TOWARDS A COMPREHENSIVE AND INTEGRATED FRAMEWORK THAT SERVES AS A BASIS TO DESCRIBE, STIMULATE AND ANALYZE INNOVATION IN INTELLIGENT PRODUCTS

MENGTING ZHANG

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Towards A Comprehensive and Integrated Framework That Serves As A Basis to Describe, Stimulate and Analyze Innovation in Intelligent Products

ZHANG MENGTING

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CERTIFICATE OF ORIGINALITY

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ZHANG MENGTING (Name of student)

Abstract

After breakthroughs in machine learning and the commercialisation of artificial intelligence technology, products have become more 'intelligent'. New features were developed, like decision-making, natural language processing, or intuitive interaction (e.g., Feil-Seifer & Matarić, 2009; Kiritsis, 2011; Leitão et al., 2015), which give products relative autonomy. Although intelligent products are still in the earliest stages of development, the influence that they will wield over everyday life will be revolutionary. In the near future, it is safe to forecast that these products may reshape most, if not all, aspects of human life. As a result, industries, companies, and product development teams need to rethink and redefine their strategy towards this change.

To equip them to take part in this new arena, this research aims to generate and structure knowledge and insights to facilitate the innovation of intelligent products across industries and society. The challenge is that effective innovations are not easily fashioned - they can only be achieved through careful design (Morris et al., 2014). As studies of intelligent product are still an emerging domain, very little research has sought to develop frameworks for understanding innovation in consumer-oriented intelligent products, especially considering its specific requirements, such as multi-sourced inspiration, dynamic agenda or complexity of characteristics.

This research gap motivates the present attempt to explore, build, describe and test a conceptual framework, which can be used to describe, stimulate and analyse innovation of intelligent products. The framework was built based on systematic literature review of 376 theoretical and empirical studies from multiple disciplines were reviewed, including design, engineering, information technology, computer science, marketing, and economics; and 202 in-depth expert interviews with experts and researchers from various disciplinary backgrounds, positions, locations, and nationalities to collect diversified insights.

The framework was then tested through an in-depth expert interview to improve its usability and flexibility; a workshop with senior high school students for its capability to stimulate innovation in intelligent products; and a case study of an intelligent unmanned automatic vehicle to demonstrate

how it can be used to describe and analyse the innovation pattern, strength and weakness, or opportunities for product development.

The research contributes to the current understanding of intelligent product innovation and can be beneficial for both academic researchers and business practitioners in the following ways:

- To describe and analyse innovation pattern of products;
- To diagnose product strength and weakness;
- To discover and forecast product evolutionary path and trend;
- To ideate a product at early stage;
- To facilitate multidisciplinary and cross-department communication and collaboration;
- To translate company's insights and strategies into actionable task.
- To transform traditional product into intelligent product types.

The research also shares a vision of intelligent product innovation in the future, which can be exploited by policy makers for industry-upgrade and transformation

Publication Arising from the Thesis

Conference and Journal papers

Zhang, M. M.,& de Bont, C. (2015). Emotional Engagement for Human-computer Interaction in Exhibition Design. In *17th International HCI Conference* (pp. 542-549). New York: Springer.

Zhang, M. M. (2014). Historic Review of Learning Curve of Innovation. In *DesignEd Asia Conference 2014*. Hong Kong: The Hong Kong Polytechnic University.

Zhang, M. M. (2014). An Investigation of Interactive Environment Design Constraints. In *The Design Research Society Conference 2014: Design's Big Debate*. Umeå: Umeå Institute of Design, Umeå University.

Zhang, M. M., & de Bont, C. (2014). Constructing the Framework of Micro Innovation for Product Design. In *Asia Design Engineering Workshop 2014*. Taipei.

Lau, N., & **Zhang, M. M.** (2011). Interaction Design and Construction of User Experience in Portable Learning Utility Solution. *Design Principles And Practice: An International Journal*, *5*(4), 453-466.

Lau, N., & **Zhang, M. M.** (2011). Learning Effectiveness in Design and Creativity through Multimedia Learning Framework Based on Online Virtual Environment. In *The CAI Conference Learning Futures: Education, Technology & Sustainability 2011*. UK.

Lau, N., & **Zhang, M. M.** (2010). Design Education towards the Second life Platform. In *The Slactions Research Conference 2010*. Hong Kong.

Zhang, M. M. (2010). The Research about Transfusion Alarm System. *In National Industrial Design Conference 2010*. Tianjin.

The publications above are generated from the PhD study. Parts of the writings are made reference to in this thesis with provided citations of sources.

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CHAPTER 1 – Introduction

1.1 Motivation for Research

Product innovation is a strategic process (de Bont, 1992). It is commonly regarded as crucial for a company to survive and succeed (Schumpeter, 1942). Product innovation is triggered or accompanied by continuous waves of technological advancement and market change (Brand & Rocchi, 2011). In pre- or non-industrial agricultural economies, product innovation focused on the enhancement of craftsmanship or durability (den Ouden, 2012). Following industrialisation, mass-produced mechanical and electronic products were created, providing further stimulus to industrial and economic growth (O'Sullivan, Perez & Sheffrin, 2011). With the rise of the Internet Age, microchips, embedded sensors and network technology enable products with capabilities like connectivity, sensing, inter-operativity, big data management, or reactivity, which together bring new opportunities to industry (Porter & Heppelmann, 2015).

After breakthroughs in machine learning and the commercialisation of artificial intelligence technology, products have become more 'intelligent'. New features were developed, like decision-making, machine learning, or intuitive interaction (e.g., Feil-Seifer & Matarić, 2009; Kiritsis, 2011; Leitão et al., 2015), which give products relative autonomy. IRobot's Roomba vacuum cleaner, for example, can methodically navigate multiple rooms on its own, increasing or decreasing suction power depending on the surface that it is cleaning. It can automatically return to the docking station when it runs out of battery. Other intelligent products like Google's autopilot car, DJI's unmanned aerial vehicle, Nest Protect, Amazon Echo, or Jibo have all gradually become part of our day-to-day reality.

Although intelligent products are still in the earliest stages of development, the influence that they will wield over daily life will be revolutionary. In the near future, it is reasonable to forecast that these products may reshape most, if not all, aspects of human life. As a result, industries, companies, and product development teams need to rethink and redefine their strategy towards this change. To equip them to participate in this new arena, this research aims to generate and structure knowledge and insights to facilitate the development and integration of intelligent products across industries and society.

1.2 Research Gap

The challenge is that effective innovations are not easily fashioned – they can only be achieved through careful design (Morris et al., 2014). Figuring out how a product could benefit from innovation is a significant agenda for many researchers. Since the 1920s, researchers and practitioners have attempted to organise the diverse range of activities involved in product innovation into distinct patterns (Godin, 2017). After examining the literature, it became clear that research on innovation for intelligent products – which should be located at the intersection of intelligent product studies, studies of product innovation frameworks, and studies of product attributes (**Figure 1**).

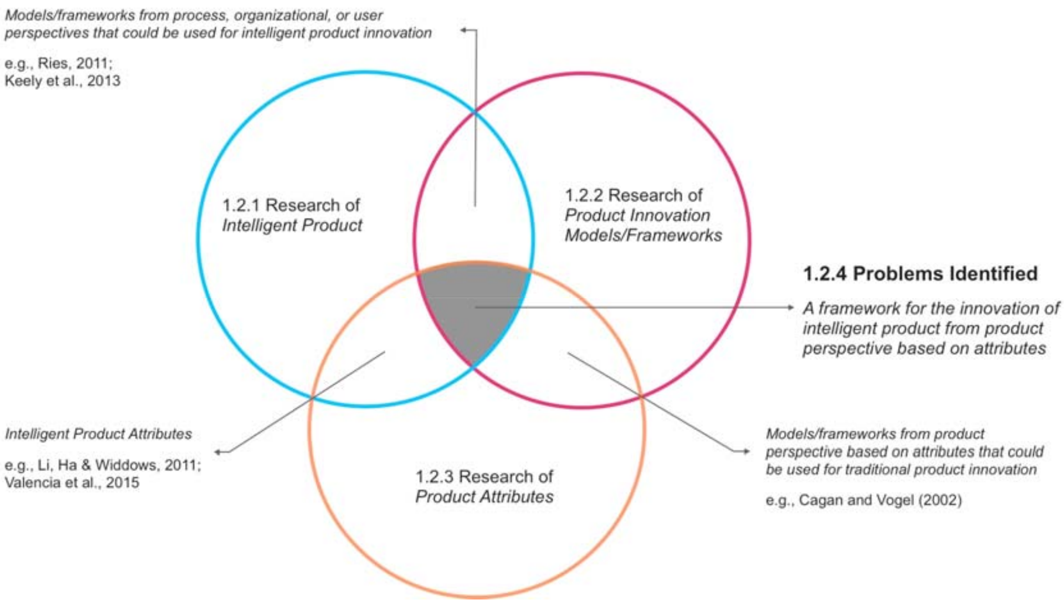


Figure 1 - Research Gap

1.2.1 Research of Intelligent Products

After examining research on intelligent products, it was found that few studies are concerned with developing frameworks for innovation in intelligent products. The earliest research and development on intelligent products was for industrial use, in an after-sales and service context, and dates to 1988 (Meyer et al., 2009). It was a computer with special functions for after sales and service, such as performance tracking and service requirements. However, applications of intelligent products quickly expanded to manufacture management (e.g., Meyer et al., 2009), logistics (e.g., McFarlane et al., 2003; Kärkkäinen et al., 2003), product life cycle management (e.g., Yang, Moore & Chong, 2009; Kiritsis, 2011), supply chain management (e.g., Wong et al., 2002), data management (Främling et al., 2012), and so on.

Later, intelligent products were developed for the consumer market and included more human-centred new features. This offered new opportunities for innovation (Norman, 2005; Rijsdijk & Hultink, 2009). Research was conducted with a focus on the methods to evaluate the usability of intelligent products (e.g., Kim & Han, 2008), users' perception of 'intelligence' (e.g., Rijsdijk & Hultink, 2009), the involvement of different stakeholders in the co-design process of intelligent products (e.g., Hribernik et al., 2011), and the application of open source platforms for intelligent product development (e.g., Nan & Shiguo, 2014).

1.2.2 Research of Product Innovation Frameworks

Reviewing the general literature on intelligent products revealed that little attention has been paid to the establishment of comprehensive and integrated frameworks for innovation in intelligent products. Previous work was reviewed to see whether it could be applied to intelligent product innovation. The review identified 103 related frameworks in total, with 38 proving especially influential based on the number of times they were cited or how important they are in their respective field or industry. These frameworks included 'Linear Innovation' (Mees, 1920), 'Market-pull Innovation' (Cook & Morrison, 1961), 'Technology-push Innovation' (Freeman, 1971), 'Stage-gate Process' (Cooper, 1990), 'Product-concept Evaluation' (de Bont, 1992), 'Value Opportunity Analysis' (Cagan & Vogel, 2002), or 'Value Framework' (den Ouden, 2012).

These frameworks were found mainly to be applied to product development in general; very few of them addressed novel requirements that attend intelligent product innovation, such as iterative processes, open platforms, multi-disciplinary collaboration, and complexity of characteristics or dynamic agendas. It was also found that these frameworks could be categorised into four perspectives: a process perspective (e.g., Cooper, 1990; Ries, 2011), a stakeholder perspective (e.g., de Bont, 1992; Osterwalder et al., 2014), an organisational perspective (e.g., Sehested & Sonnenberg, 2010; Keely et al., 2013; Moris, Ma & Wu, 2014), and a product perspective (e.g., Cagan & Vogel, 2002).

Compared with other perspectives, innovation frameworks from product perspective are not sufficient, especially considering the specific requirements of intelligent products. The product perspective perceives product innovation from the level of attributes. As innovation can be recognised as novel combinations and configurations of attributes (Schumpeter, 1942), a product innovation can be recognised as the combined results of its attributes' development. By manipulating attributes, for instance by increasing, reducing, or improving attributes or creating new ones, a product can be innovated at different levels (e.g., incrementally or radically).

1.2.3 Research of Product Attributes

Although research that connects product innovation with product attributes were not exhaustively explored, studies that only focus on attributes have a long history (e.g., Haley, 1968; Lanchester, 1971; Wu, Day & MacKay, 1988; Holbrook, 1999; Horváth, 2001; Spangenberg & Grohmann, 2003; Boztepe, 2007). Most of these research focused on the interplay between consumers/customers/users and product attributes, such as the consumer's perception, attitude, evaluation, and impression of product attributes (e.g., Haley, 1968; Lanchester, 1971; Spangenberg & Grohmann, 2003).

However, research that associates product innovation with attributes is not prevalent. Cagan and Vogel's (2002) effective and influential innovation framework, called Value Opportunity Analysis (VOA), connected product innovation with attributes. In this framework, a product can be perceived as the combination of at least seven attributes – *emotion*, *ergonomics*, *aesthetics*, *identity*, *impact*, *core technology*, and *quality* - and 23 sub attributes. Applications of the VOA framework can be varied, from describing product innovation patterns; generating innovative products; analysing strength and weakness; or evaluating innovation outcomes.

1.2.4 Problems Identified

Although a limited number of frameworks adopted the product perspective, this is an important field that should be addressed. The product perspective reveals the essence of innovation, as innovation can be seen as the deconstruction and recombining of something existed into something new (Schumpeter, 1945; Kelly, 2016).

The existing frameworks from the product perspective like VOA are extremely valuable for product innovation, however the attributes that they define are usually the attributes of traditional non-electronic or electronic product types, devoid of 'intelligent' features brought by information technology. In addition, how the "traditional" features could be rejuvenated in the new product type is also not discussed. As a consequence, the effectiveness of these frameworks in guiding intelligent product innovation could be undermined, as the various possibilities would be de-emphasised within the framework, leading to missed opportunities.

1.3 Purpose of Study

This research gap motivates the present attempt to build a conceptual framework to describe the phenomenon of product innovation, stimulate innovation activity and analyse innovation pattern in intelligent products, while encompassing both intelligent and non-intelligent attributes.

1.3.1 Stage of Study

In this research, the conceptual framework takes a broad scope of definition. It is defined as a network of linked key concepts (Jabareen, 2009). So in order to build this framework, it is important to define the key concepts and the relationship within them. Four stages are conducted to build this framework: to explore the key concepts and the relationship, to build the framework with the key concepts and relationship, to describe the framework and to test the framework (Figure 2).

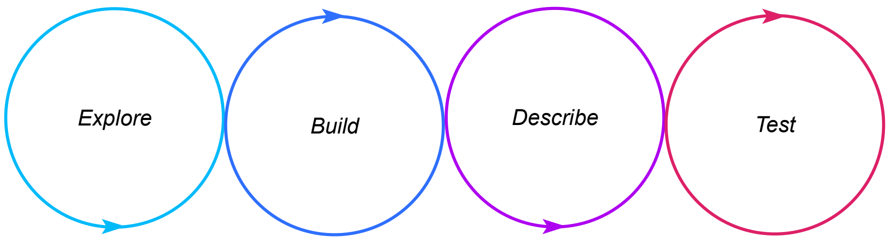


Figure 2 - Purpose of the Study

First, current product innovation frameworks, key concepts, intelligent product attributes, relationship within intelligent product attributes are explored and examined. Then, based on the attributes and the relationship, a conceptual framework can be built. In the description phase, the framework is described by explaining its attributes and their relationships, and examples for innovation. The framework is then tested with a small-scale expert interview, a workshop and case study for its capability of stimulating innovation activity and analysing innovation pattern.

1.3.2 Reseach Question

The main research question is:

How to build a comprehensive and integrated framework that serves as a basis to describe, stimulate and analyse innovation in intelligent products?

A series of sub research questions are developed to explore the question more thoroughly. The sub questions are answered in each chapter as following (Table 1):

Table 1. Sub Research Question

Chapter	Research Question
Chapter 1	Why is it interesting (from an academic and a business perspective) to focus on intelligent product innovation and why would a conceptual framework be useful?
Chapter 2	How are intelligent products defined in literature and what is the boundary of intelligent products?
Chapter 3	What would be an appropriate perspective to build a framework for intelligent product innovation?
Chapter 4	What methodology could be used to build and test a framework for intelligent product innovation?
Chapter 5	What is the classification of intelligent product attributes and what relationship could be abstracted among the attributes?

Chapter 6	What are the attributes of intelligent products (based on academic literature and on expert interviews)?
Chapter 7	How to build a comprehensive and integrated framework of attributes and what would it be like?
Chapter 8	Can the framework serve as a basis for analyzing and stimulating innovation in intelligent products?
Chapter 9	What is the contribution, limitation and future work that could be addressed about the framework?

1.4 Significance

Product innovation is generally recognised as a complex and multi-dimensional discipline (OECD, 2007). It requires the integration of technological and non-technological knowledge (Schmidt & Rammer, 2007). To understand the complexity of the phenomenon, the research emphasises the involvement of technological and non-technological factors. Knowledge and insights are gathered from disciplines like information technology design, mechanical engineering, marketing, computer science, business, electronic engineering, science and technology, manufacturing, environment and energy, and from a diverse range of stakeholders and practitioners from different backgrounds, academic disciplines, geographic locations, and nationalities, along with age and gender attributes.

The research contributes to the domains of product design, product innovation, product development, and product attributes, especially considering the intelligent types. As intelligent product studies is still an emerging domain, most previous research has focused on industry applications (e.g., McFarlane et al., 2003; Meyer et al., 2009; Kiritsis, 2011) or new opportunities, requirements or phenomenon related to its development (e.g., Norman, 2005; Kim & Han, 2008; Rijsdijk & Hultink, 2009; Hribernik et al., 2011; Nan & Shiguo, 2014). Very little research has sought to develop frameworks for understanding innovation in consumer-oriented intelligent products. The research will thus make a significant contribution to the current understanding of intelligent product studies.

The research fills the gap between a design theory of product attributes and the practice of product innovation, linking them together. This research takes one step forward of Cagan and Vogel (2002)'s landmark work. The present research advances this work by addressing both intelligent and non-intelligent product attributes. In contrast with Holbrook (1999)'s

Many previous studies sought to provide frameworks for general product types, usually non-electronic or electronic products (e.g, Cooper, 1990; Chesbrough, 2006; den Ouden, 2012).
It also contributes to the development of frameworks from the product perspective, as few studies address innovation from the level of attributes.

This framework aims to reduce paradoxical condition in product innovation. As product development team members may from multi-disciplinary background. Misunderstanding among them may undermine innovation results. Thus, a common platform upon which different parties can work together is meaningful.

These efforts will also make the present research of interest to those studying product attributes (e.g., e.g., Haley, 1968; Lanchester, 1971; Spangenberg & Grohmann, 2003). The study intends to provide a comprehensive and intiframework, comprised of over 100 attributes, classified into three levels from generalisation to specification, with two types of relationships identified among attribute groups, and a distinction drawn between intelligent and non-intelligent attributes based on insights from 376 studies.

1.5 Contribution

This research will be useful for researchers, business practitioners, and policymakers. Researchers can use the framework to describe and analyse product innovation patterns, discover the evolution of products, and forecast development trends.

Business practitioners can use the framework to accelerate the innovation process, to analyse innovation outcomes, and to engage stakeholders from different backgrounds, disciplines and departments.

The research will be especially beneficial for product development teams, including managers, designers, engineers, and marketing specialists. It will assist practitioners in innovation at early stages of product development, as brainstorming will be more effective and comprehensive. The framework can serve as a common ground for multi-discipline communication, understanding and collaboration. Experts from different backgrounds, specialties, positions and departments can use it to address their specialized concerns, balance their requirements, and reach consensus. They can use it to describe in detail the kind of product they want to make. Company decision-makers can use the framework to reflect on their existing plans and to design new ones based on the newly identified requirements of users and the fast-changing market trends. The framework can be used to translate insights and strategies into specific objectives and actionable tasks.

The research responds to the social, cultural, economic, and technological paradigm shifts happening right now. Brand and Rocchi (2011) offer a typology of economies – industrial, experience, knowledge, and transformation. We are currently in the midst of a knowledge economy but rapidly moving toward transformation, wherein people look for meaning and work in a simple, easy, enjoyable and intelligent way. Meaningful innovations will improve quality of life broadly and serve people by functioning invisibly and unobtrusively in the background, freeing individuals from tedious routine tasks.

1.6 Thesis Structure

The thesis is structured to correspond with the following research questions, with each question addressed in each chapter (Figure 3).

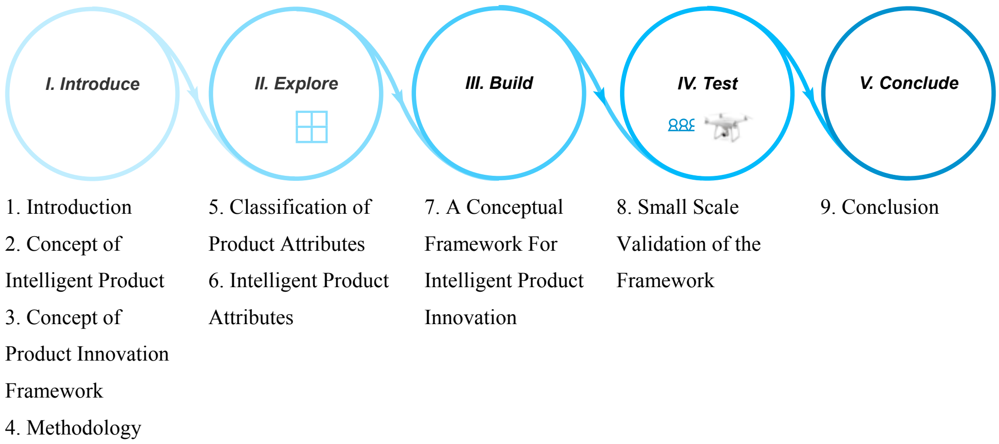


Figure 3 - Research Structure

In Chapter 1, the research focuses on the question of why it is valuable to focus on intelligent product innovation from an academic and business perspective, and why a conceptual framework would be useful (RQ1).

Chapter 2 addresses how intelligent products are defined in the literature, and what the boundary is for demarcating intelligent products from non-intelligent products (RQ2). Defining the boundaries of intelligent products is necessary before developing the framework, as the term is currently used with varied and divergent meanings in different contexts; this may lead to confusion and misunderstanding (Gutierrez et al., 2013). The lack of any specific, generally accepted and well-recognised definition of intelligent products makes it difficult to develop theoretical frameworks for its innovations. To clarify the boundary, definitions and characteristics of intelligent products in the literature were carefully reviewed to differentiate closely aligned concepts, such as smart products, Internet of Things, or robots.

Chapter 3 considers what the most appropriate perspective would be for building a framework for intelligent product innovation (RQ3). Previous research in product innovation was reviewed to identify four distinct perspectives based on process, user, organisation, and product. Our analysis suggests that the product perspective is the most appropriate for our framework development, as it investigates innovation from the essence of a product – its own ‘constructs’ or attributes. From this perspective, innovation can be achieved by manipulating a product’s attributes.

Chapter 4 identifies the methodology used to build and test a framework for the innovation of intelligent products (RQ4). The research methodology follows the framework prescribed by Creswell (2012), which details the aim, focus, methods, process, sample, data form, data analysis, results and report form.

Chapter 5 delineates the classification of intelligent product attributes and what relationships might be abstracted from these (RQ5). Classification provides a clear, effective and systematic way to review product attributes. Before investigating specific attributes, different classification schemes in the literature were systematically reviewed and analysed. Based on this analysis, four sectors were identified; these include *appearance*, *functionality*, *experience* and *meaning*. A hierarchical relationship among these four sectors was also discernible; this proves important for structuring the broader framework.

Chapter 6 then sets out to identify all of the attributes of intelligent products, based on an academic literature review and expert interviews (RQ6). A systematic review of 376 theoretical and empirical studies from multiple disciplines, including design, engineering, information technology, computer science, marketing, and economics was conducted, as were 202 interviews with experts and researchers from various disciplinary backgrounds to collect insights on intelligent product attributes. The literature review and interview transcripts were then coded and analysed, and the attributes identified were synthesised, compared, and integrated into 22 vectors and 168 attributes. These are then aligned with the classification scheme developed in Chapter 5, to test whether the scheme of four sectors is appropriate. The identified attributes and attributes in this study are more comprehensive than similar studies in various ways: numbers of attributes, sources of generation, aspects for innovation, inclusion of technological and non-technological innovation, inclusion of intelligent and non-intelligent innovation, levels of attributes, and methods of generation.

In Chapter 7, insights from the literature review, expert interviews, product attributes, and sector scheme are synthesized to build a comprehensive and integrated framework of attributes to incorporate both conventional and intelligent products (RQ7). The framework comprises the four sectors, a hierarchical relationship among sectors, and vectors and attributes. The vectors and attributes are described in detail. The appearance considers innovations in size, colour, form, material, weight, structure and craftsmanship; the function includes innovations in function, intelligence performance, core technology, and interaction method; the experience sector incorporates innovations in utilitarian experience, interaction experience, aesthetic experience, sensory experience and emotional experience; and in the meaning sector, innovations in symbolic, economic, environmental, and sociocultural meanings are discussed.

Chapter 8 evaluates whether the comprehensive and integrated framework of attributes developed can serve as a basis for describing and stimulating innovation in intelligent products (RQ8). The validity and reliability of this framework is tested through in-depth expert interviews, and then evaluated with the case study of an unmanned automatic vehicle.

Chapter 9 provides a concluding discussion of this research, outlining the key findings, contributions, limitations, and potential for future work.

Chapter 2 – Concept of Intelligent Product

2.1 Introduction

In recent years, the term ‘intelligent product’ has attracted an increasing amount of attention due to new developments in consumer markets. Nevertheless, the term remains only vaguely defined in the literature. It takes on different meanings in different contexts, leading to conceptual confusion and sometimes misrecognition (Gutierrez et al., 2013).

The lack of consensus in defining intelligent products can be ascribed to its vague boundaries. Without a common understanding of what intelligent products are and what they are not, it remains hard to describe the characteristics specific to the concept. This makes it difficult to build a design theory for intelligent products, and even more difficult to build a framework to model intelligent product innovation. As such, this chapter provides a discussion of the concept boundary. The following research questions will be addressed.

RQ2. How are intelligent products defined in the literature and what is the boundary of intelligent products?
RQ2.1 What are the definitions of intelligent products in literature?
RQ2.2 What are characteristics of intelligent products in literature?
RQ2.3 What related concepts can be differentiated from intelligent products?

In the next section, the definition of intelligent product in literature is reviewed. This is followed by a comparison with similar concepts to understand how they relate to and influence the development of intelligent products. The research method is systematic literature review, content analysis and thematic synthesis. The chapter concludes by presenting and discussing a coherent definition for intelligent products based on an understanding of their boundaries.

2.2 Method

The research was conducted in distinct stages: the identification of inclusion and exclusion criteria, and a search for relevant studies. The studies were then analysed and coded. The remainder of this section describes the details of these stages.

2.2.1 Systematic Literature Review

Systematic literature review has been used successfully in various studies to discern the core features of how a concept has been defined (Kitchenham, 2007; Dybå & Dingsøyr, 2008; Gutierrez et al., 2013). The main advantage of the method is that it can provide an exhaustive summary of current literature relevant to the research question.

2.2.1.2 Search Strategies

A number of large digital databases that are accessible at the Hong Kong Polytechnic University were searched. The databases are shown in Table 2.

Table 2. Data Source

Data Source
IEEE Explorer
Science Direct
EBSCO host
Google Scholar
Elsevier

The search terms for the study were defined based on the research question. To obtain the maximum number of possible results in the databases, the following key words were searched: *('Intelligent') AND ('Product').*

2.2.1.3 Inclusion and Exclusion Criteria

After reviewing the search results, it became evident that some results were irrelevant or invalid. Criteria were established to eliminate these papers. Only studies that met the following requirements were included in the review. The studies reviewed were:

- Written in English.
- Published up to and including 2017.
- Authored by academic researchers or business practitioners.
- Utilized qualitative or quantitative methods.

Articles with the following criteria were excluded:

- The keywords are not complete.
- The focus was not on intelligent products.

2.2.1.4 Quality Assessment

The studies were evaluated on the basis of their relevance, reliability, and validity. Six quality assessment questions proposed by Gutierrez et al. (2013) were used to select the appropriate articles (Table 3).

Table 3. Quality Criteria by Gutierrez et al. (2013)

QA	Answer
Is the study based on research methods?	Yes/No
Is there a clear statement of the aims and objectives of the research?	Yes/No
Is there a clear description of the context in which the research was carried out?	Yes/No
Are there relevant studies included in the findings?	Yes/No
Are the results evaluated in accordance with objective criteria?	Yes/No
Is there a clear statement of findings?	Yes/No

2.2.2 Content Analysis

After the systematic literature review, content analysis was used to analyse the data. Content analysis assigns codes to indicate the presence of meaningful patterns (Hodder, 1994). These methods have proven useful in a wide range of studies (Saldaña, 2015). The key characteristics of intelligent products were coded.

2.2.2.1 Coding Strategy

When coding characteristics from the selected articles, salient and essence-capturing characteristics were derived directly from the text (Hay, 2005). Ambiguous characteristics were abstracted, summarised, and interpreted based on the context of the text or pre-existing knowledge of product characteristics, as discussed in the literature.

2.2.2.2 Coding Process

Nvivo, a qualitative data analysis software was used for coding. The software is prevalently used for managing rich text-based and non-numerical data. Users can classify, sort and arrange data, examine relationships among the data and combine analysis linking, shaping, searching and modelling. The software can be used to test theories, identify trends, cross-examine information and generate in-depth analysis. Papers selected for systematic literature review were imputed into Nvivo; attributes were then coded manually. To increase trustworthiness, the coding process was conducted iteratively with reliability and consistency checks (Weber, 1990). Inspired by Hsieh and Shannon (2005), four steps were conducted for coding:

- Looking for and highlighting sentences related to definitions of intelligent products.
- Coding the characteristics of intelligent products based on the definition.
- Re-evaluating definitions to confirm whether all characteristics were coded.
- Combining coded synonyms if necessary, to reduce redundancy.

2.3 Findings

Forty-two articles related to intelligent products were identified. Of these, only eight contained clear and explicit definitions for intelligent products. The following sections provide an overview of these studies and the various definitions of intelligent products, including their specific characteristics, the context of the definitions, and any related concepts.

2.3.1 Definition of Intelligent Product in Literature

Only 8 of the 42 reviewed articles explicitly defined intelligent products. In the following paragraphs, each definition is described in detail.

Wong et al. (2002, p.1) defined intelligent products as 'encapsulat[ing] the set of capabilities associated with a commercial product, which is equipped with an automatic identification system and some advanced software' (Wong, et al., 2002, p.1). The 'set of capabilities' included:

1. Possessing a unique identity
2. Communicating effectively with an environment
3. Retaining or storing data about itself
4. Deploying a language to display its features, production requirements, etc.
5. Participating in making decisions

Wong et al. (2002) draw a distinction between 'smart' and 'intelligent': smart products possess the first three characteristics, while intelligent products possess all five. These authors further emphasised that decision-making was the most distinctive characteristic for intelligent products.

McFarlane et al. (2003, p.365) defined an intelligent product as a 'physical and information-based representation of an item, which possesses a unique identification, is capable of communicating effectively with its environment, can retain or store data about itself, deploys a language to display its features, productions requirements, etc., and is capable of participating in or making decisions relevant to its own destiny'. The properties of intelligent products proposed by McFarlane et al. (2003) are thus nearly identical to Wong et al.'s (2002).

Kärkkäinen et al. (2003, p.545) presented a system for international logistical coordination that relies on intelligent products. The technical characteristics enable the system to effect automated control, but this hinges on products' intelligence. The system included characteristics such as:

1. Globally unique identification codes.
2. Links to information sources about the product across organisational borders, either embedded within the identification code itself or accessible by some external look-up mechanism.
3. Capable of communicating what needs to be done with the product to information systems and users when needed (even pro-actively).

In research on intelligent products and systems, Ventä (2007, p.3) argued that intelligent products must:

1. Continuously monitor their status and environment.

2. Actively communicate with users, environments or other products and systems.

3. Sense, react, actuate and adapt to user requirements or environmental and operational conditions.

4. Maintain optimal performance in variable circumstances, including exceptional cases.

5. Make decisions.

In their research on designing for intelligent consumer products, Kim and Han (2008) identified six properties that a user-friendly intelligent product should have:

1. A simple, consistent, and uniform interface experience.

3. A helpful, forgiving, and error-preventive user support.

4. An adaptable, accessible, and flexible operating system.

5. A learnable memorable, familiar, predictable, and informative cognitive support.

6. An effective and efficient overall performance.

Meyer, Främling and Holmström (2009) introduced a three dimensional framework to analyse different information architectures according to what kind of intelligent products and what parts of the product lifecycle they are suited for. The framework consisted of a hierarchy of levels, from intelligence, the location of the intelligence, and the aggregate level of intelligence, and identified four capabilities of intelligent products:

1. Passive data and information collection and storage.

2. Active knowledge generation.

3. Reasoning.

4. Decision-making.

Kiritsis (2011) introduced a comprehensive, four-tiered definition of intelligent products, with multiple capabilities embedded at each level. These can be synthesised as:

1. Interaction with environments.

2. Adaption to sophisticated changing environments.

3. Identification with PEID technologies.

4. Sensing and communicating with wireless sensor networks.

5. Memory with micro–nano memory chips.

6. Data processing with micro-nano processors.

7. Communication with other products and their environment.

8. Reasoning and developing their own knowledge.

9. Decision-making.

10. Seamless interoperability of systems.

11. Exchange of dynamic data.

Leitão et al. (2015) envisaged that future manufacturing would take the form of an internationally distributed and complex system consisting of intelligent products with the following capabilities:

1. Monitoring.
2. Data analytics.
3. Self-diagnosis.
4. Self-maintenance.
5. The ability to maintain information about their own characteristics.
6. Wireless connectivity to share, in real‑time, information about their state or environment.
7. Communication with other cooperative objects in the system.
8. Information collected by the intelligent products further collected and analysed by the broader system of which it is a part.
9. System-level ability to generate knowledge, make decisions, and take action.

2.3.2 Characteristics of Intelligent Product

The coded characteristics and authors are summarised in Table 4. The most comprehensive definition was proposed by Kim and Han (2008), which covered 47.1% of all characteristics identified, followed by Leitão et al.'s definition (32.4%) and Kiritsis's definition (29.4%). While most authors stated the technological characteristics of intelligent product, only Kim and Han (2008) discussed the non-technological properties of the intelligent product (i.e., the capabilities that make an intelligent product user-friendly).

Table 4. Characteristics of Intelligent Product

Author	Characteristics	No.	PCT.
Wong et al. (2002)	Unique identity, communication effectively with its environment, Data retain and storage, display with language, participating, decision-making	6	17.6
McFarlane et al. (2003)	Unique identity, communication effectively with its environment, Data retain and storage, display with language, participating, decision-making	6	17.6
Kärkkäinen et al. (2003)	Unique identification, connection, inter-cooperation, communication	4	11.7
Ventä (2007)	Monitor, active communication, sensing, reaction, actuation, adaption, optimal performance, decision-making.	8	23.5
Kim & Han (2008)	Simplicity, consistency and modelessness interface experience; helpfulness, forgiveness, and error prevention in user support; adaptability and accessibility and flexibility of the system; learnability, memorability, familiarity, predictability, and informativeness of cognitive support; effectiveness and efficiency overall performance	16	47.1
Meyer et al. (2009)	Passive data collection, active knowledge generation, reasoning, decision-making	4	11.7
Kiritsis (2011)	Interaction, adaption, identification, sensing, memory, data processing/exchange, communication, reasoning, decision-making, interoperability	10	29.4
Leitão et al. (2015)	Monitoring, data analytics/collection, self-diagnosis, self-maintenance, knowledge carrying/generation, wirelessly connection, sharing,	11	32.4

	communication, reasoning, decision-making, and take action.		

Thirty-four characteristics of intelligent products were culled from the eight articles that provided explicit definitions. The results show that decision-making and communication were the most widely discussed (75%), followed by data collection/processing/exchange/storage/analysis (62.5%), and unique identity/identification, at 50%. With the exception of the user experiences identified by Kim and Han (2008), all of the other characteristics are purely technological characteristics (85.3%) (Table 5).

Table 5. Frequency and Percentage of Characteristics

Characteristics	Freq.	PCT.
1. Decision-making	6	75
2. Communication	6	75
3. Data collection/ processing/ exchange/ storage/ analysis	5	62.5
4. Unique identity/ Identification	4	50
5. Adaption	3	37.5
6. Reasoning	3	37.5
7. Connectivity	2	25
8. Monitor	2	25
9. Sensing	2	25
10. Actuation	2	25
11. Participating	2	25
12. Language displaying	2	25
13. Knowledge generation/carrying	2	25
14. Memorability	2	25
15. Inter-operation	2	25
16. Reaction	1	12.5
17. Interaction	1	12.5
18. Learnability	1	12.5
19. Predictability	1	12.5
20. Effectiveness	1	12.5
21. Efficiency	1	12.5
22. Simplicity experience	1	12.5
23. Consistency experience	1	12.5
24. Modelessness experience	1	12.5
25. Accessibility	1	12.5
26. Flexibility	1	12.5
27. Helpfulness	1	12.5
28. Forgiveness	1	12.5
29. Error Prevention	1	12.5
30. Familiarity	1	12.5
31. Informativeness	1	12.5
32. Self-diagnosis	1	12.5
33. Self-maintenance	1	12.5
34. Optimal performance	1	12.5

After comparison, it was found that the combination of Leitão et al. (2015) and Kim and Han (2008)'s definition offered the most comprehensive juxtaposition, covering 76% of all characteristics discussed in the eight articles (Table 6).

Table 6. Characteristics of Intelligent Product and Authors

Characteristics/Author	Wong et al.(2002)	McFarlane et al. (2003)	Kärkkäinen et al. (2003)	Ventä (2007)	Kim & Han(2008)	Meyer et al.(2009)	Kiritsis (2011)	Leitão et al.(2015)
Decision-making	✓	✓		✓		✓	✓	✓
Communication	✓	✓	✓	✓			✓	✓
Data collection/ processing/ exchange/ storage/ analysis	✓	✓				✓	✓	✓
Unique identity/ Identification	✓	✓	✓				✓	
Adaption				✓	✓		✓	
Reasoning						✓	✓	✓
Connectivity			✓					✓
Monitor				✓				✓
Inter-operation			✓				✓	
Sensing				✓			✓	
Reaction				✓				✓
Actuation				✓				✓
Participating	✓	✓						
Language displaying	✓	✓						
Knowledge generation/carrying						✓		✓
Interaction							✓	
Learnability					✓			
Memorability					✓		✓	
Predictability					✓			
Effectiveness					✓			
Efficiency					✓			
Simplicity experience					✓			
Consistency experience					✓			
Modelessness experience					✓			
Accessibility					✓			
Flexibility					✓			
Helpfulness					✓			
Forgiveness					✓			
Error Prevention					✓			
Familiarity					✓			
Informativeness					✓			
Self-diagnosis								✓
Self-maintenance								✓
Optimal performance				✓				

2.3.3 Context of Studies

The context of each of the studies is important, as context-specificities may have influenced how intelligent products were designed and thus how they would be defined. As a consequence of this, some characteristics may be overly specific to their contexts. Eight contexts have been identified (Table 7). These are informed by the wide range of areas in which intelligent products have been applied.

