidden functions*** 06 ***Method 1.2.2: User touch point*** 22 23 28 53 66 • *All communication point between users and products* 33 34 ***Method 1.2.3: Interaction System*** 15 24 25 29 31 33 35 43 44 45 48 63 64 • ***Product = Living organism*** 99 • ***3 Components*** 35 1) Input (User) Brain + 5 Senses 73 74 100 2) Mediator (Touch-point) 73 74 100 3) Output (Product response) 73 74 100 • ***Intuitive design*** 48 106
P14	. . . . . . defining each function in the product is the main issue in this activity. For your reference, in the Radical NPD project, we imagine or envisage those functions basisd on the defined development items. But, in the incremental NPD project, we add, remove or transform the existing functions basisd on the improvement items. Such a function is gathered and it forms the entire product function. Also, generally, similar functions or a similar sort of functions are placed together, forming a product inner structure as a product architecture. That is to say, each function can determine the placement of each relevant part. For example, various buttons are placed in a single operation panel for increasing usability. A display panel is placed next to the operation panel for users to see displayed outputs promptly when they are operating these buttons. This is highly related to the ergonomic design. Different placement of each part affects how much degree users use each part comfortably. These parts' size, shape and material also affect usability from the ergonomic design aspect. Sometimes, we require to develop new technology to change, generally to reduce, the size of the product' part or its entire product. It may sometimes result in the large change of the whole system. Sometimes, for the shape or material which we need to achieve to increase usability, new technologies may be demanded . . . . . When I was working at the HCD department, I utilised an anthropometric databasis provided by ergonomic labs to define proper dimensions of the product's part.	11 *Method 1.2.4* 13, 14 *From trend research analysis* 15 *Presumptive basis for division by component unit* 12 16, 17 *Presumptive basis for collaboration with functional structure in tech-driven research* 13 *Method 1.2.4* 32 *Presumptive basis for division by component unit* 14 *Method 1.2.6* 18 19 20 15 *Method 1.2.3*, 16 *Method 1.2.6* 17 *Method 1.2.6* 22 *Presumptive basis for collaboration with functional structure in tech-driven research* *Presumptive basis for division by component unit* 18 *Method 1.2.6*, 19 *Method 1.2.6* 23 24 25 *Presumptive basis for collaboration with technical size, shape and material* 26 *Presumptive basis for collaboration with required technology in tech-driven research* 27 28 *Presumptive basis for collaboration with shape and material in aesthetic-and-symbol-driven research* 20 29 *Presumptive basis for collaboration with required technology in tech-driven research* 21 *Method 1.2.6* 30 31 *Presumptive basis for division by component unit*	***Method 1.2.4: Product usage function = Operation method*** 02 03 04 06 08 10 11 12 13 27 30 34 38 41 42 57 65 • ***The way in which the series of actions is made*** 68 • ***The way of using products which follows a set of rules*** 105 Links: 04 56 10 63 13 65 14 115 50; 02 82; 36 38 103; 03 05 08 67 104; 51 69; 37 39 69 101
⋮	⋮		

Cont'd

P05 P06 Interview

Activity 1.2 — *Method 1.2.2* [22]

In the user-driven research we importantly consider user touch-points. These points are communication points between those users (I said the way to define users specifically before), and the product, (infused with very early NPD directions from trends. So, the product where those are included). We can call it "Interaction point" in other words. These points are generated from all parts where users touch. We have the referential material for more understanding of the interaction system. Each touch point naturally contains each product function. By understanding how users interact with each touch-point, we can identify more detail of each product function and their usage methods. ......

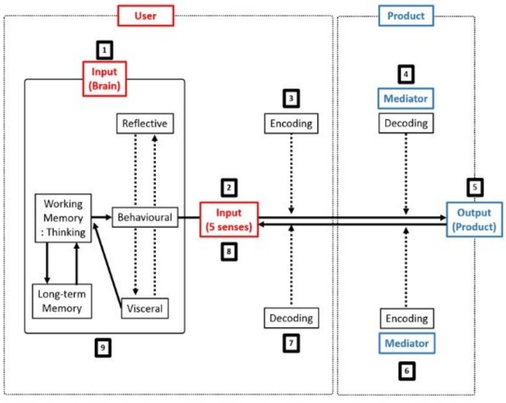
Annotations: [33] Presumptive basis for collaboration with user type in market-driven research [110]; From trend analysis [115]; [36]; [23] Method 1.2.3 ← Method 1.2.2 [24]; [35]; [34]; Presumptive basis for division by component unit [25] [116]; Method 1.2.3; Method 1.2.4 [26] [37]; Method 1.2.3 [29] [39]; [28] [38] Method 1.2.2; Method 1.2.4 [30]

When I entered this company, my initial role? position? was "CMF" (by P06). The CMF is named by each first letter of "Colour", "Material" and "Finishes". You are familiar with the former two ones I think, and the latter one may not be used to you. The finishes is the gap between each component exposed on the surface of the product. We generally call it "Parting line". Not to mention the colour and material, we also consider the parting lines. Those determine how users recognise how much degree the product is elaborately designed and manufactured ...... As you know, "Shape", "Colour" and "Material" are three main factors to determine the design of the product. Not only overall product aspect but also each part aspect are all important to determine how users feel the product emotionally with their five senses. Each emotion on each part leads up to the overall emotion on the whole product. In this emotion, symbolic images are also infused. The combination of those three factors give particular symbolic meanings to users. For example, "Large" and "Red" button "Extruded" on the surface of the medical device implies particular signals. Doctors and nurses can find the button "Rapidly" in the "Emergency" situation by the "Large" and "Red" button. They intuitively "Push" the button by its "Extruded" shape. "Slim", "Blue" and "Transparent" design of the overall product gives an emotion of a very trendy and state-of-arts device ....

Annotations: [40] [41] [42]; Presumptive basis for collaboration with CMF in aesthetic-and-symbol-driven research; [31] Method 1.2.3; [43] [44] [45]; Presumptive basis for collaboration with SMF in aesthetic-and-symbol-driven research; Method 1.2.3 [31]; [46] Presumptive basis for division by component unit; Presumptive basis for collaboration with symbol in aesthetic-and-symbol-driven research [47]; Method 1.2.6 [32]; [33] Method 1.2.3; [48]; Presumptive basis for collaboration with symbol in aesthetic-and-symbol-driven research [49]

P05 Additional material

The concept of interaction system design [35]



Own depiction, referenced from the given material

⋮

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[73] [92] [87] [88] [90]

Method 1.2.5: User environment

[37] [47] [50] [51] [54] [55] [56] [58] [60] [61]

- *Where all user actions are generated* [73] [87] [88]
  - [90] *with surroundings*
- *Where the product is situated* [73] [89]

[75] [75] [93] [94] [108] [109]

Method 1.2.3: Interaction system [21] [70] [72]

Method 1.2.6: Usability (Ergonomics)

[14] [16] [17] [18] [19] [20] [21] [32] [39] [43] [44] [46] [48] [49] [59] [62]

- *Anthropometric data (Human Centred Design - HCD)* [30] [71] [107]

[57]

- *Intuitive design* [48]

Tool 2.4: Product usage function

[59]

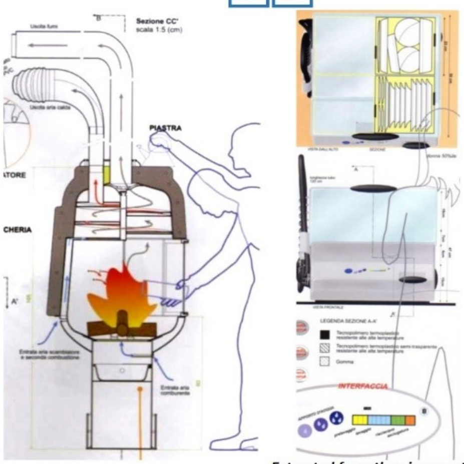
Method 1.2.7: User scenario (User story) [58]

[36]

- *Format*

Cartoon / Story / 5W1H [60] [61]

Cont'd

P19	Do you remember consumers imply everything? Therefore, the research concentrating on users is really important. By these consumers, we can know which functions are required in the product in which those trends mentioned before are reflected. We can also know how those functions are working between users and the product. basisd on this, we can devise how those functions are mechanically or electronically working in the product. Also, by their preferences, we can provide how the product looks like, how the design of the product is. The design covers all physical things such as the placement of functions and product's shape, colour and material [34 *Method 1.2.4*] [34 *Method 1.2.4*] [35 *Method 1.2.3*] [50 *From trend analysis*] [51] [52] [53] [54] *Presumptive basis for collaboration with working principle in tech-driven research* *Presumptive basis for collaboration with SCM in aesthetic-and-symbol-driven research* *Presumptive basis for collaboration with functional structure in tech-driven research*		***Presumptive basis for division with component unit*** 15 31 32 36 46 83 116
P16 P18 Interview	. . . . . . basisd on the predefined target users' information, needs which they want and related-trends, we aim at drawing a user scenario? user stories in this activity. This is to draw an overall scene or blue print of how users are using products in a certain environment. Sometimes, we draw it with the cartoon or story format to represent the sequence of using the product. The drawing includes critical product functions, operations methods, HCD data along with a narrative description by the 5W1H tool. With just a single page of the drawing, we can include many information related to users. Sometimes, we developed a coloured drawing to represent the product's colours and materials . . . . By the user scenario, we can visually understand how users formulate their lifestyle with the product . . . . [36 *Method 1.2.7*] [37 *Method 1.2.5*] [38 *Method 1.2.4*] [39 *Method 1.2.6*] [55] [56 *From trend analysis*] [57] [58] [59] [60] [61] [62] [63 *From trend analysis*] *Presumptive basis for collaboration with* *Presumptive basis for collaboration with SCM in aesthetic-and-symbol-driven research*		***Presumptive basis for collaboration*** • Market-driven research (MK) • User-driven research (UE) • Aesthetic-and-Symbol-driven research (AS) • Technology-driven research (TC) ***1) Activity ←→ Activity*** • UE ←→ MK 01 55 64 68 80 81 86
P16 Additional material	***The example scene of user scenario*** [60] [61]  ***Extracted from the given material***		• UE ←→ AS 09 12 78 96 80 • UE ←→ TC 79 95 80 ***2) Method ←→ Method*** • Product usage process (UE) ← User segmentation (MK) *Method 1.2.1* 111 ← Shape (AS) 11
P24	. . . . we regard the product as a living organism. It may sound odd, but we do that. The more and more doing that, the more successful we believe. We think users are communicating with the product when using it. By using five senses, vision, auditory, olfactory, tactile, sometimes even palate, users are interacting with the product. When you press a button, a single tiny component in the product, the product sends a variety of signals to users visually, audibly and tactically. In the system of the communication, users can more and deeply recognise functions which product provides. Understanding of this leads us to develop more emotional designs . . . In addition to this, we can identify difference which mechanical or electrical operation mechanisms involved in each communication point we should develop. In more detail, if users prefer to the softer tactile, we will develop a certain buffer placed underneath the button and study relevant technologies . . . . [63 *Method 1.2.3*] [64 *Method 1.2.3*] [65 *Method 1.2.4*] [66 *Method 1.2.2*] [99] [100 *Example*] [101] [102 *Example*] [103] *Presumptive basis for collaboration with working principle in tech-driven research*		• User touch-point (UE) ← User segmentation (MK) *Method 1.2.2* 110 → Development cost (MK) 84 → Required technology (TC) 85
:	:		

Cont'd

P28

Activity 1.2

P: The user behaviour things are researched in this activity, basisd on specific information of user groups defined in the market research, different behaviours can be revealed here. User behaviours, or user behaviour patterns mean a process, structure or system of how users deal with the target product. (In this, "Target" implies the product in which defined trends and initial NPD direction infused in). Usually, when we say a certain process, structure, and system, it includes a series of actions which are carried out, the way in which it is made, the way of doing something which follows a set of rules. So, user behaviour patterns mean a certain series of actions in using the product; the product usage process, the way in which the series of actions is made; formed depends on product functions, and the way of using products which follows a set of rules commonly presented in the same user group; the method of use. The latter one, the method of use, additionally contains many aspects such as how users interact with the product and how easy users use the product.