Table 7. Context of Intelligent Product Definition

Context	Author
Product Life Cycle Management	Meyer et al. (2009), Kiritsis (2011), Leitão et al. (2015)
Logistic Management	McFarlane et al. (2003), Kärkkäinen et al. (2003)
Manufacturing Management	Meyer et al. (2009)
Supply Chain Management	Wong et al. (2002), Ventä (2007), Meyer et al. (2009)
Asset Management	Meyer et al. (2009)
Consumer Market Use	Kim & Han (2008)

Intelligent products were first adapted for industries like manufacturing, supply chains, asset management, and product life cycle management (McFarlane et al., 2003; Meyer et al., 2009; Ventä, 2007). They have been used to manage a vast number of individual deliveries through a large supply network within a tight timeframe (Kärkkäinen et al., 2003) or to improve the product's entire lifecycle, particularly in terms of quality and customisation (Leitão et al., 2015). Intelligent products have also been used for logistic management, not just in terms of transportation but also for business operations, to provide flexible, adaptable and customer-oriented service (McFarlane et al., 2003). Finally, intelligent products are also used by general consumers as commercial products (Kim & Han, 2008).

2.3.4 Related Concepts

To define the boundary of intelligent products, it is necessary to compare the concept with adjacent terms to discern similarity and difference (Table 8). Nine related concepts were found in literature on intelligent products, including product, electronic product, smart product, smart product service system (smart PSS), Internet of Things (IoT), artificial intelligence (AI), ubiquitous computing (Ubicomp), ambient intelligence (AmI), and robotics. It is possible that more product concepts could overlap with intelligent products, such as 'digital' or 'cyber' products, but due to limited time and resources the present study limited its attention to only the most frequently co-occurring terms and concepts.

Table 8. Summary of the Related Concepts

Related Concept	Details of The Concept	Example of Author

Product	A product is anything that can be offered to a market for attention, acquisition, use or consumption. It includes physical objects, services, personalities, place, organizations and ideas.	Kotler & Keller (2016)
Electronic product	An electronic product is a product made of mechanical and electrical components.	Hoover (2014)
Smart Product	A smart product is an autonomous object, which is designed for self-organized embedding into different environments in the course of its life cycle and which allows for a natural product-to-human interaction.	Wong et al. (2002), Kiritsis (2011), Mühlhäuser (2008)
Smart PSS	Smart PSS are market offerings that integrate products and services into one single solution through the implementation of IC technology.	Valencia et al. (2015)
IoT	IoT is pervasive presence in the environment of a variety of things that through wireless and wired connections with unique addressing schemes.	Kiritsis (2011), Nan & Shiguo (2014), Mashal, et al. (2015)
AI	AI concerns how a machine perceives its environment and takes actions that maximize its chance of success at some goal, and mimics "cognitive" functions that humans associate with other human minds, such as learning and problem solving.	Russell & Norvig (2009), Kranz, Holleis & Schmidt (2010)
UbiComp System	UbiComp system is a system that incorporates omnipresent computers to serve people anywhere, functioning invisibly and unobtrusively in the background and freeing people to a large extent from tedious routine tasks.	Weiser (1991)
AmI	AmI concerns a small world where all kinds of intelligent devices are continuously working to serve inhabitants.	Mühlhäuser (2007), Gutierrez et al. (2013), Bibri (2015)
Robot	A physically embodied artificially intelligent agent that can take actions that have effects on the physical world	Kiritsis (2011)

2.4 Discussion

In this chapter, 42 studies were systematically reviewed, from which eight definitions of intelligent products were analysed and 34 essential characteristics were abstracted. 85.3% of characteristics were related to technology and function, while only five dealt with user experience. This concentration on technological characteristics could be ascribed to the early application of intelligent products to meet industry needs. Characteristics like decision-making, communication among devices, data management, or identification were designed to improve processes in manufacture, logistics, supply chain management, or product life cycle management. As intelligent products began to be integrated into consumer markets, more experiential and human-centred features needed to be developed; these are equally important for the success of innovation, given new market trends (Hassenzahl, 2003; Norman, 2005). As such, both technological and non-technological characteristics are important to consider for modelling innovation in intelligent products.

After reviewing the definitions of concepts closely related to intelligent products, analysis and synthesis revealed relationships between these adjacent terms. This is illustrated in Figure 4 below. These concepts are not disjointed sets.

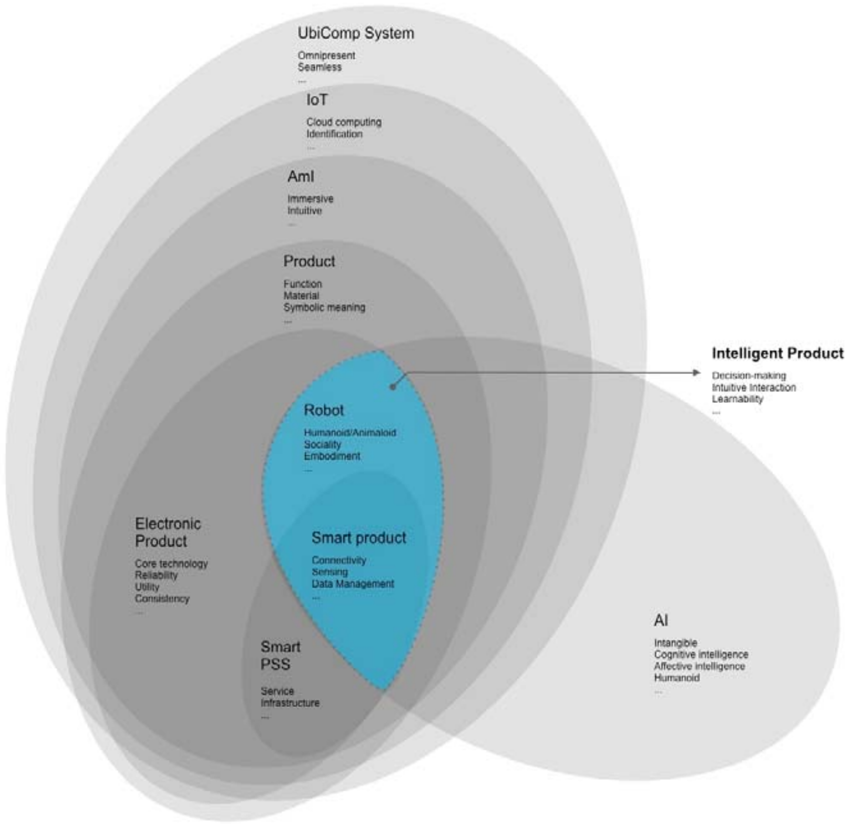


Figure 4 - Boundary of Intelligent Products

They overlap in particular ways. Intelligent products are, first and foremost, 'products', as they 'can be offered to a market for attention, acquisition, use or consumption (Kotler & Keller, 2016). This could include physical objects, services, personalities, places, organisations and ideas (Kotler & Keller, 2016). Intelligent products thus share characteristics with commercial products most broadly construed; these have been described by many scholars as comprising performance, function, material, colour, form, size, durability, or symbolic meaning, etc. (e.g., Haley, 1968; Lancaster, 1971; Holbrook, 1999; Dell'Era & Verganti, 2007).

Intelligent products also belong to the category of 'electronic product' at the current stage, as intelligent products are made of electrical components (Hoover, 2014). As such, intelligent products also possess properties of electronic products, such as core technology, reliability, utility, or consistency, etc. (e.g., Garvin, 1987; Johnson, 1989; Horváth, 2001; Cagan & Vogel, 2002). As with other electronically powered objects, it is possible in the future that intelligent products will derive their power from solar energy or wind.

A frequently mentioned alternative concept that resembles intelligent product is ‘smart product’. Some scholars argue that smart product is an interchangeable term for ‘intelligent product’ (e.g., Kiritsis 2011), while others believe that ‘intelligence’ is distinct from ‘smartnesss’ in this context (e.g., Wong et al., 2002). For instance, smart products are information-oriented, while intelligent products are decision-oriented (Wong et al., 2002). Although scholars may disagree about the precise differences between the two concepts, the consensus appears to be that both have similar information-oriented characteristics, such as connectivity, data management, or sensing (e.g., Chin, Diehl & Norman, 1988; Hassenzahl, 2004; Lee et al., 2014).

In similar vein, smart PSS is understood as a combination of smart products and services; this also shares characteristics in common with intelligent products. Features of smart PSS, like sharing, empowerment, engagement, or customisation (e.g., Xing et al., 2013; Valencia et al., 2015), could also be characteristics of intelligent products.

Another concept closely related to intelligent products is the Internet of Things (IoT). Nan and Shiguo (2014) argued that intelligent products in the IoT environment could possess the characteristics of a keen perception, intelligent processing power and natural way to interact. IoT technologies enable intelligent products to communicate with each other and their environment (Kiritsis, 2011) through shared characters like networked connectivity and identification (Atzori, Lera & Morabito, 2010; Shin, 2014).

The most distinctive characteristics of intelligent products are decision-related functions. These have been influenced by advances in artificial intelligence (AI) (Wong et al., 2002). McFarlane et al. (2003) argued that intelligent products should possess AI features. Kranz, Holleis and Schmidt (2010) also note significant overlap between the concept of intelligent product and the properties of AI, such as decision-making, context awareness, recognition, learnability, and predictability, all of which originated in AI research (e.g., Weiser, 1991; Chen & Kotz, 2000; Poslad, 2011).

Similarly, intelligent products could be considered as a component of UbiComp systems, serving people invisibly and unobtrusively in the background, freeing people to a large extent from tedious routine tasks (Weiser, 1991). However, UbiComp is a very broad concept, albeit with a unique set of characteristics, such as omnipresent, universal, distributed and seamless computing; these are desirable but not essential characteristics of intelligent products (e.g., Newell & Simon, 1959; McFariane et al., 2003).

Similarly, intelligent products could be a part of AmI (Gutierrez et al., 2013). Many research studied the design of intelligent products in intelligent environments, which support people in their daily activities and tasks in an easy and natural way (e.g., Mühlhäuser, 2007; Bibri, 2015).

To achieve the 'natural' and 'immersive' effect, intelligent products in intelligent environments need to be invisible and work consistently to serve inhabitants (Mühlhäuser, 2007).

Finally, robotics provides the form that many have recognised as the terminal stage of intelligent product development (Fong, Nourbakhsh, & Dautenhahn, 2003; Kiritsis, 2011). Intelligent products currently have the capability to complete human-designated tasks and solve problems; these are also the basic aims of robots. When intelligent products are developed with higher levels of 'intelligence' (e.g., humanoid), they will be able to internally simulate or mimic the social intelligence found in living creatures. Kiritsis (2011) described this property of intelligent products as 'wisdom', understood as the capability to recognize self-identity, reasoning at various levels of decision-making, communication with others and the environment, and maintaining a record of their own history.

In brief, there was significant overlap between the boundaries around intelligent products and several adjacent concepts, including UbiComp, IoT, AmI, general products and electronic products. These concepts cover an entire spectrum of object intelligence, from smart products – programmable, capable of carrying out a complex series of actions automatically – to robots – the physical embodiment of an artificial intelligence system, a thinking agent that senses and interacts with its world. Intelligent products can be central, with the highest level of intelligence or control authority in a distributed network, like in AmI, IoT or Ubicomp system, or they might be products with lower thresholds of intelligence, simply executing orders from some other central control.

As intelligent products are closely aligned with each of the nine concepts, there are a number of characteristics that might be derived from them to supplement insufficient or vague definitions in the literature that explicitly address 'intelligent products'.

Chapter 3 – Concept of Product Innovation Framework

3.1 Introduction

A framework is 'a real or conceptual structure intended to serve as a support or guide for the building of something that expands the structure into something useful' (Thalheim, 2011). A product innovation framework, then, is a conceptual structure intended to serve as a support to facilitate the development of an intelligent product.

The nature and structure of frameworks can vary widely. Frameworks for traditional product innovation and for intelligent product innovation should not be identical, as the properties of intelligent products and the requirements from users are quite different. Over the last 80 years, researchers have sought to create frameworks to facilitate product innovation. Product innovation frameworks have been used to pursue different goals. These include: to inspire innovative ideas (e.g., Kumar, 2013), to facilitate product development processes, to analyse and evaluate product innovation results, to analyse the direction of innovation through users' perspectives (e.g., de Bont, 1992) or to reflect innovation through social, cultural, ecological perspectives (e.g., den Ouden, 2012). Before creating a framework for the purposes of this research, it will be necessary first to identify, analyse and differentiate the already well-established frameworks. Then it will be possible to select what framework will be most suitable for modelling intelligent products.

In this chapter, the following research question is addressed:
RQ3. What would be an appropriate perspective to build a framework for intelligent product innovation?
RQ3.1 What kinds of frameworks for product innovation exist in the literature?
RQ3.2 What kind of a framework does this research intend to build?

In doing so, a critical overview of product innovation frameworks has been conducted. A range of theoretical and empirical studies were examined, analysed and classified to determine the most appropriate approach to build a framework for intelligent product innovation.

The rest of the chapter is structured as follows: first, the research method is introduced. Systematic literature review was selected as the primary data collection method. The findings are then presented, including the aims, background, and methods of the frameworks analysed. In the subsequent section, the frameworks analysed in the review are classified. After comparison and analysis, one type of framework is selected for developing a model to study intelligent product innovation.

3.2 Method

3.2.1 Systematic Literature Review

Systematic literature review was selected as the method for this research. This method has proven successful in various studies (Kitchenham, 2007; Dybå & Dingsøyr, 2008; Gutierrez et al., 2013). Its main advantage is that it can provide a complete and exhaustive summary of current literature relevant to the research question. The systematic literature review was conducted in distinct stages, starting with the identification of inclusion and exclusion criteria, a search for relevant studies, and data extraction and synthesis. The rest of this section provides details about each of these stages.

3.2.1.1 Search Strategies

A number of digital databases accessible at the Hong Kong Polytechnic University were searched. The databases are shown in Table 2.

Table 2 – Data Source

Data Source
IEEE Explorer
Science Direct
EBSCO host
Google Scholar
Elsevier

The search terms for the study were defined based on the research question. To obtain the maximum number of possible search results in the databases, the following key words were used: *('Product Innovation') AND ('Framework')*

3.2.1.2 Inclusion and Exclusion Criteria

After reviewing the papers, it became clear that a number of results from the research were irrelevant and invalid. Criteria were established to eliminate these papers. Only studies that met the following requirements were included in the review. The studies reviewed were:

- Written in English.
- Published up to and including 2017.
- Authored by academic researchers or business practitioners.
- Utilized qualitative or quantitative methods.

Articles with the following criteria were excluded:

- The keywords are not completed.
- The focus was not on product innovation.

3.2.1.3 Quality Assessment

The studies were evaluated on basis of relevance, reliability, and validity. Six quality assessment questions proposed by Gutierrez et al. (2013) were used to select the appropriate articles.

Table 3. Quality Criteria by Gutierrez et al. (2013)

QA	Answer
Is the study based on research methods?	Yes/No
Is there a clear statement of the aims and objectives of the research?	Yes/No
Is there a clear description of the context in which the research was carried out?	Yes/No
Are there relevant studies included in the findings?	Yes/No
Are the results evaluated in accordance with objective criteria?	Yes/No
Is there a clear statement of findings?	Yes/No

3.2.2 Data Extraction and Synthesis

After identifying the literature to be included, the first step was to identify different product innovation frameworks the aims and methods of the correlating papers. These frameworks were then analysed and classified. Classification can assist in describing the concept, reducing complexity, and enabling comparison (Bailey, 1994), and ultimately in determining what kind of a framework is necessary and appropriate to be built. Nvivo® software was applied to organise the qualitative data.

3.3 Findings

3.3.1 Overview of Findings

Figuring out the structure and dynamics of product innovation has been a significant research agenda for many researchers since at least the 1920s, when researchers and practitioners sought to organise the diversity of product innovations into distinct patterns (Godin, 2017). We contribute to this long research lineage.

After data extraction and synthesis, 103 studies related to product innovation frameworks were identified. From these, 38 product innovation frameworks were selected according to the frequency of their citation and their relevance to the present research questions. The selection also considered the time of publication to include the most important and influential frameworks from this varied history (Table 9).

Table 9 - Product Innovation Framework

Framework	Author
Linear Model	Mees (1920)
Market-pull Model	Cook & Morrison (1961)
Diffusion of Innovation Model	Rogers (1962)

Technology-push Model	Freeman (1971)
Problem Solving Model	Utterback & Abernathy (1975)
Means-End Chain Model	Gutman (1982)
Chain-link Model	Kline & Rosenberg (1986)
Tool-kit of habits, skills, styles, and beliefs from which people construct strategies of action	Swidler (1986)
Nissan's integrated Model	Graves (1987)
Stage-Gate Process Model	Cooper (1990)
Systems Integrating and Networking Model	Rothwell (1992)
Model of Product-Concept Evaluation	de Bont (1992)
The Development Funnel	Clark & Wheelwright (1993)
Coupling Model	Rothwell (1994)
A Model of Consumer Responses to Product Form	Bloch (1995)
Values and Lifestyles Model	Woodruff & Gardial (1996)
User Scenario	Rolland et al. (1998)
User Value Model	Holbrook (1999)
TRIZ	Altshuller (1999)
Value Opportunity Analysis Model	Cagan & Vogel (2002)
User-Centered iNPD Process	Cagan & Vogel (2002)
Open Innovation Model	Chesbrough (2006)
Emotional Connection Model	Rafaeli & Vilnai-Yavetz (2004)
Product Design Identities Model	Dell'Era & Verganti (2007)
User Value Model	Boztepe (2007)
NASA Management Process Model	von Stamm (2008)
Design Thinking	Brown (2008)
Design-Driven Innovation Model	Verganti (2009)
The Business Model Canvas	Osterwalder (2010)
Agile Innovation Framework	Ries (2011)
Value Framework	den Ouden (2012)
Ten Types of Innovation	Keeley et al. (2013)
Seven Modes of The Design Innovation Process	Kumar (2013)
Agile Innovation	Moris, Ma & Wu (2014)
Lean Product Process	Olsen (2015)
Brand Touch-point Wheel	Stein & Ramaseshan (2016)

3.3.1.1 Methods Used to Develop Frameworks in Literature

To organise the literature, we follow Cheng et al. who argued for sorting reviewed studies according to their research method (Table 11). Many studies have used multiple research methods. The top three methods used include literature research (100%), case study (38%), and experiment (18%). For instance, Dell'Era and Verganti (2007) studied 200 cases of product design to develop a product design identities model. Overall, these findings point to the fact that both empirical methods and theoretical methods were important for developing frameworks.

Table 10 – Research Method

Method	No.	Example of Framework	Example of Author
Literature	38	User-Centered iNPD Process Model	Cagan & Voge (2002)

Research		Business Model Canvas A Model of Dissatisfaction, Outrage, Satisfaction, and Delight Value Opportunity Model Product Design Identities Model Design-Driven Innovation Model Ten Types of Innovation Model	Osterwalder (2010) Berman (2005) Cagan & Voge (2002) Dell'Era & Verganti (2007) Verganti (2009) Keeley et al. (2013)
Case Study	14	Consumer Response and Product Form Model Value Framework	Bloch (1995) den Ouden (2012)
Experiment	7	TRIZ	Altshuller (1999)
Interview	5	Emotional Connection Model	Rafaeli & Vilnai-Yavetz (2004)
Algorithm Model	2	TRIZ	Altshuller (1999)
Observation	4	Design-driven Innovation Model	Verganti (2009)

3.3.2 Four Perspective of Product Innovation Frameworks

After reviewing the literature by method, it was found that product innovation frameworks could generally be classified into four groups based on the perspective they adopt for understanding innovation: process, product, user and organisational. Among the four perspectives, most studies focused on the process perspective (50%).

Table 12. Number of Framework in the Four Perspectives

Classification	No.
Process perspective	19
Product Perspective	5
User perspective	8
Organizational perspective	6

The process perspective addresses *how* innovation happens in product design. It seeks to enhance the development process, for instance, by reducing or optimising production procedures, or modifying production with the goal of enhancing product quality, performance, or appearance.

The product perspective concerns *what* to create. It intends to decode product innovation 'internally' from the 'constructs' of a product and to recognise a product as the combination of properties or attributes. The perspective explores the possibilities of how a product could be altered or designed ontologically.

The user perspective explains *why* product innovation should happen in certain ways or take certain directions, such as to meet consumer demands. It studies the interrelationships between users and products, such as user perceptions or evaluations of products, usage scenarios and needs, or the involvement of users in product innovation.

The organisational perspective investigates the role of product innovation in a company, society, or eco-system. It views product innovation 'externally': products understood as a value proposition in larger business model; the influence of product innovation on organisation structure, process, human resources, or infrastructure; the perception of product innovation from the holistic scope of social, cultural, economic, and ecological paradigm shifts, and so on.

3.3.2.1 Process Perspective

The process perspective has the longest history (Table 13). In the earliest writings on product innovation (dating to the 1920s), product innovation was understood as a linear process (Fagerberg, 2006). 'The linear model' is based on the assumption that product innovation follows sequential steps. Linear models include the 'technology-push' model, with its sequence of research, production, and development (Rothwell, 1994). Later, market elements began to be considered as stimulation in product innovation, leading to the appearance of the 'market-pull' model, which follows a sequence from market needs and development to manufacturing and sales (Cook & Morrison, 1961). Product innovation modelling later incorporated both technology and market pressures as a problem-solving approach. There are a number of limitations to considering innovation a linear process, not least of which is the inefficiencies created by sequential production processes.

Table 13. Frameworks from Process Perspective

Framework	Author
Linear Model	Mees (1920)
Market-pull Model	Cook & Morrison (1961)
Technology-push Model	Freeman (1971)
Problem Solving Model	Utterback & Abernathy (1975)
Chain-link Model	Kline & Rosenberg (1986)
Nissan's integrated Model	Graves (1987)
Stage-Gate Process Model	Cooper (1990)
Systems Integrating and Networking Model	Rothwell (1992)
The Development Funnel	Clark & Wheelwright (1993)
Coupling Model	Rothwell (1994)
User-Centered iNPD Process	Cagan & Vogel (2002)
Open Innovation Model	Chesbrough (2006)
NASA Management Process Model	von Stamm (2008)
Design Thinking	Brown (2008)
Design-Driven Innovation Model	Verganti (2009)
Agile Innovation	Ries (2011)
Seven Modes of The Design Innovation Process	Kumar (2013)
Lean Product Process	Olsen (2015)

Since the 1970s, product innovation began to be considered as an interactive process, with more or less stable relationships in space and in time (Djellal & Gallouj, 2014). From these non-linear, interactive approaches, a product would be passed back and forth between different departments or components in an organisation for better communication and time efficiency (Takeuchi & Nonaka, 1986). Designers and researchers could be connected with manufacture as well as consumers (Djellal & Gallouj, 2014). Implementations of this type of modelling include the 'chain-link' model (Kline & Rosenberg, 1986), Nissan's integrated model (Graves, 1987), the 'coupling' model (Rothwell, 1994), and the NASA management process model (von Stamm, 2008).

Beginning in the 1990s, the focus again shifted, away from interaction and towards systems integration and networking. This was due in part to increased demands for cross-departmental and cross-company management, and included the 'systems integrating and networking' model (Rothwell, 1992), the Development Funnel (Clark & Wheelwright, 1993), the 'user-centred iNPD process' model (Cagan & Vogel, 2001), and the 'open innovation' model (Chesbrough, 2006). For example, the open innovation model (Chesbrough, 2006) describes how leading firms evolved from 'closed-innovation' processes towards a more open structure to encompass all stakeholders, internally and externally, into innovation-oriented activities (Chesbrough, 2006).

Efforts from the field of design to model innovation activities were also addressed. Brown's (2008) *Design Thinking* refers to creative strategies that designers, businessmen, and problem-solvers can use during the design process to address business and social issues. The 'design-driven innovation' model describes a similar approach; it leverages designers' ability to understand and influence how people attribute meaning to things (Verganti, 2009). This process consists of three steps, listening, interpreting and addressing, whereas a related model by Kumar (2013) synthesises design innovation into seven modes.

After the 2010s, frameworks from the process perspective began to incorporate theories and practice from software engineering. The innovation process came to be seen as more flexible, dynamic and effective as a result. Ries (2011) developed a process that shortens product development cycles with 'validated learning' – rapid scientific experimentation conjoined with a number of counter-intuitive practices. With these rapid and iterative processes, progress could be measured without resorting to vanity metrics and the real needs of users could be discerned much more quickly. Olsen (2015) described a 'lean product processes as a repeatable methodology for product iteration.

3.3.2.2 Product Perspective

The frameworks from the product perspective are designed to facilitate product innovation through the manipulation of the 'constructs' of a product (Table 14). As early as 1946, Soviet engineer Genrich Altshuller and his colleagues developed a methodology called TRIZ (named for its Russian acronym; translated as 'theory of the resolution of invention-related tasks') following research on patterns in the global patent literature (1999). An important component to the TRIZ theory has been devoted to deconstruct products or strategies into controllable units, which could then be manipulated toward the invention of new products or the refinement of existing ones.

Although this research was not explicitly oriented to providing a product innovation methodology as such, it has proven widely influential across a number of fields.

Table 14 - Frameworks from Product Perspective

Framework	Author
TRIZ	Altshuller (1999)
User Value Model	Holbrook (1999)
Value Opportunity Analysis Model	Cagan & Vogel (2002)
Product Design Identities Model	Dell'Era & Verganti (2007)
User Value Model	Boztepe (2007)

Based on TRIZ, a number of frameworks have been suggested that focus on product attributes. Two important works that lay the basis for this study are User Value Models (Holbrook, 1999; Boztepe, 2007). Although the name of the models involved "user", in this research it is still categorized into the product perspective. Because both of them analyze the value that a product can bring to its user from the attributes it has. Holbrook (1999) proposed a comprehensive framework with various product attributes, such efficiency (e.g. convenience), excellence (e.g., quality), status (e.g., impression management), esteem (e.g., possession), play (e.g., fun), aesthetics (e.g., beauty), ethics (e.g., justice) and spirituality (e.g., sacredness). Based on this model, Boztepe (2007) identified four major components that related to how users perceive value, including utility, social significance, emotional connection, and spirituality. However, both of these frameworks focus on the presentation of possible attributes that a product can possess, not necessarily how they could be innovated.

One of the first studies to explicitly connect product innovation with product attributes was conducted by Cagan and Vogel (2002). They provided what they call the 'Value Opportunity Analysis' framework, which can be used to identify the aspirational attributes of a product or service and to help designers focus on key items for innovation. In this framework, a product can be analysed from seven characteristics, including emotion, aesthetics, identity, ergonomics, impact, core technology, and quality. Each of these can be further broken down into smaller units. The overall framework can be used to define program goals at the earliest stage of the product development, to create products that meet the value expectations of end users, and evaluate the outcome of product innovation efforts.

3.3.2.3 User Perspective

Some frameworks from the user perspective consider the 'interplay between designers' intentions and users' needs, perceptions, and goals' (Heskett, 2002, p. 54). Rogers (1962) studied the diffusion of innovation through a series of communication channels over a period of time among the members of a similar social system. The five-step decision-making process attempted to reflect how humans adopt innovations, and included: awareness, interest, evaluation, trial, and adoption.

In the marketing domain, many studies have been conducted to understand how and why consumers, customers, and users perceive, evaluate, or come to prefer a product. These studies have developed frameworks such as 'decision-oriented research tools' (Haley, 1968), 'means-end chain modelling' (Gutman, 1982), or the 'product-concept evaluation' model (de Bont, 1992), and so on.

Table 15 - Frameworks from User Perspective

Framework	Author
Diffusion of Innovation Model	Rogers (1962)
Tool-kit of habits, skills, styles, and beliefs from which people construct strategies of action	Swidler (1986)
Model of Product-Concept Evaluation	de Bont (1992)
A Model of Consumer Responses to Product Form	Bloch (1995)
Values and Lifestyles Model	Woodruff & Gardial (1996)
Means-End Chain Model	Gutman (1982)
User Scenario	Rolland et al. (1998)
Emotional Connection Model	Rafaeli & Vilnai-Yavetz (2004)

Many frameworks were developed to identify the specific usage, experience and interaction contexts for consumers in real world. User scenario tools were developed using examples, scenes, narrative descriptions of contexts, mock-ups, and prototypes (Rolland et al., 1998). Values and lifestyles modelling segments people according to their enduring beliefs and practices, identifying them as innovators, achievers, or thinkers (Woodruff & Gardial, 1996). Such models can help developers to establish the general positioning of a product. Osterwalder et al. (2014) developed a 'value proposition canvas' to design, test, create, and manage products and services that meet users' needs.

3.3.2.4 Organizational Perspective

Some frameworks sought to provide a view of product innovation from the perspective of how it fits into an organisation's business model. These help developers and designers to position product innovation within strategic planning. Enos (1962) introduced a process that encompasses all touchpoints of a business, from invention, securing financial backing, organisational establishment, finding a plant, hiring workers, opening markets, production, and distribution. Similarly, the 'brand touch-point wheel model' concerns all of the channels and various points in time that a potential consumer makes contact with a business, whether it is a product, service, brand or organisation (Stein, & Ramaseshan, 2016). These touch-points exert great influence on the perception and purchase decisions for consumers. Osterwalder's (2010) 'business canvas' model seeks to innovate at the level of business model, strategic management and communication. Product innovation is considered here as part of the value proposition, which provides value to customers by solving their problems or offering benefits. Similarly, Sehested and Sonnenberg (2010) reveal how an iteration between creativity and effectiveness can ensure that the visions of top management are realised through the innovation processes. Keely et al. (2013), for their part, developed and applied a proprietary algorithm to determine ten meaningful types of innovation. The ten types of innovation explore these insights to diagnose patterns of innovation within industries, to identify innovation opportunities, and to evaluate how firms are performing against competitors. Moris, Ma and Wu (2014) build on this work to provide a model of agile innovation that sustains innovation improvements in five critical performance areas: strategy, portfolio, process, culture and infrastructure.

Table 16 − Frameworks from Organizational Perspective

Framework	Author
The Business Model Canvas	Osterwalder (2010)
Value Framework	den Ouden (2012)
Ten Types of Innovation	Keeley et al. (2013)
Agile Innovation	Moris, Ma and Wu (2014)
Brand Touch-point Wheel	Stein & Ramaseshan (2016)

Some of the frameworks from the organisational perspective addressed the influence of social, cultural, economic, and ecological opportunities that could be used for product innovation. These can help to identify innovation trends in the market and to maintain an organisation's competence regarding paradigm shifts. For instance, den Ouden (2012) proposed a synthesised product innovation model that considers users, organisations, ecosystem, and society. Product innovation should not only bring utilitarian benefits to users but also social-cultural value to improve users' quality of life. When companies plan and execute innovation activities successfully, they not only take into account users' needs, but also benefits at the levels of organisation, ecosystem and whole society. The value created should be sharable.

3.4 Discussion

3.4.1 General Discussion

After reviewing the literature, it was found that many innovation frameworks were developed for, or based on, non-intelligent products. The frameworks that addressed the new requirement of innovation, such as iterative processes, open platforms, multiple inspiration sources, or dynamic agendas, are fairly recent developments, beginning in earnest in the 2010s (e.g., Ries, 2011; Keeley et al., 2013; Moris, Ma & Wu, 2014).

Most of the frameworks adopt the process perspective (50%), followed by the user perspective (21%) and the organisational perspective (15%). Frameworks from the process perspective have attracted the most attention in academic fields, most likely because this is the earliest approach (e.g., Mees, 1920). In recent years, however, attempts to model product innovation have begun to incorporate iterative processes from fields like software engineering, leading to new theories like agile innovation (Morris & Ma, 2014) or lean product innovation (Ries, 2011). These frameworks promote flexible procedures, multiple sources of inspiration, and parallel activities in the product development process, which is meaningful for intelligent product innovation.

Similarly, much research has been conducted on the user perspective. Previously, product innovation emphasised the importance of users' needs or opinions. Companies invest a lot on market research. But recently, after observing examples of radical innovation, Verganti (2009) suggested a transition from the 'direct execution' of users' ideas in product innovation to 'interpretation' first. Radical innovations, he argued, do not come from users directly.

The organisational perspective might be too broad for the research at its present stage, although it is a domain that has great promise to influence decisions pertaining to business processes, resources, and the overall outcomes of innovation activities.

3.4.2 Selection of Perspective

After examining these four perspectives, it was found that limited attention was paid to the innovation frameworks from the perspective of the product – how its 'constructs' and attributes become crucial to innovating activities. This perspective investigates product innovation from its essence, which reveals the fundamental issues in product innovation. Even fewer studies provided frameworks from this perspective for considering innovation in intelligent product design. Although the frameworks proposed by Holbrook (1999), Cagan and Vogel (2002) or Boztepe (2007) were extremely valuable in this perspective, the product attributes they defined were appropriate only for traditional non-electronic and electronic products, devoid of 'intelligent' features brought by the information technology.

A comprehensive and customizable framework to stimulate innovation in intelligent product design from the product perspective could be a valuable research opportunity. Such a framework could be used for various agendas, such as to reveal innovation patterns, to diagnose problems, to define product characteristics in early stages of development, to evaluate product innovation results, or to analyse similar products on the market.

The development of the framework should be conducted in both empirical and theoretical approaches. Methods like literature research, case study analysis and interviews can be used, as these methods have proven efficient and effective in similar arenas (e.g., Cagan & Vogel, 2002; den Ouden, 2012; Valencia et al., 2015).

Chapter 4 – Methodology

4.1 Introduction

Research is a systematic inquiry of an observed phenomenon (Gall, Borg & Gall, 1996). This research intends to explore, build, describe and test a comprehensive and integrated framework for describing, stimulating, and analyzing the innovation of intelligent products (**Figure 2**).

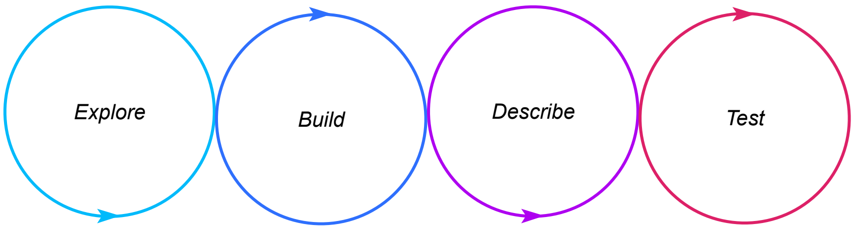


Figure 2 - Purpose of the Study

In this research, qualitative and quantitative research methods were applied. Qualitative methods were used to discover, and acquire in-depth understanding of the underlying meanings or patterns of phenomena through observation, examination, analysis, and interpretation (Denzin & Lincoln, 2005). While quantitative research is the systematic empirical investigation of observable phenomena or test hypothesis via statistical, mathematical or computational techniques (Given, 2008). The research question in this chapter is demonstrated as following:
RQ4. What methodology could be used to build and test a framework for intelligent product innovation?

In order to answer the questions, in the following section, the research methodology was introduced. It was presented following a methodology framework designed by (Creswell, 2012), with nine types of information, including the aim, focus, methods, process, sample, data form, data analysis, results and report form.

4.2 Research Methodology

Creswell (2012) provided a comprehensive and effective framework to synthesize research methods. Inspired by the framework, the research is designed in the following ways (Table 17).

Table 17 - Research Methodology

Methodology	Details

Aim	To explore, build, describe and test
Focus	Deep-angle, generalization and specification, examining the depth of the object
Methods	Systematic literature review, cluster analysis, conceptual analysis, content analysis, expert interview, case study
Process	Inductive-research question generation, evidence, materials and data gathering, inductive analysis of data, generation of framework, validate the framework
Sample	Medium samples; smaller but focused samples.
Data Form	Textual data - narrative words, categories. Data is complex and interwoven.
Data Analysis	Search for descriptions and meanings of constructs and patterns of intelligent product innovation.
Results	Particularistic findings, representation of insider viewpoint; present multiple perspectives.
Report form	Narrative report with contextual description and direct quotations from research participants.

4.2.1 Aim

This research attempts to explore, describe, build and test constructs of intelligent products; Based on it, to build a framework for describing, stimulating and analyzing the innovation of intelligent products.

4.2.2 Focus

This research focused to acquire in-depth understanding of the constructs of intelligent products, and the meanings and descriptions of them. The constructs were interpreted and described in generalized and specified manners.

4.2.3 Methods

The research nature decides what research methods that this study can select. Exploratory research often relies on qualitative research methods, such as literature review, interview, focus group, and case studies, (Shields et al., 2013). Six methods were applied in the research, including systematic literature review, cluster analysis, conceptual analysis, content analysis, expert interview, and case study (Table 18). While the validation of research is usually tested with quantitative research activity.

Table 18 - Methods of the Research

Methods	Definition	Author
Systematic literature review	A systematic search of published works to find out what is already known about the intended research topic.	Robinson & Reed (1998)
Cluster analysis	A method to classify similar objects into groups.	Aldenderfer & Blashfield (1984)
Conceptual analysis	A systematic synthesis of findings across qualitative studies, seeks to	Nelson (2006)

	generate new interpretations for which there is a consensus within a particular field of study.	
Content analysis	A systematic and replicable method for compressing many words of text into fewer content categories based on explicit rules of coding.	Stemler (2001)
Expert interview	Method in which information is obtained by asking respondents questions directly.	Yin (2014)
Case study	Study of a single phenomenon (e.g., an application, a technology, a decision) in an organization over a logical time frame.	Yin (2014)

4.2.4 Process

The proposed research was composed of the four main phases, exploration, build, describe, test and demonstrate (Table 19).

Table 19 - Research Phase

Phase	Details	Chapter
Phase 1. Explore	Sector, Relationship within sectors, Vectors and attributes	Chapter 5,6
Phase 2. Build and Describe	Conceptual Framework for Intelligent Product Innovation	Chapter 7
Phase 3. Test	Small-scale validity test, Case study	Chapter 8

The aim, structure, and inductive research question was generated first in Chapter 1. Then, the concepts and characteristics of intelligent products in literature were reviewed, analyzed and compared. Following this, frameworks for product innovation in literature were reviewed. After that, sectors were generated from systematic literature review and cluster analysis. Attributes of intelligent products were generated from a systematic literature review and expert interview. The framework is established based on the sectors, vectors, attributes and relationship among sectors. The framework is validated with small-scale expert interview and demonstrated with a case study of an unmanned aerial vehicle. The framework is reflected with limitation and future research could be conducted.

Table 20 - Research Process

Step	Method	Chapter
1. To generated aim, structure, and inductive research question.	/	1
1. To identify concepts and characteristics of intelligent products in literature	Systematic literature review, content analysis	2
2. To review literature to frameworks of product innovation	Systematic literature review	3
3. To cluster product attributes and study relationships	Systematic literature review, cluster analysis	5
4. To generate new intelligent product attributes based on the sectors, relationship, vectors and attributes	Systematic literature review, expert interview, content analysis	6
5. To build the framework	Conceptual analysis	7
6. To validate the framework	Expert interview, case study	8
7. To rethink the framework	/	9

The proposed process is iterative, which requires "a steady movement between concept and data, as well as comparative, requiring a constant comparison across types of evidence to control the conceptual level and scope of the emerging theory" (Orlikowski, 1993, p. 310).

4.2.5 Sample

Sample strategies were convenience sampling and snowball sampling. The two methods have been proved effective in various studies (Battaglia, 2008). For the first round of expert interview to generate intelligent product attributes, the sample size was 202. For the second round of expert interview to test the validity of the framework, smaller but focused samples were selected.