Presumptive basis for collaboration with user type in market-driven research 64

From trend analysis 65

40 *Method 1.2.1* · 41 *Method 1.2.4* · 42 *Method 1.2.4* · 43 *Method 1.2.3* · 44 *Method 1.2.3 + Method 1.2.6*

Presumptive basis for collaboration with user type in market-driven research

66, 67, 68, 69, 70, 104, 105, 111, 113

R: What is the meaning of "How easy"? Does it mean a specific direction to use?

44 *Method 1.2.3 + Method 1.2.6*

P: Yes, it does. It indicates the product should be designed to be feasible to use intuitively. The product should not give much time to think about how to use it. It is related to an effective arrangement of the product's functional parts and semiotic meaning of the parts' designs . . . . Also, it means the HCD aspects. Here, the word, "Easy" can be replaced with "Comfortable". User should be able to operate each function very comfortably without any critical problems. For example, if displayed texts on the screen are small marked with light colour, users have a difficulty in perceiving them. If the volume of a certain output sound is too low, users also have a difficulty in confirming whether the function that users are using is being operated well or not . . . .

45 *Method 1.2.3* · 46 *Method 1.2.6*

Presumptive basis for collaboration with functional structure in tech-driven research 112

Presumptive basis for collaboration with symbol in aesthetic-and-symbol-driven research 70

106, 107, 71

Example of interaction system (Tool 2.3) to usability (Tool 2.6) 72

P38

. . . . Researching the environment in which all using actions are and the product is situated facilitates calculating functional and mechanical dimensions of the product. If we consider usability aspect in a certain environment we can know proper dimensions of the product from the functional aspect. When developing a handle of the product, we can reason the proper range of its diameter by general width of users' palm. We can identify suitable mechanical dimensions by understanding of the relationship between the product and environment. When developing a particular product arranged inside of the built-in wardrobe, we calculate the proper size of the whole product firstly, taking the inner structure of the wardrobe's measurement. Then, the proper size of each component such as the battery and linear compressor can be managed. If the size of components which we hold now is larger than calculated size, we will attempt to reduce the mechanical size of them . . . .

47 *Method 1.2.5* · 48 *Method 1.2.6* · 49 *Method 1.2.6* · 50 *Method 1.2.5* · 51 *Method 1.2.5*

Presumptive basis for collaboration with technical size in tech-driven research 74

Presumptive basis for collaboration with technical size in tech-driven research 76

73, 75, 108

Example

Example

. . .

Activity 1.2

- Interaction system (UE) — *Method 1.2.3*
  - Shape (AS): 43, 54
  - Colour (AS): 40, 44, 54
  - Material (AS): 41, 45, 54
  - Finishes (AS): 42
  - Symbol (AS): 47, 48, 49, 70
  - Functional structure (TC): 19, 53, 112
  - Working principle (TC): 52, 102
- Product usage function (UE) — *Method 1.2.4*
  - User Segmentation (MK): 113
  - Functional structure (TC): 16, 17
- User environment (UE) — *Method 1.2.5*
  - User segmentation (MK): 91
  - Shape (AS): 114
  - Colour (AS): 98
  - Material (AS): 97
  - Working principle (TC): 95
  - Technical size (TC): 74, 76

Cont'd

P30 P37	***Task 1*** ***Activity 1.2*** In the opportunity identification work, we conduct the user-related research centrally (by P30). All things which users are doing with the product represent all other activities such as the design or technology-related activity. basisd on user-related research, those other activities can be performed more easily . . . As I said before (by 37), the cost affects everywhere. Each step of users actions on the product influences on the development costs. The point in which users touch the product generate the development costs of product's part . . . . . We consider relevant technologies involved in the part . . . . *Presumptive basis for collaboration with aesthetic-and-symbol-driven and tech-driven research* (77, 78, 79, 80) *Presumptive basis for collaboration with development cost in market-driven research* (81, 82) *Presumptive basis for division by component unit* (83) *Presumptive basis for collaboration with development cost and required technology* (84, 85) 52 ***Method 1.2.1*** 53 ***Method 1.2.2***	• Usability ***Method 1.2.6***	Shape (AS) 24 27 48 Material (AS) 25 28 Functional structure (TC) 18 20 22 Technical size (TC) 23 Required technology (TC) 26 29
P31 P32	***P:*** I said that the detailly investigating users groups/types is very important when I explained the market research activity. Identically, researching users in ***Activity 1.2*** this activity is also very important. But, a research direction is different (by P32). In this activity, we more concentrate on both how those users are using the product and in which environment those users are using the product. I think you are expert in the design engineering domain, so that familiar with "How". So, can I more focus on the issue, "Where" which many practitioners can easily overlook, today (by P31)? 54 ***Method 1.2.5*** ***R:*** Sure, I am happy to understand the user environment issue. 55 ***Method 1.2.5*** ***P:*** The user environment actually contains everything all about user actions. The environment as the word itself covers all actions users do. The environment is where the product is situated. We understand the interaction among users' actions, products, surroundings more detailly when users are taking actions. As I said, according to different user types, different product types are required. According to this, different environments exist. 56 ***Method 1.2.5*** For example (by P31), disables whose legs are inconvenience needs the wheelchair. When we design the wheelchair, we should consider particular environments where users are using it. We should design it, considering the situation in which users pass gates of bus and undergrounds and gate machines of underground stations. We also need to think where users climb stairs. We need to come up with the functional 57 ***Method 1.2.4*** and mechanical mechanisms to enable users to use it under each situation 58 ***Method 1.2.5*** more in easy way without critical problems. We need to come up with proper dimensions ***Method 1.2.6*** of the 59 wheelchair to enable users to use it in each circumstance ***Method 1.2.5*** in 60 a manner that is easy to manage. In the other example (by P32), these days washing machine is situated in the kitchen 61 ***Method 1.2.5*** to reduce users' movement 62 ***Method 1.2.6***. Users, particularly housewives, let the machine working to wash clothes while they are cooking in the kitchen or doing other things near the kitchen. In this, we consider the design aspect, in your word, the aesthetic aspect. The design of the washing machine should be harmonised with its surroundings. Users' eye and preference level of today is much higher. Unless the shape of the machine is not harmonised with that of furniture or other cooking devices in the kitchen, users will not buy it. Also, since most of the furniture and devices in US kitchen is made of stainless or wood, the washing machine should be made of the same materials. The washing machine in EU should be painted with tinted colours harmonised with colours of wallpapers of the kitchen. If the machine's colour is the primary colour or glossy colour affiliation, users will reluctant to buy it . . . . *Presumptive basis for collaboration with user type in market-driven research* (86) 87 88 89 90 91 92 93 94 109 *Presumptive basis for collaboration with user type in market-driven research* (91) *Presumptive basis for collaboration with working principle in tech-driven research* (95) *Example of user environment with aesthetic-and-symbol-driven research* (96) *Presumptive basis for collaboration with aesthetic-and-symbol-driven research* *Presumptive basis for collaboration with material in aesthetic-and-symbol-driven research* (114) *Presumptive basis for collaboration with material in aesthetic-and-symbol-driven research* (97) *Presumptive basis for collaboration with colour in aesthetic-and-symbol-driven research* (98)	• User scenario ***Method 1.2.7***	User segmentation (MK) 55 Shape (AS) 62 Colour (AS) 62 Material (AS) 62
⋮	⋮		

3.3) Performance Methods of the Aesthetic-and-Symbol-driven Research Activity in Task 1)

Participants	Phase 1: Defining meaning units *P:* Participant's dialogue / *R:* Researcher's dialogue	Classification Interconnection	Phase 2: Transformation Phase 3: Structural Description
P01 P02 P03	. . . . the opportunities can also be attained from the design aspect. It deals with exterior issues related to how to increase aesthetic values (by P01) and how to fascinate users by the product design (by P02). There are several elements for forming the aesthetic values. I definitely consider the product shape as the first (by P01). The element, the shape, serves as giving the first impression of the product. This overall impression seems to be formed through the combination of each part's shape. Inversely, some users feel the overall firstly, and then see details. These user behaviours make us recognise how much important to consider the design aspect. Some projects have a direction to change the design of the product only . . . . Product functions frequently represent acceptable shapes. The handle should be looked easy for users to grab and steer. We think the form follows functions . . . . Colour and material can be crucial factors to design the product (by P02). According to different colours and materials, the user perceives the product differently. Very often, those contain the functional aspect. In the design of public facilities such as a park bench and rental bicycle, we try to use strong and durable materials for the sustainable use. When designing a bicycle saddle, by means of R&D teams, we thoroughly consider the technical aspect such as the friction force or concentrated load in selecting proper materials. Unless we do not consider them, we cannot reduce maintenance costs. Sometimes, when a material which we need is too expensive, we develop an alternative material by ourselves (by P03) . . . . This overall research on design aspect in terms of aesthetic elements is conducted basisd on our efforts on continuous studies on trends and user demands . . . *Activity 1.3; Method 1.3.1; Method 1.3.2 & 1.3.3.; Method 1.3.3* *Presumptive basis for division by component unit* *Presumptive basis for collaboration with product function in user-driven research* *Presumptive basis for collaboration with interaction system in user-driven research* *Presumptive basis for collaboration with Technical parameter in tech-driven research* *Presumptive basis for collaboration with required technology in tech-driven research* *Presumptive basis for collaboration with development cost in market-driven research*		
P09	When we do the exterior design of the product, we are sometimes suffered from the embodiment of the shape which we came up with. It is highly related to the proper selection of materials or the high capability of the manufacturing process. Generally, the former one is more issued in the early design stage whereas the latter issue is generated in the late stage. So, I will talk about the relationship between the shape and material. There are suitable sorts of materials for different shape implementation. It is more effective to realise the radical cure types of the form by using plastic materials. There are various kinds of plastic materials and each of them has different characteristics so that matched with different shapes. The plastics also takes less money in the manufacturing than the steels. When we need more durable materials, we use reinforced plastics or sometimes just use the steels even if the purchasing costs are expensive. We also have a lab consisting of materials experts to discern the proper choice of materials and to develop new materials . . . . . . *Activity 1.3; Method 1.3.1; Method 1.3.3* *Presumptive basis for collaboration with Technical parameter in tech-driven research* *Presumptive basis for collaboration with development cost in market-driven research* *Presumptive basis for collaboration with technical parameter required technology in tech-driven research* *Presumptive basis for collaboration with development costs in market-driven research*		
P22 P33	We dedicate to reduce the gap between assembly parts (by P22), particularly the size of the bezel (by P33). This finishing touches, today, represents the degree of completion in designing and manufacturing product, which control whether users want to purchase or not. The current trend shows that the less gap between parting lines (by P22); bezels (by P33), the higher quality of the product design and manufacturing. Although it seems to be a trivial matter, we make a high commitment to this work because we have well-known this is directly connected to users' purchase . . . . . . *Method 1.3.4*		
⋮	⋮		

Activity 0.3: Improvement and Development items — 51, 87, 55, 88, 82, 99

Tool 1.3.1: Shape — 01, 02, 03, 08, 12, 25, 27, 28, 29, 37, 40, 45; 02, 53, 54, 56

CMF (Colour-Material-Finishes) — 66, 83, 93

Method 1.3.2 — *Colour*: 04, 17, 21, 23, 30, 34, 38, 41, 46, 49, 52; 13, 14, 15, 16, 17, 19, 54

Method 1.3.3 — *Material*: 05, 06, 07, 09, 10, 11, 13, 14, 18, 22, 24, 26, 29, 31, 39, 42, 43, 44, 47, 50, 53; 07, 32, 37, 53, 56, 66, 84, 92; 32; 33

Method 1.3.4 — *Finishes*: 15, 16, 19, 20, 32; 34, 32, 53

- *Gap between assembly parts*
  - → *The degree of completion in design* 24
  - → *The quality of design* 26
  - → *Decision on purchase* 25, 26

Tool 3.2 & 3.3: Colour & Material

Cont'd

35

P05 P06 P13

Method 1.3.2 27 18 Method 1.3.3

17 ……"Colour" is the design element users feel by their eye, and "Material" is the element which users feel mainly by their hand. The materials also 28 gives visual emotions to users (by P05). Each colour and material has each emotion. The red affiliation gives an ardent impression. The yellow gives calm emotion. The blue colour provides cool and urbaneness emotion. The black or grey gives luxurious and polish emotion. So, the red colour is utilised in the sports car, and black is used in electronics which has state-of-arts techs. Even, a very little bit of differences can make large emotional differences for users 31

Presumptive basis for collaboration with interaction system in user-driven research 29 30

Have you heard about the finishing touch? (by P13) The finishing touch does 19 Method 1.3.4 not seem to need to manage in the early stage, but, we should do. Despite 20 Method 1.3.4 the same finishing specifications, it may be visually different (looks wider or narrower; deeper or shallower) according to different colours or materials, 32

33 34 which cause changing them inversely . . . . . each colour and material has each

35 functional role. It is to dealt with from the semiotics or symbolic aspect. It can 21 Method 1.3.5 be unfamiliar with most of the practitioners. But, if you majored in chromatics (chromatology), it should be considered. When we develop medical devices, we normally use white or grey colour which stands for clean hygiene. Also, we utilise red colour to represent first-aid supplies. We use green and blue, complementary colours to the colour of blood, to increase visibility between parts stained with blood and clean parts. Particularly, products for children take yellow colour as the same as the colour of the chick, which looks a sort of toys. So, it makes children not afraid of being treated by the product . . . . . .