4.2.6 Data Form

The data form was narrative words, categories, which were complex, interwoven, and difficult to be measured in a quantitative way. The framework built on the data was also in the text form.

4.2.7 Data Analysis

The data was analyzed in an inductive manner. The method of content analysis was applied, which is effective in interpreting meaning from the content of text data based on explicit rules of coding (Hsieh & Shannon, 2005). Constructs of intelligent products were analyzed and coded with the method. Then the descriptions and meanings of them were provided.

4.2.8 Results

The research result is a comprehensive conceptual framework particular for intelligent product innovation. It represents the expert viewpoints based on their knowledge from academic research or practical experience. The framework presents multiple perspectives to understand and execute innovation activity.

4.2.9 Report

The final report is a thesis in narrative form with contextual description and direct quotations from the research participant.

4.3 Summary

The aim of this research is to explore, describe, build and test a conceptual framework for intelligent product innovation. Both qualitative and quantitative research methods were applied. Then the methodology of the research was presented with ten types of information. Six research methods were applied in this research, including systematic literature review, cluster analysis, conceptual analysis, content analysis, expert interview, and case study. The research was consisted of seven phases, which covering the generation of product constructs and relationships among them, the generation of the framework based on them, the small-scale validity test of the framework, and the demonstration of the framework.

Chapter 5 - Classification of Product Attributes

5.1 Introduction

Attributes are important, because consumers view each product as a collective of some attributes (Kotler & Armstrong, 1999). Innovation can be recognized as the combination (Schumpeter, 1945). Product innovation can be recognized as the new combination of its attributes. By manipulation of attributes, a product can be enhanced, improved or recreated. According to the level of manipulation or what construction is manipulated, the innovation result could be different.

As the product attributes discussed in literature are countless, it is not efficient and possible to discuss each of them one by one. So many researchers are intended to provide a sophisticated classification of product attributes. These studies of classification are very meaningful, as product attributes can be recognized, differentiated and better understood through this way. In this study, classification of intelligent product attributes is also considered necessary, as intelligent product attributes could be represented more comprehensively and systematically. In this chapter, the following research question and sub questions are answered:

RQ 5: What is the classification of intelligent product attributes and what relationship could be abstracted among the attributes?
RQ5.1 What is the concept of product attributes?
RQ5.2 What kind of classifications of product attributes can be found in academic literature?
RQ5.3 Do those existing academic studies on attributes include intelligent products?
RQ5.4 How to classify intelligent product attributes?
RQ5.5 What is the nature of sectors?
RQ5.6 What is the relationship within sectors?

Based on the research question, first, it is necessary to clarify what is an attribute, then to decide what should be categorized as intelligent products attributes. After that, the classifications of product attributes, nature and relationship discussed in academic literature were systematically reviewed. The clusters of attributes identified in literature were analyzed as an important reference. Based on them, a classification of attributes in this research was provided. In order to test whether this classification is comprehensive enough, intelligent product attributes identified in Chapter 2 were categorized with the classification. Then, the nature of sectors was discussed, which serve as a basis to define the relationship within sectors. The relationships within the four sectors are essential for building the framework, as it determines why the framework is designed in certain ways and is implied important underling requirements for product innovation.

5.1.1 Definition of Attributes

The concept of attributes evolves over time. At beginning, product attributes were approached intuitively, without any precise definition as to what a product attribute is and what it is not (Geistfeld, Sproles, & Badenhop, 1977). It emerged in academic marketing literature as early as 1968 (Wu et al., 1988). Haley (1968) was the first one to explore the different segmented customer and their preference for toothpaste. In his study, five product attributes are identified as influential attributes for consumers to make a purchase choice, including flavor, appearance, decay prevention function, brightness function, and price.

The major breakthrough of product attribute study is conducted by Lancaster in 1971 with a focus on quality. He studies the attributes of automobile systematically, from size, and comfort, quality, and performance, maintenance, and price. Based on Lancaster's research, Geistfeld et al. (1977) further explored product quality with durability and safety attributes.

Then studies of product attributes have been explored from not only functional perspective, but also symbolic and environmental perspective, although the exact word of symbolic and environment is not proposed. Cowling and Cubbin (1971) in their research of automobile quality and consumer's perception, divide product attributes into objective quality, and subjective consumer's perception. The objective quality can be calculated by width, length and capacity, while the subjective quality can be evaluated by convenience, comfort, status, life style, ethics and eco-friendliness. Bass and Talarzyk (1972) conduct an experiment about how consumer evaluated six types of daily used products (e.g., toilet tissue, lipstick or brassieres). They explore attributes like material strength, function, color, style, comfort, fit, and life style, etc. Maynes (1976) studies quality from perspective of durability, comfort, performance, convenience, safety, aesthetics, status, carry capacity, and pollution effect.

Over the last 50 years, many researchers have sought to identify new attributes of products and their influence on consumers. After Holbrook, product attributes are developed quickly and diversified. Scholars study function, quality, color, material, geometry, style, craftsmanship, functionality, ease of use, ease of care, durability, quality, fit, attractiveness, safety, comfort, self-expression, and so on (e.g., Beaudoin, Moore & Goldsmith, 2000; Hult, Keillor & Hightower, 2000; Jamal & Goode, 2001; Zhang, Li, Gong & Wu, 2002; Pratt & Rafaeli, 2006; Zhang, Yang & Lei, 2007; Dell'Era & Verganti, 2007; Reid, Frischknecht & Papalambros, 2012).

In the development of attribute studies, nearly anything of a product - either a consumer perceived benefits or objective and physical properties are qualified as a product attribute.

5.2 Method

Systematic literature review was applied to collect data. While cluster analysis method was used to organize and analyze data.

5.2.1 Systematic Literature Review

Systematic literature review has been used successfully in various studies to discern the core features of how a concept has been defined (Kitchenham, 2007; Dybå & Dingsøyr, 2008; Gutierrez et al., 2013). The main advantage of the method is that it can provide an exhaustive summary of current literature relevant to the research question.

5.2.1.1 Search Strategy

A number of large digital databases that are accessible at the Hong Kong Polytechnic University are searched. Besides, website of MIT Technology Review, Robot and Beta, and Wired are considered as a valuable source of information as recommended by the interviewees. The data sources are shown in Table 21. Searched data is organized with the management software Nvivo®.

Table 21 – Data Source

Data Source
IEEE Explorer
Science Direct
EBSCO host
Google Scholar
Elsevier
MIT Technology
Robot and Beta
Wired

The classification, nature and relationship of attributes are searched. In many research, the terms of “characteristic”, “feature” or “property” are used interchangeably for “attribute”. They are all included in the three search strings.

Table 22 - Search Strings

1. (“classification of”) AND (“product”) AND (“attributes” OR “characteristics” OR “features” OR “properties”)
2. (“nature of”) AND (“product”) AND (“attributes” OR “characteristics” OR “features” OR “properties”)
3. (“relationship of”) AND (“product”) AND (“attributes” OR “characteristics” OR “features” OR “properties”)

5.2.1.2 Inclusion and Exclusion Criteria

After reviewing the search results, it became evident that some results were irrelevant or invalid. Criteria were established to eliminate these papers. Only studies that met the following requirements were included in the review. The studies reviewed were:

- Written in English.

- Published up to and including 2017.
- Authored by academic researchers or business practitioners.
- Utilized qualitative or quantitative methods.

Articles with the following criteria were excluded:

- The keywords are not completed.

5.2.1.3 Quality Assessment

The studies were evaluated on the basis of their relevance, reliability, and validity. Six quality assessment questions proposed by Gutierrez et al. (2013) were used to select the appropriate articles (Table 3).

Table 3. Quality Criteria by Gutierrez et al. (2013)

QA	Answer
Is the study based on research methods?	Yes/No
Is there a clear statement of the aims and objectives of the research?	Yes/No
Is there a clear description of the context in which the research was carried out?	Yes/No
Are there relevant studies included in the findings?	Yes/No
Are the results evaluated in accordance with objective criteria?	Yes/No
Is there a clear statement of findings?	Yes/No

5.2.2 Cluster Analysis

Cluster analysis is the classification of similar objects into groups, where the number of groups and their forms are unknown (Aldenderfer & Blashfield, 1984). The classification is formed through mapping the similarities or dissimilarities of subjects on multiple dimensions (Henry et al., 2015). Usually, clustering analysis is used with continuous data in quantitative research, but Henry et al. (2015) stated that binary data from qualitative research could be clustered as well. In this research, the product attributes from the literature review are clustered.

5.3 Findings

After reviewing, 21 related studies were identified from literature. Among them, 33 clusters of attributes were discussed. 33 clusters of attributes could be further classified into four sectors of appearance, function, experience and meaning. It was found that appearance and function sectors are concrete and objective sectors. While experience and meaning sectors are abstract and subjective sectors. There is a hierarchical relationship between the two pairs of sectors. The sectors and the relationship are essential for building the framework.

5.3.1 Classification of Attributes in Literature

33 clusters of attributes were identified from 21 studies (Table 23). In the following section, they were displayed and discussed.

As early as 1975, Young and Feigin identified three groups of attributes, including functional, emotional and psychological attributes. However, they didn't specify the exact definition of the three groups. Later, Park, Jaworski and Maclnnis (1986) in their research of strategic brand management studied three groups that influenced the perceived brand position, including functional, symbolic and experiential attributes.

Table 23 - Classification of Attributes in Literature

Author	Classification	Attributes
Young & Feigin (1975)	Functional Emotional Psychological	Clean, protection Delight Confident
Park et al. (1986)	Functional Symbolic Experiential	Problem solving Self-enhancement, role, belongings, or self-identity Pleasure, cognitive simulation
Babin et al. (1994)	Utilitarian Hedonic	Instrumental, functional Aesthetic, experiential, emotional
Holbrook (1999)	Utilitarian Social Emotional Altruistic	Efficiency, excellence Status, esteem Play, Aesthetics Ethics, spirituality
Green & Jordan (1999; 2002)	Functionality Usability Aesthetics Ergonomics Emotional Symbolic	 Easy to use Pleasure Value, tastes, hopes and fears
Horváth (2001)	Functionality Experience Communicative and expressive power Private Meaning	Usability, utility, practicality Experiential, hedonic and aesthetic Personal role, social relationship Private experience expression
Ashby & Johnson (2002)	Technical Industrial	Mechanical and thermal performance, durability Personality, satisfaction
Voss et al. (2003)	Utilitarian Hedonic	Effectiveness, helpfulness, function, necessity, practica Fun, exciting, delightful, thrilling, enjoyable
Norman (2004)	Appearance Experience Meaning	Initial impact Look and feel Self-image, memories, messages
Snelders &	Hedonic	Aesthetics

Schoormans (2004)	Symbolic Ergonomic	Status, self-expressiveness Practicality, usefulness
Crilly et al. (2004)	Aesthetics Semantic Symbolic	Attractiveness Expressed function, mode-of use and qualities Personal and social significance
Hassenzahl (2004)	Pragmatic Hedonic Aesthetic Emotional	Utility, usability Self-development, self-expression Beauty Satisfaction, pleasure
Lenau & Boelskifte (2004)	Sensorial Symbolic Stylistic	Feel, smell, auditory, taste, visual, texture, form, optics Aggressive, cheap, classic Modernist, futuristic, stream form, contemporary, pop,
Rafaeli & Vilnai-Yavetz (2004)	Instrumental Aesthetic Symbolic	Functionality Aesthetic pleasing Company's image and identity
Pratt & Rafaeli (2006)	Physical Social	Material, durability, sturdiness, senses Instrumental, aesthetic and symbolic meaning
Dell'Era & Verganti (2007)	Function Symbolic Emotional Aesthetic	Operation Geometry, colour, material, surface
Rindova & Petkova (2007)	Aesthetic Functional Symbolic Emotional	Certain, safe, excitement, enthusiasm
Rampino (2011)	Aesthetic Use Meaning Typological	Shape, size, proportion, colour Usability, maintainability, safety, reliability, quality
Gemser et al. (2011)	Functional Experiential	Technology, functionality, ease of use Sensorial, symbolic, emotional
Lee et al. (2011)	Appearance Performance Communication power	Colour, shape, proportion, material Prototypicality Usefulness, ease of use, Innovativeness of technology Identity, value, private experience

Zhang & de Bont (2014)	Appearance Aesthetics Function Usability Quality Core Technology Experience Emotion Value	Form, colour, material Taste, style Connection, communication Ease of use, compatibility Durability, stability Component Interactive, comfort, convenient, caring Interesting, enjoyment, adventure, confident Psychological needs, physical needs, cost efficiency, sustainabi

Babin, Darden and Griffin (1994) assessed consumers' evaluations of a purchasing experience along utilitarian and hedonic attributes. Voss, Spangenberg, and Grohmann (2003) share similar view with Babin et al. (1994). They identify ten important attributes of utilitarian and hedonic attributes from an integrated view. The utilitarian attributes include effectiveness, helpfulness, function, necessity, and practicality. While hedonic attributes include fun, exciting, delightful, thrilling, and enjoyable emotional feelings.

Holbrook (1999) developed a more comprehensive framework of consumer value with four clusters of attributes: utilitarian, emotional, social and altruistic attributes from three dimensions: intrinsic and extrinsic, self-oriented and other-oriented, and active and reactive. Compared with empirical research, it is the first time that altruistic attributes were considered equivalently important to other three attributes. The utilitarian cluster includes attributes of efficiency (e.g., convenience), and excellence (e.g., quality). The emotional cluster includes attributes of play (e.g., fun) and aesthetics (e.g., beauty). The social cluster includes attributes of status (e.g., impression management) and esteem (e.g., possession). The altruistic cluster includes attributes like ethics (e.g., justice) and spirituality (e.g., sacredness). For instance, fair-trade coffee may encompass ethic attributes.

The clusters discussed above are more with theories in marketing and business perspectives, while the attributes' classification is also studied in the design domain. Green and Jordan (1999; 2002) observed that the focus of product design had shifted from functionality, usability or aesthetics to other human factors, such as ergonomics and pleasant. Because the daily business of designing and producing consumer products became highly structured and reliable, products were difficult to be differentiated only based on functionality, usability or aesthetics. In order to increase market competitiveness, other human factors such as "joy in use" should be considered in product design and innovation. Product should not only be designed from functional, physical and cognitive levels, but also symbolic and emotional level with consideration of people's values, tastes, hope and fears.

Horváth (2001) studied role of product design in consumer judgment through four clusters of attributes: 1) the functionality and utility, 2) experiential, hedonic and aesthetic attributes; 3) communicative and expressive attributes; 4) private meaning. Functionality includes usability, utility, and practicality, which fulfills users' needs and advances their lives. Experience refers to that in the process of a product fulfills user's needs, whether the experience is enjoyable in sensual, aesthetic and emotional way. Horváth (2001) separated symbolic cluster into two parts: communicating public symbolic meaning and expressing personal symbolic meaning. The public symbolic meaning refers to how a product can express personal role and social relationship. While personal symbolic meaning refers to a product's ability to express private experiences. For this research, the personal and public symbolic meanings can be integrated into one.

Norman (2004) changed the concept to be suitable for design practice based on classical affective, behavior and cognition model of attitudes. He stated that emotions have a crucial role in the human ability to understand the world, and how they learned new things. When designing daily product, it is important to analyze products in a holistic way to include their attractiveness, their behavior, and the image they present to the user. In this work on design, these different aspects of a product were identified with different levels of processing by people: visceral, behavioral, and reflective. These three levels translate into three different kinds of design. Visceral design deals with the initial impact, the appearance of a product. Behavioral design refers to the look and feels as total experience of using a product. Reflective design concerns the image of a product portrays, the message it delivers, and the owner's state it expresses.

Snelders and Schoormans (2004) in their study of the relation between concrete and abstract product attributes identified three clusters of attributes: hedonic, symbolic and ergonomic attributes. The hedonic cluster includes attributes of pleasure to the senses (e.g. aesthetics). Symbolic cluster relates to status, image and self-expressive motives. Ergonomic cluster includes practicality and usefulness of features.

Crilly, Moultrie and Clarkson (2004) studied consumer's response to design through three clusters: aesthetic impression, semantic interpretation and symbolic association. Specifically, authors suggested that it was not entirely accurate to describe the product as having aesthetic, semantic and symbolic attributes. The categorization is used to reflect "cognition driven by both the perception of tangible stimuli and pre-existing knowledge" (p. 533).

Hassenzahl (2004) stated four clusters, including pragmatic, hedonic, aesthetic, and emotional attributes. In his interpretation, pragmatic attributes are "connected to the users' need to achieve behavioral goals" (Hassenzahl, 2004, p.322). Hedonic attributes are primarily related to the users' self, which can be further subdivided into stimulation (e.g., self-development) and identification (e.g., self-expression). Through objects, individuals want to be seen in specific ways by relevant others, such as more successful, confident, and powerful.

Lenau & Boelskifte (2004) tested sensorial, symbolic and stylistic clusters using words in order to delineate product personality for design practice. The sensorial cluster includes attributes of feeling, smell, auditory, taste and visual, texture, form and optics. The symbolic cluster refers to aggressive, cheap, or classic impression. Stylistic attributes include art nouveau, modernist, futuristic, stream form, contemporary, pop, and retro, etc.

Rafaeli & Vilnai-Yavetz (2004) argued that the aesthetic, instrumental, and symbolic clusters of attributes were connected to consumer' sense making of the product. Different from previous scholars who analyzed symbolism from consumer's personal perspective, they emphasized on how the company could communicate its messages through symbolic attributes, such as the creation of a brand name, an image, and an identity.

Pratt and Rafaeli (2006) identified two product clusters: physical and social. Products are physically constructed with tangible materials (e.g., durability and sturdiness) and intangible user's perception (e.g., sense). Products are also socially constructed through meaning of instrumental, aesthetic and symbolic attributes. The meaning of these attributes is conveyed through products, perceived and interpreted by users, who will communicate and diffuse their perception and interpretation to others in the society. When these individual opinions are collected, they will press the development of culture.

Dell'Era & Verganti (2007) conducted an empirical study to explore innovation and imitation strategy of design language. In the research, they examined four clusters of attributes: functional, symbolic, emotional and aesthetic. Functional cluster can satisfy the operative needs of the customer. Emotional and symbolic clusters contribute to the origin of meaning, which aims to satisfy the emotional and sociocultural needs of the consumers. In the relationship with level of innovation, they suggest that aesthetic attributes are more related to incremental innovation, while functional and meaning innovation may create incremental or radical innovation.

Rindova and Petkova (2007) investigated the relationship between the interplay of functional, symbolic, aesthetic cluster of product and emotional reaction of consumers in incremental and radical innovation. They found that incremental level of functional innovation is more easily to be accepted and perceived as "certain" and "safe" product, as it fits easily with consumer's knowledge about an existed product. In comparison, radical innovation, due to its sever incongruity with the existent scheme, is more difficult to be accepted. Consumers may feel "uncertainty", "intensified" and negative emotions about radical innovation. In order to change their reaction, symbolic and aesthetic attributes could be used to reduce the level of incongruity and trigger familiarity, which leads to the acceptance of radical innovation. In incremental innovation, they can be used to increase the congruity, which may differentiate a product from homogeneous competition.

Based on Holbrook (1999)'s theory, Boztepe (2007) identified clusters of utilitarian, social, and emotional attributes and how they derived user value. The utilitarian cluster includes attributes of convenience, performance and quality, safety and economy. Social cluster includes attributes of social prestige and identity. The emotional cluster includes pleasure and sentimentality.

Rampino (2011) presented an innovation pyramid that categorized four product clusters in product innovation: aesthetic innovation, innovation of use, meaning innovation and typological innovation. Different from other scholars, Rampino argued that emotional and symbolic innovation as meaning innovation. While usually, researchers identified the emotional, experiential, and aesthetic clusters as the same group.

Gemser, Candi and van den Ende (2011) conducted an empirical study to investigate how design can improve company performance. They defined two kinds of design: design for function and design for experience. Functional cluster has three attributes: technology and functionality and ease of use. Experiential cluster encompasses sensorial, symbolic and emotional attributes.

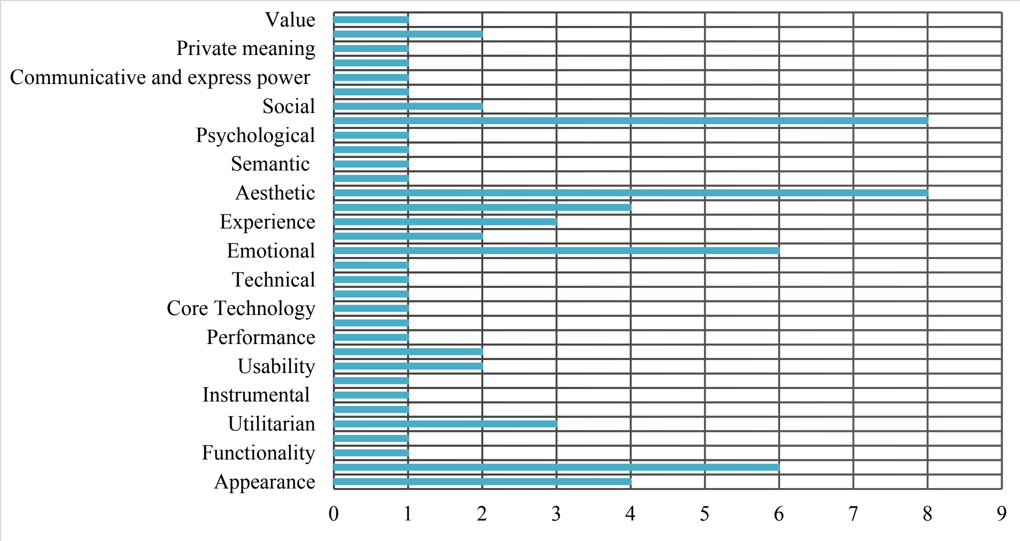
Lee, Ha and Widdows (2011) studied the appearance, performance, communicative power and their relationship to experiential status. In the research, they identified how appearance, performance and communicative power influence consumer's cognitive and experiential status.

Ashby & Johnson (2014) specified the nature of product design as design of technical and industrial attributes. Technical design describes how a product works and how it is made. It includes technical functioning of the product: its mechanical and thermal performance and durability, etc. Industrial design describes a product's personality or character. It includes the satisfaction afforded by the product: the visual and tactile attributes, associations and perceptions, historical antecedents.

Zhang and de Bont (2014) in their study of product attributes and innovation provided a comprehensive system of attributes, including clusters of functional, appearance, experiential, aesthetic, emotional, psychological, symbolic, social, and altruistic attributes. Their classification covered major clusters discussed in literature.

After reviewing the 21 studies, it was found that 33 clusters were discussed. The clusters and frequency of clusters were listed below (Table 24). Among them, the aesthetic (N=8), symbolic (N=8), and functional (N=6) have been mentioned most. All of the studies were focused on the non-electronic and electronic product types. None of them concentrated on intelligent product type. None of intelligent product attributes was classified in the studies reviewed.

Table 24 − Frequency of Clusters



5.3.2 Nature of the Attributes in Literature

The classification of attributes in this thesis was not only based on the classification of attributes in literature, but also on the nature of attributes. Attributes with the same nature should be classified into the same cluster. In the literature reviewed, researchers identified three types of nature of product, including subjective and objective (e.g., Maynes, 1976), concrete and abstract (e.g., Olson & Reynolds, 1983), and intrinsic and extrinsic (e.g., Olson, 1977). In the following, the four types of nature were examined.

5.3.2.1 Subjective and Objective

The objective attributes are quantitatively measurable and physical properties of a product, such as the size, ride qualities, maintenance, and price of automobile (Lancaster, 1971). While subjective attributes concerns consumers' subjective judgments, perceptions, attitudes directed toward specific features (e.g., convenience, durability) (Geistfeld et al., 1977).

5.3.2.2 Concrete and Abstract

Attributes could also be organized according to their abstraction level (Johnson, 1989). Concrete attributes are the objective properties of a product that can be directly measured and experienced by touch or visually perceived (Olson & Reynolds, 1983). They can be tangible, such as color, size, or intangible such as weight, or functions. Compared with concrete attributes, abstract attributes connect more with consumer's expectation and perception, because in human memory most of information is represented abstract levels (Johnson, 1989). They are the intangible and subjective aspects of a product, such as experience, emotional association, and symbolic meaning, determined individually (Snelders & Schoormans, 2004).

5.3.2.3 Intrinsic and Extrinsic

Attributes can be categorized as intrinsic and extrinsic attributes (Fandos & Flavián, 2006). Intrinsic attributes refer to a property of a material itself or within, which cannot be changed without altering the nature of the product (Olson & Jacoby 1972; Olson 1977). Extrinsic attribute is a property that is not inherent or part of the physical product, but they can serve as general indicators across all types of products (Zeithaml, 1988). For instance, the intrinsic attributes of food could be color, flavor, smell, or appearance. Extrinsic attributes could be a brand name, price, or country of origin.

In literature and practice, both intrinsic and extrinsic attributes are essential for product innovation. However, due to limited time and efforts, only intrinsic attributes were considered in this thesis. So extrinsic attributes like price, frequency of repair, packaging, brand, recommendation, the country of origin, warranty, information provided, service-availability, product availability, credit availability, capital intensity, and transfer of ownership was excluded.

5.3.3 Relationship of Attributes in Literature

Many scholars studied the relationship of attributes. The relationship is very important, as it determines how the framework is built and how to innovate the product.

Green and Jordan (2002) stated a hierarchical relationship among product attributes. Functionality is a pre-requisite of usability, but it does not guarantee usability and there is a hierarchical relationship among functionality, usability, emotion and symbolism. After fulfilling the functionality and usability needs of people, products should also be “living objects”, which can be related to with symbolic meaning. Products that bring emotional benefits, such as pleasure are more attractive than a product that can only perform as a tool. Similar argument has been frequently used to measure whether and in which level a product fulfills users’ needs (Lewalski, 1988; Yalch & Brunel, 1996; Rafaeli & Vilnai-Yavetz, 2004; Chitturi, Raghunathan & Mahajan, 2008).

Other scholars argued that a continuum lies between concrete attributes and abstract attributes (e.g., Geistfeld et al., 1977; Zeithaml, 1988; Johnson, 1989; Grunert & Grunert, 1996). Concrete attributes are the basic attributes, upon which lie abstract attributes. Abstract attributes are actionable through concrete attributes. Users can derive the presence of abstract attributes from the presence of concrete attributes, through summation and concentrating information (Olson & Reynolds, 1983; Johnson, 1989). Abstract attributes could be captured from several concrete attributes (Shocker & Srinivasan, 1974; Snelders & Schoormans, 2004).

5.4 Discussion

5.4.1 Four Sectors of Attributes

The 33 clusters of attributes can be further categorized into four groups, following criteria of below:

- Clusters with similar meaning
- Clusters with close relationship

Group 1 describes the physical existence of a product. The existence could be visually perceived, such as the shape, size, proportion and color of a product (Lee et al., 2011).

Author	**Group 1**	**Group 2**	**Group 3**	**Group 4**
Young & Feigin (1975)		Functional	Emotional	Psychological
Park et al. (1986)		Functional	Experiential	Symbolic
Babin et al. (1994)		Utilitarian	Hedonic	
Holbrook (1999)		Utilitarian	Emotional	Social Altruistic
Green & Jordan (1999)		Functional Usability Ergonomic	Aesthetic Emotional	Symbolic
Horváth (2001)		Functionality	Experience	Communicative and express Power Private Meaning
Ashby & Johnson (2002)		Technical Industrial		
Voss et al. (2003)		Utilitarian	Hedonic	
Norman (2004)	Appearance		Experience	Meaning
Snelders & Schoormans (20		Ergonomic	Hedonic	Symbolic
Crilly et al. (2004)			Aesthetic Semantic	Symbolic
Hassenzahl (2004)		Pragmatic	Aesthetic Hedonic Emotional	
Lenau & Boelskifte (2004)			Stylistic Sensorial	Symbolic
Rafaeli & Vilnai-Yavetz (20		Instrumental	Aesthetic	Symbolic
Pratt & Rafaeli (2006)		Physical		Social
Dell'Era & Verganti (2007)		Functional	Aesthetic Emotional	Symbolic
Rindova & Petkova (2007)		Functional	Aesthetic Emotional	Symbolic
Rampino (2011)			Aesthetic	Meaning

			Mode of Use	
Gemser et al. (2011)		Functional	Experiential	
Lee et al. (2011)	Appearance	Performance		Communicativeness
Zhang & de Bont (2014)	Appearance	Function Quality Core Technology Usability	Aesthetics Experience Emotion	Value

Group 2 describes how a product is able to finish a task, achieve a behavior or solve a problem. Previous researchers used different terms to refer to similar meaning of functionality, including functional, functionality, function, utilitarian, pragmatic, and instrumental (e.g., Young & Feigin, 1975; Babin et al., 1994; Green & Jordan, 1999; 2002; Hassenzahl, 2004; Rafaeli & Vilnai-Yavetz, 2004). While usability, ergonomic, performance, quality and core technology belong to the function related clusters (e.g., Horváth, 2001; Hassenzahl, 2004).

Group 3 refers to the sensational experience of users when using a product, such as the emotional experience, aesthetic experience, and sensorial experience. Some researchers use "appearance" and "aesthetics" interchangeably (e.g., Rampino, 2011), while others distinguish one from another (Lee et al., 2011; Zhang & de Bont, 2014). This thesis takes the later approach regarding appearance as objective representation of a product. Aesthetics concerns the human's subjective perception of appearance (e.g., Horváth, 2001). It is considered as an experience attributes (e.g., Zhang & de Bont, 2004).

Group 4 concerns the content that a product communicates to its user or what a user needs the product to communicate to others (Rampino, 2011), such as the symbolic meaning, private meaning or social meaning.

After organizing the four groups, each of the group was given a name, following criteria of below:

- The frequency in the literature reviewed.
- Whether the term is representative enough for the group.

Group 1 is named as appearance, as it is the only cluster of the group. Group 2 is named as function, as it is a frequently used, more representative and easy to generalize them in both academic and industry. Physical, technical and industry has been less mentioned in the research reviewed. Group 3 is named as experience, as emotional, hedonic, aesthetic, or sensorial attributes all are related to experience. The term of experience can represent this group. Group 4 is named as meaning, as psychological, symbolic, social or altruistic attributes all are perceived as a meaning that a product transferred.

Table 25 - Four Sectors of Attributes

Sectors of Attributes
Appearance
Functionality
Experience
Meaning

As the sectors were not generated from intelligent products related research, it is necessary to test whether the four sectors can be used to organize intelligent product attributes. In the following section, intelligent product attributes captured in Chapter 2 (see Table 5) were categorized within the four sectors (Table 26).

Table 26 - Categorization of Intelligent Product Attributes with Four Sectors

Sectors	Attributes
Appearance	/
Function	Data management/collection/exchange/storage/analysis Decision-making Identification Connectivity Communication Monitor Inter-operation Tracking Sensing Adaption Reasoning Actuation Interaction Knowledge generation/carrying Learnability Memorability Predictability Responsiveness Language displaying Forgiveness
Experience	Effectiveness Efficiency Participating Simplicity experience Consistency experience Modelessness experience Flexibility Helpfulness
Meaning	/

It was found that all of the attributes could be categorized within the four sectors. So the sectors identified in this chapter are comprehensive enough to organize the intelligent product attributes discussed in the literature. It was also found that all of the attributes reviewed were categorized into function and experience sectors. It indicated that studies of intelligent product attributes concentrated on these two areas or/and these two sectors are innovated more. Although no attributes can be categorized into appearance and meaning sectors, it only means that studies reviewed in Chapter 2 were not conducted in this area. It does not mean that intelligent product does not have the appearance and meaning related attributes, or the innovation of intelligent product could not happen in appearance and meaning sectors. On the contrary, it demonstrated the opportunity gap that industry and academic field can make more efforts on.

5.4.2 Nature of the Four Sectors

The appearance and functionality sectors are defined as objective and concrete sectors. They describe the universal and quantitatively measurable properties of a product, which are independent of user's judgment or perception (Table 27).

The experience and meaning sectors are defined as subjective and abstract sectors, which are generated with subjective perception, interpretation, or judgment (Table 27).

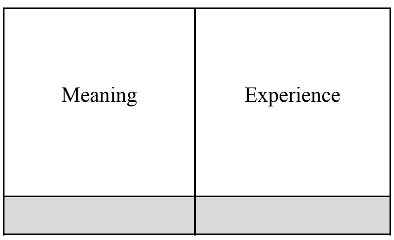
Table 27- Nature of the Four Sectors

Objective and Concrete	Subjective and Abstract
Appearance	Experience
Functionality	Meaning

5.4.3 Relationship Within The Four Sectors

As appearance and function are considered as concrete sectors and experience and meaning are understood as abstract sectors, there is a hierarchical relationship between them (**Figure 5**). In the figure, the appearance and function were placed at the bottom, while experience and meaning were illustrated above to represent their higher level of abstraction.

Appearance and function serve as basis, through which experience and meaning can be achieved. Appearance enables a product to physically exist in reality. Function provides meaning for its existence. Experience and meaning can be recognized as the combined results of appearance and functionality.



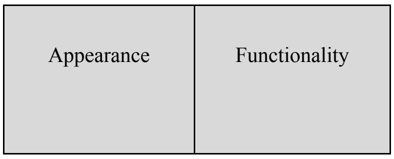


Figure 5 - Relationship within the Four Sectors

Experience can be captured from appearance and function. The design of appearance can affect product experience (Wagner, 1999). As aesthetic experience is derived from the appearance, the change of color, shape, or proportion may alter user's visual perception (Bloch, 1995). The emotional experience can be aroused from appearance as well. Whether the buttons are easy and pleasant to press can be the consequence of balancing form, size, material and texture. Different product appearance can trigger an emotional response, such as "cheerful", "boring", "friendly", or "rude" (Sassoon, 1992; Vihma, 1995). Sensorial experience can also be stimulated by appearance (Rampino, 2011), such as sense of cold from metal material. Functionality plays an important role in the user's perception (Bürdek, 2005; Lee, Ha & Widdowss, 2011). It determines the nature of fulfilling a given purpose, which is capable of creating enjoyable activities, sensual pleasure, and aesthetic experience (Spangenberg, Voss & Crowley, 1997). The functionality can affect user's aesthetic experience. A helpful and well-designed product can be perceived more pleasant. As emotional experience tends to correspond, respectively to functionality, by improving product's quality and performance, the emotional and psychological status of users can be more satisfied, pleased and confident (Young & Feigin, 1975; Holbrook & Zirlin, 1983; Hassenzahl, 2004).

Meaning can be captured from appearance and function. Product appearance can influence how users perceive product meaning. Users do not judge the form of a product isolated, but by associating it with the information and knowledge absorbed in social, cultural and economic meaning (Krippendorf, 1996). Appearance possesses visual and semantic information, which is obvious for users to capture and interpret (Bloch, 1995). Angular forms are associated with masculinity or strength, while roundness evokes femininity, an easy-going, or weakness (Schmitt & Simonson, 1997). The change of product functionality may bring new meaning to a product. For instance, after Siri is applied to iPhone4, the smart product has a new function of intelligent personal assistant and knowledge navigator. The new function can answer vocal questions, make recommendations, and perform actions by delegating requests to a set of Web services. In order to achieve these functions, Siri involves a number of core technologies, such as automatic speech recognition, natural language processing, question analysis, data mashups to interface with third party search operations, and machine learning to adapts to the user's individual language usage and individual searches (preferences) with continuing use, and returns results that are individualized (Turner, 2011).

In this chapter, the classification of attributes identified in literature was examined. Four sectors were identified including appearance, function, experience and meaning. The four sectors were not generated from literature related to intelligent products, but from non-electronic products and electronic products. After testing the four sectors with intelligent product attributes identified in, it was found that the four sectors were comprehensive enough. Among four sectors, appearance and function are concrete and objective, while experience and meaning are abstract and subjective. A hierarchical relationship exists between the two pairs of sectors.

In the next chapter, a large amount of unidentified intelligent products' attributes will be captured from various sources. It is possible that the four sectors may not sufficiently include all of the attributes. So after identifying intelligent product attributes, they will be categorized into the four sectors to test. The sectors and their relationship are essential for building the framework, as they determined how the framework is designed.

Chapter 6 – Intelligent Product Attributes

6.1 Introduction

In order to build a framework based on attributes, it is a priority to identify the attributes of an intelligent product. Abundant research of product attributes in literature could be used as reference for the study of intelligent product attributes. As stated in Chapter 2, most of intelligent product attributes were discussed from a technological perspective. It is possible that non-technological attributes are equivalently essential for intelligent product innovation, as they play an important role in consumer's decision of purchase or evaluation of a product (e.g., Haley, 1968; Hult et al., 2000). As non-technological attributes were discussed adequately in literature, a critical overview of product attributes studies needs to be conducted.

Although product attributes have been exhaustively studied in literature, it is possible that some attributes are not explored thoroughly yet. Because intelligent product is an emerging category in the consumer market, some new attributes innovated in business practice have not attracted enough attention in the academic field. These attributes could be as influential as they represent the new needs from users or even shifts of paradigm in product development. In order to reveal the potentially valuable attributes, an empirical study is required. An interview was conducted with practitioners and academic scholars to investigate these novel attributes of intelligent product. The research question and sub questions addressed by this chapter are:

RQ6. What are the attributes of intelligent products (based on the academic literature and on expert interviews)?
RQ6.1 What are the intelligent product attributes generated from literature?
RQ6.2 What are the intelligent product attributes generated from interviews?
RQ6.3 Could the attributes generated from the two sources be organized with the four sectors identified?
RQ6.4 What are the similarity and difference between attributes generated from the two sources?
RQ6.5 Could the intelligent product attributes generated from the two sources be integrated?

To answer the research questions, the rest of the chapter is structured as following: first, the research method was introduced. Systematic literature review was conducted on 376 theoretical and empirical studies. Not only product attributes in general, but also attributes in related product categories were included (e.g., smart product, IoT, robot). These attributes could be used as reference for the generation of intelligent product attributes. Second, 202 valid interviews were conducted with experts and researchers worldwide to collect inspiring insights on the topic of intelligent product attributes. Then, the literature selected and interview transcripts were coded and analysed. The attributes identified were synthesized, compared, and integrated.

6.2 Method

First, data was collected through a systematic literature review and interview. Then the data were analyzed through content analysis.

6.2.1 Systematic Literature Review

Systematic literature review has been used successfully in various studies to discern the core features of how a concept has been defined (Kitchenham, 2007; Dybå & Dingsøyr, 2008; Gutierrez et al., 2013). The main advantage of the method is that it can provide an exhaustive summary of current literature relevant to the research question.

6.2.1.1 Search Strategy

A number of large digital databases that are accessible at the Hong Kong Polytechnic University are searched. Besides, website of MIT Technology Review, Robot and Beta, and Wired are considered as a valuable source of information as recommended by the interviewees. The data sources are shown in Table 28. Searched data is organized with the management software Nvivo®.

Table 28. Data Source

Data Source
IEEE Explorer
Science Direct
EBSCO host
Google Scholar
Elsevier
MIT Technology
Robot and Beta
Wired

As the innovation of intelligent product is related to various disciplines, the advanced search mode is applied with related published fields and period of all years (Table 29).