36 Example of symbolic function of colour

37 Colours and materials influence on the external quality of the product by P06 21 22 Method 1.3.2 & 1.3.3 Activity 1.3 and P13). When we use more luxury colour and materials, it is highly possible 38 39 that users feel and perceive the product is luxury . . . . . . Even though it increase the development cost, we pay attention to embody more polished

Presumptive basis for collaboration with interaction system in user-driven research

40 41 Presumptive basis for collaboration with development cost in market-driven research

37 colours and materials. Sometimes, if there are not manufactured colours 23 24 Method 1.3.2 & 1.3.3 circulated in the market, we develop our own paints and varnishes to more accurately realise the colour which we want 42

Presumptive basis for collaboration with required technology in tech-driven research

Method 1.3.5: Symbol

21

- **Shape, Colour, Material has symbolic functions** 31 36

99

Method 1.3.6: Aesthetic-and-Semantic board

Image map

51

- **Aesthetic-and-Semantic board toolkit** 100

Board in which aesthetic and semantic elements are marked in the target product

- **Image map toolkit** 101

Quadrant in which an overall image of the target product is situated according to X-and-Y axis are representing

Presumptive basis for division with component unit

02 43 57 58 59 71 97

P15 P17

43 Presumptive basis for division by component unit

. . . . When we design each part of the product, we should think about 25 whether the form or used materials 26 are possible within the range of their Method 1.3.1 Method 1.3.3 44 dimensions. If you design them blind without the consideration, we frequently realise later that each design is not feasible to be embodied. A

Presumptive basis for collaboration with technical size in tech-driven research

27 certain shape cannot be possible to manufacture within the range of small Method 1.3.1 sizes. In order to manufacture it, we may need to develop new manufacturing techs or equip a new production system with a large amount of money. It will be high risk as long as it is not guaranteed that high reward can mainly be 28 Method 1.3.1 caused by the shape. . . . . . . the part made of the nonelastic material but looks really fancy may not be fit into the assigned area of the product due to Method 1.3.3 its nature of non-flexible dimension change. Even, if it is the flexible material, 29 49 we need to calculate the degree of the predicted elasticity to confirm the part made of the material can be fixed into the assigned area of the product. . . . .

Presumptive basis for collaboration with technical size in tech-driven research 45

46 Presumptive basis for collaboration with required technology in tech-driven research

Presumptive basis for collaboration with development cost and profits in market-driven research 47 48

Presumptive basis for collaboration with technical parameter in tech-driven research

50 Presumptive basis for collaboration with technical size in tech-driven research

Presumptive basis for collaboration

- Market-driven research (MK)
- User-driven research (UE)
- Aesthetic-and-Symbol-driven research (AS)
- Technology-driven research (TC)

1) Activity ↔ Activity

- AS ↔ MK 40 47
- AS ↔ UE 60 62 64 81
- AS ↔ TC 80 98

Cont'd

P19

Activity 1.3

. . . . . . Apart from functionality and quality of the product, the design of the product is one of the important considerations from the consumers' needs and trends. In these days, the design is a very critical issue because there are no huge differences between products from the function and quality aspect. Determinants for good designs and bad designs are the product's form, colour, material and finishes. After the brief form of the product is determined, colours and materials are selected accordingly. In the case of the issue where the noticeable trend is related to the colour: I can say the colour of the year is violet, we decide the colour first, and then we come up with shapes and materials well-harmonised with the colour. In the early design stage, we should handle these determinants in great detail. It means we need to not only overall product but also detailed parts of the product. Sometimes, the details contribute to the change of the overall (normally in incremental NPDs). On the contrary to this, if we conduct the overall design initially, fulfil with initial directions, we then start to manage the design from the small part

P24

As I said, we regard the product as one living organism. We think users are communicating with the product when they are using the product. This mindset still continues when we conduct this activity. Users feel the product's style with their four senses except for the palate: they do not usually eat the product. Anyway, they interact with product's shape, colour, material and any other physical things. There are particular forms, colours and materials that certain user types feel wonderful and cool. I think this is also seen as certain design trends representing those user types. When users give a signal by operating one part of the product, like saying 'I am using this function', the product responses with the shape, colour or material of the part-related to the function. For example, when users push a button on the touch-screen, the product gives a signal by a generated ring surrounding the button for users' visual perception, a changed colour of the button itself for users' visual perception, a generated sound for users' acoustic perception, and a generated vibration for their tactile perception. Like this, when we deal with the product as the living organism, we can design it more in depth . . . .

P28

There are each helpful shape, colour and materials to increase usability. The intuitive design, behaviour-induced design or behaviour affordance design simplifies the operation of the product and contributes to the ease of use. Obviously, shape, colour and material may sometimes make it possible. The knob type of the keypad induces the turning/spinning action to users. The lever arm of the keypad makes users recognise the action of pulling down or up. By arranging more contrasting colours between various functional buttons of the control panel, it helps users to use more important functions first. The more rounded body of the portable product let users grab it more comfortably. In addition, if the rubber material covers its part in which users touch frequently, they feel more comfortable. Namely, the shape, colour and material element can help to facilitate users' actions in the easier way . . . .

. . .

2) Method ⟷ **Method**

- Shape (AS) — *Method 1.3.1*
  - User segmentation (MK): 62, 64
  - Development cost (MK): 47
  - Profit forecasting (MK): 48
  - Interaction system (UE): 05, 61, 63, 65, 73, 89, 91, 94, 95
  - Product usage function (UE): 04, 06, 73, 95
  - User environment (UE): 85, 86
  - Usability (UE): 67, 68, 69, 73, 74, 89, 90, 94, 95
  - Working principle (TC): 70, 91
  - Technical size (TC): 44, 45
  - Required technology (TC): 46
- Colour (AS) — *Method 1.3.2*
  - User segmentation (MK): 62
  - Development costs (MK): 40
  - Interaction system (UE): 08, 27, 29, 31, 38, 61, 63, 65, 73
  - Product usage function (UE): 73
  - User environment (UE): 85, 86
  - Usability (UE): 67, 68, 69, 73, 74
  - Required technology (TC): 42

Cont'd

P29

. . . . nowadays, the development of new materials has emerged as a major interest. It leads that a new design involves new materials. Even if a very tiny part of the product is embodied by a new material, its influence can be huge. For example, a newly developed tempered glass type of the display which can display hologram images was a key item of the new product. We were full of hope. But, the durability of the attachment between the tempered glass and the body of the product was too low. Consumers had to frequently visit an official repair store. Contrary to our expectation, it came to a rapid decline in sales. We lost customer credibility and loyalty, and it led declining sales of other products produced in our company, too. But, we achieved success to develop a reinforced adhesive after years of hard work. The new adhesive was transparent [redacted]. And, it was not able to leave any stains in the attachment part. So, the new adhesive was not for the edge of the glass only but for the full-part of the glass, which led to increasing the adhesive power. Like this, new materials development requires cutting-edge technologies and those materials and techs contribute to the generation of new designs . . . .

Annotations: 98 *Presumptive basis for collaboration with required technology in tech-driven research*; 75; *Activity 1.3*; *Method 1.3.3*; 43; 97 *Presumptive basis for division by component unit*; *Presumptive basis for collaboration with technical parameter and required technology in tech-driven research* 79; 76 *Presumptive basis for collaboration with technical parameter in tech-driven research*; 77 *Presumptive basis for collaboration with required technology in tech-driven research*; 44 *Method 1.3.3*; 78 *Presumptive basis for collaboration with required technology in tech-driven research*; *Activity 1.3*; 80

P32

When we design the product's exterior, its appearance, we need to consider environments in which the product is situated. I mentioned this once when explaining the importance of understanding user environment. Because I have told the basic concept of this at that time, I would like to give a detailed example to help your understanding more in this. Our design concept of all home appliance lines was to contribute to making a living room and kitchen like an art gallery. So, the shape of the air conditioner, TV, refrigerator, washing machine, dishwasher and micro-oven was formed by dynamic curve type. Colours of them were comprised of various coloured-patterns as if those look like action paintings. The surface of them was made of high glossy materials. The combination of each element, the shape, colour and material, successfully contributed to making the living environment the art gallery. But, we overlooked the visual harmonisation among appliances, furniture and any other elements of the housing. The design of appliances was too unique to be harmonised with other elements of the housing. So, the design strategy was failed in the end . . . .

Annotations: *Activity 1.3*; 81 *Presumptive basis for collaboration with user environment in user-driven research*; *From trend analysis*; 82 *Method 1.3.1* 45; 83; *Method 1.3.2* 46; 84 *Method 1.3.3* 47; 85; *Presumptive basis for collaboration with user environment in user-driven research*; *Presumptive basis for collaboration with user environment in user-driven research* 86

P37

. . . . The trend of products' shape is always changed. In the past, customers preferred the crude design style. They liked the design of the machine which looks like utterly the machine. So, mechanical tools were designed basisd on the nature of mechanical tools thoroughly. The trend of the day contributed to following the concept of the intuitive design to enable users to manipulate machines instinctively with less specifically described manuals. Workers of the day in the field of construction as able to operate the machine in easy way. They were able to confirm how the machine is mechanically operated, with their eyes. Actually, I still prefer this design concept. I think it is better for the machine to look like the machine. But, now the trend has been changed. Users more like soft design types. As a result, machines are sometimes seemed to be toys for infants. Their colour and materials as well as the shapes, are things which we can observe in toys. The design of the power drill seems to be a water gun for children. But, as the shape of the water gun and its parts are similar to that of the drill and its control parts, there is no critical issue in using it while keeping the intuitive design aspect. Psychologists say the design style contributes to relaxing workers mental and physical condition and it leads to maintain the safer working. Consequently, the new advantage from the safety aspect is added to the existing advantage from the functional aspect . . . .