Table 29 - Related Published Field

Technological Field	Non-technological Field
Information Technology Computer Science	Business Marketing Economics
Mechanical Engineering Electronic Engineering	Design
Science and Technology Environment and Energy	
Manufacturing	

It is possible that some characteristics still haven't been systematically proposed. However, the current literature of intelligent products is not sufficient to be used to identify these characteristics. As previous research demonstrated that certain concepts exhibit similarity and difference with intelligent products (see Chapter 2), the attributes of these related concepts could be used as reference for generating intelligent product attributes.

As attributes from related product types can be used as reference (see Chapter 2), they were included in the searching keywords as following. In many research, the terms of "characteristic", "feature" or "property" are used interchangeably for "attribute". Therefore, they are also included in the search string (Table 30). Ten searches were conducted independently.

Table 30 - Search string

1. *("Product") AND ("attribute" OR "characteristic" OR "feature" OR "property")*
2. ("Electronic") AND ("product") AND ("attribute" OR "characteristic" OR "feature" OR "property")
3. *("Smart") AND ("product") AND ("attribute" OR "characteristic" OR "feature" OR "property")*
4. *("Smart PSS") AND ("product") AND ("attribute" OR "characteristic" OR "feature" OR "property")*
5. *("AI") AND ("product") AND ("attribute" OR "characteristic" OR "feature" OR "property")*
6. ("Ubicomp") AND ("product") AND ("attribute" OR "characteristic" OR "feature" OR "property")
7. ("IoT") AND ("product") AND ("attribute" OR "characteristic" OR "feature" OR "property")
8. ("Robot") AND ("product") AND ("attribute" OR "characteristic" OR "feature" OR "property")
9. ("AmI") AND ("product") AND ("attribute" OR "characteristic" OR "feature" OR "property"
10. ("Intelligent") AND ("product") AND ("attribute" OR "characteristic" OR "feature" OR "property")

6.2.1.2 Inclusion and Exclusion Criteria

After reviewing the papers, it was found that some results from academic research were irrelevant and invalid. Criteria were established inspired by Dybå and Dingsøyr (2008) as following:

- Written in English.
- Published up to and including 2017.
- Authored by academic researchers or business practitioners.
- Utilized qualitative or quantitative methods.

Articles with the following criteria were excluded:

- The keywords in studies were not complete.
- The keywords in studies were not as a combination.

6.2.1.3 Quality Assessment

The studies were evaluated on the basis of their relevance, reliability, and validity. Six quality assessment questions proposed by Gutierrez et al. (2013) were used to select the appropriate articles (Table 3).

Table 3 - Quality Criteria by Gutierrez et al. (2013)

QA	Answer

Is the study based on research methods?	Yes/No
Is there a clear statement of the aims and objectives of the research?	Yes/No
Are there relevant studies included in the findings?	Yes/No
Are the results evaluated in accordance with objective criteria?	Yes/No
Is there a clear statement of findings?	Yes/No

6.2.2 Expert Interview

The method of semi-structured interview is applied. This method has been used successfully in various related research. The main advantage of the method is to get the in-depth, representative and comprehensive information around a topic through subject's point of view (McNamara, 1999).

6.2.2.1 Sampling Strategy

The whole population related to intelligent product innovation included all experts and scholars from various disciplines worldwide. The exact whole population was difficult to examine. Considering this situation, the sample could not be selected based on randomization (Guest, Bunce & Johnson, 2006; Saunders, Lewis & Thornhill, 2012). A subjective judgment of the sample size is required. In this research, the sample size was determined following two principles. The interviewees were recruited until no new intelligent product attributes were found in their answering. The interviewees were recruited based on limited time and expense of the research. The ideas, opinions and answers from the interviewees could be used as representative opinions of the whole population.

Two non-probability sampling methods - convenience sampling and snowball sampling were applied in this research. Interviewees recruited from these methods are more readily and easily accessible with geographical convenience, availability at a given time, or the willingness to participate (Heckathorn, 1997). Data could be collected in a short duration of time with higher efficiency and less expense. The disadvantages of the methods could be potential bias and difficulty for generalization.

6.2.2.2 Inclusion and Exclusion Criteria

In order to maintain validity and reliability, criteria below were used to select the samples:

- The sample should match the target population on certain characteristics (Doherty, 1994).
- The sample's geographic location, nationality, and background should have diversity (Saunders, Lewis & Thornhill, 2012).
- The sample should hold sufficient knowledge and experience to answer the questions.
- The sample should be able to be accessed with affordable time and expense.
- The sample should include interviewees from the business field and the academic field.

In this research, interviewees that meet the criteria are recruited through the researcher's working, study, and personal network, including:

- Colleagues in previous working companies.
- Experts, researchers and scholars in the Hong Kong Polytechnic University
- Experts and scholars known in conferences and events, like Design Education Conference, Business of Design Week, HCI International Conference, and Asian Design Engineering Workshop, etc.
- Experts and scholars accessed via social network, like LinkedIn.

6.2.2.3 Interview Strategy

Mixed mode interview was conducted, including the face-to-face interview, email interview, and message interview. Face-to-face interview can facilitate a real and close connection between the interviewer and interviewee, which make them disclose their in-depth opinions more easily (Denscombe, 2003). But it also costs more time and expense compared with the other two methods. So email interviews and message interviews were conducted, as the quality of responses gained through them is much the same as face-to-face interview (Denscombe, 2003). The two methods enable interviewees more time and flexibility to think about answers without transcription errors. However, multiple senses' interaction is deficient between interviewers and interviewees.

Interview questions in written and spoken format:
Q1: *What characteristics/features does intelligent product* (e.g., wearable, intelligent home appliances) *have?*
Q2. Could you give an example to explain?

30 minutes to 1 hour face-to-face interview was conducted in School of Design, The Hong Kong Polytechnic University or at the place chosen by interviewees. Two research questions were asked sequentially. In order to get in-depth information from interviewees, follow-up questions were asked. The interviewees' response was recorded under their permission.

Message interviews were conducted with Wechat APP, which has the largest group of active users in Asia (Statista, 2016). The questions were sent to interviewees through the APP, then the interviewees respond with either written or voice message. The process was iterative and conversational, in order to fully understand the meaning that interviewees intended to express. The ambiguous answers were clarified through follow-up messages.

Email interviews were conducted with interviewees globally. Most of the emails were sent through LinkedIn account of the researcher. The advantage of LinkedIn is that it is the world's largest professional network. Interviewees recruited from LinkedIn were willing to respond. The background information of interviewees is available on the website, which made it easy to decide whether they met the selection criteria. Interviewees reached through LinkedIn emails include experts, scholars worldwide. Interviewees were also recruited and communicated with an email address directly.

After interview, interviewees were encouraged to recommend their acquaintances, colleagues or friends as new interviewees. The process continues until the sample size was believed to be saturated for this study.

6.2.3 Content Analysis

After gathering data from systematic literature review and interview, content analysis was used to analyze the data. Content analysis refers to assign codes to indicate the presence of interesting and meaningful patterns (Hodder, 1994). The methods have been proved to be useful in various related research (Saldaña, 2015).

6.2.3.1 Coding Strategy

When coding attributes from selected articles and interview transcripts, salient and essence-capturing attributes were derived directly from the text data (Hay, 2005). While ambiguous attributes were abstracted, summarized, and interpreted from their underlying context based on pre-existing knowledge of product attributes discussed in literature.

6.2.3.2 Coding Process

The software of Nvivo was used for coding. Selected papers from systematic literature review and transcripts from interviews were input into the Nvivo software first. Then attributes were coded manually. In order to increase trustworthiness, coding process was conducted iteratively with consistency according to Weber (1990). Inspired by Hsieh and Shannon (2005), five steps were conducted for coding:

- Looking for and highlight the sentence related to product attributes.
- Coding all of the highlighted text by using the predetermined attributes discussed in literature.
- Text that could not be coded with the predetermined codes would be given a new code.
- Going through all of the highlighted text again to confirm whether all attributes have been coded.
- Combining the synonyms coded attributes if necessary.

6.3 Findings

6.3.1 Overview of Attributes' Literature

376 papers and articles were selected from a systematic literature review based on the inclusion and exclusion criteria (Table 31). In the following section, overview information gathered was shown, including the source of literature, background of authors, and the context of the studies was displayed.

6.3.1.1 Source of Studies

The major sources of information were journal (N=217) and conference (N=84), while important contents from the Internet were also included (N=45).

Table 31 - Source of literature

Source	No.
Journal paper	217
Conference paper	84
Internet article	45
Book	23
Phd thesis	4
Working paper	3

6.3.1.2 Background of Authors

The backgrounds of authors were identified according to their faculty, school, department, institution or company's department in the published articles (Table 32). Papers from different important disciplines were included.

Table 32 - Background of Authors

Technological Field	No.	Non-technological Field	No.
Information Technology	37	Design	51
Mechanical Engineering	35	Marketing	35
Computer Science	33	Business	32
Electronic Engineering	32	Others	43
Science and Technology	31		
Manufacturing	29		
Environment and Energy	7		

6.3.1.3 Context of Studies

178 articles explicitly focused on attributes' studies (**Figure 6**). The context of attributes studies can be classified into four groups, including consumer and attributes, product design and attributes, measurement of attributes, and fundamental concept of attribute (**Figure 6**).

Haley (1968) was the first to study product attributes and customer's preference. Lanchester (1971) introduced the idea that products were consumed for the characteristics they possess. Wu, Day and MacKay (1988) studied how product attributes influence consumer's preference of a product with an experimental test. Horváth (2001) studied the role of product design in consumer judgments of product attributes, such as functionality, experience or meaning. Voss, Spangenberg and Grohmann (2003) develop a scale that measures consumer attitude toward product attributes.

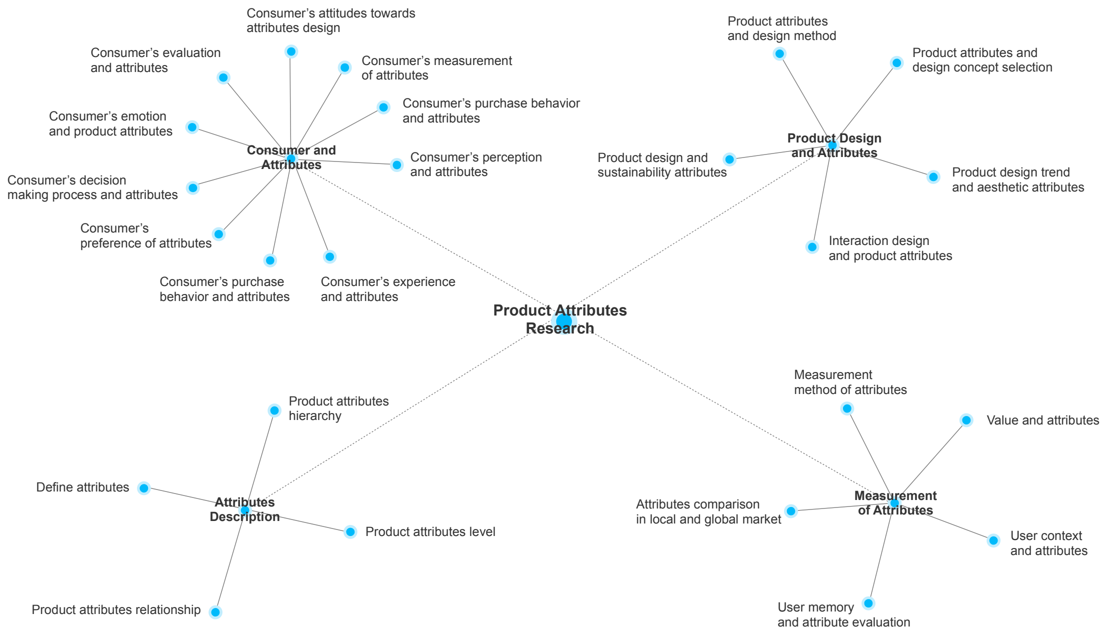


Figure 6 - Context of attributes' studies

Among the research of product attributes, some of them focused on the specific attributes of intelligent products. Hassenzahl (2004) studied the interplay of beauty, goodness and usability of intelligent products. Li, Ha and Widdows (2011) explored how high-technology attributes influence consumer responses from cognition and emotions. Valencia et al. (2015) identified eight characteristics of smart PSS. However, at the current stage, exploration of intelligent product attributes was not exhaustive. Only limited literature in this area was founded.

198 articles were indirectly related to attributes' studies (**Figure 7**). The context of these studies can be classified as the following:

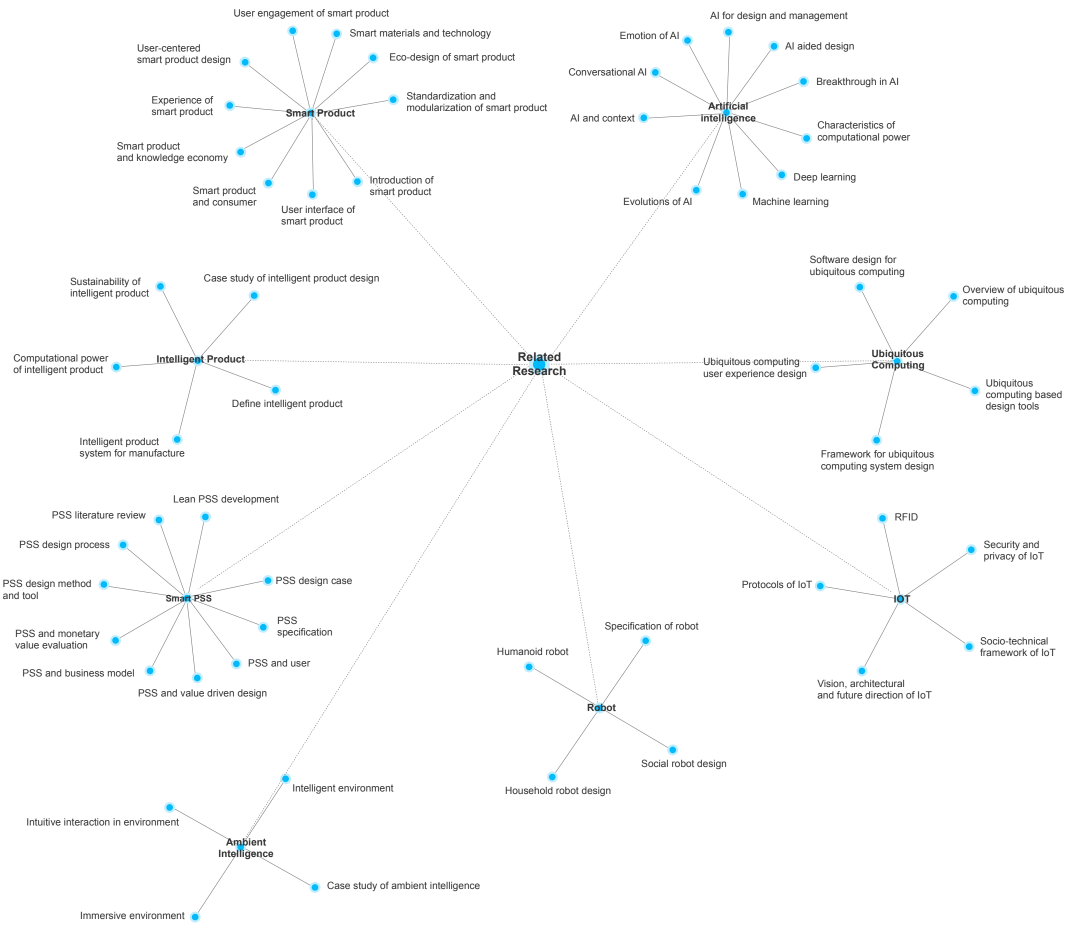


Figure 7 - Context of Related Studies

6.3.2 Attributes from Literature

The overall number of attributes coded from literature was too large to describe one by one. In order to manage and analyze them more efficiently and clearly the attributes were further combined, reduced, or organized according to the criteria of below (Table 33).

Table 33- Criteria of Organization

1. Inclusion criteria	•Attributes that were important; •Attributes that were representative; •Attributes that can be generalized; •Attributes with high frequency;
2. Exclusion criteria	•Attributes that were not clearly defined; •Attributes that were not frequently discussed; •Attributes that were hard to generalize;
3. Combination criteria	•Attributes with causal relationship; •Attributes with subordinate and superordinate relationship; •Attributes with similar meaning;

After further organization, 155 attributes coded from literature were identified. The attributes were listed below according to their frequency (Table 34).

Table 34 - Attributes from Literature

Attributes	Freq.
1. User-friendly	302
2. Quality	229
3. Performance	219
4. Interaction experience	203
5. Function	188
6. Data Management	181
7. Cost efficiency	169
8. Networked	160
9. Connectivity	154
10. Integrated	150
11. Core Tech	147
12. Size	146
13. Intuitive Interaction	146
14. Environmental	145
15. Economic	142
16. Material	138
17. Intelligence	137
18. Interesting	131
19. Satisfaction	125
20. Social	124
21. Understandability	123
22. Reliability	122
23. Computational power	122
24. Compatibility	121
25. Energy and resource sharing	120
26. Learnability	117
27. Local	115
28. Form	112
29. Comfortable	108
30. Speed	107
31. Sharing	103
32. Weight	102
33. Safety	101
34. Utility	101
35. Cultural	100
36. Problem solving	99

37.	Security	95
38.	Sense of power	94
39.	Openness	92
40.	Style	90
41.	Effectiveness	87
42.	Identity	86
43.	Usability	82
44.	Proportion	80
45.	Engagement	80
46.	Useful	79
47.	Color	78
48.	Adaptive	77
49.	Embedded tech	77
50.	Efficiency	75
51.	Sustainability	75
52.	Screen tech	72
53.	Emotional	72
54.	Autonomous	68
55.	Trust	68
56.	Sensing	67
57.	Monitor	67
58.	Planning	66
59.	Length	65
60.	Privacy	65
61.	Identification	65
62.	Accuracy	64
63.	Aesthetic	64
64.	Fun	64
65.	Tracking	61
66.	Free of frustration	58
67.	Battery tech	55
68.	Convenience	55
69.	Social status	54
70.	Symbolic	54
71.	Communication	52
72.	Stability	51
73.	Invisibility	51
74.	Simplicity	51
75.	Recognition	50
76.	Decision-making	49
77.	Affective	48

78.	Anticipatory	45
79.	Seamless	44
80.	Inter-operability	44
81.	Life style	44
82.	Structure	42
83.	Sense of belonging	42
84.	Enjoyable	40
85.	Exciting	39
86.	Durability	36
87.	Customization	32
88.	Empowerment	32
89.	Community transformation	32
90.	Proactive	30
91.	Texture	29
92.	Gesture control	29
93.	Utilitarian experience	29
94.	Craftsmanship	28
95.	Responsiveness	26
96.	Ergonomic	26
97.	Context-awareness	25
98.	Personalization	24
99.	Moral	24
100.	Humanoid	22
101.	Interaction method	21
102.	Luxury	21
103.	Human-centered	21
104.	Synchronized	20
105.	Social Welfare	19
106.	Width	18
107.	Height	18
108.	Reasoning	18
109.	Immersive	18
110.	Confident	17
111.	Spiritual	17
112.	Type-in	16
113.	Memorable	16
114.	Elegance	16
115.	Product life cycle management	15
116.	Capacity	13
117.	Self-organization	13
118.	Delightful	13

119.	Ethics	10
120.	Sentimental	9
121.	Sensory experience	8
122.	Trend	7
123.	Self-management	6
124.	Helpful	6
125.	Adventure	6
126.	Pattern	5
127.	Consistency	5
128.	Quietness	2
129.	Unity	2
130.	Necessity	2
131.	Organic	1
132.	Angular	1
133.	Aerodynamic	1
134.	Flat	1
135.	Squared	1
136.	Rounded	1
137.	Metal	1
138.	Rubber	1
139.	Smart material	1
140.	Bending	1
141.	Stress	1
142.	Proportional	1
143.	Balance	1
144.	Symmetry	1
145.	Rhythm	1
146.	Harmony	1
147.	Logical	1
148.	Passive	1
149.	Tactile	1
150.	Olfactory	1
151.	Auditory	1
152.	Taste	1
153.	Sense of Place	1
154.	Point in Time	1
155.	Sturdiness	1

In order to compare and integrate attributes more systematically and efficiently, attributes captured from literature were categorized into the four sectors (see Table 27 in Chapter 5) in the following sections (**Figure 8**).

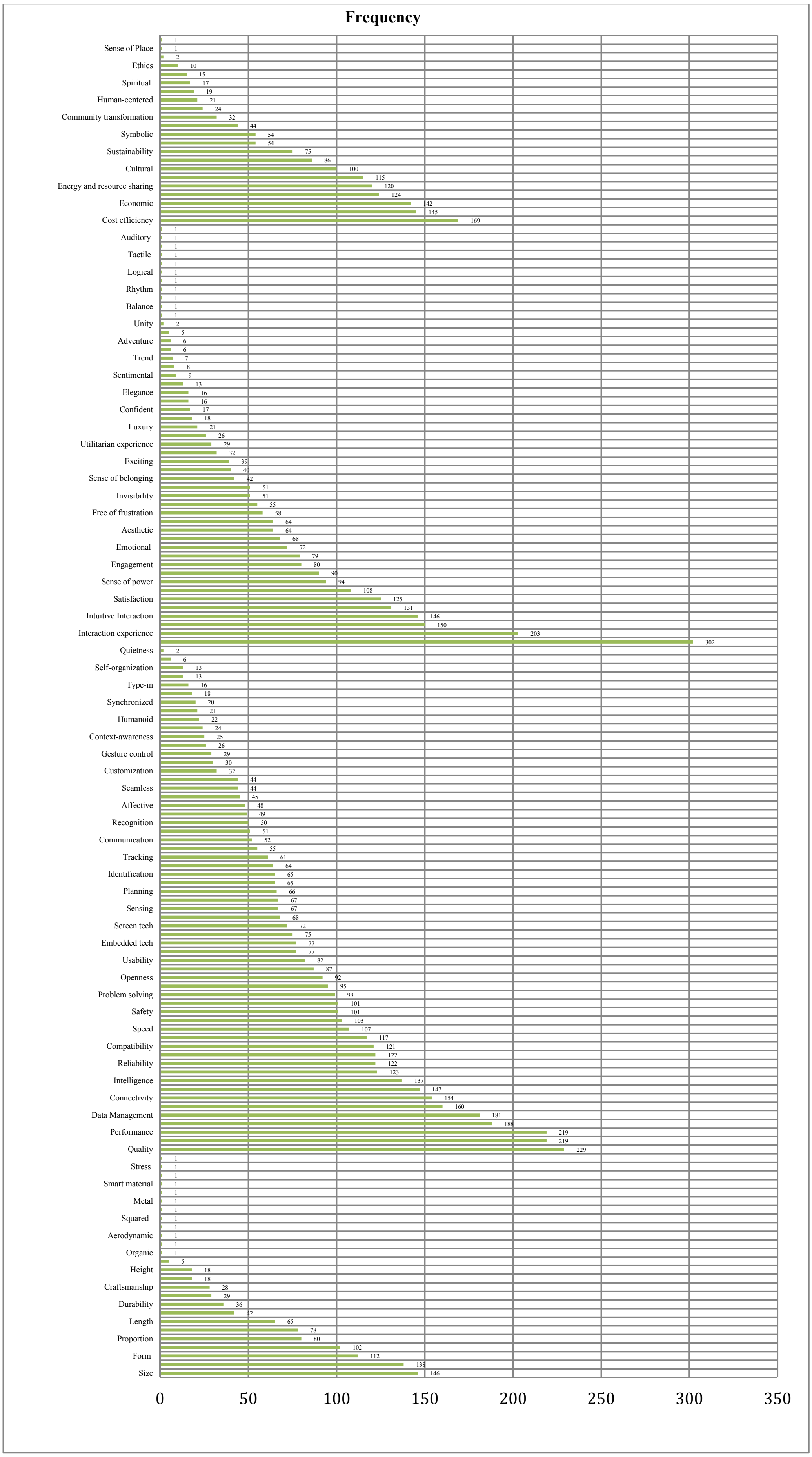

Frequency
Sense of Place
Ethics
Spiritual
Human-centered
Community transformation
Symbolic
Sustainability
Cultural
Energy and resource sharing
Economic
Cost efficiency
Auditory
Tactile
Logical
Rhythm
Balance
Unity
Adventure
Trend
Sentimental
Elegance
Confident
Luxury
Utilitarian experience
Exciting
Sense of belonging
Invisibility
Free of frustration
Aesthetic
Emotional
Engagement
Sense of power
Satisfaction
Intuitive Interaction
Interaction experience
Quietness
Self-organization
Type-in
Synchronized
Humanoid
Context-awareness
Gesture control
Customization
Seamless
Affective
Recognition
Communication
Tracking
Identification
Planning
Sensing
Screen tech
Embedded tech
Usability
Openness
Problem solving
Safety
Speed
Compatibility
Reliability
Intelligence
Connectivity
Data Management
Performance
Quality
Stress
Smart material
Metal
Squared
Aerodynamic
Organic
Height
Craftsmanship
Durability
Length
Proportion
Form
Size
1 1 2 10 15 17 19 21 24 32 44 54 54 75 86 100 115 120 124 142 145 169
1 1 1 1 1 1 1 1 1 1 1 2 5 6 6 7 8 9 13 16 16 17 18 21 26 29 32 39 40 42 51 51 55 58 64 64 68 72 79 80 90 94 108 125 131 146 150 203 302
2 6 13 13 16 18 20 21 22 24 25 26 29 30 32 44 44 45 48 49 50 51 52 55 61 64 65 65 66 67 67 68 72 75 77 77 82 87 92 95 99 101 101 103 107 117 121 122 122 123 137 147 154 160 181 188 219 219 229
1 1 1 1 1 1 1 1 1 1 1 1 5 18 18 28 29 36 42 65 78 80 102 112 138 146
0
50
100
150
200
250
300
350

Figure 8 - Attributes in Four Sectors

6.3.3 Overview of Interview

In the following section, overview information of interviewees gathered was displayed, including the number of interviewees, their age, gender, background, position, geographic location, and nationality.

6.3.3.1 Number of Interviewees

Valid interviews in total were 202. At first 300 interviewees were invited, including100 persons accessed face-to-face. 100 interviewees accessed with mobile message APP and 100 persons accessed with email. However, responses from mobile message APP and email were much less than face-to-face interview. More interviewees were recruited from these two sources. In total, 450 interviewees were invited in total. Among them, most interviewees were invited from email (N=200). The highest response rate was from face-to-face interview (N=75%). The highest validity rate was from face-to-face interview as well (N=100).

Table 35 - Number of Interviewees

	Face-to-face	Mobile Message APP	Email	In Total
Interviewee Invited	100	150	**200**	450
Response	75	**88**	62	225
Response Rate	**75%**	58%	26%	/
Valid Response	75	**76**	51	202
Validity Rate	**100%**	86%	83%	/

6.3.3.2 Age of Interviewees

Practitioners and academic scholars from different ages were selected. Most interviewees were at the age between 26 and 35 (N=149), 73% of the total interviewees.

Table 36 - Age of Interviewees

Age	No.
1. 26-35	149
2. 36-45	29
3. 46-55	17
4. 56-65	7

6.3.3.3 Gender of Interviewees

The majority of interviewees are male, which consists 83.7 % of sample. While female interviewees are 33 persons, representing 16.3% of the sample.

Table 37 - Gender of interviewees

Gender	No.
Male	169
Female	33

6.3.3.4 Background of Interviewees

The interviewees were recruited from four main backgrounds: business (N=42), IT and engineering (N=76), design (N=75) and others (N=9). The selection of interviewees considered a variety of related disciplines of intelligent product innovation.

Table 38 - Background of interviewees

Main Background	No.	Sub Background	No.
1. Business	42	Business Marketing Finance	11 13 18
2. IT and Engineering	76	Information Technology Computer Science Mechanical Engineering Electronic Engineering	42 17 11 6
3. Design	75	Interaction Design Industrial Design Graphic Design Art Architect	30 38 3 2 2
4. Others	9	Physics Lawyer IT journalist Medical and Health Sociology	1 2 3 1 1

Among the four backgrounds, responses from interviewees in business background were mostly got from mobile message APP interview (N=24). Responses from interviewees at IT and engineering background were mostly got from face-to-face interview (N=37). Responses from interviewees to design background were generated from mobile message APP interview (N=30).

Table 39 - Background of Interviewees and Interview Modes

	Face-to-face	Mobile Message APP	Email	Total
Business	12	**24**	11	42
IT and Engineering	**37**	28	30	76
Design	22	**30**	10	75
Others	4	5	0	9
Total No.	75	76	51	202

6.3.3.5 Position of Interviewees

The interview was intended to generate a holistic view from both business practitioners and academic researchers (Table 40).

Table 40 - Number of Academic Researchers and Business Practitioners

Field	No.
Academic researcher	**159**
Business practitioner	43

In order to ensure a variety of opinions, experts and scholars from different levels were invited. For practitioners, interviewees from three kinds of position were invited, including director position

(N=51), manager position (N=51), and specialist position (N=57). For academic researchers, both scholars (N=16) and research students (N=27) were invited.

Table 41 - Position of interviewees

Main Position	No.	Sub Position
1. Director position	51	Director / CEO / Founder / Principal / President
2. Manager position	51	Manager / Startup partner / Chief specialist / Senior consultant / Team leader
3. Specialist position	57	Designer / IT expert / Marketing specialist / Software engineer / Hardware engineer
4. Scholar position	16	Dean / Professor /Associate professor /Assistant professor / Lecture
5. Research student position	27	Phd student / Mphil student / Master student / Research assistant

All specialists (N=57) recruited were at the age between 26 and 35. Most of managers (N=39) were at the age between 26 and 35. Most of directors (N=23) recruited were at the age between 26 and 35. Scholars recruited were from different ages. All of the research students recruited were at the age between 26 and 35.

Table 42 - Age and Position of Interviewees

Age	No.	Position	No.
1. 26-35	149	Director position Manager position Specialist position Scholar position Research student position	23 **39** **57** 3 27
2. 36-45	29	Director position Manager position Specialist position Scholar position Research student position	**16** 8 0 5 0
3. 46-55	17	Director position Manager position Specialist position Scholar position Research student position	**7** 4 0 **6** 0
4. 56-65	7	Director position Manager position Specialist position Scholar position Research student position	**5** 0 0 2 0

For each position, interviewees from different backgrounds were included to ensure the variety of opinions (Table 43).

Table 43 - Background and Position of Interviewees

Background	No.	Position	No.
Business Marketing Finance	42	Director position Manager position Specialist position Scholar position Research student position	9 19 9 3 2
IT CS Mechanical Engineer Electronic Engineer	76	Director position Manager position Specialist position Scholar position Research student position	15 17 25 6 13

Interaction Design Industrial Design Graphic Design Art Architect	75	Director position Manager position Specialist position Scholar position Research student position	26 14 18 7 10
Others	9	Others	9

Most directors (N=25) responded were through email interview. Most managers (N=25) and specialists (N=33) responded were from mobile message APP interview. Most scholars (N=12) responded were from email interview. Most research students (N=20) responded were from face-to-face interview.

Table 44 - Interview Modes and Position of Interviewees

	Face-to-face	**Mobile Message APP**	**Email**	**Total**
Director position	15	11	**25**	51
Manager position	14	**25**	12	51
Specialist position	**22**	**33**	2	57
Scholar position	4	0	12	16
Research Student position	20	7	0	27
Total	75	76	51	202

6.3.3.6 Location of Interviewees

Interviewees were located in four continents, including Asia, North America, Europe, and Australia, 15 countries and regions. As the research was conducted in Hong Kong, most of the interviewees (N=102) recruited located in Hong Kong.

Table 45 - Location of interviewees

Location	**No.**	**Location**	**No.**	**Location**	**No.**	**Location**	**No.**
Asia	169	North America	22	Europe	9	Australia	2
1. Hong Kong	102	8. US	21	10. UK	3	15. Australia	2
2. India	4	9. Canada	1	11. Netherland	3		
3. China mainland	57			12. Denmark	1		
4. Singapore	3			13. Germany	1		
5. Iran	1			14. Swiss	1		
6. Japan	1						
7. Malaysia	1						

6.3.3.7 Nationality of Interviewees

The interview not only considered the location, but also the diversity of nationality. Interviewees were recruited from 24 countries in Asia, North America, South America, Europe, and Australia continents.

Table 46 - Nationality of interviewees

Nationality	**No.**	**Nationality**	**No.**	**Nationality**	**No.**	**Nationality**	**No.**
Asia	155	North and South America	19	Europe	25	Australia	3
1. China mainland	129	10. US	14	13. France	8	25. Australia	3
2. HK	14	11. Canada	4	14. The Netherlands	3		
3. India	5	12. Uruguay	1	15. Germany	2		
4. Korea	2			16. Italy	2		
5. Iran	1			17. Russia	2		
6. Japan	1			18. UK	2		
7. Malaysia	1			19. Belgium	1		
8. Singapore	1			20. Denmark	1		

9. Turkey	1			21. Finland	1		
				22. Ireland	1		
				23. Portland	1		
				24. Sweden	1		

6.3.4 Attributes from Interview

The overall number of attribute coded from interview was too large to describe directly. It was found that some of them could be further combined, reduced, or organized according to the criteria of below (Table 47).

Table 47 - Criteria of Organization

1. Inclusion criteria	•Attributes that were important; •Attributes that were representative; •Attributes that can be generalized; •Attributes with high frequency;
2. Exclusion criteria	•Attributes that were not clearly defined; •Attributes that were not frequently discussed; •Attributes that were hard to generalize;
3. Combination criteria	•Attributes with causal relationship; •Attributes with subordinate and superordinate relationship; •Attributes with similar meaning;

After further organization, 111 attributes coded from interview were identified. The attributes were listed below according to their frequency (Table 48).

Table 48 - Attributes from Interview

Attributes	Freq.
1. Connectivity	58
2. Interaction experience	58
3. Integrated	41
4. Data Management	34
5. Intelligence	32
6. Simplicity	25
7. Personalization	21
8. Adaptive	20
9. User-friendly	19
10. Networked	18
11. Synchronized	18
12. Autonomous	17
13. Decision-making	17
14. Immersive	16
15. AI	15

16.	Human-centered	15
17.	Size	14
18.	Sensing	14
19.	Emotional	14
20.	Context-awareness	13
21.	Anticipatory	12
22.	Communication	11
23.	Inter-operability	11
24.	Life style	11
25.	Learnability	10
26.	Interaction method	10
27.	Sustainability	10
28.	Convenience	9
29.	Intuitive Interaction	9
30.	Core Tech	8
31.	Computational power	8
32.	Security	8
33.	Affective	8
34.	Customization	8
35.	Aesthetic	8
36.	Material	6
37.	Speed	6
38.	Sharing	6
39.	Battery tech	6
40.	VR	6
41.	Social	6
42.	Contextual	6
43.	Form	5
44.	Understandability	5
45.	Efficiency	5
46.	Privacy	5
47.	Recognition	5
48.	Seamless	5
49.	Standardization	5
50.	Constant iteration	5
51.	Invisibility	5
52.	Necessity	5
53.	Weight	4
54.	Compatibility	4
55.	Embedded tech	4
56.	Gesture control	4

57.	Responsiveness	4
58.	Self-learning	4
59.	AR	4
60.	Sentimental	4
61.	Cost efficiency	4
62.	Cultural	4
63.	Reliability	3
64.	Openness	3
65.	Stability	3
66.	Humanoid	3
67.	Notify	3
68.	Self-adjustable	3
69.	Voice control	3
70.	Free of frustration	3
71.	Cross medium interaction	3
72.	Energy efficiency	3
73.	Color	2
74.	Craftsmanship	2
75.	Durability	2
76.	Smaller	2
77.	Lighter	2
78.	Thinner	2
79.	Aluminum	2
80.	Performance	2
81.	Performance	2
82.	Problem solving	2
83.	Proactive	2
84.	Self-management	2
85.	Modularization	2
86.	Gaze control	2
87.	Interesting	2
88.	Comfortable	2
89.	Engagement	2
90.	Trust	2
91.	Enjoyable	2
92.	Environmental	2
93.	Local context	2
94.	Symbolic	2
95.	Time efficiency	2
96.	Quality	1
97.	Identification	1

98.	Accuracy	1
99.	Thinking	1
100.	White	1
101.	Grey	1
102.	Black	1
103.	Metallic	1
104.	Artistry	1
105.	Larger	1
106.	Exquisit	1
107.	Sophisticated	1
108.	Distributeion of weight	1
109.	Scarcity	1
110.	Uniqueness	1
111.	Antique	1

In order to compare and integrate attributes more systematically and efficiently, attributes captured from interview were categorized into the four sectors (see Table 27 in Chapter 5) in the following sections (**Figure 9**).

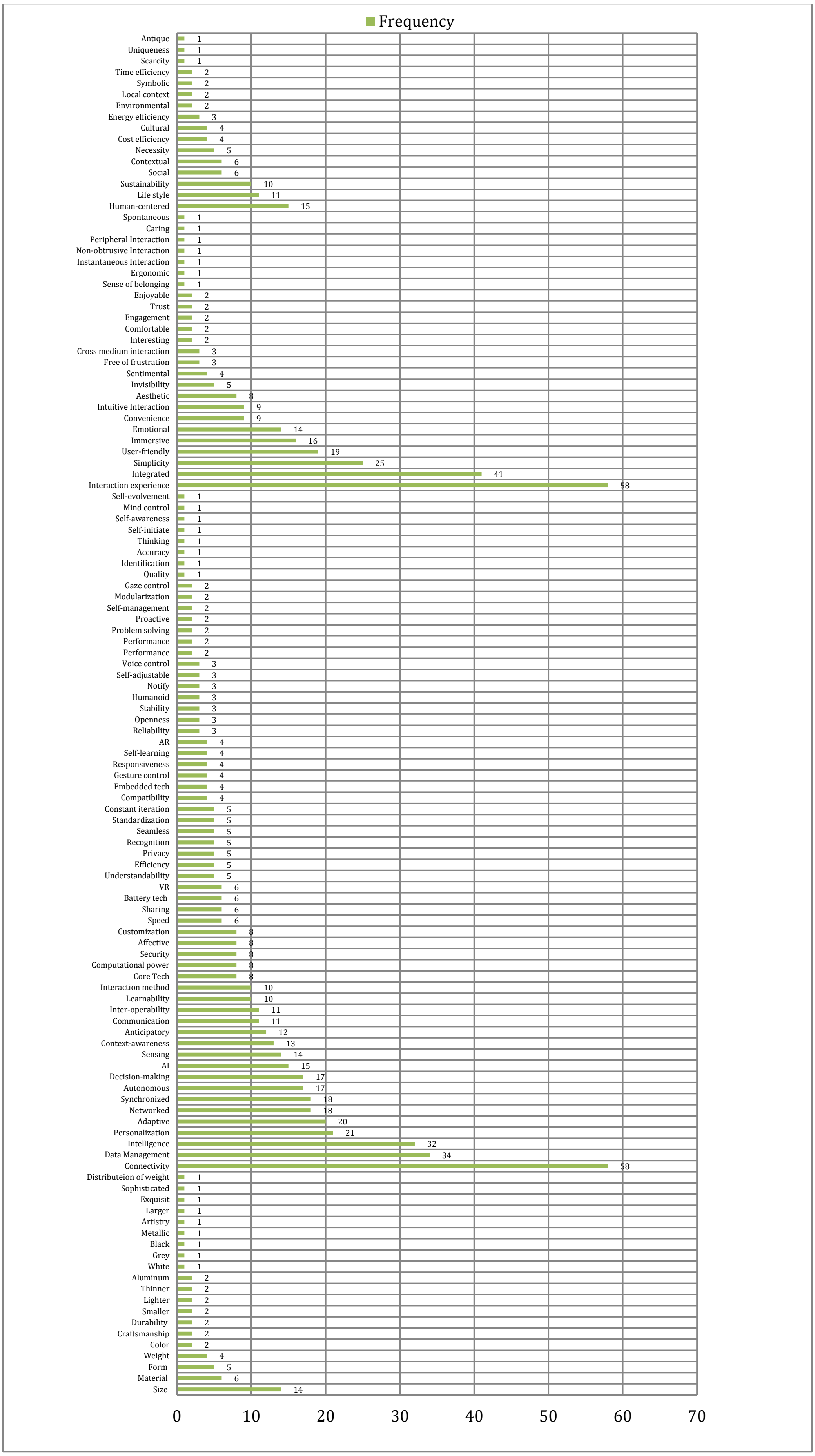

Frequency
Antique 1
Uniqueness 1
Scarcity 1
Time efficiency 2
Symbolic 2
Local context 2
Environmental 2
Energy efficiency 3
Cultural 4
Cost efficiency 4
Necessity 5
Contextual 6
Social 6
Sustainability 10
Life style 11
Human-centered 15
Spontaneous 1
Caring 1
Peripheral Interaction 1
Non-obtrusive Interaction 1
Instantaneous Interaction 1
Ergonomic 1
Sense of belonging 1
Enjoyable 2
Trust 2
Engagement 2
Comfortable 2
Interesting 2
Cross medium interaction 3
Free of frustration 3
Sentimental 4
Invisibility 5
Aesthetic 8
Intuitive Interaction 9
Convenience 9
Emotional 14
Immersive 16
User-friendly 19
Simplicity 25
Integrated 41
Interaction experience 58
Self-evolvement 1
Mind control 1
Self-awareness 1
Self-initiate 1
Thinking 1
Accuracy 1
Identification 1
Quality 1
Gaze control 2
Modularization 2
Self-management 2
Proactive 2
Problem solving 2
Performance 2
Performance 2
Voice control 3
Self-adjustable 3
Notify 3
Humanoid 3
Stability 3
Openness 3
Reliability 3
AR 4
Self-learning 4
Responsiveness 4
Gesture control 4
Embedded tech 4
Compatibility 4
Constant iteration 5
Standardization 5
Seamless 5
Recognition 5
Privacy 5
Efficiency 5
Understandability 5
VR 6
Battery tech 6
Sharing 6
Speed 6
Customization 8
Affective 8
Security 8
Computational power 8
Core Tech 8
Interaction method 10
Learnability 10
Inter-operability 11
Communication 11
Anticipatory 12
Context-awareness 13
Sensing 14
AI 15
Decision-making 17
Autonomous 17
Synchronized 18
Networked 18
Adaptive 20
Personalization 21
Intelligence 32
Data Management 34
Connectivity 58
Distributeion of weight 1
Sophisticated 1
Exquisit 1
Larger 1
Artistry 1
Metallic 1
Black 1
Grey 1
White 1
Aluminum 2
Thinner 2
Lighter 2
Smaller 2
Durability 2
Craftsmanship 2
Color 2
Weight 4
Form 5
Material 6
Size 14
0
10
20
30
40
50
60
70

Figure 9 - Attributes in Four Sectors

6.3.5 Comparison and Integration of Appearance Attributes

In appearance, 45 attributes were coded from both sources in total. 25 attributes were coded from literature, while 20 attributes were coded from interview (Figures 10 and 11).

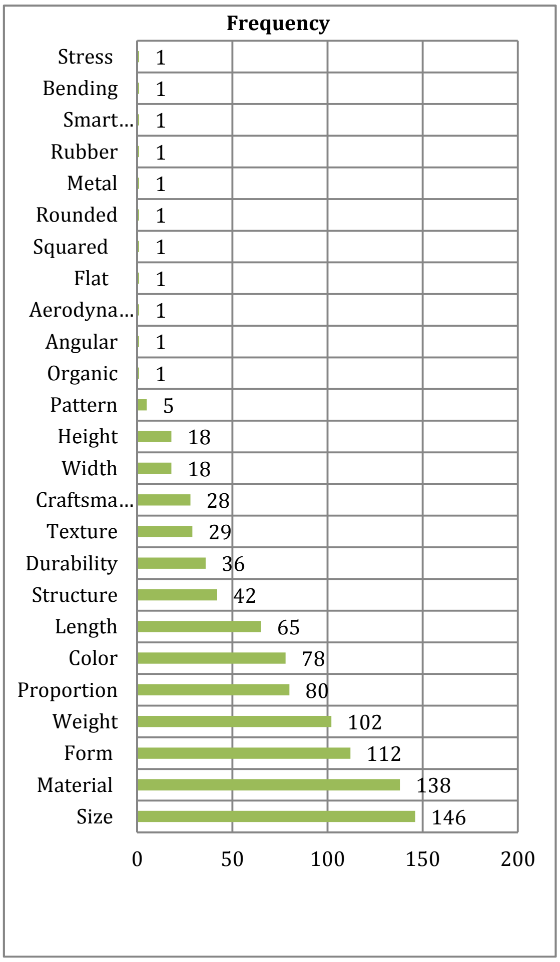


Figure 10 - Appearance Attributes from Literature

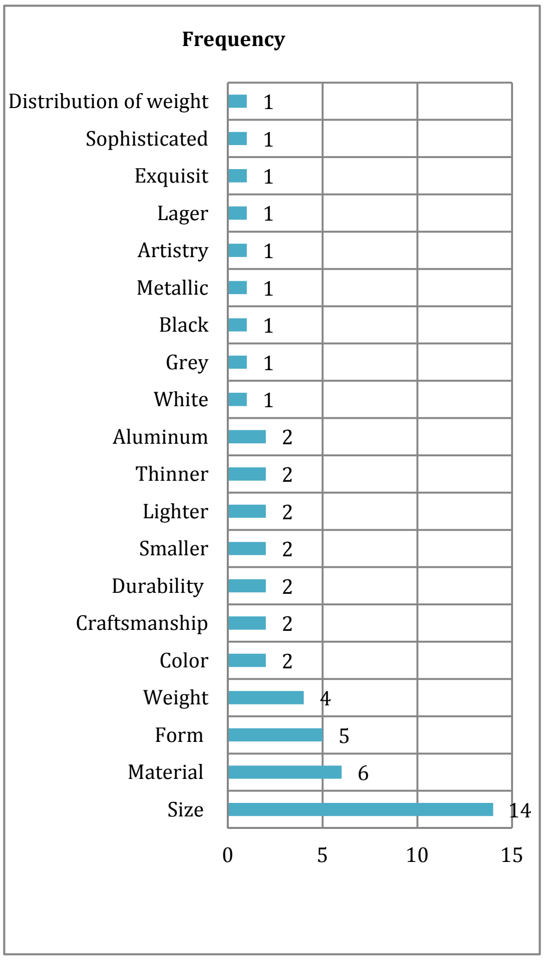


Figure 11 - Appearance Attributes from Interview

6.3.5.1 Compare of Appearance Attributes

In appearance sector, the most highly mentioned attributes from literature include size (N=146), material (N=138), form (N=112), weight (N=102), proportion (N=80) and color (N=78). In comparison, the most frequently mentioned attributes from interview were size (N=14), material (N=6), form (N=5), weight (N=4), and color (N=2).

After comparison, it was found that, 7 attributes were generated from both literature and interview (Table 49). 18 attributes were generated from literature only, while 13 attributes were captured from interview only.

Table 49 - Attributes of Appearance Sector

Literature and Interview	Freq. in Literature	Freq. in Interview	Literature	Freq.	Interview	Freq.
1. Size	146	14	Proportion	80	Smaller	2
2. Material	138	6	Length	65	Lighter	2
3. Form	112	5	Structure	42	Thinner	2
4. Weight	102	4	Texture	29	Aluminum	2
5. Color	78	2	Width	18	White	1
6. Craftsmanship	28	2	Height	18	Grey	1
7.			Pattern	5	Black	1
8.			Organic	1	Metallic	1
9.			Angular	1	Artistry	1
10.			Aerodynamic	1	Larger	1
11.			Flat	1	Distribution of weight	1
12.			Squared	1		
13.			Rounded	1		
14.			Metal	1		
15.			Rubber	1		
16.			Smart material	1		
17.			Bending	1		
18.			Stress	1		
19.			Sturdiness	1		

6.3.5.2 Integration of Appearance Attributes

Appearance attributes generated from literature and interview could be further combined, reduced and integrated following the criteria of organization discussed above (Table 50).

Some attributes have the subordinate and superordinate relationship, which could be further combined. The attributes of size, color, form, material, weight, and structure were mentioned with high frequency (Table 50). They were also considered as superordinate attributes in many studies (e.g., Lenau & Boelskifte, 2004; Dell'Era & Verganti, 2007; Rampino, 2011). For instance, durability could be considered as an attribute of craftsmanship. So they were considered as attributes, while the rest were recognized as attributes.

Table 50 - Attributes of Appearance Sector

Attribute	Literature Freq.	Interview Freq.
1. Size	146	14
3. Form	112	5
4. Material	138	6
5. Weight	102	4
2. Color	78	2
6. Structure	42	/

7. Craftsmanship	28	2

The attributes coded from both of the sources were considered as representative attributes that both academic field and business field agreed on its importance. These attributes were included.

Attributes with complicated meanings and difficult to be categorized were reduced. Proportion can be regarded as the combination of form and size. Pattern can be recognized as a combination of different colors. Texture can be seen as the results of form design and material processing. These three attributes were not included.

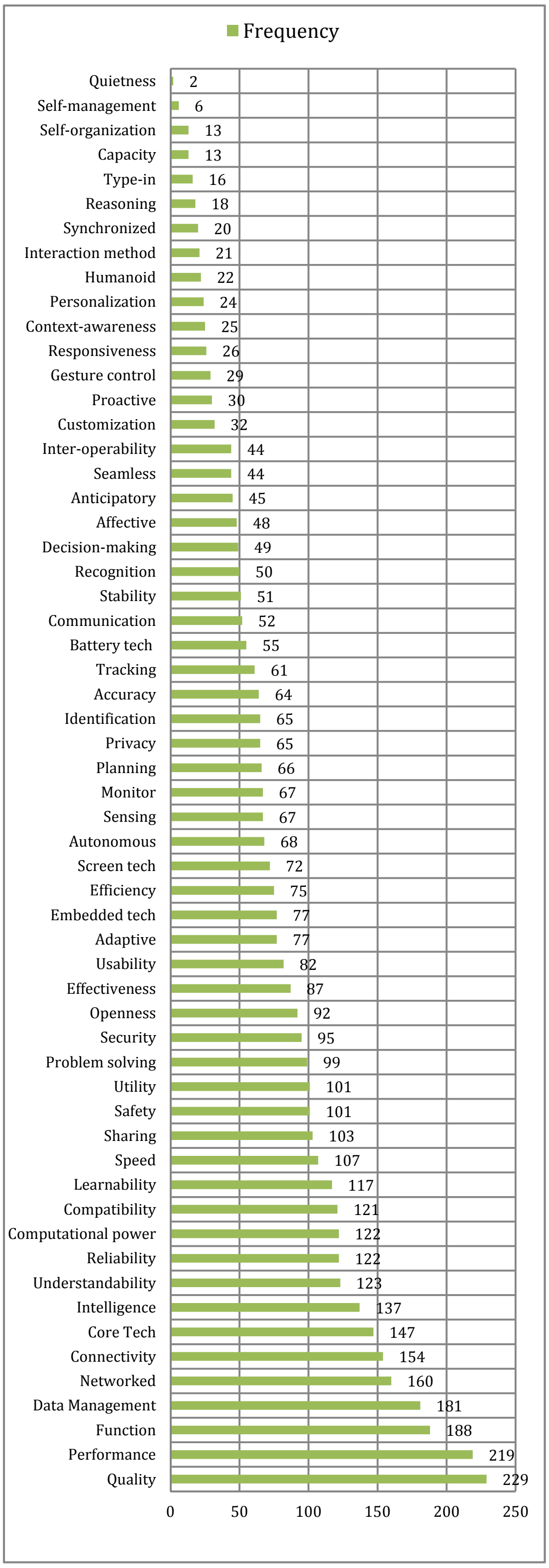
After combination and reduction, the attributes could be integrated as follows (Table 51). In total, appearance sector has seven attributes, and 28 attributes.

Table 51 - Vectors and Attributes of Appearance Sector

Vectors	Attributes from Literature and Interview	Attributes from Literature	Attributes from Interview
1. Size	/	1. Width 2. Length 3. Height	4. Smaller 5. Larger
2. Color	/	/	6. White 7. Grey 8. Black 9. Metallic
3. Form	/	10. Organic 11. Angular 12. Aerodynamic 13. Flat 14. Squared 15. Rounded	16. Thinner
4. Material	/	17. Metal 18. Rubber 19. Smart material	20. Aluminum
5. Weight	/	/	21. Lighter 22. Distribution of weight
6. Structure	/	23. Bending 24. Stress	/
7. Craftsmanship		25. Sturdiness	

6.3.6 Comparison and Integration of Function Attributes

In function sector, 118 attributes were coded in total. 58 attributes were coded from literature review, while 60 attributes were coded from interview (Figures 12 and 13).



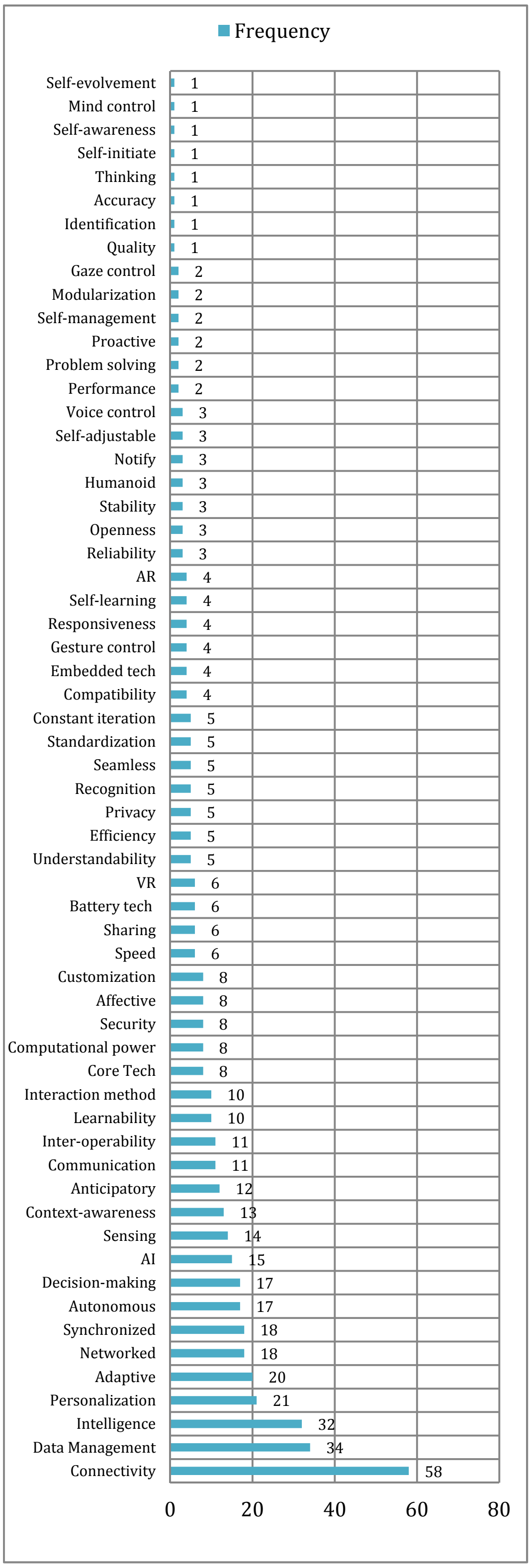


Figure 12 - Function Attributes from Literature

Figure 13 - Function Attributes from Interview

6.3.6.1 Compare with Function Attributes

In function sector, the most frequently mentioned attributes from literature review included the fundamental requirement of a product, such as quality (N=229), performance (N=219), function (N=188), which represent the basic needs of users; followed by information-oriented functions, such as data management (N=181), networked (N=160) and connectivity (N=154); then the intelligent features (N=137), such as understandability (N=123) and learnability (N=117). After that, attributes about the system were discussed, such as reliability (N=122), compatibility (N=121), and security (N=95), followed by the technology-related attributes, such as computational power (N=122), embedded tech (N=77), and screen tech (N=72).

In comparison, the most frequently mentioned attributes from interview were on information-oriented functions and decision-oriented functions, including connectivity (N=58), instantaneous data management (N=34), intelligence (N=32), personalization (N=21), adaptive (N=20), synchronized (N=18), networked (N=18), decision-making (N=17), autonomous (N=17), and AI (N=15).

After comparison, it was found that, 45 attributes were generated from both literature and interview (Table 52). 14 attributes were generated from literature only, while 16 attributes were captured from interview only.

Table 52 - Attributes of Function Sector

Literature and Interview	Freq. in Literature	Freq. in Interview	Literature	Freq.	Interview	Freq.
1. Quality	229	1	Function	188	AI	15
2. Performance	219	2	Safety	101	VR	6
3. Data Management	181	34	Utility	101	Standardization	5
4. Intelligence	137	32	Effectiveness	87	Constant iteration	5
5. Networked	160	18	Usability	82	Self-learning	4
6. Connectivity	154	58	Screen tech	72	AR	4
7. Core Tech	147	8	Monitor	67	Notify	3
8. Understandability	123	5	Planning	66	Self-adjustable	3
9. Reliability	122	3	Tracking	61	Voice control	3
10. Computational power	122	8	Reasoning	18	Modularization	2
11. Compatibility	121	4	Type-in	16	Gaze control	2
12. Learnability	117	10	Capacity	13	Thinking	1
13. Speed	107	6	Self-organization	13	Self-initiate	1
14. Sharing	103	6	Quietness	2	Self-awareness	1
15. Problem solving	99	2			Mind control	1
16. Security	95	8			Self-evolvement	1
17. Openness	92	3				
18. Adaptive	77	20				
19. Embedded tech	77	4				

20.	Efficiency	75	5				
21.	Autonomous	68	17				
22.	Sensing	67	14				
23.	Privacy	65	5				
24.	Identification	65	1				
25.	Accuracy	64	1				
26.	Battery tech	55	6				
27.	Communication	52	11				
28.	Stability	51	3				
29.	Recognition	50	5				
30.	Decision-making	49	17				
31.	Affective	48	8				
32.	Anticipatory	45	12				
33.	Seamless	44	5				
34.	Inter-operability	44	11				
35.	Customization	32	8				
36.	Proactive	30	2				
37.	Gesture control	29	4				
38.	Responsiveness	26	4				
39.	Context-awareness	25	13				
40.	Personalization	24	21				
41.	Humanoid	22	3				
42.	Interaction method	21	10				
43.	Synchronized	20	18				
44.	Self-management	6	2				

6.3.6.2 Integration of Function Attributes

Attributes generated from literature and interview in function sector could be further combined, reduced and integrated following the criteria of organization discussed above (Table 53).

Some attributes have the subordinate and superordinate relationship, which could be further combined.

The attributes of function (e.g., Voss et al., 2003), intelligence, performance (e.g., Ashby & Johnson, 2014), core technology (e.g., Cagan & Vogel, 2002; Zhang & de Bont, 2014), and interaction method were mentioned with high frequency (Table 53). They were also considered as superordinate attributes in many studies. So they were considered as attributes, while the rest were recognized as attributes of them.

Table 53 - Attributes of Function Sector

Attribute	Literature Freq.	Interview Freq.
Performance	219	2
Function	188	/
Intelligence	137	32
Core Tech	147	8
Interaction method	21	10

The attributes coded from both of the sources were considered as representative attributes that both academic field and business field agreed on its importance. These attributes were included.

Attributes with complicated meanings and difficult to be categorized were reduced. Although quality (e.g., Rampino, 2011), usability (e.g., Horváth, 2001), and utility (e.g., Horváth, 2001) were mentioned a lot in both literature and interview with broader meaning, they were not identified as key attributes. Their meanings are too multi-dimensional. Quality can be recognized as attribute of hardware related to craftsmanship (durability, and sturdiness), material composition, mechanical performance (e.g., reliability or safety), or software and system performance stability, efficiency, or accuracy (e.g., Lancaster, 1971; Beaudoin et al., 2000; Jamal & Goode, 2001; Hult et al., 2000; Zhang et al., 2002; Cagan & Vogel, 2002; Wijnstra, 2003). Similarly, usability concerns concepts like "easy to use" (Green & Jordan, 1999; 2002), efficiency, stability, accuracy, informativeness, maintainability, understandability, or learnability of a product (e.g., Chin, Diehl & Norman, 1988; Shackel, 1991; Keinonen, 1998; Hassenzahl, 2004). Likewise, utility is likewise. In order to avoid confusion, the three concepts were not included directly, but in terms of its attributes.

In this research, the information-oriented functions, like connectivity, networked, monitor, inter-cooperated, or sensing are considered as a function related attributes. While the decision-oriented properties, like problem solving, cognition, or learnability are considered as intelligent attributes.

After combination and reduction, the attributes could be integrated as follows (Table 54). In total, the function sector is consisted of five attributes, and 67 attributes.

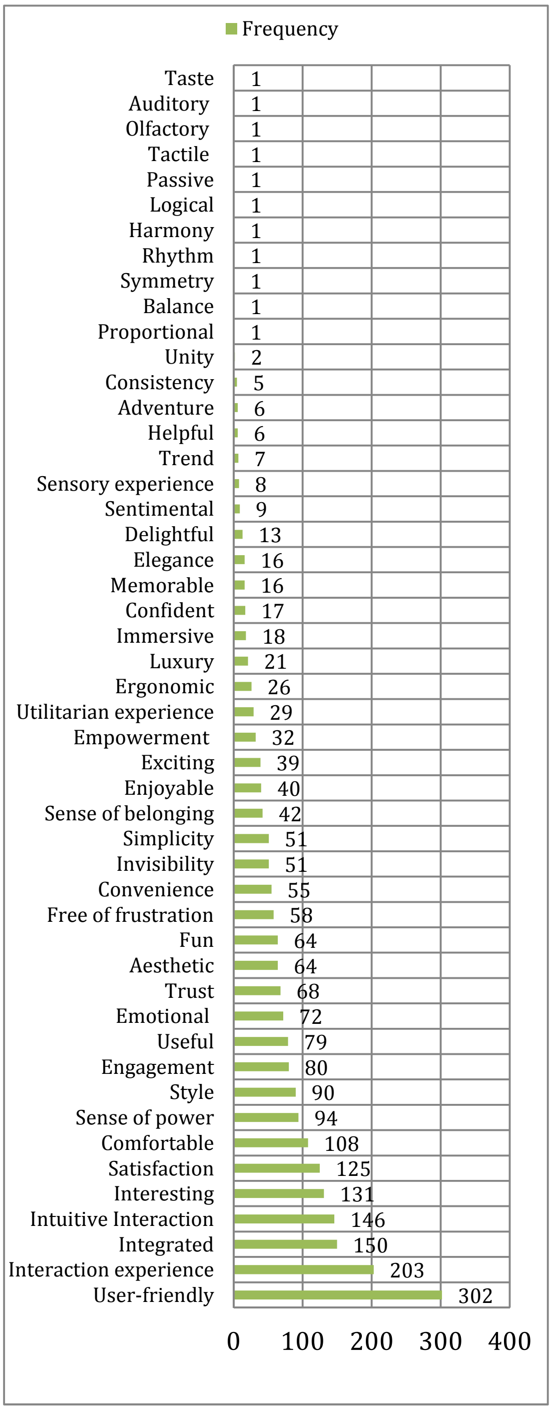
Table 54. Vectors and Attributes of Function Sector

Vector	Attributes from Literature and Interview	Attributes from Literature	Attributes from Interview
1. Function	1. Data Management 2. Sharing 3. Sensing 4. Identification 5. Customization 6. Inter-operability 7. Synchronization	13. Coordinated 14. Monitor 15. Tracking	16. Notify 17. Modularization 18. Constant iteration

	8. Connectivity 9. Networked 10. Seamless 11. Openness 12. Personalization		
2. Intelligence	19. Problem solving 20. Self-management 21. Learnability 22. Communication 23. Decision-making 24. Affective 25. Anticipatory 26. Proactive 27. Responsiveness 28. Context-awareness 29. Humanoid 30. Adaptive 31. Understandability 32. Autonomous 33. Recognition	34. Planning 35. Reasoning 36. Self-organization	37. Self-initiate 38. Self-evolvement 39. Self-learning 40. Self-adjustment 41. Thinking 42. Self-awareness
2. Performance	43. Speed 44. Reliability 45. Compatibility 46. Stability 47. Accuracy 48. Efficiency 49. Effectiveness 50. Security 51. Privacy	52. Capacity 53. Quietness 54. Safety	55. Standardization
3. Core Tech	56. Computational power 57. Embedded tech 58. Battery tech 59. AR	60. Screen tech	61. AI 62. VR
4. Interaction Method	63. Gesture control	64. Type-in	65. Voice control 66. Mind control 67. Gaze control

6.3.7 Comparison and Integration of Experience Attributes

In experience sector, 74 attributes were coded and organized from literature and interview in total. 49 attributes were coded from literature (Figure 14), while 25 attributes were coded from the interview (Figure 15).



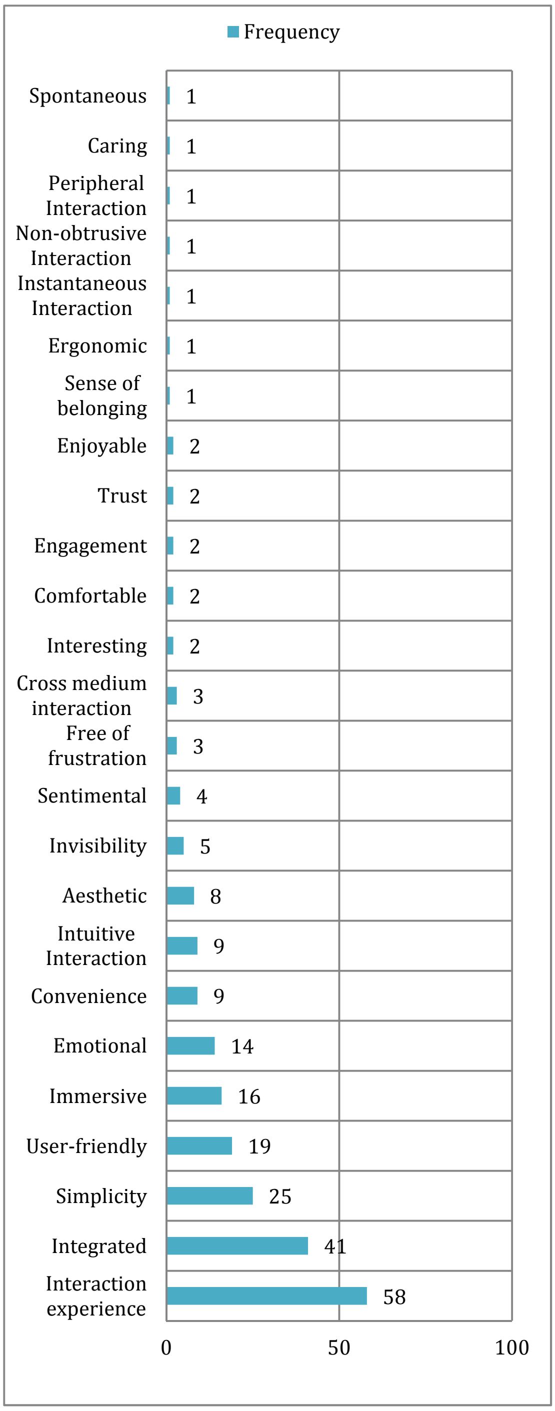


Figure 14 - Experience Attributes from Literature

Figure 15 - Experience Attributes from Interview

6.3.7.1 Compare with Experience Attributes

In experience sector, the most high frequently discussed attributes in literature review include the basic requirement, such as user-friendly (N=302), satisfaction (N=125) and comfortable (N=108); followed by experience created in the process of human product interaction, such as interaction experience (N=203), integrated (N=150), intuitive interaction (N=146), engagement (N=80); then the emotional experience, such as interesting (N=131), emotional (N=72), and trust (N=68). After that is an aesthetic experience, such as style (N=90) and aesthetic (N=64).

The most highly mentioned experience attributes from interview include interaction experience (N=58), integrated (N=41), simplicity (N=25), user-friendly (N=19), immersive (N=16), emotional (N=14), convenience (N=9), intuitive interaction (N=19), aesthetic (N=8), and invisibility (N=5).

After comparison, it was found that, 19 attributes were generated from both literature and interview (Table 55). 30 attributes were generated from literature only, while 6 attributes were captured from interview only.

Table 55 - Comparison of Attributes from Literature and Interview

Literature and Interview	Freq. in Literature	Freq. in Interview	Literature	Freq.	Interview	Freq.
1. User-friendly	302	19	Satisfaction	125	Cross medium interaction	3
2. Interaction experience	203	58	Sense of power	94	Instantaneous Interaction	1
3. Integrated	150	41	Style	90	Non-obtrusive Interaction	1
4. Interesting	131	2	Useful	79	Peripheral Interaction	1
5. Comfortable	108	2	Fun	64	Caring	1
6. Engagement	80	2	Exciting	39	Spontaneous	1
7. Emotional	72	14	Empowerment	32		
8. Trust	68	2	Utilitarian	29		
9. Aesthetic	64	8	Luxury	21		
10. Free of frustration	58	3	Confident	17		
11. Convenience	55	9	Memorable	16		
12. Intuitive Interaction	146	9	Elegance	16		
13. Invisibility	51	5	Delightful	13		
14. Simplicity	51	25	Sensory experience	8		
15. Sense of belonging	42	1	Trend	7		
16. Enjoyable	40	2	Adventure	6		
17. Ergonomic	26	1	Helpful	6		
18. Immersive	18	16	Consistency	5		
19. Sentimental	9	4	Unity	2		
20.			Proportional	1		
21.			Balance	1		
22.			Symmetry	1		
23.			Rhythm	1		
24.			Harmony	1		
25.			Logical	1		

26.			Passive	1		
27.			Tactile	1		
28.			Olfactory	1		
29.			Auditory	1		
30.			Taste	1		

6.3.7.2 Integration of Experience Attributes

Experience attributes generated from literature and interview could be further combined, reduced and integrated following the criteria of organization discussed above (Table 56).

Some attributes have the subordinate and superordinate relationship, which could be further combined. The attributes of utilitarian experience, interaction experience, aesthetic experience, sensorial experience, and emotional experience were mentioned with high frequency (Table 56). Previous researchers discussed a lot of utilitarian experience (e.g., Babin et al., 1994; Holbrook, 1999; Voss et al., 2003), emotional experience (e.g., Young & Feigin, 1975; Holbrook, 1999; Green & Jordan, 1999; Hassenzahl, 2004), aesthetic experience (e.g., Snelders & Schoormans, 2004; Rafaeli & Vilnai-Yavetz, 2004), and sensorial attributes (e.g., Lenau & Boelskifte, 2004; Gemser et al., 2011). Interaction experience was usually discussed in human computer interaction fields, which were emphasized a lot in the innovation of commercial intelligent products in recent years. So the five attributes were considered as attributes, while the rest were recognized as sub attributes of them.

Table 56 - Attributes in Experience Sector

Attribute	**Literature Freq.**	**Interview Freq.**
Utilitarian experience	29	/
Interaction experience	203	58
Aesthetic experience	64	8
Sensory experience	8	/
Emotional experience	72	14

The attributes coded from both of the sources were considered as representative attributes that both academic field and business field agreed on its importance. These attributes were included.

Elegance were considered belonging to the attribute of style. They were not included in the framework directly.

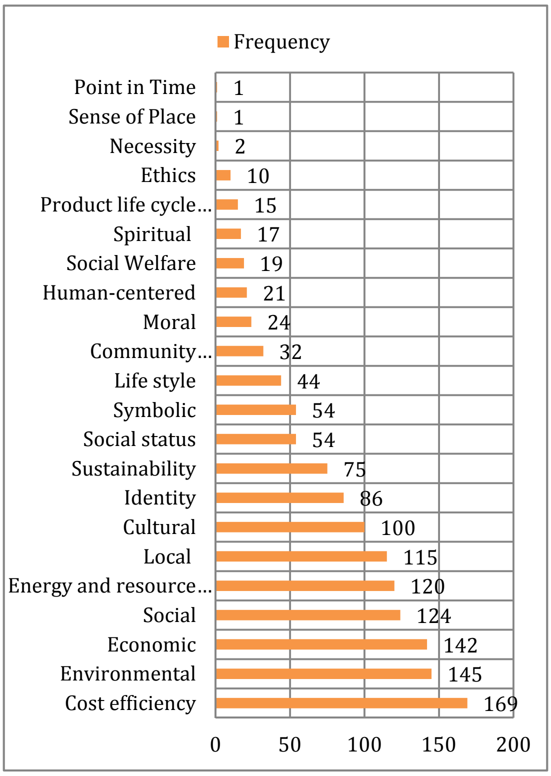
After combination and reduction, the attributes could be integrated as follows (Table 57). In total, the function sector is consisted of five attributes, and 49 attributes.

Table 57 - Vectors and Attributes of Experience Sector

Vectors	Attributes from Literature and Interview	Attributes from Literature	Attributes from Interview
1. Utilitarian Experience	1. User-friendly 2. Integrated 3. Comfortable 4. Convenience 5. Ergonomic 6. Engagement	7. Consistency 8. Helpful 9. Useful 10. Empowerment 11. Simplicity	12. Spontaneous 13. Invisibility
2. Interaction Experience	14. Intuitive interaction 15. Immersive	16. Logical interaction 17. Passive interaction	18. Non-obtrusive interaction 19. Cross medium interaction 20. Instantaneous interaction 21. Peripheral interaction
3. Aesthetic Experience	/	22. Style 23. Trend 24. Unity 25. Proportional 26. Balance 27. Symmetry 28. Rhythm 29. Harmony	
4. Sensory Experience	/	30. Tactile 31. Olfactory 32. Auditory 33. Taste	/
5. Emotional Experience	34. Interesting 35. Enjoyable 36. Free of frustration 37. Trust 38. Sense of belonging	39. Fun 40. Adventure 41. Delightful 42. Exciting 43. Confident 44. Memorable 45. Sense of power 46. Satisfaction 47. Luxury	48. Sentimental 49. Caring

6.3.8 Comparison and Integration of Meaning Attributes

In meaning sector, 35 attributes were coded from both sources. 22 attributes were coded from literature, while 16 attributes were coded from interview.



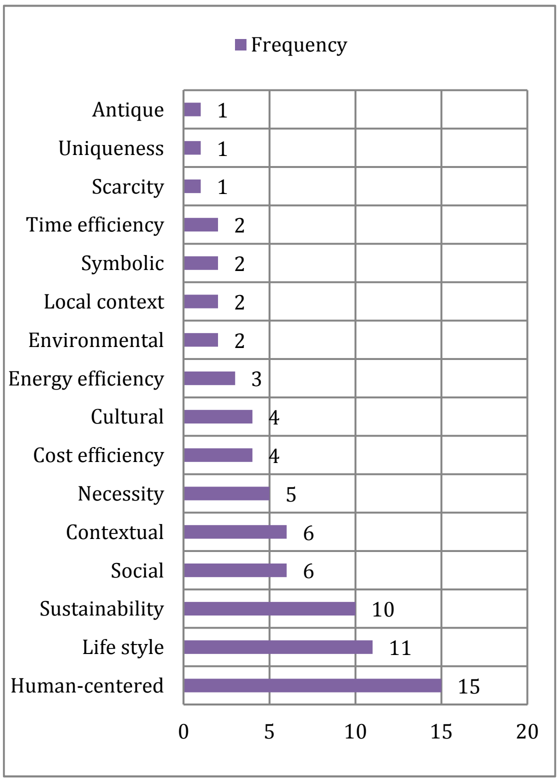


Figure 16 - Meaning Attributes from Literature

Figure 17 - Meaning Attributes from Interview

6.3.8.1 Compare of Meaning Attributes

In meaning sector, the most frequently discussed attributes in literature review include cost efficiency (N=169), energy and resource saving (N=120), local (N=115), identity (N=86), sustainability (N=75) and social status (N=54).

In comparison, the most frequently discussed attributes from the interview include human-centered (N=15), life style (N=11), sustainability (N=10), social (N=6), and contextual (N=6).

After comparison, it was found that, 10 attributes were generated from both literature and interview (Table 58). 12 attributes were generated from literature only, while 6 attributes were captured from interview only.

Table 58

Literature and Interview	Freq. in Literature	Freq. in Interview	Literature	Freq.	Interview	Freq.

1. Cost efficiency	169	4	Economic	124	Energy efficiency	3
2. Environmental	145	2	Energy and resource sharing	120	Contextual	6
3. Social	124	6	Identity	86	Time efficiency	2
4. Local	115	2	Social status	54	Scarcity	1
5. Cultural	100	4	Community transformation	32	Uniqueness	1
6. Sustainability	75	10	Moral	24	Antique	1
7. Life style	44	11	Social Welfare	19		
8. Symbolic	54	2	Spiritual	17		
9. Human-centered	21	15	Product life cycle management	15		
10. Necessity	2	5	Ethics	10		
11.			Sense of Place	1		
12.			Point in Time	1		

6.3.8.2 Integration of Meaning Attributes

Meaning attributes generated from literature and interview could be further combined, reduced and integrated following the criteria of organization discussed above.

Some attributes have the subordinate and superordinate relationship, which could be further combined. The attributes of symbolic meaning, economic meaning, environmental meaning, cultural meaning and social meaning were mentioned with high frequency (Table 59). All the five attributes were mentioned in literature, while four attributes were mentioned in interviews. Symbolic meaning (e.g., Park et al., 1986; Green & Jordan, 1999; 2002; Rafaeli & Vilnai-Yavetz, 2004) and social meaning (e.g., Holbrook, 1999; Pratt & Rafaeli, 2006) were discussed a lot in literature. Although economic meaning, environmental meaning and cultural meaning were not explicitly categorized into meaning sector in literature, they were also been studied a lot. So they were considered as vectors, while the rest were recognized as attributes of them.

Table 59 - Attributes of Meaning Sector

Attribute	Freq. in Literature	Freq. in Interview
Environmental meaning	145	2
Economic meaning	142	/
Social meaning	124	6
Cultural meaning	100	4
Symbolic meaning	54	2

The attributes coded from both of the sources were considered as representative attributes that both academic field and business field agreed on its importance. These attributes were included.

After combination and reduction, the attributes could be integrated as follows (Table 60). In total, the meaning sector has five vectors, and 23 attributes identified from literature and interview.