Annotations: *From trend analysis* 87; *Method 1.3.1* 48; 88 *Example of trend analysis affecting aesthetic-and-Symbol-driven research*; 89 *Presumptive basis for collaboration with interaction system and usability in user-driven research*; 90; 91 *Presumptive basis for collaboration with the machine working principle*; *Method 1.3.2* 49; *Method 1.3.3* 50; 51 *Method 1.3.1*; 92; 93; 94 *Presumptive basis for collaboration with interaction system and usability in user-driven research*; 95

:
:
Presumptive basis for collaboration with product function, interaction system and usability in user-driven research

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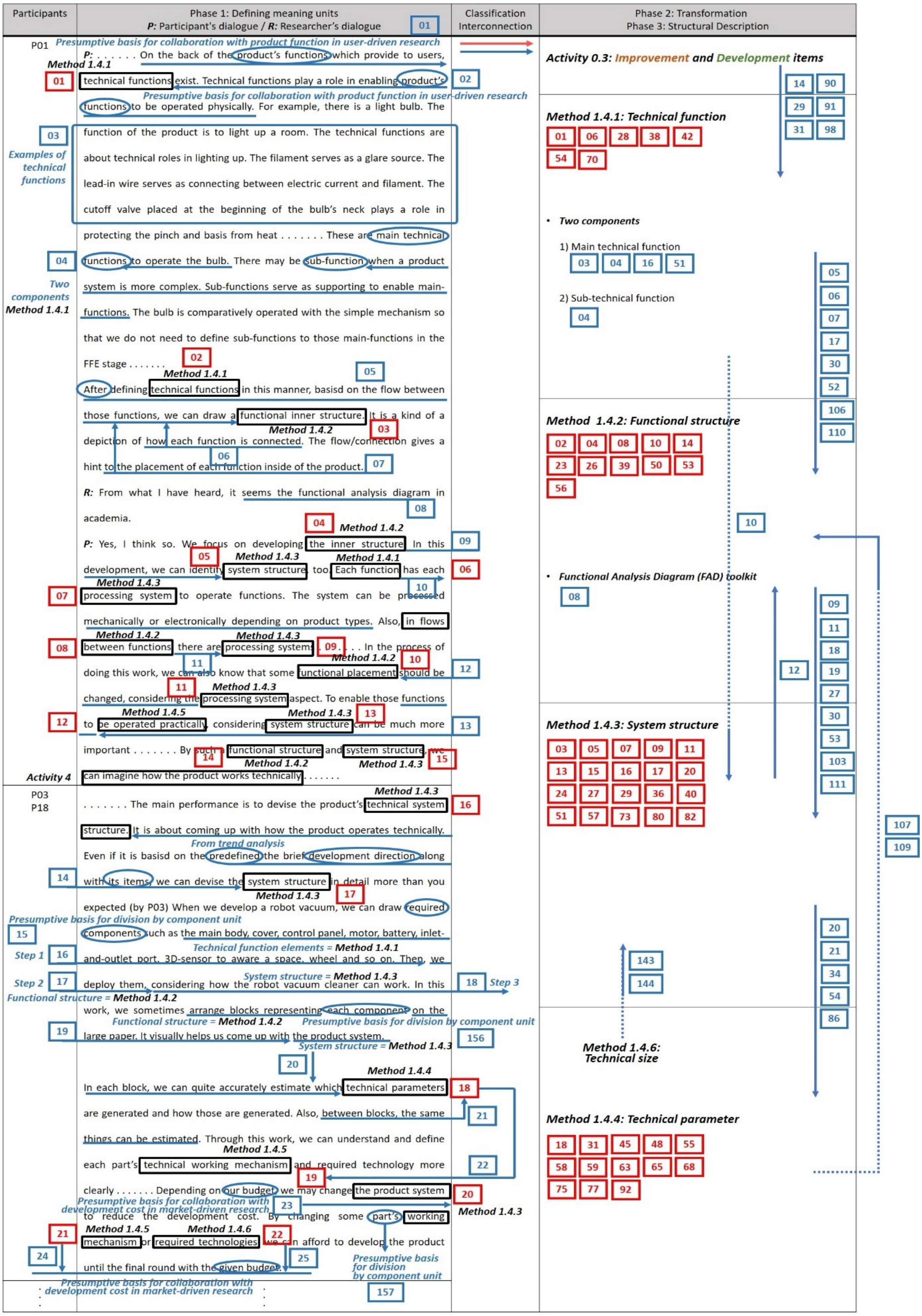
- Material (AS)
  Method 1.3.3

Area	Codes
User segmentation (MK)	62
Development cost (MK)	11, 20, 23, 41
Interaction system (UE)	08, 28, 30, 31, 39, 61, 63, 65, 73
Product usage function (UE)	73
User environment (UE)	85, 86
Usability (UE)	67, 68, 69, 73, 74
Technical parameter (TC)	09, 10, 18, 21, 49, 76, 79
Technical size (TC)	44, 50
Required technology (TC)	12, 22, 75, 77, 78, 79

3.4) Performance Methods of the Technology-driven Research Activity in Task 1)



Method 1.4.1: Technical function

Method 1.4.3: System structure

Cont'd

136 137 140

P14

.... In the case of the project basisd more on users, product functions for users initiate the whole project. On the other hand, In the case of the project more inclined to new technologies, the technologies lead the whole project. In the former case, by considering how users are using the product and which functions users are using, the product architecture and its system structure can be devised. We also define technologies demanded to operate the product system. In the latter case, basisd on new technologies applied to the product development, product architecture and their system structure can be developed. The meaning of technologies is closer to the technological functions reasoned from the trend analysis than exact names of technologies. Because, before developing the system structure, it is generally difficult to know exactly what the required technologies are . . . basisd on each part's system flow, we can know relevant parameters in each part so that specifically understand each operation mechanism. After then defining the working mechanisms, the range of dimension for the product and its parts can be estimated, considering other aspects such as usability, user environments and so on . . .

Presumptive basis for collaboration with product function in user-driven research (26)

From trend analysis

Presumptive basis for division by component unit (33, 37)

Presumptive basis for collaboration with usability and user environment in user-driven research (38)

Method 1.4.5: Working principle

12 19 21 32 41 60 62 71 74 76 78 86 88 90

P15, P17

One of the issues which we cannot overlook in this activity is to define a technical size of the product. With the minimalism trend, agendas in the most projects always include how to reduce sizes. When I (P17) was involved in developing the TV display, our consideration was on both how to develop the wider full-HD screen from usability aspect and how to reduce its thickness and the size of the bezel from the technological aspect. From the usability aspect, we needed to develop the 100 inches of the widescreen to give an emotion where users feel in the theatre. But, when the width of the screen is very wide, users cannot see the screen all at once. So, we needed to devise the curved screen to enable users to see the entire screen without any problems wherever they sit around the TV. In order to realise these development directions in practice, we had to develop new technologies such as 1) the very tiny size of the high-quality semiconductor which can be equipped into the inside of 5mm thickness screen, 2) the 100 inches wide and-curved screen which can display unbroken pixels, and 3) the durable screen despite of being curved ....

= Width

Presumptive basis for collaboration with usability in user-driven research (40)

Presumptive basis for collaboration with usability and finishes (41)

Presumptive basis for collaboration with interaction system in user-driven research (42)

Examples (44)

Presumptive basis for collaboration with usability in user-driven research (45)

Method 1.4.4: Technical parameter

Method 1.4.6: Technical size

33 34 64 66 67 69 79 81 84 85 87 89 91

Method 1.4.4: Technical parameter — Method 1.4.3: System structure

P29

.... the core mission in this activity is how to actuate the product with the technical system involved various technologies which fit into the target market and users. Doesn't it sound very complex? Although this work is still and always challenge us, we have done relatively well so far with our technique. Although the technique I said seems grandiose and complicated, there may not be much to it ...... Firstly, basisd on trends, we make a list of which product functions users need and which technical elements we need to realise those functions. Next, we draw a brief product architecture and its system structure. Then, considering a reality more, we specify the structure with parameters. Through this progress, we can envisage both an overall working mechanism and specific parts working mechanisms in operating the product and its functions ......

Presumptive basis for collaboration with user types and market positioning in market-driven research (47, 48)

From trend analysis (49)

Presumptive basis for collaboration with product function in user-driven research (50)

Step 1 (51) *Step 2* (52) *Step 3* (53) *Step 4* (54) *Step 5* (55)

Presumptive basis for division by component unit (56)

Method 1.4.7: Required technology

Technology Road Map (TRM) toolkit

22 25 30 37 43 46 47 49 52 61 72 83

115 135 156

Cont'd

P22
P37

We dedicate to not only develop new technologies to provide new or advanced technical functions to the product but also develop new materials used in the product. By only changing materials used in the product, by just changing a single part's material, the product itself can be a totally new thing to users, basisd on new trends, we can recognise which materials are needed to purchase and newly developed. For example (by P37), the trend of the product material was the metal material. From our research, target users felt that the product made of the silver metal looks fancier. But, the cost of buying the stainless material was very expensive. Also, we was not able to use the aluminium material which is relatively cheaper, because the solidity of the material is quite low so that it is easy to be dented with weak pressure. So, we came up with the tech to basically use the plastic material covered with the vinyl material which provides a feeling of the metal. It was very hard work. First of all, it was not easy to develop the new material itself. Also, even though we developed it successfully from the visual aspect, it did not pass various durability tests such as the strength, high-and-low temperature, friction, abrasion, etc. But, we did not have much time to compensate defects because the trend was changing rapidly. We highly needed to develop it successfully and get much profit to comparatively low investment cost, we still decided not to buy the metal material. With various vendors' attempt,

P23
P26
P28

. . . . Through understanding which functions users use and how they feel during using them, we can identify various things from R&D aspect. The R&D team's key issue is to devise product inner structure with its system in the FFE stage. Just identifying which technologies are required to develop the product is not enough. basisd on the product functions, we can know needed components and their brief placements. The placements are also decided by the technical function and nature of each component (by P28). The battery is a very heavy part so that should be placed at the bottom of the product. The heat outlet port is for the emission of the heat so that should be placed in the upper part of the product. By such considerations, we can come up with the product's inner structure. Furthermore, by understanding of the relationship between each part, we can develop the system structure. We can also know expected technical parameters in each part or between parts. For example (by P28), when users are pulling down the lever arm, we can know the range of the physical force to deliver from the lever arm to the other part placed inside of the product, basisd on this work, we can change its existing working principle or find the most proper one as the alternative. To embody the alternative one, we may need to develop a new technology . . . . . . For the example (by P26), let's suppose that users do not prefer a high-decibel of sound, e.g. a clicking sound during manipulating a certain mechanical control panel. If we find the sound is generated from a certain part's mechanical movement, We may need to devise the control panel's operation mechanism itself newly like an electromagnetic touch-panel. But, the budget can be a constraint condition to develop it. It will take much HR, time and any other costs. Also, the planned launching schedule or initially targeted market can be other constraints. So, I always feel the NPD is not easy

Annotations: Activity 1.4; Method 1.4.1; Method 1.4.7; Method 1.4.4; Method 1.4.2; Method 1.4.3; Method 1.4.5; Need new technologies; From trend analysis; Presumptive basis for division by component unit; Presumptive basis for collaboration with material in aesthetic-and-symbol-driven research; Presumptive basis for collaboration with user-driven research; Presumptive basis for collaboration with interaction system in user-driven research; Presumptive basis for collaboration with development costs in market-driven research; Presumptive basis for collaboration with development cost and profit in market-driven research; Presumptive basis for collaboration with product function in user-driven research; Parameter; Technical function; Functional structure; Presumptive basis for collaboration with interaction system and usability in user-driven research; Presumptive basis for collaboration with development cost in market-driven research; Presumptive basis for collaboration with target market in market-driven research

:

Presumptive basis for division with component unit

15, 33, 37, 56, 58, 105, 108, 112, 123, 124, 138, 148, 156, 157

Presumptive basis for collaboration

- Market-driven research (MK)
- User-driven research (UE)
- Aesthetic-and-Symbol-driven research (AS)
- Technology-driven research (TC)

1) Activity ⟷ Activity

- TC ⟷ MK: 47, 48
- TC ⟷ UE: 59, 101, 102
- TC ⟷ AS: 128, 129, 133

2) Method ⟷ Method

- Technical function (TC) *Method 1.4.1* ← Product usage function (UE): 01, 02, 50
- Functional structure (TC) *Method 1.4.2* ← Interaction system (UE): 102
  - ← Product usage function (UE): 26, 101, 104
- System structure (TC) *Method 1.4.3* ← Development cost (MK): 23
  - ← Interaction system (UE): 102
  - ← Product usage function (UE): 26, 101