Table 60 - Vectors and Attributes of Meaning Sector

Vector	Attributes from Literature and Interview	Attributes from Literature	Attributes from Interview
1. Symbolic meaning	1. Life style	2. Identity 3. Social Status 4. Sense of place 5. Point in time	/
2. Economic meaning	6. Cost efficiency 7. Necessity	8. Time efficiency	9. Scarcity 10. Uniqueness 11. antique
3. Environmental meaning	12. Sustainability	13. Product life cycle management 14. Energy and resource sharing	15. Energy efficiency
4. Cultural meaning	16. Local	17. Moral 18. Spiritual 19. Contextual 20. Ethics	/
5. Social meaning	21. Human-centered	22. Community transformation 23. Social Welfare	/

6.3.9 Comparison of Attributes and Sub Attributes among the Four Sectors

6.3.9.1 Comparison of Attributes among the Four Sectors

In function sector, among the five attributes, performance (N=219), function (N=188) and core tech (N=147) have been mentioned most in literature, but with low frequency in interview. Intelligence has been mentioned highly in both literature (N=137) and interview (N=32). In comparison, interaction method has been not discussed less in literature (N=21) and moderate in interview (N=10).

In experience sector, among the five attributes, interaction experience has been mentioned the most in both literature (N=203) and in interview (N=58).

Table 61 - Frequency of Attributes

Attributes	Freq. in Literature	Freq. in Interview
1. Performance	219	2
2. Interaction experience	203	58
3. Function	188	/
4. Core Tech	147	8
5. Size	146	14
6. Environmental meaning	145	2
7. Economic meaning	142	/
8. Material	138	6
9. Intelligence	137	32
10. Social meaning	124	6
11. Form	112	5
12. Weight	102	4
13. Cultural meaning	100	4
14. Color	78	2
15. Emotional experience	72	14
16. Aesthetic experience	64	8
17. Symbolic meaning	54	2
18. Structure	42	/
19. Utilitarian experience	29	/
20. Craftsmanship	28	2
21. Interaction method	21	10
22. Sensory experience	8	/

In appearance sector, among the seven attributes, size has been mentioned a lot in both literature (N=146) and in interview (N=14), followed by material.

In meaning sector, environmental meaning (N=145), economic meaning (N=142), cultural meaning (N=100) and symbolic meaning (N=54) have been mentioned a lot in literature, but all of them were mentioned less in interview.

6.3.9.2 Comparison of Attributes

After comparison, it was found that four attributes were listed in top ten of both literature and interview, including user-friendly, data management, networked, connectivity, integrated. Among them, user-friendly and integrated belong to experience sector, while data management, networked, and connectivity belong to function sector. None of attributes from appearance and meaning has been ranked among the top ten. It is reasonable to imply that both academic researchers and practitioners consider user-friendly as a characteristic that first discussed about traditional non-electronic product, is still considered as the most fundamental requirement of intelligent product. It reflected the priority in the needs of human beings.

Table 62 - Frequency of Attributes

Number	From Literature	Freq.	From Interview	Freq.
1.	User-friendly	302	Connectivity	58
2.	Data Management	181	Integrated	41
3.	Cost efficiency	169	Instantaneous data management	34
4.	Networked	160	Simplicity	25
5.	Connectivity	154	Personalization	21
6.	Integrated	150	Adaptive	20
7.	Intuitive Interaction	146	User-friendly	19
8.	Interesting	131	Synchronized	18
9.	Satisfaction	125	Networked	18
10.	Understandability	123	Autonomous	17

6.4 Discussion

Compared with the characteristics of intelligent products abstracted from literature (see Chapter 2. Section 2.3.2), attributes generated in this research are comprehensive in several ways, including number of attributes, source of attributes, technological and non-technological attributes, intelligent and non-intelligent attributes, aspects of attributes and levels of attributes.

6.4.1 Number of Attributes

The number of attributes generated from this research is much more than that generated from literature of intelligent products identified in Chapter 2. The original attributes from literature were 155, while from expert interview were 111. After first round of integration, the number of attributes reduced to 129 in literature and 102 in expert interview (Table 63). Then attributes from literature and interview were combined, reduced, and integrated. After second round of integration, the total number of attributes was 190, which were further classified into 22 attributes and 168 attributes.

Table 63 - Number of attributes

Source	Original	1st Integration	2nd Integration
Literature	155	129	/
Expert Interview	111	102	/
Total	226	232	190

The total number of attributes and attributes in this research is much more than attributes proposed by each author, as well as the sum of the attributes (N=34) (Table 64). The number of attributes is important in this study, as it represents the number of opportunities that is possible for product innovation. The more attributes identified, the more opportunities that can be explored in the innovation of intelligent products.

Table 64 - Comparison of attributes number

Author	No.
In This Research	190
Wong et al. (2002)	6
McFarlane et al. (2003)	6
Kärkkäinen et al. (2003)	4
Ventä (2007)	8
Kim & Han (2008)	16
Meyer, Främling & Holmström (2009)	4
Kiritsis (2011)	10
Leitão et al. (2015)	11

6.4.2 Source of Attributes

Majority of attributes were generated from both sources, which made them more reliable. Among the 22 attributes, 82% of them were generated from both literature and interview, which suggests high possibility that these attributes were accepted in both academic field and business world (Table 65). It also provided solid evidence to justify the classification of attributes from both literature and interview.

Table 65 - Source of Attributes

Sector	From Literature and Interview	Only From Literature	Only From Interview
Appearance	7	/	/
Function	4	1	/
Experience	3	2	/
Meaning	4	1	/
In Total	18	4	/

Still many attributes were generated from both sources. Among the attributes, 62 were generated from literature and interview (37.1%), 67 were generated from literature (39.5%), and 39 were generated from interview (23.4%). It is worth noticing that many new attributes were only mentioned by interviewees, which may represent the latest development in intelligent products; the new opportunities that need to be addressed; or the research gap that can be fulfilled.

Table 66 - Source of Attributes

Sector	Attributes from Literature and Interview	Attributes from Literature	Attributes from Interview
Appearance	1	15	13
Function	41	11	15
Experience	14	28	7
Meaning	6	13	4
In Total	62	66	39

6.4.3 Aspects of Attributes

Four aspects for innovation were identified in this research, while only two were identified in previous research identified in Chapter 2. In this research, among the four aspects, it was found that function sector has the most attributes (N=67), almost 40.1% of the total attributes, which attracts most attention in both academic research and business practice. Followed by experience sector with 49 attributes (29.3%). Although many previous attributes' studies focused on product appearance, actually not many attributes (N=28) were identified in this sector. Especially, in interview, appearance of intelligent products was considered as an underdeveloped field, which requires more exploration and innovation. Among the four sectors, meaning has the least attributes, which presents great opportunities as well as challenge for both researchers and practitioners.

Table 67 - Aspects of attributes

Sector	No. of Attributes In This Research	No. Attributes In This Research	No. of Attributes In Chapter 2
Appearance	7	28	/
Function	5	67	29
Experience	5	49	5
Meaning	5	23	/

If compare the attributes in this research and attributes in Chapter 2 (seen as the similar level for manipulation), it was found that previous research examined in Chapter 2 only discussed from functional and experiential aspects, which are the aspects that are most easily influenced by technological advancement. However, the other two aspects are also equivalent important for the innovation of intelligent products. As the more aspects realized, the more perspectives and insights for intelligent product innovation could be generated. For instance, if the innovation of intelligent products only focuses on the improvement of its performance, or enhancement of its efficiency, new opportunities like to design a mind-blowing appearance; or create a product that emotionally connects with users could be missed.

6.4.4 Technological and Non-technological Attributes

The number of technological attributes and non-technological attributes identified in this research is far more than that of previous studies in Chapter 2. The two approaches attracted a longer and important discussion in the literature of product innovation, as product innovation requires the integration of technological and non-technological factors. This integration is not merely a one plus one process, but an intertwined, dynamic and iterative process - to continuously see and explore technological factor through a human-centered way (Norman, 2005), and to explore new possibility for non-technological innovation from the multiple sources of social, cultural, economic and technological paradigm shifts.

Table 68 - Technological attributes and non-technological attributes

Approach	No. of Attributes In This Research	No. of Attributes In Chapter 2
Technological Attributes	67	29
Non-technological Attributes	100	5

6.4.5 Intelligent and Non-Intelligent Attributes

Intelligent attributes are the specific attributes that belong to intelligent products. Traditionally, the disputes were focused on the technological and non-technological innovation. Questions were always raised like which-driven-which, such as technology-driven innovation, design-driven innovation, meaning-driven innovation or user-driven innovation or which is more important. But for intelligent products, a new and more specific argument can be raised, like whether intelligent attributes or non-intelligent attributes are more important for the success of intelligent products, or how to balance innovation of intelligent attributes and non-intelligent attributes.

Table 69 - Intelligent Attributes and Non-intelligent Attributes

Approach	No. of Attributes In This Research	No. of Attributes In Chapter 2
Intelligent Attributes	25	9
Non-intelligent Attributes	142	25

But before the beginning of such discussion, it is important to at least identify the intelligent attributes and non-intelligent attributes. In comparison, the numbers identified in this research is far more than the numbers identified in previous research. Only nine intelligent attributes in total were identified in Chapter 2, including decision-making, communication, adaptive, reasoning, reaction, learnability, predictability, self-diagnose, and self-maintenance.

6.4.6 Levels of Attributes

The intelligent product attributes discussed in this research can be classified into three levels – sectors, vectors and attributes, while they were only described as one level in the research discussed in Chapter 2 (Table 70). The three levels draw a clear distinction from generalization to specification. Companies and development team could think clear about general and strategic direction of the intelligent product innovation first, before diving into specific situations and getting lost in unimportant details.

Table 70 - Levels of attributes

In This Thesis	In Literature
Sectors	Attributes
Vectors	

Attributes	

6.4.7 Methods to Generate Attributes

More research methods are used in this research to generate intelligent product attributes. The systematic literature review of attributes provides a holistic frame, following which ensures the results to be comprehensive and systematic. The interview results represented the most updated and conspicuous development in the industry and in the market. The integration of attributes from the two methods complement each other as an integral system.

Table 71 - Methods to generate attributes

	In This Thesis	**In Previous Research**
Methods	Systematic Literature Review, expert interview	Case study

In brief, four sectors, 22 vectors and 168 attributes identified in this section can be recognized as a comprehensive answer to the RQ6. The comprehensiveness can be represented in the number of attributes, source of attributes, aspects of attributes, inclusion of technological and non-technological attributes, inclusion of intelligent and non-intelligent attributes, levels of attributes, and methods to generate the attributes.

The classification of attributes was not absolutely definite and objective. The judgment not only relies on the classification in literature, but also on its application in practice. Some important attributes were especially identified, in order to draw more attention in the product innovation process. For instance, aesthetic experience to some extent could be recognized as visual sensory experience. An example of an aesthetic experience is the enjoyment a user experiences from hearing the sound produced by the fragile porcelain lid when it is placed on the mug (Desmet & Hekkert, 2007). But in this thesis, it was separated from sensory experience as an independent attribute, in order to emphasize its importance in product innovation.

The attributes and attributes identified in this section were based on the current knowledge of intelligent products from literature and interview. It is possible that as the product type develops, new important attributes would appear.

The research results from Chapter 5 and Chapter 6 can be further integrated. Based on the sectors, vectors and attributes, and relationship within sectors, the following diagram can be drawn (**Figure 18**).

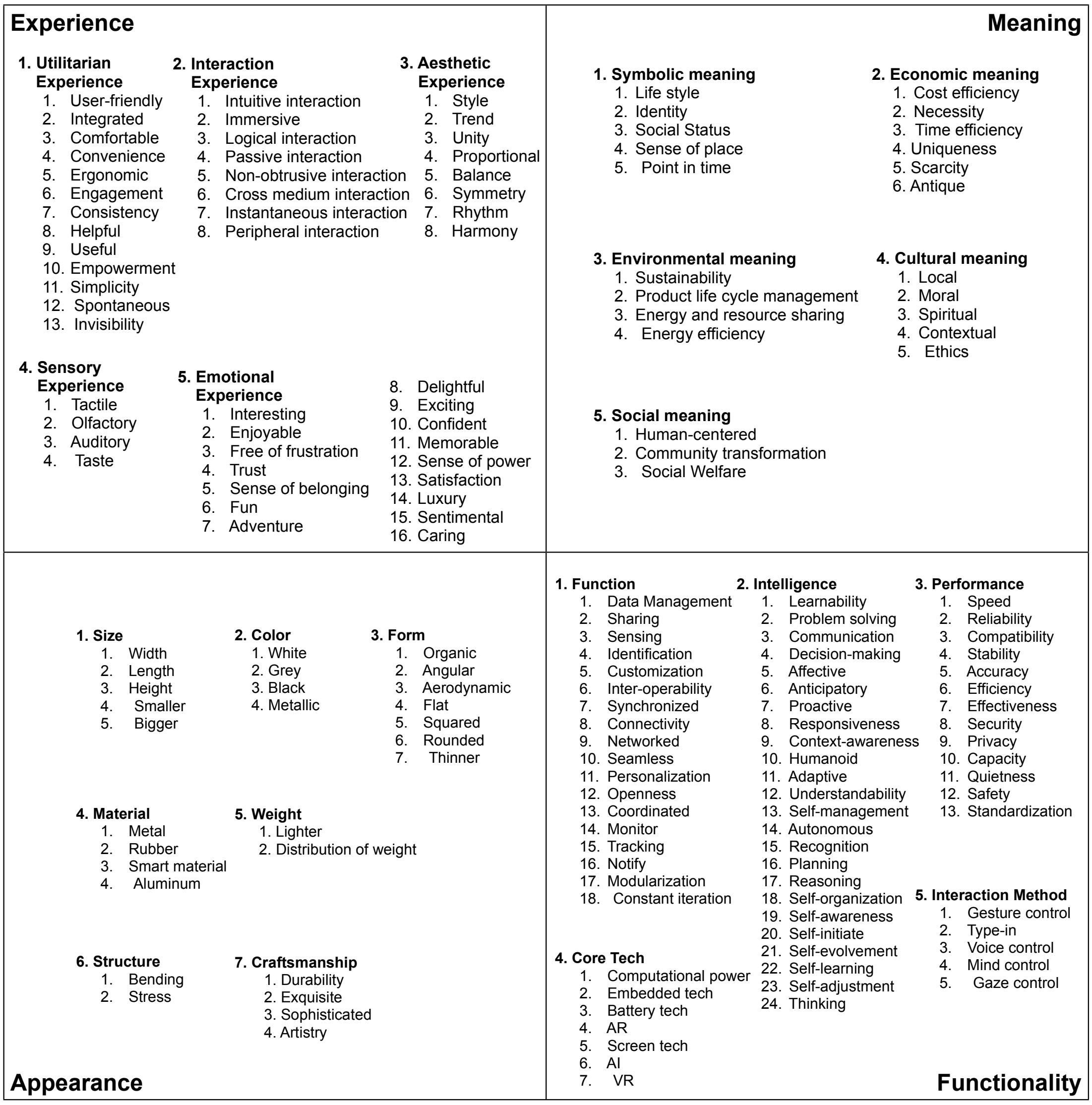


Figure 18 - Sectors, Vectors, Attributes and Relationship within Sectors

Based on **Figure 18,** in next chapter, the framework was established for the innovation of intelligent products.

Chapter 7 – A Conceptual Framework for Intelligent Product Innovation

7.1 Introduction

A conceptual framework is a network, or "a plane, of interlinked concepts that together provide a comprehensive understanding of a phenomenon or phenomena" (Jabareen, 2009, p.51). It lays out the key factors, constructs, attributes or variables, and presumes relationships among them (Miles & Huberman, 1994).

A review of the multidisciplinary literature on intelligent product reveals a lack of a conceptual framework for understanding its complexities and facilitating its innovation. A comprehensive framework is considered important for intelligent product innovation, which is also the main aim of this research. This framework does not intend to provide a causal or analytical setting, but rather an interpretative approach that could inspire and stimulate product innovation activity. Designers, developers and managers could use it for understanding, analysis or innovation of an intelligent product.

According to Miles and Huberman (1994) and Jabareen (2009)'s description, in order to build a conceptual framework, at least two kinds of components were necessary: key concepts/factors/constructs/attributes/variables and relationships among them. In previous sections, the intelligent product attributes and relationships among attributes were identified, which could be used to build the framework. In this chapter, the following research questions were answered:

RQ7. How to build a comprehensive and integrated framework and what would it be like?
RQ7.1 What are the attributes of the comprehensive and integrated framework and how are they defined?
RQ7.3 What kinds of innovation opportunities could be drawn from the framework?
RQ7.4 What are attributes from the pre-intelligent era and what are the ones that exemplify intelligence?

In the following section, the research method of conceptual analysis was introduced, which was used to construct the framework. After that, the main findings - the overall framework was presented. Sectors, vectors and attributes, which consist the framework was described with examples of expert interview results. The innovation opportunities of attributes were identified

7.2 Method

7.2.1 Conceptual Analysis

Conceptual analysis is an effective method to build conceptual framework (Jabareen, 2009). It is a "systematic synthesis of findings across qualitative studies, seeks to generate new interpretations for which there is a consensus within a particular field of study" (Jensen, & Allen, 1996; Sandelowski, Docherty, & Emden, 1997; Nelson, 2006).

7.2.1.1 Procedure of Conceptual Analysis

Jabareen (2009) proposed a procedure of conceptual analysis for building a conceptual framework (Table 72). The first five steps have been executed in previous Chapters. The spectrum of multidisciplinary literature regarding intelligent product was mapped (Chapter 2). The framework for product innovation has been discussed (Chapter 3). Then through extensive reading, attributes of intelligent product were identified, deconstructed, classified and integrated into sectors, vectors and attributes (Chapter 5 and Chapter 6). At the same time, the relationships within sectors were discussed.

Table 72 - Procedure of Conceptual Analysis (Jabareen, 2009)

1. Mapping the selected data sources
2. Extensive reading and categorizing of the selected data
3. Identifying and naming concepts
4. Deconstructing and categorizing the concepts
5. Integrating concepts
6. Synthesis, resynthesis, and making it all make sense

The aim of this chapter is to synthesize the sectors, vectors and attributes, and relationship into a conceptual framework. This process is iterative and includes repetitive synthesis and resynthesize until the framework makes sense.

7.3 Findings

The framework is constituted of four sectors, relationship within sectors, vectors and 168 attributes. The attributes can be considered as 168 innovation opportunities that development team can work on (**Figure 19**). The framework was named as "The Intelligent Product Innovation Framework" and simplified as "the framework".

It was found that the opportunities can be further categorized according to their innovation level. In literature, many researchers conduct research to identify levels of innovation, such as incremental innovation and radical (Schumpeter, 1942), discontinuous innovation (Robertson, 1967), competent-destroying innovation (Tushman & Anderson 1986), drastic innovation (Reinganum, 1985), or disruptive innovation (Moore, 2005). Over years, the classification of incremental innovation and radical innovation is widely accepted in both academics and practice (Norman &

Verganti, 2014).

However, it is hard to identify the exact distinction among the innovation levels of the opportunities in any ways that mentioned in previous studies. No unified standardization could be found currently among the opportunities. While this classification of opportunities is important, as users of the framework can quickly and effectively identify innovation pattern, problems and new gaps of products that they analyze or intend to develop. Hence, based on observation, the opportunities have been classified into three innovation levels from, incremental, micro, basic, or easier to higher, radical, macro, high added valued or difficult. They were just simply named as level 1, level 2, and level 3 for distinction from lower hierarchy inside to higher hierarchy outside following the direction of arrows.

For instance, within intelligence vector, level 1 innovation of an intelligent cleaner can be its capability to plan a route for cleaning when requests by its owner. In the scenario of level 2 innovation, an intelligent cleaner can sense the condition of home, calculate necessary time in advance, and clean a room before a user comes back from a trip. In level 3, an intelligent product not only can plan, solve a problem, make-decisions, learn users' habits, predict, and proact, it also develops personality, like naturally communicate with its user, sense his/her mood.

In the following section, the description and explanation of the four sectors, 22 vectors and 168 opportunities were provided. The vectors were marked according to what sector they belong to. For instance, size is marked as “A1”, as the first vector described in the sector of appearance.

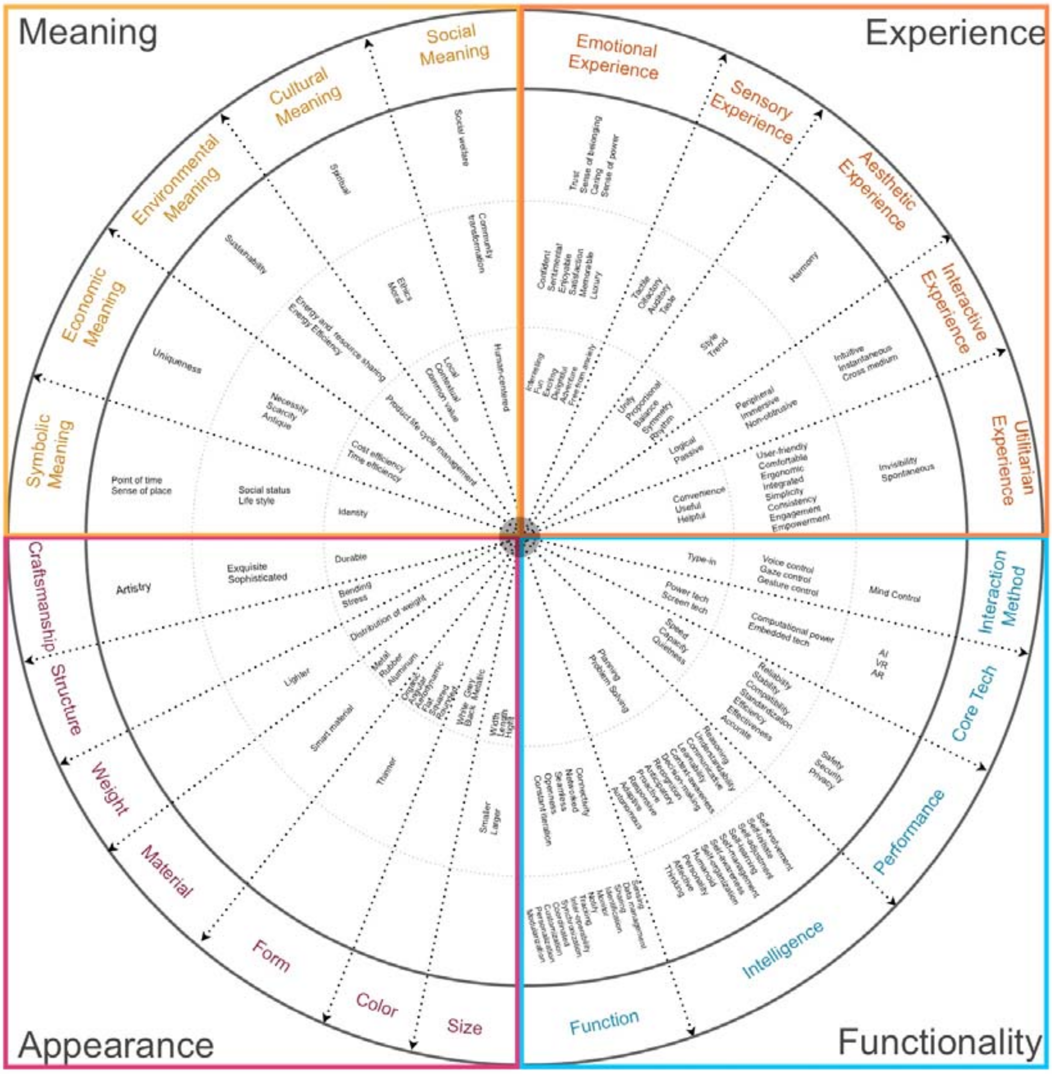


Figure 19 - The Intelligent Product Evolution Framework

7.3.1 Appearance Innovation

Appearance refers to the visual captured objective attributes of a product. It plays an important role to differentiate a product from others in market competition and influence a consumer's perception of a product (Kotler & Rath, 1984; Ulrich & Eppinger, 2003). In this thesis, seven attributes of appearance were identified, including size, weight, material, form, color, structure and craftsmanship.

> *Apple represents the dominant design of intelligent product. After it launches iPhone 4, all of smart phones look like iPhone 4. When Apple uses aluminum in iPhone 5, not only smartphones, but also many intelligent products use aluminum materials. The design of intelligent products is prevalently homogenous. However if products don't follow Apple's appearance, they will not be considered as "successful" product and accepted in the market.*
>
> *Jun Su, CEO of Smart Mi*

In this thesis, seven vectors of appearance were identified, including size, weight, material, form, color, structure and craftsmanship (**Figure 20**).

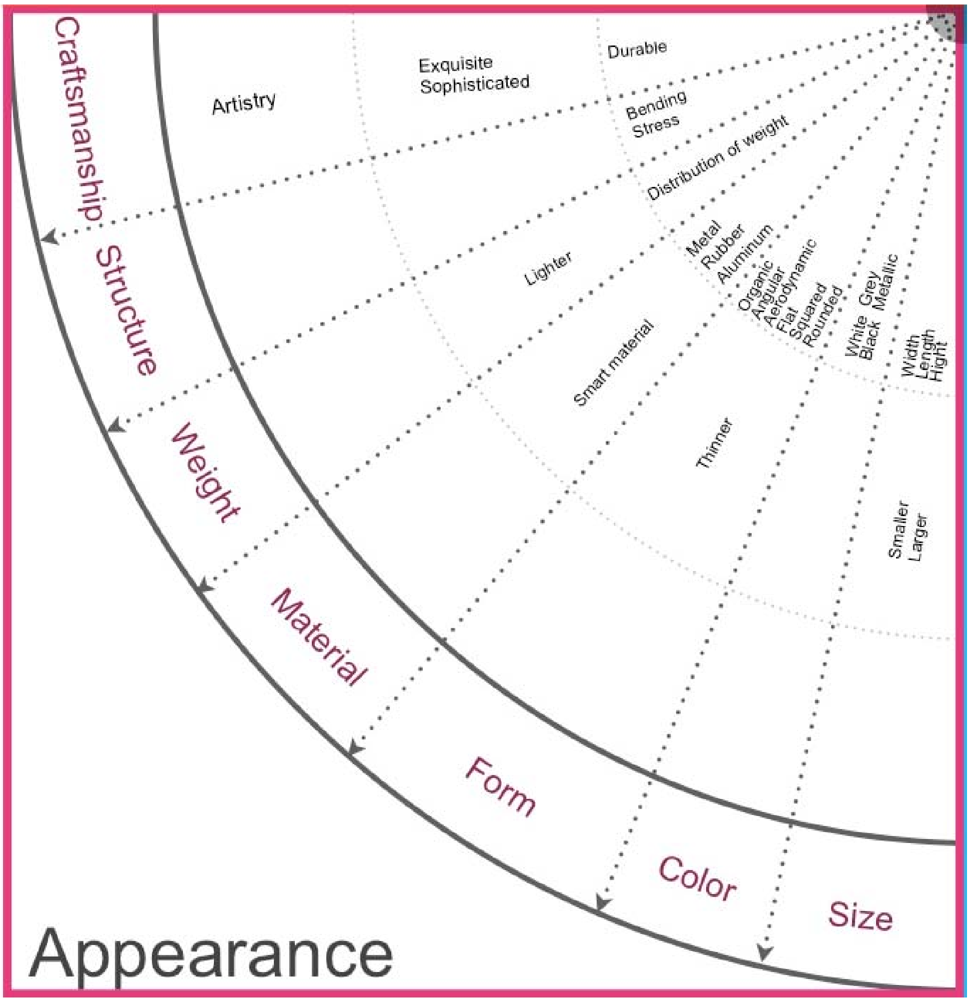


Figure 20 - Appearance innovation in the framework

A1. Size Innovation

Size is the dimensions of a thing, which can be measured as length, width, height, diameter, perimeter, or volume, etc. Size can be described with width, height, and length, which is the basic three-dimensional information of a product.

> *…when comes to products, such as wearable, intelligent product needs to be smaller, lighter. It requires certain shape (of design) and low electricity consumption.*
>
> *Xun Ji, startup founder*

Level 2 has attributes like smaller or larger. For instance, by reducing the size of its chips, sensors and battery, an intelligent product can be smaller. When "smaller" develops to an extreme, it could be superseded by "invisibility" - technology embedded inside platform, environment, or even inside human body. But for some product category, it is not the "smaller" or the "larger" the better. For instance, a smartphone screen is considered "large" enough after it breaks the 5.5-inch barrier in industry standard with enough space for contents display, while able to fit in just about any pocket and usable with one hand. While for other product category, the size can be deliberately to be made bigger (e.g., smart TV).

A2. Color Innovation

Color is the visual perceptual property perceived by the senses. Only level 1 color innovation is described from the selected literature and interview, which is the static color. According to interview results, the design of intelligent product commonly use colors like white, grey, black and metallic color. This result coincides with social and cultural trends toward simplicity.

> *Most of intelligent products are used silver, white, grey, or black (colors), which are a little boring in my personal experience. One reason could be that the traditional home appliances selects these color schemes. In order to merge into the existing system without obtrusive feelings, the color of intelligent product needs to follow the main stream. For instance, smart power adaptors are always designed with white color, because the wall and all of the sockets are white.*
>
> *Xue Xue, Startup Founder*

However, the innovation of colors can be more "intelligent". With the application of smart materials, a product can change color according to the users' needs.

A3. Form Innovation

Product form refers to how surface elements are blended into a whole as a particular shape. Two levels of form innovation were identified. Level 1 refers to the form design in traditional product, such as organic, angular, or aerodynamic, which were popular in product design history. The form of intelligent product can follow these trends, recreate them, or explore new ways of expression.

> *Intelligent product hasn't developed new forms yet. Most of the industrial design (of intelligent product) is similar to the style of traditional electronic product. Designers have new chances and challenges to define new expression of intelligent product form.*
>
> *Jun Su, CEO of Smart Mi*

> *With new manufacture methods, such as 3D printing, same material can be shaped into complex and sophisticated form, which can be personalized for individual use.*
>
> *Zhongyan Wu, IT journalist*

Level 2 can be the dynamic form that realized by the new technology. Instead of being static and pre-constructed, in the future, the form of intelligent product can be radically innovated and reconfigured by the products themselves to react to changing environmental conditions. From this perspective, the product is not only intelligent, but also “alive”, thus products will be innovated and designed in many new startling ways.

A4. Material Innovation

Material is a physical substance or mixture of substances that constitute a thing. The attributes in material innovation have been classified into two levels. Level 1 refers to the traditional materials, which are non-living matter that can be used for production process, such as metal, rubber or aluminum.

Level 2 includes smart materials. For instance, some materials can emit light efficiently. Some materials are reactive, the color or form of which can be changed by exposure to stimuli, such as stress, moisture and temperature. In the future, materials even have the capability to see, hear and sense their surroundings; communicate; store and convert energy; monitor health; and control temperature (Moruzzi, 2016).

A5. Weight Innovation

The weight is the force on the product due to gravity. The touch of weight enables users a new perspective to experience the differences of products. Level 1 weight innovation includes attributes like balance or distribution of weight. If designers not pay attention to it, it may disturb and make users feel uncomfortable.

> *Users' feeling of weight can be connected to quality. Although there is a trend for intelligent products to become lighter, thinner and smaller, for some product categories, it is not the lighter the better, such as mobile phone. If the mobile phone is too light, it might be considered as a product with low quality.*
>
> Xue Xue, Startup Founder

Level 2 includes attributes like “lighter”. Lighter materials are used more commonly to replace traditional materials, such as carbon fiber in automotive design. Especially for intelligent products, the whole industry pursuit that the lighter the possible for portability. However, the sense of the weight can also be associated with the quality of a product in certain circumstances. Thus, sometimes the lighter may not be the better. Product designers and developers need to evaluate how weight is perceived appropriate in user's mind.

A6. Structure Innovation

Product structure refers to the arrangement of and relations between the parts or elements that consist a product. A well-designed structure of a product can make the product more durable and stable. Its design involves the balance between basic standardization of components and the specific requirements to ensure lower manufacture cost as well as higher product variety. It relates to the new application of raw materials, new ways of assemblies, new arrangements of components and parts. It refers to the flexibility of product structure, which can be created in using process.

> *The product structure is important for product design and innovation. The internal structure determines the external form of a product. Vice versa, the product design may push product structure's innovation.*
>
> *Xia Meng, Industrial Designer of Startup*

Only Level 1 attributes for structure innovation were identified, including bending and stress.

A7. Craftsmanship Innovation

Craftsmanship refers to the degree of quality a product exhibited as a result of manufacturing, such as fit, finish, fashioning and maintenance. Other product attributes are greatly affected by the quality of the craftsmanship (e.g., reliability). Three level of craftsmanship innovation was identified. Level 1 includes attributes like durability, which intends to meet instrumental performance expectations within user's tolerances (Cagan & Vogel, 2001).

> *Intelligent home product design can learn from traditional and modern furniture design, instead of only adopting high-tech and simplicity style. The "intelligence" can be hidden under the natural wood material, high quality craftsmanship. The intelligent functions can appear surprisingly when users are using them. It is also much easier for "old-school" people to accept the products and embed them in their original home appliances system.*
>
> *Xiaoqian Ma, master student of Computer Science, Columbia University*

Level 2 refers to the sophisticated and exquisite details of craftsmanship, which represent the taste, lifestyle, and even symbolizes the social status of its user. In Level 3, a product can be recognized as an "artwork", impeccable, natural or unique. The three levels of craftsmanship have already existed in fashion industry, such as the difference among mass-produced, pret-a-porter and haute couture. In intelligent product, the development of technology can also make it possible, such as the improvement from mass-produced, customized to personalization.

7.3.2 Function Innovation

Function refers to the utilitarian consequences of a product, for example the fact that it might accomplish a physical or cognitive task, solve a problem according to user's needs or fulfill a purpose that the product is designed or expected for (Park et al., 1986; Green & Jordan, 1999; Rafaeli & Vilnai-Yavetz, 2004; Boztepe, 2007).

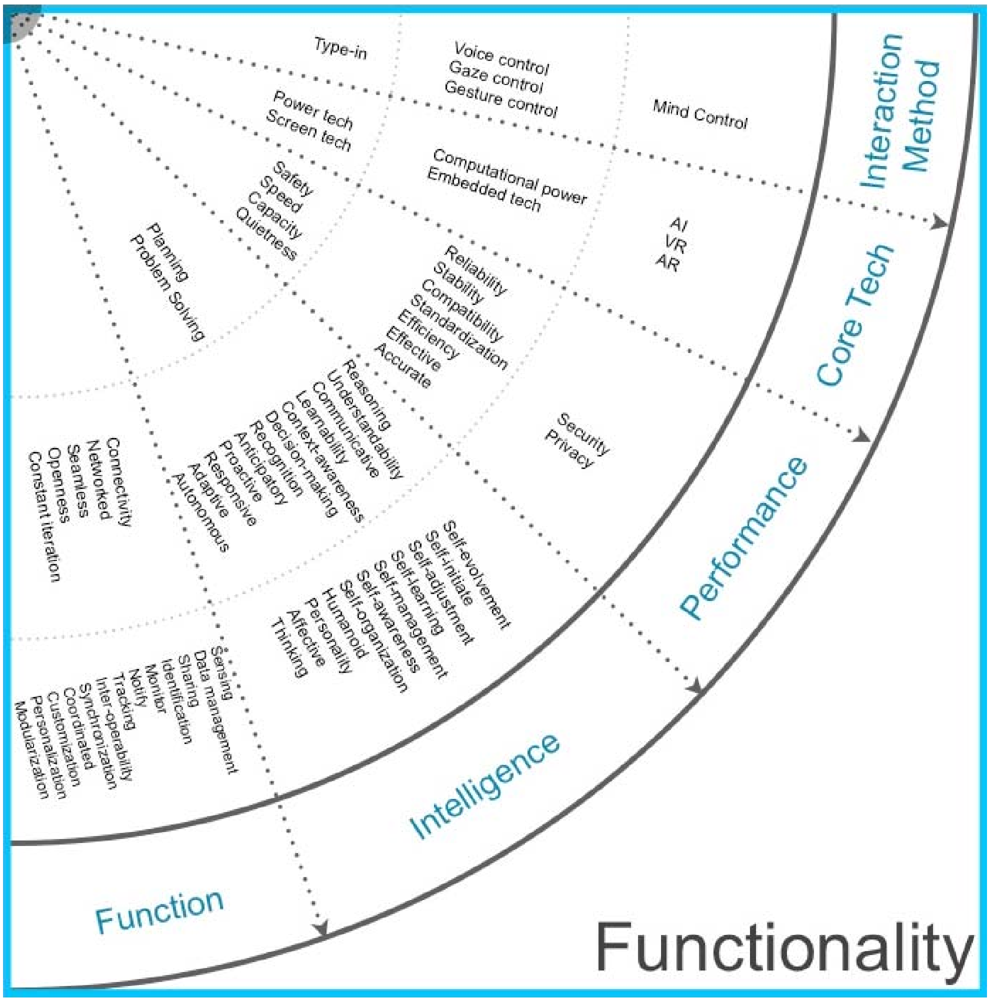


Figure 21 - Function innovation in the framework

F1. Function Innovation

Level 1. The basic functions of intelligent products refer to the exact problems a product solves or main tasks it finishes, which provides value for its user, such as to wash clothes, clean room or kill germs, etc.

> *The prioritized capability of a product is to solve problem. Such as the mission of air condition is to cool air. Refrigerator is to store food freshly. Vacuum cleaner is to clean. Roomba is an intelligent product. Its basic role is to clean your home.*
>
> *Xia Meng, Industrial Designer of Startup Company*

Level 2 refers to the functions that related to how a product is connected to a network or with other products, with capabilities like connectivity, networked, seamless, openness of system, and constant iteration. These capabilities enable a product to be connected to network, other intelligent products, system, platform or environment, with the development of Internet and wireless networks, such as Bluetooth, WiFi, and 4G. The requirement of data exchange and information sharing requires an intelligent product to be open, which allows it to iterate, upload and update dynamically.

Compared with traditional products, such as a laptop computer, the characteristics of my smartphone that I value the most are its ability to connect with various devices and services, such as immediately uploading photos to Dropbox; connect with my car's entertainment system to provide music while driving; or just being able to do many things with something that fits in my hand.

Ken Lunde, Senior computer scientist of Adobe

These new devices have the ability to inform their human users in a simple way, either directly or via smartphones, and they are connected and controlled either directly like a watch or via a smart phone, or both.

Erol Gelenbe, Prof, head of intelligent system, Imperial College London

Intelligent products are connected and allow you to store data digitally and review it over time without manual entry into another software program to convert to statistical data. They have the probability of be of use in a health improvement or health preventative situation.

Lorraine Justice, Dean of College of Imaging Arts and Sciences, Rochester Institute of Technology

Level 3 refers to information-related products. Level 3 is information-oriented functions, which relates to how data is generated, gathered, transferred and primarily used, with capability like sensing, data management, sharing, identification, monitor, notify, tracking, inter-operability, synchronization, coordinated, customization, personalization and modularization. Information and data can be synchronized, communicated, and shared between products, or between product and users over time and space. Intelligent product can be monitored, inter-controlled, interoperated with other products or systems, locally or remotely. Large quantity of data can be gathered in the process. Sensing allows intelligent products to generate original data, which can be used for identification of its location or condition, and notification to its users or to other products. The big data generated and gathered in various ways can be collected and used in both quantified and qualified ways. Developers and designers can discover patterns and real users' needs behind and innovate new products or functions based on it.

Innovation (of intelligent product) requires advanced algorithm, big data, and data visualization.

Larry Keeley, President, Co-founder at Doblin Group

Like Nest, it can collect data and connect with your mobile phones. Through data analysis it understand your needs and habits. It connects to Internet to accumulate data, based on which then it has unlimited possible functions by synchronizing with other devices, through smartphone as controller.

Gonglue Jiang, User Experience Designer, Google

F2. Intelligence Innovation

In literature, some scholars stated the different level of intelligence (e.g., Wong et al., 2002, Kiritsis, 2011). The degree of intelligence an intelligent product may exhibit varies from simple data processing to complex pro-active behavior (McFarlane et al., 2003; Kärkkäinen et al., 2003). Influenced by these insights, three levels of intelligence were identified.

Intelligence is about processing by taking sensed data into account and actuating based on the results of processing. The least intelligent ones can simply actuate, like washing machine that goes through predefined cycles of washing based on direct user input. The intelligent ones have increasing levels of sensing, and take this data in processing to take decisions as to what to.

Amaresh Chakrabarti, Professor, Indian Institute of Science

The intelligence of intelligent product can have three process: cognition, understanding, make-decision, experience accumulation and eventually self-evolving.

Jiawei Gu, Chief Designer of Baidu Institute of Deep Learning

Level 1 includes the primary capability that intelligent products were designed for: problem solving and planning. The capabilities determine behavior that will maximize the likelihood of goal satisfaction in a dynamic and uncertain environment (Gunderson & Gunderson, 2004).

Level 2 relates to the decision-oriented innovation, including reasoning, understandability, communicative, learnability, context-awareness, decision-making, recognition, anticipatory, proactive, responsive, adaptive, and autonomous.

Compared with traditional product, intelligent products have three main difference in its components: 1) processor and memory; 2) telecommunication module; 3) personalized software. In another word, intelligent products are the traditional electronic product with an intelligent computer. But from user experience aspect, intelligent products are much more different from traditional product.

Haofu Wen, Starup Founder

The basis of "intelligence" is big data and deep learning algorithm, which makes hardware to learn through data by sensors in various scenarios.

Jiawei Gu, Chief Designer of Baidu Institute of Deep Learning

An intelligent product can make decisions autonomously. If temperature of the outside environment is higher that day, an intelligent product would make a decision to heat the clothes by providing less heat thereby saving energy. Or if the amount of clothes is less, it would use less amount of water. If the pipe for waste is kept in a stored condition, it would not start the machine.

Amaresh Chakrabarti, Professor of Indian Institute of Science

Artificial intelligence is an important feature of intelligent product. From my understanding, affective is one of the attribute that intelligent product differentiates itself from traditional product. Intelligent product can sense the emotion of users and provide service either physical or emotional to the users.

Zulikha BT Jamaludin, Professor, UUM College of Arts and Sciences, University Utara Malaysia

Based on the information and data sensed and gathered, intelligent product can comprehend complex ideas, reason, learn knowledge, recognize speech, pattern, facial expression, and visual category. These capabilities make an intelligent product can aware and comprehend its physical environment, user's condition, or the existence of other intelligent product, the system or platform it connected.

With context-awareness, intelligent product can not only sense and recognize the context, but also react to it. This reaction can be responsive - responding to users' commend, behaviors, preference and using scenario; or proactive - explicitly taking into account of events happen possibly happen in the future.

The proactive of intelligent product relies on its anticipatory capability - to predict user's next action, behavior, expectation, or needs based on data gathered and pattern it's discovered. It can predict the future state of the environment, such as temperature or weather.

While how an intelligent product reacts to a context or how to use the predictions is associated with decision-making capability. The decision-making can be passive or positive. An intelligent product can assist its user to make choice and select actions with sufficient information required, which is currently the main choice for most of such product. Or it can be actively making actual decisions autonomously with minimum or without human intervention.

Level 3 relates to innovation related to humanoid, with cognitive and affective abilities. It can imitate cognition, behavior, appearance and all the possible aspects of human beings, such as human-like facial expression, femininity, human-like movement, natural language communication, and soft touch (Fong et al., 2003; Feil-Seifer & Matarić, 2009). It includes capabilities like self-evolvement, self-initiate, self-adjustment, self-learning, self-management, self-awareness, self-organization, humanoid, personality, affective and thinking. The learnability is not static in this level, but dynamic as self-learning, through which an intelligent product can achieve self-evolvement.

> *The quick answer to your question about what differentiates intelligent products is that they are self-aware, self-learning, context-sensitive, responsive, and autonomous.*
>
> *Vijay Kumar, Professor, Institute of Design, IIT*

This autonomous behavior has different levels, when it develops to higher level, an intelligent product can achieve self-management, self-organization, self-governing, self-determination, self-iteration and eventually self-evolvement and independence (Gunderson & Gunderson, 2004).

Intelligent product can/will detect and distinguish its users' emotional states, produce emotions, invoke feelings in the users, or appear sensitive to the users. The emotional interaction between users and the product will enhance using experience.

Intelligent product can achieve real meaning of "communication", not only communication with other products through machine language, but with users in natural language mutual understanding. It can understand human needs, physical and emotional through communication.

It can actively modify or improve itself to adapt to user's emotional status, changing environment, or a new using scenario. Similarly, it can achieve high level of personalization, either passively by users, such as recommendation and managing contents or actively by the product itself. The interaction between users and products can be more meaningful and sensible.

F3. Performance Innovation

Performance describes how well a product solves problems. Different from traditional products, intelligent products are consisted of physical hardware components and non-physical system and software, which are closely associated with the performance of intelligent products. The innovation of performance has been divided into three levels. The first level refers to the basic performance of a product, such as safety, speed, and capacity. The second level relates to the higher requirement of performance, such as reliability, efficiency, or compatibility of the product. The third level involves the most essential performance of an intelligent product, such as security and privacy.

Level 1 of performance innovation includes the enhancement of safety, speed, capacity, and quietness. The safety of an intelligent product refers to the condition of users' protection from or unlikely to cause danger, risk or injury. Physically, the innovation of safety could be to change sharp corners of intelligent product especially used for children or elders to avoid danger. Non-physically, the information of intelligent products stored and presented needs to be accurate and safe to be used in other context. An intelligent product needs to operate with high speed for process, response, react, or display. The enhancement of speed can be achieved by simplifying software design, or increasing of the read-only memory. Capacity can be storage capacity - the amount of energy that an intelligent product can hold; or carrying capacity - the maximum volume a product can carry, etc.

Level 2 includes reliability, stability, compatibility, standardization, efficiency, effective and accurate Reliability refers to the capability of a product to maintain its level of performance under stated conditions for a stated period of time. The innovation of reliability can be the improvement of system maturity, fault tolerance, recoverability, compliance, error correction & prevention, and stability. Many interviewees express their dissatisfaction with the reliability of current intelligent products and points out it is one of the essential attributes that designer and developer should focus.

> *Intelligent product is still considered as trendy product instead of "real product", because of lack of reliability. "Real product" provides sense of trust - people can rely on the product. It is stable for long-term use, such as Nokia. It has good quality, reliable performance as a stable symbol of traditional mobile phone. In comparison, many products, such as Sony, although it has fancy appearance and new functions, its reliability and stability is less than Nokia.*
>
> *Yingrui Li, Engineer*

> *At first, I think that intelligent products make us lazy by simplifying our work and life.Then, I think that intelligent products make us diligent by increasing efficiency of our life and work. So people has extra time to do more things. In the future, I think intelligent products can ultimate change us. People will reconsider the possibility of life and themselves.*
>
> *Roger Sun, Designer*

> *Compatibility and standardization would lead to free sharing across platforms and all a greater benefit for all tech companies instead of pursuing petty monopolies on split market segments.*
>
> *Ghormley James, Design and manufacturing engineer of ATL Tech*

> *In industry, unfortunately, people like to invent their own protocols, their own apps, and their own networks for their smart devices. If you are a homeowner you will find it very inconvenient to have disconnected intelligent devices. For example, in my home, I use Nest Thermostat + Nest*

Cam + Carbon dioxide sensors. The experience is almost perfect. They talk to each other, and adapt each other when I add more Nest products to my home.

Jiayu Zhou, Assistant Prof. of Computer science at Michigan University

Efficiency of intelligent product concerns how much time, energy, resources and efforts costs to finish a task. The innovation of efficiency could be the enhancement of technology, or the design of its hardware or software. Effectiveness concerns an intelligent product's capability of producing a desired result or the ability to produce desired output.

Compatibility refers to the ability to integrate different types of devices, technologies and services into the network. The compatibility innovation could be achieved in hardware perspective, which relates to handle various data communication methods, computational and storage methods, and different technologies with flexibility and stability. It also requires software or system support, which relates to the openness of supporting a large amount of variety applications with diverse features and requirements.

Standardization refers to unified standard, or at least generally accepted standards for products of a variety of brands to be connected into a network, a platform or with other products smoothly. The innovation of standardization could be data standardization, interface standardization, same user terminal protocol and transfer protocol. The standardization could also be developed in user experience perspectives, such as similar control, interaction methods, and connection ways. So users do not need to learn how to use the product even buy a new one.

Level 3 refers to even higher level of performance from economic and social perspectives, with attributes of the security and privacy, etc. Security is an essential attribute of intelligent product, as one major social concern related to intelligent product is its potential negative impact due to its learning, reasoning and data exchange capabilities. Its system or software can be intruded with severe consequences in performance, such as system disruption, information hacked and stolen, and various safety issues. The innovation of security concerns the design and optimization of hardware, software, data and procedures. It is a challenging task to maintain the openness, flexibility and efficiency of intelligent products.

One important function of intelligent product is remote control. Users can control home appliances on the way to work or back home. They can monitor home condition or even their family members to make the sense of "everything is under control".

Nan Xia, Design Researcher

Google Project glass maybe still exist, but Google underestimate people's tolerance of privacy invading. But once humans can make agreement about the new rules about privacy, the intelligent product such as Google glass will have tremendous potential. Right now the *companies are still testing the boundary of how much people can accept and compromise, then revise and test again. Although Google glass is rejected in public use, but similar products are popular in private use. For instance, virtual reality glass has great market in adult movie. So the basic line of intelligent product should not intervene other people's life, the boundary of privacy has not been established yet.*

Tao Du, Phd student of Optical Science, The Hong Kong University of Science and Technology

Besides security, privacy is another important issue concerning intelligent product. Especially compared with traditional non-intelligent electronic products, the connectivity, embedded control, data sharing and exchange features of intelligent product make it more vulnerable to be intruded, watched, which cause privacy violation. Users now concern more about their personal information and require their power to know, determine and control what personal information to be accessed, gathered, shared, disclosed, in what ways, by whom and for what purpose. However, till now, rules and guidelines of privacy towards intelligent product haven't been established yet among companies, users and legislators, as conceptualized view of privacy will not work because of the complexity of the new relationship in information age. So how an intelligent product is designed and developed under an "appropriate" concept of privacy is important. Develop team should consider the balance between the protection of their users' privacy as well as the requirement of data gathering and exchange. Without the consensus of privacy, even if an intelligent product performs well, it is easily to be challenged in consumer market. Several ways may

F4. Core Tech Innovation

Core tech determines the most essential technologies that used in an intelligent product to generate its core functions. It can differentiate a product from its competitors identically, if it is used appropriately. In order to establish this advantage, core tech can be cutting-edge, but also "advanced yet acceptable" It means that the core tech must be advanced enough in the product category or industry to provide sufficient functions. At the same time, the technology needs to be stable, reliable and user-friendly to meet user's expectations. The innovation of core technology can be achieved in the methodological perspectives or practical invention and application of new materials, new structure. In this research, the innovation of core technology is discussed from the second perspective, as the scientific methods are not the focus of this research. Based on the development of current technologies used in intelligent product development, core tech has also been classified into three levels.

A lot of companies achieved disruptive innovation fail. Because they appear in wrong time, without arousing notice from others, or too advanced to understand and accept by general public. Apple is the first company to use multi-touch sensing surface in mobile phone, but it is not the company to invent gesture control. Considering of digital camera, Kodak is the first *company to invent it, but it didn't put it in the market, on the contrary. It hid it for years. It is Fuji to release it on the market after nearly 15 years after its creation.*

Don Norman, Director of The Design Lab at University of California

Core technology is considered as an independent attribute, as it is a distinct existing from function and performance. A product can be innovated and differentiated from other competitive products because of a cutting-edge technology.

Level 1 of core technology is related to the basic technology, which support the operation of an intelligent product, such as power technology (power tech), or material technology and so on. Power tech concerns how energy is harvested, conserved and consumed. For intelligent product, due to its mobility and smaller size, the existing power processing procedure and energy capacity are too low to cope with its application. The innovation of power tech can be the development of new energy generation methods, energy transmission methods, or more efficient energy storage sources, such as batteries or fuel cells. For instance, energy can be harvest from body motion or heat, which enable long time usage of wearable.

The innovation of product is constrained by the technology of battery and material, as well as wireless network development. If these technologies are advanced enough, the breakthrough of intelligent product can happen.

Wim Wang, IT Expert

The battery technology cannot support the boom of intelligent product. Wearable relies too much on battery technology. Although Samsung uses Graphene battery, which doubles the existent electricity volume, the breakthrough of intelligent product is still difficult.

Miao Dai, IT Journalist

Level 2 describes the technologies support the main function of the intelligent products, such as computing power, or embedded technology. Intelligent products can interpret a command and execute it as a series of mathematic problems. This requires strong computing power to support the calculation. Especially when many of the intelligent products are designed much smaller, the implanted computers need to be smaller, faster and powerful enough. Computing power can be briefly understood as how fast a device can perform an operation. So the computing power can be innovated in aspects like response time, processing speed, channel capacity, latency, bandwidth, relative efficiency, or power consumption, and other factors that influence the its performance.

Today, it is almost impossible to find a product without computer inside of it. In fact most products have more than one computer inside of it. Designer's job is to make technology understandable and usable for people, but you cannot do that unless you understand the technology and people. So we need computing people, mechanical engineer, and biological *scientist (in developing a product). Computing is extremely important, because it is almost everything. Because everything we are building today have computing and communicating within them. Even clothes today have computer, lights and all sorts of exciting things in it.*

Don Norman, Director of The Design Lab at University of California

Intelligent product will integrate into our lives. A slice of smart glass can be embedded into retina and change our biological function - to see more clearly, far and record the vision. Intelligent products do not need to be tangible, but invisible, which can connect with other embedded chips in human body.

Wenhua Li, PhD student of Design, the Hong Kong Polytechnic University

Embedded technology is the technology to integrate devices into products, platform or environment. These devices used to control, monitor or assist the operation of the "thing" that they are integrated into. For intelligent product, the product itself can become and embedded product, such as smart lenses embedded into human body. Or the product can be embedded with chips in different ways. As the key element of embedded tech is "integral", its innovation could be addressed in its adherence and integration. The performance depends on the specific embedded context, as the embedded device needs to work with other mechanical components, or sub-systems (or human body) harmoniously.

Level 3 refers to the important technologies that could be widely used in the intelligent product in the future. Due to the limited development, these technologies although reveal their great potential, they haven't be fully applied in commercial usage yet. One of the most relevant technologies is AI. Intelligent product does not necessarily to become a real AI product, but it has many AI features, such as reasoning, problem solving, learning and so on. The innovation of AI can be applied and developed to match the specific context of intelligent product.

Intelligent product by its old definition refers to electronic product that runs extendable operating system, which from my point of view enabled the flourishing of today's smart devices. I think I mentioned personal definition of New-Gen Intelligent product, which is any electronic device that is designed following the principle Human Centered Design. But I do believe the next generation of intelligent product should be equipped with Artificial Intelligence and really being smart in an automatic mean rather than loaded with a preset Human considered system.

Xiaojiao Xu, Associate Industrial Designer, Logic PD

Virtual reality has been as an advanced technology has been used in intelligent product more than before. The intelligent product was being developed beginning with reflecting the reality progressively with an aim of achieving the virtual reality. However, unless we were in the world Matrix, where simulation could be directly projected to the brain without affecting human's sensory organs, it still has a long way to achieve the virtual reality. Up to now, to achieve higher *degree of reality is a hot discussion. Nowadays, people turn more and more sci-fi into reality. For example, the technology of cloaking was well developed and it seems to become more popular. Facebook spent 20 billion dollars on the virtual reality glasses based on the technology of cloaking. The adult film industry also makes use of this technology widely.*

Tao Du, PhD student of Optical Science, The Hong Kong University of Science and Technology

Another possible technology mentioned by interviewees that could be used in intelligent product is virtual reality (VR). This technology can be used in intelligent product to create images, sounds and other sensations that resemble physical presence or imaginary scene. For instance, VR goggles can be combined with UAVs. When flying UAVs, users can experience flying with their own eyes.

The innovation of intelligent product can apply augmented reality to create digital image and sound and projects them in the real environment. With this technology, illusion of virtual objects can be integrated in the real environment. Users can have an incredible and immersive experience with the product. For instance, the Rideon Ski Goggles is an intelligent skiing googles that facilitate skiing and create a more interesting skiing experience.

F5. Interaction Method Innovation

The interaction method in this framework refers to how users make commends or interact with the intelligent products to trigger reactions or finish tasks. Compare with keyboards or touch screen input, interaction methods develop towards more implicit forms of inputs that support natural human forms of communication, such as facial expressions, hand gestures, body movement, speech, and so forth. In this research, the interviewees mentioned several interaction methods of intelligent products, including voice control, gesture control, eye movement control, and even mind control. According to the level of interaction, the interaction methods can be further analyzed from three perspectives.

Level 1 refers to the basic ways that trigger reaction of intelligent products can be keyboard input to type-in or press, with buttons or keys to act as a mechanical or electronic switch. It is the most early and common way of human machine interaction that applied widely in many products. The keyboards can have various size and forms, such as laptop size for computer, or smaller size with numerical keypad on watch and so on. Some keyboards are designed to be more ergonomic, such as game controller to be hand-held. As the development of smart phones, the physical keys has transformed into virtual keys that displayed on the screen, which serves similar functions.

Level 2 of interaction method is more flexible and natural, as users do not need to rely on keyboards to interact with a product. Development team needs to understand human body language, thus building a richer bridge between human and machine with new interaction methods, such as multi-touch interaction, facial expression control, hand gestures, body movement, voice control are developed. Intelligent product can apply these interaction methods to create new experience. With multi-touch interaction, users can drag, resize, and rotate photos, videos and electronic documents. With gesture control, users can control intelligent product by making hand gesture in air, such as moving 3D objects in a virtual environment, etc. Users can turn on or off a product with eye movement, or facial expression.

More function options. e.g., voice activation "movie time" ... your furniture, lighting and TV and speaker will all change for you.

Samuel Lee, Designer of Powertech

Smart devices can be controlled by gesture to change its model. For example, when you raise your hand, the table and chair can change the height. When you fold your hands, the furniture will fold itself as well. With your figure touch and move on the smart thermostat, the indoor temperature can be changed.

Zhongyan Wu, IT journalist

Level 3 of interaction method refers to the interaction methods that users can control or interact with devices without physically interact with them, such as mind control. Mind control is known as brain-computer interface (BCI), which is a direct communication pathway between brain and a machine. With this interaction method, intelligent product can read users' brainwaves and transform them into meaningful information, which trigger certain functions. For instance, Emotiv is a BCI headset that can understand and decipher basic mental commands. If it is connected with UAVs, when users are making mental commands, such as push, pull, levitate, or rotate, it can detect them and trigger UAVs to take actions. It can also identify emotion of users with facial expressions such as blinks, frown, surprise, and smile, which is possible to trigger reaction of intelligent products to the emotional status of its users. The intelligent product with BCI can be widely applied in many industries, such as education, mobility, automotive, aerospace, gaming, marketing, media, and entertainment and so on.

I thought mind control is possible in the future. Human can control various products with their mind. In the TV series of Black Mirror, chips are embedded into eyes, people can record their daily life through it. These recorded life scenes can be synchronized on TV screen through mind control and shared with their friends.

Qi Liu, engineer

Every ordinary static product and electronic product, when embedded the chip, can become intelligent product. The chip can be designed to enable personalization. According to the users' age, profession, education, and preference, the intelligent product can serve them with personal experience. The embedded chip can make intelligence invisible and easy to diffuse.

Mingjie, PhD student of Design, Tongji University

Watch is no longer for time-tracking, it is like a mini portable computer with emails, social media & music. The technology will be much more advance within a short period of time. I believe in the future, it will transform into a thin piece of material, implant into human skin.

Betty Sit, Founder & Design Director of Betty's Design

7.3.3 Experience Innovation

At its core, experience is the state that users has been personally affected through observation or using a product. What people actually desire is not products, but the experiences products provide (Pine & Gilmore, 1999). Experience can be reflective or operative (Margolin, 2002). It is all the ideas, emotions, memories that created in the moments of engagement, or touch-points between users and products.

Experience innovation is extremely important for product innovation, as in reality a product is all about the experience (Norman, 2009). The better the experience a product enables for the user, the greater the value of the product to the consumer (Cagan & Vogel, 2002). Experience attracts a lot of attention in product design and development over recent years (Gemser et al., 2011). It is found that companies placing significant emphasis on experience design contributes more to financial performance, if the experiential design of a product is innovative (Gemser et al., 2011).

…I believe any desired product both new and old have qualities that hold the attention of the user. Anything from the physical properties like materials and shape to more of the emotional properties like what the product represents outside of the context of use.

When we look at products we are looking at products that make it easier or more enjoyable to complete a task. The calculator is a good example of this. As there is always the human input the product becomes an extension of your capabilities, access to knowledge with little effort, and a communication tool to connect with the people closest to you. These products today often tackle two or more of the needs we have with respect to efficiency and communication.

Oluwaseyi Sosanya Co Founder, Gravity Sketc

In the following section, the experience innovation of intelligent products was analyzed from four vectors: utilitarian experience, emotional experience, aesthetic experience and sensory experience.

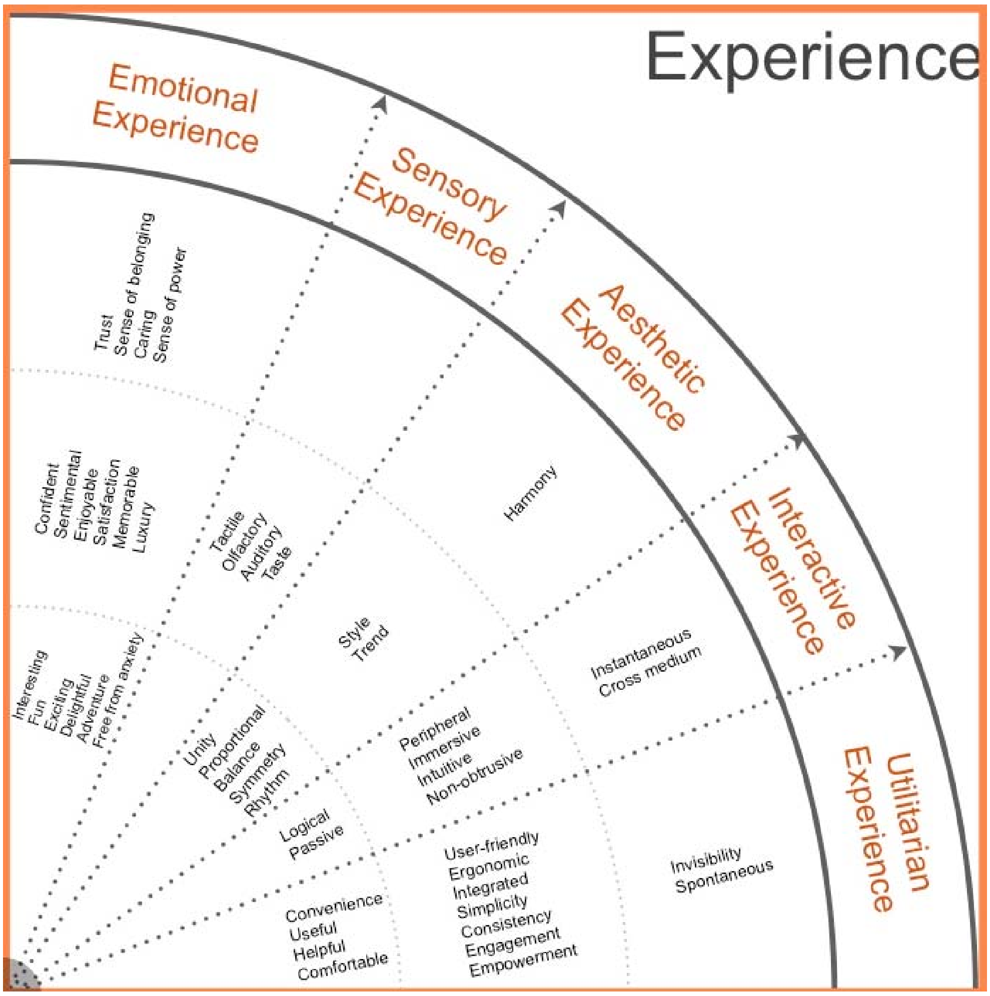


Figure 22 - Experience innovation in the framework

E1. Utilitarian experience Innovation

Utilitarian experience in this research refers to user's experience of using an intelligent product, especially relating to the product's function. The utilitarian experience has been understood from three levels.

Level 1 refers to the basic requirement of using a product, such as convenience, useful, helpful. It means that the product should at least cause no additional trouble, anxiety and attract extra efforts of users. As intelligent product combines software and hardware, the products become much more complex. It is easy for intelligent products to have errors or hard to use or to interact with it, which is not only helpful for users, but also cause more troubles.

I always have a simple rule about these kind of hi-tech things. THEY DO NOT WORK!
Or at least they don't do anything much better than low-tech solutions!
Davies Howard, Professor and Advisor to the Dean, Department of Management & Marketing, Faculty of Business of PolyU

I hope the intelligent product could solve the pain points or itchy point of the user. Energy-saver (no need to charge everyday), and safe. For example, if smart bracelet is heavy to carry on, without waterproofing and could not work without cell phone, I think of such product is useless…

Jie Zhou, Startup marketing specialist

Compared to traditional products, intelligent products have a higher dependence on its physical environment. For example: You must access Internet to support the products. Perhaps one day when Internet becomes a virtual generally supplied energy, similar to electricity, intelligent products can be prevalent.

Nan Xia, Design Researcher

(Intelligent product can) Make life easier and comfortable.

Ale Urrutia, Co Founder, Colorale Design

Level 2 of utilitarian experience includes user-friendly, ergonomic, integrated, simplicity, consistency, engagement, and empowerment. This level means that compared with traditional products, intelligent products broaden a horizon with a more comprehensive and sophisticated using experience for the users. Intelligent product should also apply principles of ergonomics, such as easy and comfortable to identify, reach, grasp, or manipulate with suitable size and shape. From this perspective, the innovation of intelligent products should not be created out of new technology, but should inherit the traditional achievements.

From an ordinary user perspective, I think the intelligent product is not user-friendly enough. For example, although smart socket has visual programming functions, but in fact it had little connection with its user. If there is a template in advance to preset scene, it would be better. Same observation is made on smart glass. It only has single function and relies too much on cell phones. The glass could not be used when it is out of battery…

Bob Ding, IT Expert

Before, when we buy a washing machine, we intend to use it to wash clothes. But now when we buy intelligent washing machine, we expect it to have integrated functions, such as remote control, automatic playing music, or automatic ordering washing powder functions. Similarly, before mobile phone is only used for making calls and texting messages, but now it is a small computer that we wish it can do everything. This is not simply to add new functions, but to select relative functions based on using scenarios and integrates them into a system.

Haofu Wen, Fano Lab CEO

For people to engage these products and fall in love with them, they need to be simple, simple, simple. I feel the successful products will be the ones that have edited DOWN the complexity to the MOST RELEVANT features only and then spend all their energy on making them easy to learn/use and beautiful. That's it. The bigger issue with IoT products is that they need to find the "killer application." I don't need my toaster to talk to my shoes unless there is a simple and compelling reason!

Brian Matt, Co Founder, Stratosphere Labs, LLC

There is yearning for simplicity and control. People feel anxiety about intelligent products, because they are very complex, too much information, high-tech and difficult to learn.

Dr. Surya Vanka, Director of User Experience at Microsoft

…objects should have some simple functions not try to pack too many functions into one thing (most people will only use a small part of the functionalities of advanced designs, e.g. phone, camera, etc...)

Veronique Lafon-Vinais, Associate Professor of Business Education of HKUST

Intelligent product, such as wearable currently offers brands entire new ways to engage their consumers and create value and meaning… Currently the most obvious ones are the trackers, but I believe this is going to become more interactive and participatory. Once these devices actually become intelligent and already work on their own initiative, based on what they have learned from you, then new possibilities will be created for brands to take advantage of.

Mario Van Der Meulen, Executive Creative Director Asia of LPK

As intelligent products combine hardware and software application, or connect and coordinate with other intelligent products, it requires high level of integration in order to prevent conflict of the system or confusion of the users and maintain its efficiency. The integration can be reflected from the implication of design language, or engineering concepts, such as design of hardware and interface, or the using and interacting logics. Integration is not simply to add new functions, but to select relative functions based on using scenarios and integrates them into a system.

Simplicity is simple to understand. It implies beauty, purity, or clarity and intuitively recognizable. Compared with traditional products which emphasizes simplicity from industrial design perspective, intelligent product should integrate simplicity in each aspect, hardware design, system design, interface design, function design, using and interaction logic design, which means the each touch points with users to denote freedom from effort or confusion. For instance, intelligent products may have countless possible functions. These functions should not be all included in the design, but reduced, organized and prioritized.

Consistency is important for intelligent products, as it makes action and results predictable. It can speed up the user's learning curve, so users can recognizes them smoothly for what they are when encountered, which may avoid confusion and frustration. Intelligent products can be designed with internal and external consistency. Internal consistency refers to the consistency within a product. For instance, by specifying a contract between programmer and system, the system memory will be consistent, which may reduce errors. User interface needs to be designed with a coherent framework, which enables users to make choices in a continuous manner. External consistency means that a product is designed to be consistent with other products or platform conventions.

User engagement refers to the experience that created in the process that users are connected with a product through various ways of interaction. For instance, users can be involved in the early product development. The iteration of product can be based on user's feedback. In order to innovate influential engaging experience, designers and developers need to understand the deep aspirations of users and use them to create meaningful connections with users. Engagement experience can make users' lives more memorable, delightful, and even magical.

User empowerment refers the experience of autonomy and self-determination by making decision and taking action according to their wills. It can also mean to access knowledge and service, which overcomes their sense of powerlessness. The Intelligent product innovation can enable users to enrich their own knowledge, skills and experience, increase their confidence, and feel more powerful. By using the products, users have more chance to strengthen their social connection and explore more opportunities.

Level 3 is implicit and spontaneous utilitarian experience. It means that intelligent products are no longer passive existence, but actively immerse into each aspects of daily life even without the notice of human beings. Implicit or invisible utilitarian experience is about the ability to accomplish a desired task seamlessly rather than being noticed. Right now, each intelligent product comes with its own APP, its own logic of interaction, and all require special attention from users. The innovation of intelligent product can move towards the integration of these differences.

…(intelligent product's) integration into living space should be seamless rather than obtrusive.
Veronique Lafon-Vinais, Associate Professor of Business Education,
The Hong Kong University of Science and Technology

Intelligent device intends to actively involve in and influence user's life to receive feedback. While, traditional product is designed to be passively influential and change people's life. In comparison, intelligent devices have more intrusive nature. That's one of the reasons that the project of Google glass is terminated. It also explains why most of intelligent products on the market are "moderate" products (e.g., wearable). As the development of technology, it is possible to make the product "invisible". Then people may not feel being offended.

Nan Xia, design researcher, The Hong Kong Polytechnic University

The future of intelligent products are ambient displays, tangible user interfaces, context-aware computing, attention-sensitive interfaces which all target the seamless invisibility. Spontaneous utilitarian experience is initiated by a user's requirement spontaneously, and reactive interactions of the intelligent product are triggered in response to another interaction.

Mark Weiser's "Computer for the 21st Century" (1991)

E2. Interaction Experience

Interaction experience refers to the experience that happen when users are interacting with a product (Boztepe, 2007). Different from utilitarian experience which especially focuses on the functional experience when users are using the product, interaction experience may not deliberately refers to "using". It can be the overall experience that users interact with an intelligent product. The interaction experience in this research has been understood from three levels. The first level includes logical and passive interaction experience that many traditional electronic products are designed with. The second level includes intuitive, natural and immersive interaction experience, which current intelligent products companies intend to achieve. While the third level refers to interaction experience, instantaneous interaction, or cross medium interaction, which intelligent products are still developed at a primary stage

Level 1 is logical and passive interaction, which is adopted in the standardization as an accepted basis for some early intelligent products, such as computer and mobile phones. However, as technology develops and users' requirements for interaction increase, the logical and passive interaction methods do not provide sufficient support for a number of user scenarios.

Level 2 of interaction experience in intelligent products can be intuitive, peripheral or immersive. Intuitive interaction provides natural, unobtrusive and fluent experience. Intelligent product can be innovated with implicit control methods (e.g., gesture), through which the product can capture information about the user context, and thus adaptively or autonomously respond to their needs and behaviors (Boztepe, 2007). With intuitive interaction, users can manipulate a product in a natural way with less conscious and minimal knowledge.

Our interaction with the product should go with our natural way of thinking and doing. Not to learn new logic or think against the natural thought flow.

Partho Guha, Director, Elephant Strategy + Design

…interface should be simple, intuitive (think Apple products) - no more having to read complex instruction manuals.

Veronique Lafon-Vinais, Associate Professor of Business Education, *The Hong Kong University of Science and Technology*

The most natural human machine interaction is human-like interaction. Users cannot be consciously aware of the cognition requirement of interaction and technology.

Jiawei Gu, Chief Designer of Baidu Institute of Deep Learning

The concept of peripheral interaction is relevant to implicit utilitarian experience. As computers and screens are used everywhere and at any time, intelligent products have occupy a lot of time and efforts of our lives. To avoid being overburdened by technology and take back the control of their lives, intelligent products can be designed with peripheral interaction experience. It means that users do not require to pay focused attention to use and engage with, only when necessary. It points a new direction for intelligent product innovation - to be effortlessly and unconsciously, as a seamless part of our everyday routines.

Intelligent product innovation should focus more on human-product natural interaction and peripheral interaction, which free users from distraction (e.g., low lighting E-ink screen). People pay too much attention to mobile phones, which occupies their efforts, time, attention, and resources. If all of the intelligent products require such high attention, users will become too busy, tired and hard to focus on meaningful things. The life quality will decline. So intelligent products could be able to be embedded in the physical environment. For instance, the chair can sense the physical condition of body and adjust its surface to provide the best and healthy experience to reduce the possibility of spine diseases.

Yi Shi, Associate Professor, Guangzhou Academy of Fine Art

Immersive interaction experience relates to the capability to create a real-time interactive environment, which enables users to experience and extend their sense of presence overlaying of virtual and the real. Intelligent product that innovates in this aspect can heighten users' experience with more sensorial contact by reflecting or invoking their mood.

Level 3 includes instantaneous and cross medium interaction. Instantaneous interaction experience is the momentary experience, that users get when interact with an intelligent product (e.g., google glass). The interaction experience of intelligent products is crucially based on how fast humans can perceive information and the speed that a system can respond to a comment. Users are able to recognize very short temporal delays (Raaen & Eg, 2015). But this delay acceptability is highly context-dependent. While the responsiveness of a system can vary from a few milliseconds to a few seconds (Seow, 2008). Till now, intelligent products that innovate with instantaneous interaction are a new territory. How to define a suitable and comfortable responsive time and methods that matches user and products are great challenge and opportunity for development team.

Google glass is an example that requires instantaneous interaction. It provides momentary experience that users instantly get from the interface. Instantaneous interaction is key difference among computers, mobile phones and a Google glass. For example, a computer user normally will spend a long period of time to go through contents on the screen. In comparison, they may only spend several minutes, or an hour with their mobile phones. When they are using Google glass, they may expect response appear in front of your eyes within 1 or 2 seconds. When you are sitting on a table, you expect a menu will appear on the Google glass instantly together with the picture of the dish, taste, and reviews. Instantaneous interaction is closely related to the using context.

Yushi Wang, Researcher of Steelcase

Cross medium interaction experience describes the possibility that users can transfer information or action across different products and environment and interact with them freely and simultaneously. These mediums can be intelligent products or non-electronic objects. Cross medium interaction create a seamless environment that merge virtual and real world. For instance, in Ironman, the information on a Pad could be transferred on the wall, or projected on smart glass, or displayed as 3D object in the air, which can be controlled with gesture.

The most impressive and important wearable could integrate multiple functions with small size, ease of use, and convenience. As the size of such wearable is small, the screen can also be small. So if it can easily project the screen in the air and be controlled through gesture or voice, it would be much better. Then users can deal with messages or work without only focus on the screen of mobile phones.

Huibin Xian, Manager, Investment Bank

E3. Aesthetic Experience

Aesthetic experience refers to how beauty is appreciated. It can be derived from appearance factors in this framework, such as color, shape, texture or material. The aesthetic experience involves a product's capacity to impress, delight one or more of sensory modalities. Intelligent products - as a new territory of product innovation are still at the stage of exploring aesthetic possibility. The aesthetic experience mainly belongs to visual domain. It is also related to other senses of humans, hearing, touch, taste, and smell. This research does not aim to distinguish which domain that aesthetics are mainly concerned, but to focus on its importance for product design. It is identified as a separate factor in the experience innovation. The aesthetics experience can be studied from three levels. The first levels refer to the basic elements that constitute aesthetic quality. The second level concerns style and trend, based on the first level, which is popular at certain time. The third level is more related to emotional satisfaction and personal feelings, that aesthetics experience may bring, such as harmony, natural, peaceful, or permanent, which can be valued regardless of time and difference of humans.

Not only technology, but also craftsmanship, as artifact of aesthetics and meaning, with limited production, highly personalized.

Dr. Jorn Buhring, Research Assistant Professor, Ignite Innovation Program Leader of The Hong Kong Polytechnic University

Aesthetics (of intelligent products) is more important compared with before, as users are more mature. In the fierce market competition, most of the first impression of product and brand are still based on visual impression, functional experience, rather than interaction experience.

Manav Gupta, CEO of Brinc

Level 1 refers to the basic elements of a product that contribute collectively to aesthetic quality, such as unity, proportion, balance, symmetry, rhythm, and so on. These attributes of traditional products have been studied for a long time, however their applications in the intelligent products haven't been fully explored.

Level 2 includes style and trend. In product design history, many popular styles existed, such as elegance, simplicity, sexy, high-tech, cool, pop or delicacy and so on. The trend includes futuristic, retro, modernist, classic, and so on. An intelligent product can adopt different style and trend. For example, it could have the simplicity, undecorated and technological sophisticated style and follows the trend of futuristic.

Most smart products on the market may now be too avant-garde fashion flaunting their attributes, positioning themselves by making clean break with traditional furniture, more or less to labeling their products as future products. Sometimes, over modern design will cause aesthetic fatigues. It will be less recognizable.

Xiaoqian Ma, master student of Computer Science, Columbia University

Level 3 refers to the emotional pleasant, aesthetic value that may transcend time and culture, such as harmony. Harmony, natural, or peaceful is a state of mind or atmosphere that can be created when using an aesthetic product. It means timeless aesthetics, which does not aim to be fashionable for a period of time, but lasts for many years. It represents a universal beauty, which most humans can appreciate regardless of their backgrounds, cultures, or regions. For intelligent products, it brings a new possibility for traditional static beauty with interactive aesthetics, which relates to beauty of use, engagement or connection with physically contact. It requires a graceful integration of design, arts and technology.