Cont'd

Participant	Transcript	Technical elements	Related elements
P28	.... In the same context, to pull down the lever handle, there are the proper length and thickness of handle from the ergonomic aspect. I will not explain this in detail because I explained before. In this view, we need to consider them from the other aspect. It is the technical aspect. Because of the technical nature of the handle's material and shape, the dimension of the handle may be changed. Also, the dimension of other parts mechanically connected to the handle can be decided by the handle's dimension. The handle's dimension can be changed again due to the dimension of other parts .... In the past, we needed to develop a lamp emitting the low degree of luminous intensity to protect users' eyesight. But, to enable users to recognise the light comfortably, the size of the lamp should be large. But, if the lamp is larger, it does not look fancy. So, we had to develop a small size of the lamp emitting the low luminous intensity but it should be functionally very well. It was very hard work to find the optimum level between the luminous intensity from the technical aspect and the size of the lamp from ergonomics and design aspect	• Technical parameter (TC) *Method 1.4.4*	Interaction system (UE) 113 125 Usability (UE) 125 Shape (AS) 121 Material (AS) 120
		• Working principle (TC) *Method 1.4.5*	Market positioning (MK) 119 Development cost (MK) 24 118 Interaction system (UE) 116 150 User environment (UE) 151 154 Usability (UE) 117 151
P31	.... There is the concept of the technical function in developing the product. Unlike the product function for users, the technical function contains a technical understanding or description of working mechanisms and relevant technologies in operating the product. To operate one product, it requires a technical system structured with connected each part actuating working mechanisms. The systematic connection between those working mechanisms leads up to the overall operation mechanism of the product. Sometimes, we dismantle overall mechanisms to define each part's mechanism. To reduce works in the late stage of the project, we generally define specific parameters in each working mechanism in this stage, and inversely, by defining specific parameters we can understand those working mechanisms .... We need to consider where the product can be situated. According to the given situation, the size of the part and overall size thereof can be changed from the generally fixed range of technical sizes of them. To fit the system into the range of the size, we may need to develop a new system structure or we may need to develop new technologies to reduce the size. Also, we need to sometimes adjust the size due to usability the human factor engineering . . .	• Technical size (TC) *Method 1.4.6*	Interaction system (UE) 42 150 User environment (UE) 39 142 147 151 153 Usability (UE) 38 40 41 127 130 132 146 151 Shape (AS) 121 Material (AS) 120
P38	.... I think it will be better to give an example to increase your understanding. Most of the practitioners overlook to consider the environment surrounding the product when they think about the size of the product and its parts. In the case of very poor designers, considering the environment in which the product is situated, they do not calculate the size of the drawer and the radius of its movement (pull-out and push-in). If users situate the product in a certain place and its size and radius of movement are larger than the given space, users cannot use the function of the drawer. To solve this problem, we may need to reduce the technical size of the overall drawer or some parts of the drawer. Also, we may change to the working mechanism from the pull-out and push-in to the pull-down and pull-up. In this process, we may need additional parts, required technologies or materials . . .	• Required technology (TC) *Method 1.4.7*	User segmentation (MK) 48 Market positioning (MK) 47 Development cost (MK) 25 93 99 100 Interaction system (UE) 92 95 User environment (UE) 155 Usability (UE) 45 Material (AS) 57 96
⋮	⋮		

4) Idea Generation-Screening Task (Task 2)

Participants	Phase 1: Defining meaning units *P:* Participant's dialogue / *R:* Researcher's dialogue	Classification Interconnection	Phase 2: Transformation Phase 3: Structural Description
P07	The idea generation is for us to come up with specific methods to embody each opportunity explored in the new business discovering stage. All discovered information in the previous stage can be regarded as opportunities. Because, if we fully utilise those data to develop a new product, the product will be updated or designed newly. So, we can say no matter what the information is, all information has the possibility to provide new opportunities to create new design. Of course, among information, there is various degrees of making huge or small differences in the design. We usually reason acceptable ideas logically. Sometimes, we generate idea randomly by using methods which you also know such as brainwriting-and-drawing, SKEMPER, group horning, etc. But, the effectiveness is too low to applied to the development actually. So, we use those kinds of methods, when we are exhausted to generate idea and we judged where there is no possibility to generate any other ideas through our logical thinking way. Our idea generation technique includes a series of steps. In the series, there is a step of what to know to realise opportunities, a step on what to know before to do that step, and a step on what to do for these two steps. To obtain specific ideas, we reason them step by step, we break down ideas on the logical flow. In these works, each feasibility check is essential. We prioritise them with the different levels of the feasibility . . . . . *(Annotations: Task 2; Basic concept; Task 1; Logical ideation processing; Intuitive ideation processing; Step 4; Step 3; Step 1 & 2; Screening; Multi-levels; 01–08)*	01 02 03 04 05, 06 (Pattern 1) 09 10	**Opportunity identification-and-screening task (Task 1)** *Presumptive basis for four ideation activity domains*: 43, 52, 60, 69, 70 01, 02, 11, 12, 14, 15, 20, 21, 28, 29, 30, 31, 37, 41, 42, 55, 56, 57, 58 **Idea generation-and-screening Task (Task 2)** **Performance method: Logical ideation processing** **Idea generation (4 steps)**: 01, 03, 09, 12, 14, 16, 28, 35, 39 • Series of ideation work: 06 • Phased reasoning ideation: 26 • Break down ideation: 08, 13 05, 18, 19 – Increase creativity, Novelty **Intuitive Ideation Processing**: 02, 10, 15, 24, 25 • Brainstorming-writing toolkit • SCEMPER toolkit • Group horning toolkit: 03 **Idea screening (3 Steps)**: 08, 11, 13, 20, 36, 42
P19	The idea generation is to devise proper methods required to actually materialise elements discovered in the previous task. The method is a kind of specific action plan to materialise those elements. For us, the ideation is a kind of process to specify those opportunities more, so that changes into actionable methods . . . Sometimes, we start to generate any ideas randomly without profound thinking and then convergently filter and generalise those ideas forward to predefined ideal status of methods. Sometimes, we divergently specify discovered opportunities, generating possible options along with rational evidence. Then, by the expert group discussion, we prioritise them at different levels from the feasibility aspect. We prefer the latter direction because it is generally difficult to predefine the ideal status of methods before generating ideas. Even, very occasionally, we use the former one when we have troublesome to come up with the possible ideas by the latter direction or ideas from the latter method seems to be less novelty . . . *(Annotations: Task 2; Basic concept; Task 1; Logical ideation processing; Intuitive ideation processing; Screening; Step 1; Step 2; 09–15)*	11 13 10 14 26, 12 (Pattern 2; Logical ideation processing) 15 18, 19	**Step 1 – Initial ideas to materialise opportunities** • Pattern 1: 06, 21 • Pattern 2: 26, 17, 37, 40 • Pattern 3: 29, 32 08, 15, 24, 32, 63, 76
P34	Our main works aim at finding workable solutions. Solutions themselves can more specify new opportunities. We produce all solutions for each opportunity identified in the previous step. It is sometimes only one but usually can have a lot of alternatives. In each solution, we dig up what reasons to make solutions imperfect or make them workable. To get more insights into those reasons, once again we dig up what reasons to make those reasons imperfect or make them reasonable. After that, we categories those phased reasons into similar categories with connecting to each solution. As a result, we can deeply understand the relationship among opportunities, solutions and reasons why those solutions are highly feasible or less feasible. *(Annotations: Basic concept; Task 1; Step 1; Step 2; Step 3; Screening; 2 levels; 16–20)*	21 22 24, 25 (Pattern 2) 24, 25 20, 27	**Step 2 – Supportive reasons and rational evidence for initial ideas** • Pattern 1: 04 • Pattern 2: 27, 18, 22, 38, 41 • Pattern 3
⋮	⋮		

Cont'd

P25 28 Basic concept 30 Basic concept 31 Basic concept 33 32	Our company's main role is consulting other product design companies, so that the idea generation and opportunity identification task are sometimes combined. We regard opportunities themselves as ideas which can be applied to the product development. But, we frequently need the idea generation (Task 2) performance separately to specify (29) defined opportunities (Task 1) further. On the relationship between opportunity identification and idea generation, we approach with the cause-and-effect structure. The opportunity is regarded as the cause, and the idea is regarded as the effect. So, it is the same as where since we have a certain opportunity which we need to materialise, we need ideas for the materialisation. . .When we (21) get our teeth into ideas deeply (Logical ideation processing) more and more, we always try to keep (Step 1:) "Why we need this idea" (22) in our mind. That way make the idea useful to reflect on the product. Unless we (Step 2 & 3) don't generate ideas in that way, (34) most of ideas will be useless. Sometimes, randomly very (Intuitive ideation processing) creative ideas can be achieved with our inspiration. After all, when we track back to find sources of those ideas, after all, we realise that our logical thinking way was working automatically on the back of that inspiration. So, we think there is nothing generating by chance. (36) It leads us to the cause-and-effect structure and makes us always think "Why we need this idea"	28 24 25 Pattern 2 35 The relationship between logical and intuitive ideation process	Step 3	Specific ideas to materialise initial ideas • Pattern 1 06 • Pattern 2 • Patter 3 30 31 34 07 38 25 39 33 08
			Step 4	Supportive reasons and rational evidence for specific ideas along with their features, strength and weakness • Pattern 1 05 • Pattern 2 19 22 • Pattern3 61
P38 31	When we produce ideas (Task 2) on each item defined in (Basic concept 37) identifying the opportunity (Task 1), we generally operate our thinking process as following three directions: (59) How might we practically reflect those items in the development? (Step 1) To do so, in what specific ways might we reflect those items in the product? (38) To do so, how we do? (30 Step 2') (39) Also, we think about 'What', 'How' and 'More How'. (Step 2'') (32) (34) 'What' indicates opportunities. 'How' means the idea as (Step 1 to 2) the specific way to realise the opportunity.	29 Pattern 3 28 Logical ideation processing	Step 5	Comparative analysis of strength and weakness of ideas 36 64 78
P05 P06 42 45 46 52	The ideation is (40) not to create something out of nothing. It is to further specify opportunities identified in advance (Task 1), to make those opportunities have a more realistic. It will easy for you understand with the example. In the opportunity discovery stage, we define a certain part of the product consist of a streamlined body covered with reddish colour, made of steel. (43) In this, how can we approach to further specify those elements, 'Streamlined', 'Reddish', 'Steel'. (Presumptive basis for connection with the aesthetic-and-symbol-driven research) As I said before, for the embodiment of the streamlined shape, a particular kind of steels exist. For gaining reddish colours on the surface, (44 Presumptive basis for collaboration) there is a proper kind of steels. Also, there are other factors to affect the embodiment. So, under those considerations, we can specify several particular red colours (Idea) among (Specify) varied reddish colours (Opportunity). We can specify several particular steel materials (Idea) among (Specify) various steels (Opportunity). When defining each (47) particular red colour and steel material, we usually utilise colour and material scope which assigns codes (numbers) (48) to each colour and material. Codes for colour (49) is made up of the CMYK or RGB colour variance, and material codes come from the combination of alphabetical and numeric identifiers provided by the international standard. Also, we sometimes search possible vendors or OEMs to manufacture it to appropriate more accurate budget.	41 35 Logical ideation processing Example 60	Step 6	2 levels: much or less feasible ideas 20 36 • Predefined criteria + Group discussion 10 14 16 27 65
			Step 7	Priority of ideas 13 36 • Predefined criteria + Group discussion 10 14 16 27 34 65
	Presumptive basis for connection with the market-driven research 52 | 51 Presumptive basis for collaboration with market-related and aesthetic-and-symbol-driven ideation			

Cont'd

P13

Usually, people regard the idea generation as creating a totally new thing. But, in product development, if we consider the development progress, it is not to create the new thing as if God created the world. Generating the new thing which people usually regard have already been conducted when setting up the initial development direction basisd on user demands and trends, by the thinking process of "What if this kind of product will be provided to users.". In this task [Task 2: the ideation] is in the linkage of the [Task 1: opportunity discovery]. Ideas which we need to come up with is in terms of how to further advance those opportunities to be feasible. Whereas those [Task 1: opportunities] were abstract ones to some extent, [Task 2: ideas] can be more specific ones. Those ideas include specific direction for advancing those opportunities more. For example, when we developed a medical cart to move various medical devices along with emergency kits, we specified several parts such as a handle, attachable storage shelf and caster. Those three had already been defined as parts which had needed to be improved. For the handle, [Step 1: various types of] handles which had used in the cart before were nominated along with [Step 2: their merits and] faults. We also referenced many types of handles in other types of products along with their merits and faults basisd on various conditions defined in the previous stage, we prioritise them one by one. Then, we were able to get three types as the most possible handles. For the attachable storage shelf, we searched diverse types of storage shelf from various perspectives, e.g. the shape, the number of storage spaces, whether the lid exist, etc. We listed all characteristics with pros and cons. Then, we compared them with considering the environment of A&E and ergonomic data. We also compared them, considering other various technical aspects. We categorised them into highly possible or less possible ones. For the caster, the same progress was implemented. In generating various possible casters, various aspects were treated: 1) How many casters are proper for the cart in A&E in which doctors and nurses usually move the cart rapidly and roughly, and 2) when those users are moving the cart with that behaviour, how much-concentrated load each caster can bear. Then, the most possible caster types were defined . . . . .

Annotations: 53; 54; 55 Basic concept; 56; 57 Basic concept; 58; 73 2 steps of Logical ideation processing; 35 Method 2.6; 62 Presumptive basis for division by component unit; 37; 38; 63; 68; 64 Presumptive basis for screening work; 68; 65; 66; 67 3 steps of screening; 36; 61 Example; 69 Presumptive basis for connection with the user-driven research; 70 Presumptive basis for connection with the technology-driven research; 71 Presumptive basis for connection with the user-driven research; 72 Presumptive basis for connection with the technology-driven research; 73 Presumptive basis for collaboration between user-driven and tech-driven ideation

P28

In our company, [Task 2: the idea generation] is a kind of digging work with generating possible options to specify [Task 1: opportunities]. We compare [Step 1: those options] basisd on [Step 2: pros and cons] with considering other factors which can affect those options. As I give you the proper example, let's suppose that a certain operation mechanism along with the processing system and technical parameters as an opportunity to be materialised are given to you. In this, the proper working mechanism is a kind of lever-arm structure. There are many operational mechanisms for the lever-arm structure. So, you can generate all possible lever-armed mechanisms as ideas with their pros and cons. On the other hand, to some extent, if the lever-armed mechanism has been already defined specifically in the previous stage, e.g. pull-up-and-down, you can generate more detailed several pull-up-and-down mechanisms such as whether the lever moves in a straight line, diagonal line or curve line, etc. Then, you prioritise them by considering other conditions such as usability, aesthetics, preference, etc. If you can or the schedule permits you, you can deep inside to specify them with approaching to the reality more and more . .

. . .

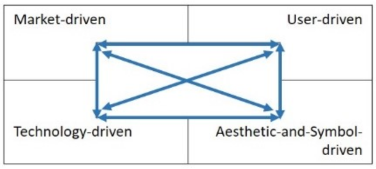
Annotations: 74 Basic concept; 75; 40; 77 Presumptive basis for collaboration; 41; 76; Method 2.7; 39 Logical ideation processing; 79 Presumptive basis for connection with the technology-driven research; 78 Example; Method 7.1: Alternatives; Method 7.2: Pros and Cons; Method 7.1: Alternatives; 42; 79 Presumptive basis for collaboration with the user-driven and aesthetic-and-symbol ideation activity

Presumptive basis for conducting with component unit

60 61 62 78

Presumptive basis for collaboration

19 44 51 73 77



Example

- Market-driven ideation

  52

- User-driven ideation

  69

- Aesthetic-and-Symbol-driven ideation

  60

- Technology-driven ideation

  70

5) Requirements List and Mission Statement Task (Task 3 and 4)

Participants	Phase 1: Defining meaning units *P:* Participant's dialogue / *R:* Researcher's dialogue	Classification Interconnection
P01	The mission statement is written on one sheet with our project title, aim and objectives. Mission statement also covers overall product functions, technical features, design and market-related information. The difference with the requirement list, the mission statement should be simpler, condensing contents. Because its purpose is to always keep the product development directions and related-information as simple as possible in our mind	01 Task 4; 01 Format; 02 Contents; 03 Contents; Presumptive basis for connecting to Task 1 and 2; 04 Degree; 05 Content 3; 06 Degree
P03	Do you know the difference between "Spec" and "Specs"? "Spec" means each data which were researched and analysed before. "Specs" is a set consisting of each spec. So requirement list does not means a list of "Spec" but a list of "Specs". . . . . . . We usually make the list of "Specs" basisd on 1) product features such as functions, technologies, design and markets, under the scope category, 2) the development time, under the schedule category, and 3) costs and teams in charge of each action, under the resource category . . . . . . The more specific requirement list, the easier performance of the next step	02 Task 3; 07 Purpose; 08 Content with 3 categories; 09 Presumptive basis for connecting to Task 1 and 2; 10 Degree
P06	Along with basic contents such as product functions, related-technologies, design considerations and market strategies, we also emphasis on the financial index when making the requirement list. If we overlook this, actual NPD cannot proceed any more due to the financial crunch . . . . We call this "Mini-map of the product development".	11 Contents; 12 Presumptive basis for connecting to Task 1 and 2; 13 Contents; 14; 03 Task 3; 15 Purpose
P16	Drawing up the product specification is a kind of developing "Initial Overall Map" for the product development. It includes the target market, positioning strategy, the product function and technologies, product benefits, and product attributes . . . . The more specific product specification, the better . . Product specifications are divided into "Must criteria" and "Should criteria". The must criteria is for requirements which we must apply to the product. The should criteria is for requirements which are not surely necessary to be reflected in the product	04 Task 3; 16 Purpose; 17 Contents; 18 Degree; 05 Task 3; 19 2 levels; 20 2 levels
P22 P23 P27	. . . . . Making out the requirement list is, literally, to list and arrange all the features and properties of the product. Usually, we try to put all those things in one or two pages, by utilising the table chart format. In the format, we divide those requirements into two groups, an Essential and Selective one. Requirements assigned to 'Essential' means that those must be reflected in the development. Requirements assigned to 'Selective' indicate that those can be reflected in the product optionally. We consider this list to be "blueprint" as an essential advance preparation for the actual product development . . . . . . After this work, we define one statement of project purpose by summarising the requirement list. We usually call it the mission statement or project brief. Along with one statement, several development objectives in which key requirements are reflected can also be developed	06 Task 3; 21 Purpose; 22 Format; 22 2 levels; 23 2 levels; 24 Purpose; 07 Task 3; Task 4; 25 Task 3; 08; 10; 09; 26; 27 Purpose; 28 Contents
P25	The requirement list is literally to make up the list consisting of requirements which should be applied to the development. In the list, 1) target market segments, 2) channels to reach those segments, 3) product cost and price, 4) functionality, 5) features, 6) technologies on which the product will rely, 7) design specs, 8) an allocation of resources are included. . . . . Along with requirements with the text format, some images to help to understand contents of requirements can be put together	11 Task 3; 29 Purpose; 30 Contents; 31 Presumptive basis for connecting to Task 1 and 2; 32 Format
P37	Some practitioners do not deal with technical specifications in the requirement list. Because they think that it will be fine to manage them in the actual development stage. But, it is a huge fault. If we do not manage in in the early design stage, the concept design can have imperfect since no technical specifications are reflected in the concept. So, testing the prototype devised based on the product concept will be less meaningful. Particularly, in the case of the workable prototype, the test will be much less meaningful. Therefore, the more specific specifications, the better the following implementations . . .	33 Reasons for making up requirements between Task 1-and-2 and Task 5-and-6; 34 Degree
⋮	⋮	

Phase 2: Transformation Phase 3: Structural Description	
Opportunity identification-and-screening task (Task 1)	
Idea generation-and-screening task (Task 2)	03, 09, 12, 31, 33
Requirement list (Task 3)	02, 02, 02, 02, 02, 02, 02, 02
Concept	• *A list of specification* 07, 21, 29 • *Detail mini-map and blueprint* 15, 16, 24
Contents	*Target market information, Market positioning-and-distribution strategy, Product functional-and-technological features and relevant specifications, Exterior design elements, Financial index* 08, 11, 13, 17, 30, 24
Format	• *One of two page o table chart* 22, 32 *Text + Image* • *2 levels* 19, 29, 22, 23 *Essential (Must) + Selective (Should)*
Degree	*Specific* 10, 18, 33, 34
Mission statement (Task 4)	25, 26
Concept	• *Development direction brief* 05 • *Design brief* 27
Contents	• *Project title, aim and objective* 28 • *Core contents of requirements* 28
Format	*Within one page* 01
Degree	*Condense* 04, 06

6) Conceptual Design Task (Task 5)

Participants	Phase 1: Defining meaning units *P:* Participant's dialogue / *R:* Researcher's dialogue	Classification Interconnection
P02	Some companies devise concept designs at random. They draw 50 to 100 designs continuously, generating different concepts to some extent or to a large extent. Then, they choose the best design with their criteria derived from the requirement. However, we have quite systematic method to devise the conceptual design. In the first step, we devise the basic, um .. principal concept by using various figures for each part. Using those figures help us not only understanding principal conceptual form of the product simply but also generating many concepts varied from each other. Next, we choose three to five concepts which we think the best. Then, we interjoin those figures devised for each part, structuring the product form. Usually 3 to 5 principal conceptual designs are devised. In the next step, we reflect the function and system structure in each principal conceptual design. In this process, the principal design is elaborated to become closer and closer to the realistic product form. We also mark dimensions on those concepts as schematic conceptual design work. As doing the final work, we refine those designs to have more look like the product form. We call it a styling conceptual design. On each design, we discuss their characteristics of each design	05 *Activity 5.1* 07 08 *Activity 5.2* 09 10 *Activity 5.3*
P13 P28	In the concept design stage, we usually utilise a particular phased-technique. For example (by P13), the medical cart generally consists of main six parts such as a shelf for medical devices, steering handle, mainframe, attachable storage shelf, frame for the caster and caster. For each part, we create possible conceptual designs with very simple forms, from five to ten, sometimes twenty. Then, we choose three concepts in each part and combine them by structuring the medical cart form. We conduct this work iteratively with choosing different concepts in each part. After that, we can find some possible combinations. Among them, we select optimum three. Then, elaborate them more until it looks fancy and closer to the real product. For instance (by P28) . . . . . . for each requirement, many conceptual designs can be generated. Also, for the entire product and for its parts, many conceptual designs can be derived with rough forms. Then, we compare each of them and combine them which we regarded as good to generate several concepts of the whole product. Among those conceptual designs, we select the best five ones and conduct the stylising work from the range of the entire product to its part. In the styling work, individual designers' competency are significant to derive the product concept fascinating users.	12 *Activity 5.1* 13 *Activity 5.3* 14 *Activity 5.1* 15 *Activity 5.3*
P25 Dismantle	Specifications [redacted] and those are reflected one by one in the concept design . . . . We dismantle the product by the product specification unit. We apply each spec in each dismantled part one by one, generating partial product concepts. Then, we integrate them, then, do it again, considering the structure of the product which we defined before. Then, we generate the whole product concept.	16 *Activity 5.1* 17 *Activity 5.2*
P05 P06	We tried to create conceptual designs as many as possible. So, sometimes, many members are mobilised in this work. Among numerous concepts, the design which has been survived to the last can go to the next stage. Rather than having a particular technique for creating the conceptual design, we leave it to the capability of each designer. Designers try to derive the best concept basisd on considerations which have to be reflected in the design . . . To express the concept closer to the more realistic product, we prefer reflecting colours and materials in the concept. So, we can receive help from computer-aided programmes such as Rhino, 3D-max, etc	18 *Intuitive conceptual design* 19 *Similar to Activity 5.3 in systematic conceptual design*
⋮	⋮	

Phase 2: Transformation / Phase 3: Structural Description		Codes
Requirement list task (Task 3) / ***Mission statement task (Task 4)***	*Visual embodiment*	03 19 27 28 32 34 35 36 45 47 48
Conceptual design (Task 5)		
1) Systematic conceptual design processing		04 11 20 21 25
Activity 5.1: Principal conceptual design		05 12 14 16 20 21 22
Step 1	*Figure typed designs by product component unit*	04 13 21 28
Step 2	*Optimal designs in each component*	05 14 22
Step 3	*Figure typed designs for the entire product*	06 15 23
Step 4	*Optimal designs for the entire product*	16 24
Activity 5.2: Schematic conceptual design		07 08 17; 08 30
Step 5	*Reflect of function and system structure*	25 38
Step 6	*Mark dimension*	09
Activity 5.3: Styling conceptual design		09 10 13 15; 17
Step 7	*Hand-drawing*	23 38 39
Step 8	*Computer-aided drawing*	40 41

Cont'd

P16 P22 P23 P27

The development of the conceptual design is to confirm the product design visibly before going to the actual embodiment of the NPD. The reason to perform the conceptual design is to visually identify how the product will look like if we develop the product basisd on the requirement list. Even though it is visual design only, we can estimate the design from the functional and technical aspect. Sometimes, we develop the overall conceptual design briefly to get a very rough feel for the design concept. Sometimes, we decompose the whole product by the requirement unit and then design it one by one. It leads up to the entire form of the conceptual design at the end. The entire form looks like the articulated product yet, so we need to conduct the refinement to connect each part smoothly. We also refine outlines to infuse a particular style into the design. We infuse the emotion of colour and material into the concept (P22, 23 and 27). We iteratively refine it until it is satisfied with our standard . . . . . .

Annotations: Task 5; 34; Task 5; Task 3; 35; Presumptive basis for connection with requirement list; 36; 22 Activity 5.1; 37; Task 3; Systematic conceptual design 20 Overall → Part; 21 Part → Overall; 23 Activity 5.3; 38; 39; 40; 41

P20 P31

When we design the concept of the product in systematic way, we sometimes use 'Round robin' method to integrate all members ideas into the concept at the same time. Design concepts from designers' inspiration are not satisfied with our assessment criteria or regarded as not different from previous ones or competitors', we use this method. We sit around the table first. We place the requirement list next to each of us. Sometimes, we attach the list printed on a large paper to the wall. Sometimes, we utilise the beam projector to share the list together. Then, the first member draws the product concept on the paper or tablet PC. The concept can be a whole product or a part of the product. It is up to his/her mind. The second person receives the same paper in which the first person drew the product concept, and draws the product concept successively. If the whole product concept is drawn on the paper and the concept does not meet your criteria, the second person can draw another whole product concept next to it. On the other hand, if the overall product concept is satisfactory to the second person's preference, he/she can derive the concept of the product part. In the case of the third person, if there are two concepts for the whole product, he/she can draw the concept of the product part inside of one of the whole product concepts which he/she prefers. In this, he/she can draw the concept of the product part structurally very close to the product part devised by the previous member, considering the function structure. Also, the third member can just draw the product part concept which the member wants. In this way, the paper continues to be delivered to each member until all requirements are exhausted . . . . . .

Annotations: Task 5; Systematic conceptual design 25; 43 Purpose 1; 42 Recommended method which can be applied to Activity 5.1 and 5.3; Intuitive conceptual design 26; 44 Purpose 2; Task 3; 45 Presumptive basis for connection with requirement list; Performance procedure 46 Overall → Part, Part → Overall; 50 Presumptive basis for division by component unit; Presumptive basis for division by component unit 51; Apply to Activity 5.2; Presumptive basis for division by component unit 52

P33

When we conduct the conceptual design, we try to reflect the understanding of user's needs, their interactions and experiences, product functions and technologies in one concept. Common artefacts of conceptual design are expressed with 2D-sketches and 3D-models. We indiscriminately develop concepts, keeping those considerations in mind. Sometimes, the number of concepts was more than 200. We print all of them and attach them to four walls of a room. In order to select the best one and several alternative ones, many team members including our CEO have a long discussion. Some of them look like the same design, but we know a small difference can make a big difference. So, we minutely examine one by one, compared with each other. Even, we continually refine the concept which we selected lastly . . . . . .

Annotations: 47; Task 5; Task 1 to 4; 49; 27 Intuitive conceptual design; 48; 54; 53 Step 1; Step 2; 57 Reason for generating a large number of concepts; 55 Step 3; 56

: Step 4 :

2) Intuitive conceptual design processing

01 18 19 27

Involve in each step of systematic conceptual design

- Depend on competencies and inspires of designers

31

- Example toolkit

Brain-drawing

01 53

Round-robin

42 43 44 45

Presumptive basis for conducting with component unit

10 11 12 20 29

31 50 51 52

7) Prototyping Task (Task 6)

Participants	Phase 1: Defining meaning units *P:* Participant's dialogue / *R:* Researcher's dialogue	Classification Interconnection	Phase 2: Transformation Phase 3: Structural Description
P02	01 *Activity 6.3* . . . . After the test of the workable prototype, when the result is successful, along with the requirement list, conceptual design in which the function and system structure and even schematic dimensions are reflected, and the prototype, we go to the next stages such as the detail design stage and embodiment stage. basisd on those reliable outcomes produced in the FFE, we can conduct the detail design and its embodiment considering the actual manufacturing of the product, without critical issues in an easier way . . 02 03 29	01 *Presumptive basis for connection between Task 5 and Actual NPD stage*	***Conceptual design Task (Task 5)*** ***Physical embodiment*** 05 32 38 01 02 04 06 07 08 18 19 37 39 ***Prototyping Task (Task 5)***
P03 P17 P26	04 *Presumptive basis for connection with Task 5* After the concept design . . . . . . *Task 6* the mock-up task is in terms of [redacted] and realisation of them into physical designs. The 2D-3D drawings can have been already been devised at the end of the concept design. In the past, those drawings aided by computer programmes were conducted at the beginning of the prototyping phase. basisd on those drawings *Task 6* physical mock-ups were made. But, today, those drawings are conducted at the end of the concept design as the meaning of completing the styling work. And, it serves as a bridge between the concept design and prototyping developing the *Task 6* physical mock-up. When we want to estimate the real form and proportion of the product immediately, we develop 02 *Activity 6.1* a brief physical model rapidly with is a iso pink or foamboard. Next when we would like to estimate not only the real form of the product and its proportion but also its colour and material more accurately, we make a more 03 *Activity 6.2* detailed mock-up visually similar to the real product. Then, when we want to estimate how the product and its functions work, we develop a *Activity 6.3* workable prototype. 04. 05 06 *Presumptive basis for connection with Task 5* 07 *Presumptive basis for connection with Task 5* 08 09 10 11 12 13 14 17	*Activity 6.1* 15 *Activity 6.2* 16 *Activity 6.3*	***Activity 6.1: Soft-prototyping*** 02 05 • ***Form and Proportion check*** 10 • ***Iso-pink and Foamboard*** 11 12 15 ***Activity 6.2: Hard-prototyping*** 03 07 10 • ***Shape-Colour-Material check*** 13 39 14 16 21 ***Activity 6.3: Workable-prototyping*** 01 04 06 08 11 • ***Functional and Technical operation check*** 17 20 24
05 06	As I said before, through the 3D modelling work in the conceptual design stage, we briefly check the product from the shape, colour and material *Presumptive basis for connection with Task 5* aspect. *Task 6* In the prototyping stage, we check 05 our development from two aspects. The first one is to check *Activity 6.1* a cubic effect and proportions of the product, and the other one is to 06 check *Activity 6.3* how the product will work if we develop it to the end. In particular, the latter aspect is conducted with two kinds of the prototype. In more concentrating on checking the physical operation of the product, 20 we develop the workable system structure only without developing a shell of the product. To confirm not only the physical operation of the product but also the product appearance, form and proportion, 08 *Activity 6.3* we 39 develop the workable system structure inside of 07 *Activity 6.2* the shell which the shape, colour and material are reflected. After 21 conducting a test with this prototype, if the result is satisfactory, our development will go to the next stages, a detailed development, actual embodiment, etc. But, if the test result is not satisfied with our expectation, the project will go back to the previous stage related 30 to problems identified in the test, or the project can be expired forcefully according to the extent of the test result	18 19 22 *Presumptive basis for connection with actual NPD stage*	
⋮	⋮		

Cont'd

P11	We highly dedicate to developing a prototype which works actually. Even, when we make the prototype by 'Lego', we use do not use just 'Lego', but use 'Technical Lego' enabling the physical operation of the prototype. The reason why we significantly concern the development of the workable prototype is if we do not check how it works in the early stage, we can have a really hard time due to unexpected problems in the actual development stage. Even, we may not continue to execute the project anymore in the actual development stage if in the too much late stage we find critical problems related to the operation of the product. Also, if those problems cannot be resolved within a few months, the project can be postponed indefinitely . . . . . . (09 Activity 6.3; 23; 24; 27; 28)	26 Presumptive basis for connection between with actual NPD stage	*To detect problems which can occur in the actual NPD phase from visual, functional and technical aspect* 27 28 29 30 32 01 03 22 26 31 36
P23 P27	Before going to the actual product development, through a prototype, we practically check various aspects which were theoretically treated in previous tasks. If the target product is actually developed to launch to the real market, which problems relevant to the product exterior can arise in the target product and whether the product can work without functional and technical problems can be estimated. If we do not detect any critical obstacle against going to the next actual development stage, we can start to develop the product actually basisd on what we have conducted so far. Of course, we can be faced with other unexpected problems during the actual development stage, but at least we have to detect and reduce any possible problems during the FFE as much as we can. This is the main reason for conducting the FFE . . . (31; Task 6; 32; 10 Activity 6.2; 11 Activity 6.3; 34; 35 *Ultimate purpose*)	36 Presumptive basis for connection between with actual NPD stage 33	***Actual NPD phase*** • ***Detail design task*** • ***Embodiment design task***
P36 P38	In our process, [redacted] includes prototyping. We generate product concepts through hand drawings, 2D-Illustrates, 3D-Rhinos and mock-ups in sequence. These works are to confirm whether concept designs are feasible from visual aspect. For confirming from the functional and technical aspect, we develop the prototype which works physically. . . . . . . (Task 6; Task 6; 37 *Presumptive basis for connection with Task 5*; 38; 39 *Presumptive basis for connection with Task 5*)		
⋮	⋮		

Appendix 4:
Survey Sheet

1) Relevant Information

- The overall structure of the survey strictly follows the structure of the given model, which you were trained on previously.
- The survey generally consists of seven sections (this may vary depending on the main-modules). This survey sheet is specifically comprised of seventeen parts.
- This survey is measured with a seven-point Likert-scale. Rate answers on a scale of 1 – 7.
    - 7: Very strong positive
    - 6: Strong positive
    - 5: Positive
    - 4: Neutral
    - 3: Negative
    - 2: Strong negative
    - 1: Very strong negative
- For a single module (sub- or composition-module), there are two questions:
    1) The first question relates to the quality of outcomes in Module X
       e.g. To what extent are the quality of outcomes in Module X fulfilled with the criteria, in your organisation?
    2) The second question: related to the usefulness of conducting Module X
       e.g. To what extent are the usefulness in conducting Module Y fulfilled with the criteria, in your organisation?

  In the survey sheet, the section coloured in blue concerns the quality of outcomes in each module. The section coloured in green concerns the usefulness of conducting each module. For the section coloured with grey, please describe module's strengths and weaknesses that you wish to convey.
- These sets of questions are identically applied to each module in terms of both contextual performance and concurrent collaboration.

  In some modules, e.g. Main modules 0, 3, 5, 6, for validating concurrent collaboration, you can just answer the questions in the section coloured in red.

  e.g. To what extent are you satisfied with Module X in terms of concurrent collaboration?

2) Survey Sheet

MM: Main module

SM: Sub-module

CM: Composition-module

Module 0) Contextual Performance

MM 0 (Preliminary Task)						
SM IC 0.1	SM IC 0.2	SM IC 0.3		SM RC 0.1	SM RC 0.2	SM RC 0.3

Module 0) Concurrent Collaboration

Module 1) Contextual Performance

MM 1 (Opportunity Identification-Screening Task)

SM 1.1 (Market Research)			
CM 1.1.4	CM 1.1.3	CM 1.1.2	CM 1.1.1
	CM 1.1.7	CM 1.1.6	CM 1.1.5

SM 1.2 (User Research)						
CM 1.2.1	CM 1.2.2	CM 1.2.3	CM 1.2.4	CM 1.2.5	CM 1.2.6	CM 1.2.7

SM 1.4 (Technology Research)					
CM 1.4.7	CM 1.4.6	CM 1.4.5	CM 1.4.3	CM 1.4.2	CM 1.4.1

SM 1.3 (Aesthetic-and-Symbol Research)					
CM 1.3.1	CM 1.3.2	CM 1.3.3	CM 1.3.4	CM 1.3.5	CM 1.3.6

Module 1) Concurrent Collaboration

The first form

SM 1.1	SM 1.2	SM 1.4	SM 1.4
CM 1.1.1 & 1.1.4	CM 1.2.4	CM 1.4.1	CM 1.4.7

The second form

SM 1.1	SM 1.3	SM 1.4	SM 1.4
CM 1.1.1 & 1.1.4	CM 1.3.1 to 1.3.3	CM 1.4.1	CM 1.4.7

The third form

SM 1.1	SM 1.2	SM 1.4	SM 1.4
CM 1.1.1 & 1.1.4	CM 1.2.5 to 1.2.6	CM 1.4.5	CM 1.4.6

The fourth form

SM 1.2	SM 1.4
CM 1.2.1 & 1.2.2	CM 1.4.2

The fifth form

SM 1.2	SM 1.4	SM 1.4
CM 1.2.3	CM 1.4.4	CM 1.4.5

The sixth form

SM 1.2	SM 1.3	SM 1.4	SM 1.4
CM 1.2.3	CM 1.3.1 to 1.3.3	CM 1.4.4	CM 1.4.7

The seventh form

SM 1.2	SM 1.3	SM 1.2	SM 1.4	SM 1.4
CM 1.2.3	CM 1.3.1 to 1.3.3	CM 1.2.6	CM 1.4.5	CM 1.4.6

The eight form

SM 1.2	SM 1.3	SM 1.4	SM 1.4
CM 1.2.5	CM 1.3.1 to 1.3.3	CM 1.4.4	CM 1.4.7

Module 2) Contextual Performance

MM 2 Idea Generation-Screening Task

SM 2.1 (Market Ideation)				SM 1.1
CM 2.1.4	CM 2.1.3	CM 2.1.2	CM 2.1.1	

SM 1.2	SM 2.2 (User Ideation)			
	CM 2.2.1	CM 2.2.2	CM 2.2.3	CM 2.2.4

SM 2.4 (Technology Ideation)				SM 1.4
CM 2.4.4	CM 2.4.3	CM 2.4.2	CM 2.4.1	

SM 1.3	SM (Aesthetic-and-Symbol Ideation)			
	CM 2.3.1	CM 2.3.2	CM 2.3.3	CM 2.3.4

Module 2) Concurrent Collaboration

SM 2.2, 2.3 & 2.4 (User + Aesthetic-and-Symbol + Technology Ideation)	SM 2.1 (Market Ideation)

SM 2.1, 2.3 & 2.4 (Market + Aesthetic-and-Symbol + Technology Ideation)	SM 2.2 (User Ideation)

SM 2.1, 2.2 & 2.4 (Market + User + Technology Ideation)	SM 2.3 (Aesthetic-and-Symbol Ideation)

SM 2.1, 2.2 & 2.3 (Market + User + Aesthetic-and-Symbol Ideation)	SM 2.4 (Technology Ideation)

Module 3) Contextual Performance

Module 3) Concurrent Collaboration

Module 5) Contextual Performance

MM 5 (Conceptual Design)								
MM 3	SM 5.1 (Principal)				SM 5.2 (Schematic)		SM 5.3 (Styling)	
	CM 5.1.1	CM 5.1.2	CM 5.1.3	CM 5.1.4	CM 5.2.1	CM 5.2.2	CM 5.3.1	CM 5.3.2

Module 5) Concurrent Collaboration

Module 6) Contextual Performance

MM 6 (Prototyping)			
MM 5	SM 6.1 (Soft Type)	SM 6.2 (Hard Type)	SM 6.3 (Workable Type)

Module 6) Concurrent Collaboration

Appendix 5:
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Appendix 6. Glossary

The terminology employed here is defined in the context of rotating internal flows.

Enterprise classifications

Term	Definition
Large corporation	The meaning of *large corporation* is the same as we typically understand it. This type of company generally operates by developing varied product lines of different types by way of a structured and organised system staffed with significant personnel resources.
Small and Medium-sized Enterprises (SMEs)	Regarding the number of employees, the medium-sized enterprise is smaller than 250, while a small enterprise is no more than 50. With respect to annual turnover, the former type earns less than 50 million pounds; for the latter, less than 10 million. The SMEs in this research are primarily defined as design specialty firms and NPD consultancies engaged in practical design activities in the whole range of the FFE. The SMEs which concentrate on production activities in the later stage of the NPD process are not cases for this research. To foster effective communication working environments, the large corporations and SMEs of today tend to require both employees who specialise in a single area (referred to as 'specialists') and in multidimensional areas (referred to as 'generalists') to a greater or lesser degree, regardless of companies' size.
Start-up	As the name suggests, this type of company tends to be newly formed, looking to find new business and new markets for their ideas. They typically have no more than 10 employees. They also cannot afford to conduct practical design activities yet. Instead, they focus on specifying their new ideas for new markets.

Expert qualifications

Expert	Experts as defined in this thesis have higher-education backgrounds (a Master's degree or above) in NPD-related disciplines. They will have also worked for more than seven years in their field, with most being senior or head researchers, with backgrounds indicating expertise in a specific domain as well as experience in a multitude of functional areas. They possess in-depth knowledge both in terms of design and in terms of running a business. They have the ability to establish new projects by themselves as well as lead given projects. They also have achievements in researching new product development methods and applying them to their various projects. Most of them thus have a reputation as competent NPD performers in their organisations.

Hierarchical FFE units

Task	The broadest unit making up the FFE phase, covering tasks of any kind, including opportunity identification tasks, idea generation tasks, requirements list tasks, conceptual design tasks, prototyping tasks, etc.
Activity	The subordinate unit to the task unit in that its actions aim to accomplish that task, e.g. a market and technology research activity for an opportunity identification task, or a workable prototyping activity in a prototyping task, etc.
Performance method	Actual instructions describing how to conduct each FFE activity.
Toolkit	A physical and functional construct in which the performance method is structured. The toolkit has an explicit form and frameset in which input and outputs related to product development parameters, variables, and constraints are produced. Toolkits can help to increase effectiveness in executing performance methods from a usability standpoint.

Appraisal criteria for toolkit

Concreteness: How much detail is provided to structure and operate toolkits?

Functionality: How well do toolkits cover various functional areas?

Contextuality: How well do toolkits interlock with each other for contextual performance?

Cooperability: How are toolkits structured and operated for concurrent collaboration?

FFE performance structure and its operating mechanism

Contextual performance

Outcome resources from previous performance methods flow into subsequent performance methods as input resources; output parameters from previous toolkits flow into subsequent toolkits as input parameters. In short, input and output resources (parameters) in each performance method (toolkit) interlock. Therefore, performers can explicitly understand the purpose and role of each performance method (toolkit).

Concurrent collaboration

Each of the performance methods (toolkits) involved in cross-functional work are structurally connected with each other. Outcome resources (output parameters) of performance methods (toolkits) involved in certain collaborations are linked to one another. Therefore, performers can explicitly understand the purpose and role of each performance method (toolkit) involved in the collaboration form.

Overall attributes of FFE model

Data-driven type

A model with the capability to not only produce data but to process it. This feature is distinct from the performative type of model. For instance, if data are generated but not processed (with each datum existing independently), the model can be considered to be performative. However, if the model has the structure to process parameters in a certain manner, e.g. input and output parameters interlock consecutively for contextual performance and concurrent collaboration, the model can be regarded as data-driven. This feature contributes to reduced ambiguity caused by different subjective interpretations of the same information.

Agile development A model with the capability to accelerate the speed of progress in the FFE.

Incremental and Radical NPD An incremental NPD aims to create products which have never been developed before, while a radical NPD targets products which will be improved based on new needs/problems identified from previous versions.

Explicitness and Responsiveness characteristic An explicitness characteristic is generally identified in fixed process structures which have advantages in terms of controlling performance directions and outcomes, e.g. linear, phased-process, etc., whereas a responsiveness characteristic is identified in flexible process structures which foster creative performance behaviour, e.g. spiral, recursive process, etc.

Procedural and Performative structure A procedural model provides the anatomy of phases and relevant sub-phases for a performance order. On the other hand, a performative model provides a platform wherein performers can use the model physically and functionally with data produced in the model itself.

Model type classification

Technology-push model A model optimised for dealing with issues related to R&D (i.e. engineering and manufacturing), to increase the precision of products as well as reduce errors and risks.

Market-push model A model designed to handle issues related to markets for improving the hit rate of the released product and for responding to market conditions rapidly.

Coupling model	The technology-push and market-push types are physically integrated into a model. Thereby, traits for these two types are explicitly identified in the model structure. The model tends to provide functions related to the two functions separately.
Interactive model	The technology-push and market-push types are not only physically integrated into a model but also functionally intertwined and infused into a model. Even though these two types are not identified clearly in the model structure, functions related to the two types tend to be well-connected in the model.
Network model	Along with features of the interactive model, the network model provides the functions of other domains (industrial design, design management, etc.). Also, the model is designed such that it enables external as well as internal resources with a networking system.
Data-driven model	Along with the features of the network model, the data-driven model has the ability to process NPD-related information.

FFE functional domains

Four functional domains	In this thesis, four functional domains are referred to, including the following four NPD-related sectors: 1) market-driven, 2) user-driven, 3) aesthetic-and-symbol-driven, and 4) technology-driven sectors.

FFE model constituents

Main module **Sub-module** **Composition-module**	The FFE model developed in this thesis is structured with three kinds of constituents. *Task* units in the hierarchical FFE units are assigned to the main module units. *Activities* are assigned to the sub-module units. *Performance method/Toolkit* units are assigned to the composition module units. The FFE model constituents therefore also have a hierarchical relationship.

Ideation processing

Logical ideation processing	In this thesis, logical ideation processing is defined as having a series of reasoning structures based on the relationship between ideas, supportive reasons, and rational evidence.
Intuitive ideation processing	On the other hand, intuitive ideation processing is defined as generating ideas by relying more on the use of inspiration ("gut feelings") without any given formal structures.

Conceptual designing

Systematic conceptual design

In this thesis, a systematic conceptual design is defined as a design with a series of structures for devising conceptual designs. The structure consists of three phases as follows:

Principal conceptual design	The first phase aims to develop initial concepts for a simple form, using basic figures such as circles, triangles, rectangles, parallelograms, etc.
Schematic conceptual design	The next phase reflects various function and system structures in the initial principal concepts, by assembling and disassembling components in a different way. The physical dimensions of the components are applied in this phase.
Styling conceptual design	The final phase aims to elaborate the schematic concept designs by refining the outlines of the overall product concepts and applying colours and materials. Through this phase, product concepts are made closer to being an actual product.

Intuitive conceptual design

On the other hand, an intuitive conceptual design is defined as devising concepts by relying more on the use of inspiration ("gut feelings") without using any given formal structures.