E4. Sensory Experience

Sensory experience describes something related to sensation - an experience that users feel with their physical senses. Sensory experience is very important, as it influences user's perception, cognition, and emotion, which can create an interpersonal intimate, which influence their judgment of a product.

Only level 1 sensory experience is defined, including tactile, olfactory, and auditory and taste sense.
Tactile experience refers to the physical interaction that happens between users and products, such as the soft touch of sofa. It is the only sense that requires contact with the skin. Products can have different tactile feelings, such as soft, hard, warm, cold, light, heavy, flexible, or stiff. Auditory experience is what one hears, such as the sound of a car door closing. Olfactory experience is how a product is smelled, such as fresh, stale, natural, artificial and so on.

The innovation of sensory experience can be the creation of new sensory experience; the integration of sensory experience in a new way; the elimination of negative and undesirable experience, such as noise; the application of a more suitable sound. In brief, the innovation of sensory experience needs to be consistent with the perception and anticipation of users.

E5. Emotional Experience

Emotional experience is what users feel when interacting with a product. It can be raised unconsciously by cognitive and sentimental appraisals of a product. The innovation of emotional experience refers to the creation of enjoyable interaction, which cause sensual pleasure. Three levels of emotional experience were identified.

Level 1 includes interesting, fun, exciting, delightful, adventure, and free from anxiety. Interesting can be related to fun, surprising or amazing which contains more information due to its ambiguity and intriguing. As intelligent products usually have multiple functions and higher level of complexity, the interesting experience might encourage continuous explorations. While fun, exciting, delightful and adventure are positive experience to describe a momentary experience, which provide users with joy.

When using intelligent product, it is easy for new beginners or elder person to feel anxiety or even fear, if they are confused or helpless. As many intelligent products are high-tech products, users may be afraid to damage the equipment or embarrassed if they make mistakes.

> *Smart products right now are far from intelligent. Real intelligence is to create easier, enjoyable and intuitive experience. But many smart products create more trouble and consume more efforts from users than it is supposed to be.*
>
> *Kang, Startup founder*

Level 2 includes confident, sentimental, enjoyable, satisfactory, memorable, and luxury. The enjoyable experience of a user toward an intelligent product can relate to emotional (e.g., fun), sensorial (e.g., delicate taste), physical (e.g., touch), psychological (e.g., satisfaction) or social (e.g., romantic relationship). Intelligent products can bring novelty, surprise, to influence the environment that the user located, to extend the knowledge of the user, to bring intimacy with others, to feel sense of control, or to make one's life better. All these results can contribute to the creation of enjoyable experience.

Users that master high technology may enjoy themselves and feel more self-confident (Jordan, 2000). The user-friendly experience and intuitive interaction can enhance user's confidence. For instance, compared with other "demystified" computers, people who previously have been lacking self-confidence that use iMac in a more confident frame of mind. Users that adopt the intelligent product may consider themselves as "pioneers", leading or at least keeping up with the trend, instead of feeling out-of date. This may increase their sense of confidence. Besides, intelligent product can empower users with knowledge, skills and social connection, which may also strengthen self-confidence. Reliable intelligent product can support user's motivation and reduce helpless feeling, thus to increase sense of control and power.

When using a product for a long time, users can feel sentimentally connected to a product, especially when the product belongs to or was used by a family member. Or it was received as a gift from a friend or a person one loves. It represents a particular life event that is meaningful to the user. Compared with traditional product, intelligent product may be lack of sentimental bond with its user, with its high-tech style and short time possession.

> *I can give you is that the classical products are here to stay, and grow old together with its owner. You can attach even to defects like an old car. The products are many smart things, allow you to communicate, be update and connected to the world, but (if you exclude that contain photos and many personal data) have no sentimental value. Like a clock that is handed down from father to son, or the furnishings of the house, biking, etc ...So maybe new product must to be developed to remain or be durable in the life of the people.*
>
> *Luigi Memola, Senior Concept Artist & Designer, STUCK Ltd Singapore*

Users usually expect an intelligent product to behave positively in the most expeditious, considerable and beneficial manner. If the expectation is met, users will satisfy and build trust on it. However, as intelligent product industry is still at primary developing stage, it is easy for products to have errors in operation. The errors can be maximized if it happens occasionally, which cause negative effect on users' trust. Besides, in some condition, the intelligent product itself is "rationally" perfect, the "errors" occur in the using process, if it's "too" novelty and unfamiliarity.

Therefore, in designing and developing an intelligent product, various possible conditions need to be considered, such as misuse, disuse, abuse of automation, or over-trust.

Level 3 refers to trust, sense of belonging, caring, and sense of power. Sense of belongingness is the human emotional need to be accepted as a member of a group (Fiske, 2004). When using similar products, users can have an “inherent” feeling of belonging and be an important part of something greater than themselves. The connectivity and sharing nature of intelligent product enable users to build relationship with others through various ways, such as comments, likes, share, and activity engaging.

> *As our everyday lives became more and more connected to the Internet, smart products were designed as physical products that would benefit from and become a part of a connected ecosystem. In the system, people are looking for sense of belonging through social connection and networking.*
>
> *Nelson Wah, Principal, Industrial Design, Nelson Wah Design*

The caring experience refers to display of kindness and concern for others. It is a personal, connected and intimating experience. Compared with non-electronic product, intelligent products have more chance to be caring with much stronger sensing technology, computational power and context-awareness capability. The design and development of intelligent products has more possibility to be considerable and caring, such as to offer recommendation proactively.

7.3.4 Meaning

Meanings are what we attach to the product. The meaning of a product depends on how human beings to make sense of it (Margolin & Buchanan, 1996). It reflects social, cultural, and psychological dimensions of being human. Users can identify the meaning of a product through a cognitive process. After seeing or using a product, they will recognize messages that conveyed from the product, associate with their memory, interpret them, and assign expressive attributes to the product (Boztepe, 2007). The process is unconscious, personal and emotional, which influences a lot on intelligent product innovation. Intelligent product should not only innovate in functional or experiential attributes, but also meaning attributes, to deliver profound and sustained values to users. Five types of meaning innovations were discussed, including innovation of symbolic meaning, economic meaning, environmental meaning, cultural meaning, and social meaning.

> *Where before the product and its function ruled the strength of a brand, this will shift to what that product means and does beyond its initial function.*
>
> *Mario Van Der Meulen, Executive Creative Director Asia of LPK*

It is simply to understand purpose and meaning of experience for end consumers - What is benefit; what is way to control and manage IoT devices, Should we allowed devices to automatically link each other's or do we need security…how sensors and environment communicates with users? How to make sense to all of it.

Juha Kosonen, Chief Designer, Huawei Device MBB&Home, Dreamlab, Huawei Technologies

Each of them should serve a purpose and enhance user's life….Otherwise it is only a gadget….

Philippe Vergez, Executive Creative Director, Evita Peroni/Deichmann+Co

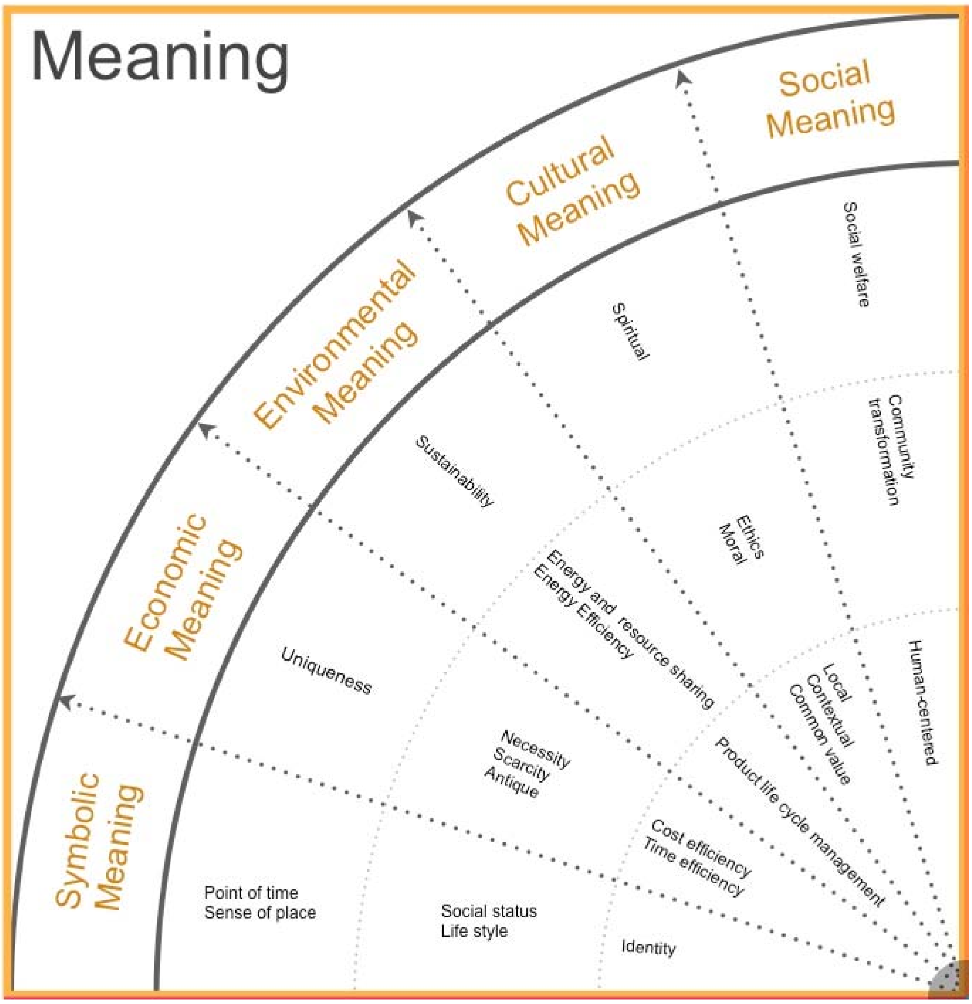


Figure 23 - Meaning Innovation in the framework

M1. Symbolic Meaning

Symbolic meaning is a sign that indicates, signifies, or is understood as representation of an idea or a concept (Govers & Mugge, 2004). The symbolic meaning of a product is what the product is intended to convey to its user or what message that the user intends to present to the world. The products are frequently subject to multiple interpretations, and can have both intended and unintended symbolic meaning. Compared with traditional product, the design and development of intelligent product hasn't fully explored this area yet. In this research, symbolic meaning has been categorized into three levels.

Level 1 relates to symbolic meaning from private perspective, which include self-identity and self-expression, intend to assign personality or express self-identity, belief, or values through product they use. It is important for an intelligent product to develop its personality, as it is found that people are more attached to products with similar personality to their own (Govers & Mugge, 2004), because these products can communicate about their users. For instance, users of intelligent product can denote how and to what extent they are capable of handling high-tech products. The message transferred behind it can be how cool and fashionable they are, or how smart they are, etc. In addition, intelligent product with personality can differentiate itself from fierce competition in the market.

Level 2 relates to social roles and relations of users, including social status and life style. Products can represent users' position or rank within the society. For instance, luxury products can demonstrate wealth and high social status of a person. Products can also denote the lifestyle, interests, opinions, or behaviors of a user, such as green lifestyle, bohemian lifestyle, and so on. As users intend to choose products that are considered appropriate for their social image (Cătălin & Andreea, 2014), it is important for develop team to innovate intelligent products in this feature.

Level 3 relates to ultimate meaning of a product in time and space, referring to point of time and sense of place (Cagan & Vogel, 2002). A product can represent a particular moment, a special or unique place that relates to its users. It can foster a sense of authentic human attachment, a feeling, perception or sense of belonging with point of time and sense of place. The style, form, shape, or color of the product can considered as special "mark" in history. So intelligent product innovation should not only consider symbolic meaning from personal or social level, but also its significance in history and in space. For instance, iPhone 4 is definitely a representative product in 2010 with its influence from America to the whole world.

M2. Economic Meaning

Economic meaning relates to users' evaluation of the product value or benefit (Boztepe, 2007). It relates to the exchange between sacrifice (e.g., price) that a user paid, and the benefit that he or she gets in return (Wang et al., 2004). The price paid is not the only measurement for economic value. In this research, economic meaning has been analyzed from three levels.

Level 1 includes cost efficiency, time efficiency, which describe the basic economic value that an intelligent product can provide for its user. It can facilitate daily work, such as cooking, cleaning, information searching, which frees them from tedious tasks. People can have less time for working and more time to enjoy life, learn and focus on the things they are interested. Compared with electronic products, intelligent products are more connected, intelligent and collaborative, which may handle complex task that only can be finished with large scale of equipment and a lot of labors.

Level 2 refers to scarcity, necessity and antique, which distinguish an intelligent product from its competitors with great advantage. Intelligent products need to solve "real" problem for users and provide necessary values. Otherwise they are only decorative trendy gadget. Most intelligent products on the market till now are still at the stage of adding more information-oriented functions, such as gathering health data, displaying them, analyzing them and so on. Even if based on the information that it can detect a disease, it cannot cure it, which is the most desired part from user's perspective. So how to define and develop the most significant solution is still a challenge for most of intelligent product companies.

> *Right now, the value of intelligent device is not apparent. They just add things to it. It is not necessary. This direction we are heading are very vague. There is no need for everything to be intelligent, but there will be more smart devices. For instance, the refrigerator, it can track what you have, what you need.*
>
> *Dr. Erez, PhD student of Design-Led Innovation, Queensland University of Technology*

Even at advanced states of technology, some intelligent products can still be scarcity, because of limited resources, complex craftsmanship or technique and so on. Due to the advanced technology and high cost of manufacture, it is possible that many intelligent products are hard to buy after its first launch. The condition may change if shows its great potential in the market. Scarcity can also be created intentionally as a marketing scheme to promote sales.

Level 3 refers to uniqueness, which describes the irreplaceable nature of a product. Uniqueness of a product describes a state or condition wherein the product is too special, unusual or valuable which any other products cannot take place of it. A unique product can stand out from other competitive products within the same category because of the special value it can provide for users. It can extend the boundaries of users' knowledge, experience or capability. For instance, an intelligent product that especially made from an antique product can be desirable, because it combines beauty of time as well as miracle of technology.

M3. Environmental Meaning

The innovation of intelligent products needs to minimize negative effects on the environment. Pollution, overpopulation, industrialization has become great burden to the eco-system. The popularity of global consumerism has made the condition worse. It is imperative to search and apply new methods to reduce the consumption of materials and energy for product. Compared with traditional products, intelligent products are more integrated with consistent iterate system, which has more chance to be environmental friendly. In this research, the innovation of environmental meaning has been analyzed from three levels.

Level 1 refers to the basic concept of product life cycle management with eco-friendly process. Product lifecycle management is the process of managing the entire lifecycle of a product from inception, engineering design, extraction of materials, manufacture, distribution, to use and disposal. All these process has environmental impact. The intelligent product could be innovated at each stage to improve the use or reuse of resources, minimize possible waste and optimize energy usage. For instance, at design stage, the engine of automobile can be designed with connected system, which can gather information of location and time of day. When users are driving to recorded location, the car can proactively optimize engine tuning and influence driver's behavior.

Level 2 concerns the possible new technology and new methods of energy and material usage that could be applied in product development. Intelligent product innovation can apply new energy and materials in the development, such as green energy and materials with low carbon footprint. Green energy can be consumed with less environmental effect and manageable collateral effects compared with traditional energy, such as solar energy. Intelligent product innovation can use more local materials or biodegradable materials, which has low carbon footprint, and conduct principles of reduce, reuse, recycle and refuse. New business framework can be developed with the innovation of intelligent products, such as data storage sharing, hardware sharing, transferring of product ownership, intelligent transportation system, and intelligent city and so on.

Level 3 includes sustainability as one overall ideal that can guide the development of intelligent product innovation and even the whole industry towards a long-lasting future. Sustainability is the endurance of ecosystems, with the target to achieve human-ecosystem equilibrium. Healthy environment are essential for the survival of human beings as well as other species on earth. However, in light of climate change, environmental degradation, population explosion and unlimited pursuit of economic growth regardless of the price paid, environmental sustainability is a great challenge for human beings. In order to achieve this ideal, the development of intelligent product needs to involve knowledge from domains like green chemical engineering, environmental resources management, environmental protection and conservation, as well as conservation biology. Sustainable innovation of intelligent products is no longer an isolated activity that conducted by a single company, but a shared responsibility taken by all stakeholders.

Sustainable is a must like using renewable energy, biodegradable materials, less harm to environment. Hardware can be upgraded instead of buying a new one may be also good. For example the concept from Toyota, they want to use hydrogen as car fuel so only water will be generate by the product. May be the car has sensors to detect if any dangerous near you and sensor for light intensity and air condition to adjust the interior environment. Connected to Internet to provide you the best driving route to your destination base on updated traffic data. To upgrade the car, may only need to upgrade what u want ~like outlook, engine...,etc and all unwanted stuffs are biodegradable or reuse.

Sunny Cheung, Product Designer

M4. Cultural Meaning

Cultural meaning has demonstrated its homogeneous and heterogeneous nature among different nations, races and groups of people. Due to globalization, application of Internet, and international travel, ideas, meanings and values can be exchanged much more freely around the world. This process is further strengthened by the product consumption following international trend, taste, or style simultaneously worldwide. So it is common that people, especially young people share similar values, beliefs or norms from different nations and regions. They not only understand, but also create and diffuse new consumption cultures as collective cultural identities. Different cultures are increasingly understood and interconnected than any time before.

People from different cultural background may also interpret the same product differently, because this interpretation depends on their values, beliefs, and norms growing from the specific cultural background for a long time. So when designing an intelligent product for a local market, the development team needs to consider about the cultural diversification and understand the local context, convention, ethics and spiritual belief. Otherwise, the cultural conflict may cause severe cultural conflict, or even crisis, which may lead to market failure or even political issue.

So the innovation of intelligent product needs to consider both similarity and difference among cultures. The cultural meaning has been analyzed from three levels.

Level 1 refers to the local context and universal values that specific intelligent product innovation is relevant to. The innovation of intelligent product needs to consider local context and universal value. Users from different background may have different using behavior. The innovation of intelligent product needs to conduct in-depth research about user scenario or using context of the target users. The innovation needs to consider universal values that shared similarly by users worldwide, because of the maximum of market margin. The development team should find a way to balance the requirements.

Intelligent product is a "product understand YOU". The air fryer of Philips is such a product. Chinese peoples like to cook and deep fat frying is always applied. However, we Chinese also concern about health, so with Air fryer you can have good yummy dishes in a less oily way - that is healthier lifestyle. With the design, there is less smoke of oil, which is another headache we had for Chinese kitchen.

Lydia Mak, Art Director, Visual Trend Analysis, Philips Design

When Philips design hair dryer for China market, we found that the space of living in China is not big. Users do not need big and very powerful hair dyer, instead, they prefer lighter, smaller and ordinary one for home daily use. Their perception of color is also different from European people. Instead of strong color, users in China prefer pastel color, which is softer. We also found a lot of Chinese people's hairstyle is not big and exaggerated, but natural and soft. In order to fit into local context, we hire an Asian model with natural hairstyle instead of European model.

Another project about contextual design is for India. We found that some India people in slums only earn two dollars per day for their work. We intend to design better product to improve their living condition. It is very difficult for foreigners that locate in Europe to conduct in-deep research, as well as wealthier Indian people, because of the serious limitation of social class. Therefore we hire people from slums to give suggestions for our design. We first design solar energy lamps on desk, which is both affordable and eco-friendly in a long-term consideration. But the feedback suggests that Indian does not prefer lamp on desk, they like light that hangs on the ceiling, because that's what the rich family have - to represent their high identity. According to the context, we design a hook to hung up the lamp.
Prof.ir. M.A. Voûte (Ena), Dean of Industrial Design Engineering, Delft University of Technology

The second level refers to moral and ethical issues of intelligent products. The acceptance of intelligent product ethics in different culture may be different. However, there should be some basic consensus of it among all the human beings. As intelligent product becomes smarter, users can be concerned with the moral behavior of both the people who develop the products and the product itself. For instance, many governments listen to mobile phones' conversation and monitor online speech, with help of intelligent product. If the product's ability of understanding natural language and speech has progressed, it is possible that all people have no more online privacy. If the right falls into wrong hand, the consequence could be unpredictable. Another concern is that when intelligent product evolves at certain level, it can make decisions by itself and may harm human beings, either in daily use or for military aim. So intelligent product innovation is presented with ethical dilemmas.

Level 3 concerns spiritual meaning that intelligent product may bring to its users. Spiritual meaning refers to sacredness brought by a product. It can have various implications. Intelligent product can liberate humans from tedious work on physical and mental level - from cleaning house to organizing and analyzing documents. It free people with time for self-accomplishment, self-examination, or the seeking for spiritual life. People one day may reexamine the relationship between human beings and the product. Intelligent products are more humanoid, interactive, or emotional, it is possible that users can attach their emotion to the product. The role of product as merely tool may change from static and lifeless object, to a metal or plastic "living organism". So what extent should intelligent product to be designed like a "living thing" is a question that the development team needs to figure out.

M5. Social Meaning

Social meaning refers to the potential impact a product may exert or benefits it can bring to all stakeholders in the society. Intelligent products can have variety effects on the life style of its user, from improving the social well-being of the group, to improve labor condition or fair trade, to creating new social setting. The innovation of intelligent products should not only focus on the product itself, but what welfare it can contribute to a group of people, a community, a society, and even the whole human beings. In this research, the innovation of intelligent product in social meaning can emphasize in three levels.

> *Social responsibility is connected with the customer's personal value system and can often build brand loyalty. Charitable donations, safe work environments, and health and family-oriented benefits all promote the corporate image. The company, however, can positively affect society through the product itself. Based on users' preference to buy products that benefit rather than hurt the environment or social groups, opportunities exist to add value to a product through social and environmental impact. Products can also have social impact by effecting changes in how people communicate and interact with each other. This Value Opportunity and its related social and environmental attributes are probably the least explored of all the VOs. Yet they continue to have a growing effect on product development.*
>
> *Cagan and Vogel (2002, p.65)*

Level 1 refers to human-centered design, as the basic requirement innovation, which should be the baseline of all the product development. The innovation of intelligent products should consider the well-being of individual, the dignity, and the happiness of human being. It should respect the difference of humans with empathy and consideration, especially for child, senior, and disables. The innovation of intelligent products should fulfill not only obvious human needs, but also the underlying desires of humans - to be understood, to be empowered with knowledge and skills, and to grow continuously.

…Because it is designers' responsibility to communicate how mechanics that ran invisibly by computers and electronics work. This led to today's state which is where we are, which is focus on people understand how people function so and understand things so that we can design things that people can actually use. That is called human centered design…

Don Norman, Director of The Design Lab at University of California

Level 2 concerns community transformation. Intelligent products can contribute to the transformation of community by facilitating users with better working and education conditions; improving the health condition of residents; or providing open platform for all stakeholders. For instance, 3D printing machine can be located in some remote community, which allows residents to print their daily ware with ease and lower price. The waste materials can be recycled to ensure sustainability of the environment.

The intelligent product has peer influence. For instance, the reason that I use Nike fuel band is because that many of my friends use it. So we can share data and compare data on online platform. It makes the individual activity more socially engaged and interesting. It changes the exercise behavior of users.

Tianjiao Wang, Phd student of Computer Science, The Chinese University of Hong Kong

Level 3 relates to social welfare, that intelligent products can help to achieve. For instance, freemium framework of intelligent products enables users with low or zero cost of hardware, software, and service. More people can afford intelligent products and enjoy their benefits. Intelligent products, together with free international Wi-Fi project, user-generated content, and free education opportunities on Internet, knowledge, skills, and experience will be disseminated and revolutionize the world.

The context is that previously, devices such as computers and smart phones and tablets were designed to connect to the Internet to share and receive information. This previous trend was known as the "Information Age". Then the Internet became a platform for social networking, connecting people in new ways, and affecting our daily lives like how we shop, communicate, watch television, exercise, and work.

Nelson Wah, Principal, Industrial Design, Nelson Wah Design

7.4 Discussion

In this chapter, the framework for the innovation of intelligent products was established and described. Four sectors, 22 vectors and 168 innovation opportunities were discussed. The opportunities were further classified into three levels. The "intelligence" vector is the one that exemplify “intelligence” of a product, which differentiates an intelligent product from other similar concepts.

After comparison, it was found that currently the innovation of intelligent product appearance has not been explored exhaustively. Only material attribute has been developed in an innovative way. Smart material has been used to make it adaptive or reactive to the change of temperature or environment. Other vectors in this sector are still conventional; even they can be refined or improved beautifully. According to the expert interview results, the focus of appearance innovation is majorly on high-tech feeling, smaller size, thinner form, lighter weight or simplicity of expression. New opportunities of appearance have not been tackled enough. For instance, the appearance of intelligent product can absorb the design experience from traditional product, such as the application of natural material, classic craftsmanship, or combination of tradition and novelty. Therefore, this sector has not been fulfilled with opportunities yet. How intelligent products could be innovated in this aspect is still unfolded.

Most attention has been addressed in function sector. Most of the innovation opportunities at level 1 have already been achieved. However, due to limited technological development, how to tackle the level 3 innovation opportunities is a great challenge for the industry. In experience sector, focus was on utilitarian experience and interactive experience. While most of experience of emotional and aesthetic innovation was accumulated from traditional electronic or non-electronic product types, how intelligent products innovate in these vectors is unfolded. How intelligent product innovate in sensory experience has not been discussed enough, which requires further efforts. The meaning sector is a new sector that attracts attention in recent years. How intelligent products contribute to meaning change, from social, cultural, economic, environmental and personal levels are still known. What is known is that the transformation is under its way. It is sure that intelligent products, or the new possibilities brought by the intelligent products will shape values, civilization and transform the society towards a more equal, knowledgeable and human-centered world.

Chapter 8 – Small Scale Validation of the Framework

8.1 Introduction

The aim of this chapter is to validate the conceptual framework proposed in Chapter 7. The criteria for the validation of qualitative research are still open to discussion (Sousa, 2014). Various guidelines have been suggested for the validation of qualitative research. The assessment of scientific knowledge involves three major concepts, namely, validation, reliability and generalization. A suggestion is made for qualitative research to emphasize the notions of trustworthiness of the method, coherence of results, and transferability and application of results (Lincoln & Guba 1985; Hill et al. 1997). Based on limited time and recourses, a small-scale validation research was conducted. In this section, the following questions were asked.

RQ8. Can the comprehensive framework serve as a basis for describing, stimulating and stimulating innovation in intelligent products?
RQ8.1 Does the framework present a reasonable theory for scholars studying the phenomenon from different disciplines and practitioners?
RQ8.2 What is the advantage and disadvantage of the framework? How to improve the disadvantage of the framework?
RQ8.4 How to use the framework?

In order to answer the questions, two studies were conducted. An expert interview was conducted with scholars and practitioners. Their responses were categorized and analyzed, based on which the framework was further improved. Then in order to demonstrate the usage of the framework, a case study was conducted with Phantom 4, an intelligent product from DJI.

8.2 Method

A small-scale validation research is conducted to test the framework with expert interview and case study.

8.2.1 Expert Interview

A second round of interview was conducted in order to gain initial primary response to the framework. Unstructured interview was selected, considering its advantage of spontaneity and natural response of the interviewees (Klenke, 2008). Interviewees may share their true comments about the framework.

8.2.2.1 Sampling Strategy

The advantage of convenience sampling method is its effectiveness during exploration stage of the research area, and when conducting pilot data collection in order to identify and address shortcomings associated with questionnaire design (Battaglia, 2008). Ten face-to-face interviewees were recruited for the interview.

8.2.2.2 Inclusion and Exclusion Criteria

In order to maintain validity and reliability, criteria below were used to select the samples:

- The sample should match the target population on certain characteristics (Doherty, 1994).
- The sample's geographic location, nationality, and background should have diversity (Saunders, Lewis & Thornhill, 2012).
- The sample should hold sufficient knowledge and experience to answer the questions.
- The sample should be able to be accessed with affordable time and expense.
- The sample should include interviewees from business field and academic field.

In this research, interviewees that meet the criteria are recruited through the researcher's working, study, and personal network, including:

- Colleagues in previous working companies.
- Experts, researchers and scholars in the Hong Kong Polytechnic University
- Experts and scholars known in conferences and events, like Design Education Conference, Business of Design Week, HCI International Conference, and Asian Design Engineering Workshop, etc.
- Experts and scholars accessed via social network, like LinkedIn.

8.2.2.2 Interview Procedure

The face-to-face interview was conducted from half an hour to one hour. During the process, the framework was first presented to the interviewees. Then the researcher briefly introduced the framework. After reading the framework, the interviewees were invited to make comments about the framework and suggestions to improve the framework. Based on their responses, the researcher asked followed up questions to understand more about their real meaning.

8.2.2 Case Study

Case study is when researcher explores an in-depth phenomenon, event, activity, or process (Creswell, 2012). Detailed information is collected using a variety of data collection methods through multiple sources over a sustained period of time (Stake, 1995). Case-study research can mean single and multiple case studies (Yin, 2014). In this thesis, case studies are selected to validate the framework for case analysis. Unmanned aerial vehicle is selected as case study subject. The aim of case studies is to demonstrate how the framework can be used to analyze product innovation in practice.

8.2.3 Workshop

Workshop originally means ‘a place where things are made or repaired’ (Merriam-Webster, 2016). It is used to arrange a group of people to learn, to acquire new knowledge, solve problems collaboratively, or innovate in relation to a domain-specific issue (Ørngreen & Levinsen, 2017).

8.2.3.1 Workshop Strategy

In this research, a participatory workshop was conducted to test whether the framework can be used to generate innovative ideas and facilitate innovation with collaborative efforts. The workshop was held in the Affiliated Secondary High School of South China Normal University with 35 students separated into seven groups (Table 73).

Table 73 - Basic Information of Workshop

Time duration	**1 hour**
Location	Affiliated Secondary High School of South China Normal University, Guangzhou, China
Number of participants	35
Age	15-17
Occupation	Students
Groups	7
Language	Chinese

8.2.3.2 Workshop Process

The workshop was conducted with four steps (Table 74). First, participants choose a group and sit aside round tables. Basic concepts of intelligent products innovation, examples, the aim and process of the workshop, and the framework were introduced (Photo 1). Each group selected one product type among socket, drone, air conditioner and speaker, and developed it into an intelligent product.

Table 74 – Workshop Process

Step 1	**Introduction of The Sectors** • Team built up • Concept introduction • Product type selection • Introduction of the framework
Step 2	**Description and Design** • Self-introduction • Brainstorming • Idea generation • Description and design

Step 3	**Presentation and Voting** • Presentation of the final design • Public voting
Step 4	**Evaluation** • Questionnaire

Then participants were invited to introduce themselves briefly and brainstormed about the topic they choose (Photo 2). In order to encourage creative and cognitive thinking, questions like following were asked:

- Which and why the product type is selected?
- Who are the target users of the product?
- What are the problems of the current product type?
- How to solve the problems?
- Could you briefly describe the product that you intended to innovate?

Participants used colored pens to draw the framework, wrote down ideas in on the notes and stick them to the framework, and discussed the product they intended to innovate in details.

Photo 1 - Introduction of The Workshop

Photo 2- Group Discussion

Participants collaboratively worked together and synthesized ideas into final design (Photo 3). Then the final design was presented it in groups (Photo 4). After that, suggestions and comments among groups were encouraged. The most popular design was voted.

Photo 3 - Synthesis of Ideas

Photo 4 - Group Presentation

Finally, a questionnaire was distributed to the participants to evaluate the workshop and help participants to reflect what they have learned and accomplished in this workshop.

8.2.4 Content Analysis

After gathering data from expert interview, content analysis was used to analyze the data. Content analysis is to assign codes to indicate the presence of interesting and meaningful patterns (Hodder, 1994). The methods have been proved to be useful in various related research (Saldaña, 2015).

8.2.3.1 Coding Strategy

When coding contents from interview transcripts, salient and essence-capturing contents were derived directly from the text data (Hay, 2005). While ambiguous contents were abstracted, summarized, and interpreted from their underlying context based on pre-existing knowledge discussed in literature.

8.2.3.2 Coding Process

The software of Nvivo was used for coding. Interview transcripts were input into the Nvivo software first and coded manually. In order to increase trustworthiness, coding process was conducted iteratively with consistency according to Weber (1990). Inspired by Hsieh and Shannon (2005), three steps were conducted for coding:

- Looking for and highlight the sentence related to comments, suggestions, and questions
- Assigning the key meaning of the sentence
- Going through all of the highlighted text again to confirm again

8.3 Findings

8.3.1 Findings From Expert Interview

Ten interviewees responded to the invitation. Both academic field and business field were covered. The majority of interviewees were from design, engineering, and IT backgrounds.

8.3.1.1 Analysis of Interview Results

The interview results can be grouped into three categories: comments, suggestions, and questions. After categorization, 13 comments, 14 suggestions, and 8 questions were found (Table 75).

Table 75 – Categorization of Interview Results

Comments	1. The framework is practical.
	2. The framework is comprehensive.
	3. The framework can be helpful for real business.
	4. The framework might constrain creativity, as radical innovation is to break the existent rules.

	5. It can help the development team to save time and resource. 6. It can help to avoid misunderstanding among departments. 7. The framework is effective, but it might be hard to use in business. 8. The framework can be practical for companies. 9. The framework helps companies to guide the direction of innovation. 10. The framework makes abstract product concept into a concrete and actionable thing.
Suggestions	1. The target audience of the framework should be more specific. 2. The framework concerns both design and engineering requirement at early stage. 3. A common ground for multi-disciplinary communication, and collaboration. 4. It can improve communication and synchronization between designers and engineers. 5. With the framework, the development team can decide which opportunities to innovate and which not, and focus on the important opportunities since product briefing and defining stage. 6. The scope of the innovation is important. 7. Before using the framework for product innovation, the development team should understand the context of use, the business model of the company, and real needs of users. 8. It is a challenge to make the framework open, dynamic, and updated. 9. Keep the framework open and flexible to encompass more characteristics of the intelligent products. 10. The framework can be tested with real business cases and experiment. 11. If the framework has priority or weighting of opportunities, companies can determine which opportunities were necessary, which are optional for innovation, or which are additional. Then they could allocate resources for innovation. 12. It is important to make it simple, efficient and easy to use. 13. The framework could use more vivid presentation methods, such as radar map, illustrative diagrams, or table. 14. The opportunities should not be isolated, but related. 15. The same opportunities can have various weighting across product categories. Opportunities from the same product category might have similar weighting. 16. The framework can be made into an APP, a software, or an online platform (e.g., like Google Docs) as a "real" tool. 17. The team can score the opportunities according to their importance. Based on the score, the tool can visualize the importance of opportunities, suggest allocation of human resources and financial resources, suggest the cost of developing each opportunities. 18. The tool can be linked with manufacture and suppliers in Pearl River Delta.
Questions	1. Is there a mathematical model behind that can prove their correlation? 2. Is there any way to quantify the framework through algorithm? 3. Could team with less experience use this framework to create great products? 4. How to give weighting according to product category? 5. Who should give weighting, users, innovation team or the framework itself? 6. If the framework becomes a tool, can it be inputed with big data and make analysis based on it? 7. Can the product concept generated from this framework based on big data become a comparatively universal product concept? 8. Is it possible that if the data is big enough, the framework predict the radical innovation/dominant design in certain product category?

After analyzing, it was found that eight positive and two negative comments could be synthesized from the comments (Table 76). The framework has the benefits like practical, helpful, and effective. It could help development teams to save time and resource in product innovation; to define a product at early stage of product development and guide the direction; to stimulate multidisciplinary communication and collaboration; and change abstract ideas into concrete and actionable schedules.

The research is practical for industry. The beneficial parties of this research can be more specific. You can say that people from various backgrounds can use this research, businessmen, designers and engineers, but who is the major audience. It's better to narrow the audience into specific group.

Kees Dorst, Professor of Design at Sydney University of Technology

There are general four stages for product innovation from the product idea to the final user – to define user's needs, design, manufacture and delivery. When designers are designing, they may not think about manufacture and technological structure very much, but only creativity and aesthetics. When the design comes out, it may be not producible. Because there is no such technology or materials or if there is the cost is too high. Or there are engineering constraints that cannot be broke. When engineers do their work, they may not think about aesthetics, or consumers' needs at first, but how to achieve it with technology. Therefore products developed from an engineer-leading company may not be user-oriented.

So it is important to enable both designers and engineers to find a common ground, which they can communicate and collaborate. For this framework, it is important to include attributes from both sides. It needs to encourage designers to consider about the possibility of product realization and engineers to consider about user experience at early stage. With this framework, they can decide which attributes to innovate and which not (by marking on the attributes). Thus the product development team can keep focusing on the important attributes as early as in product briefing and defining stage. It can improve communication and synchronization between designers and engineers, save time and resource, and avoid misunderstanding among departments.

Ing. Jonathan C. Borg Professor of Faculty of Engineering, Ultra University

While the framework has the potential of constraining creativity and not easy to use, which need to be addressed in the future study.

The framework is a specific tool for designers to innovate. It could be helpful for real business. As it identifies attributes where designers and engineers can innovate. It could also be possible to constrain creativity. As radical innovation is to break the existent rules, real opportunity may *happen beyond the attributes already known. A challenge is to make this framework open, dynamic, and updated.*

Carl-Johan Skogh, director of studies Child Culture Design, University of Gothenburg

Table 76 – Comments from Interview

Advantage	Disadvantage
1. Practical 2. Helpful 3. Effective 4. Comprehensive 5. Save time and resource 6. Avoid misunderstanding among different parties 7. Guide the direction of innovation 8. Change abstract concept into concrete and actionable thing	1. Constrain creativity 2. Hard to use

It was found that the suggestions could be synthesized into six actionable suggestions, which require future in-depth research (Table 77). The actionable suggestions include the specifying the target audience; providing instructions for users; making the framework open, flexible, dynamic, updated, simple, easy to use, and efficient; testing it with business case; and using vivid demonstration methods.

The model (framework) looks very interesting. I'm really looking forward to see the further development with case elaboration and experiment in business. In order to keep the model (framework) open, it needs to be flexible. For Ten Types of Innovation, we keep on updating in order to embrace new ideas.

Larry Keeley, President, Co-founder at Doblin Group

Before going to the details of specific product attributes, the scope for innovation is very important. The perspective needs to zoom out from the specific function, and appearance of a product, into a much broader one, the context of use, the overall business model, to understand the needs behind the needs, or the way to communicate with users.

Prof. Ena Voûte, Dean of Industrial Design Engineering, Delft University of Technology

While the problems that cannot be solved in this research includes how to calculate the priority and weighting, and necessity of the opportunities; and its realization as a more practical business tool.

There are so many attributes in the framework. The framework is very comprehensive. Do they have priority? How to weight different attributes? If it has priority, companies can decide which *attributes were necessary, which are optional for innovation, or which are additional. Then they could allocate resources for innovation.*

The framework is effective, but it might be hard to use in business. How to make it into a more simple, efficient and easy to use is very important for its diffusion. It could use more vivid presentation methods, such as radar map, illustrative diagrams, or table to show it.

The framework can be practical for companies. Companies can use the framework to evaluate its competitors' products. After comparing, it would be clear that which attributes were similar, which attributes are lack, and how to make it better. For instance, if the interactive experience has not been developed, then the design team needs to make it better. Or if after evaluation, all of the attributes have been well developed, then the companies can consider about the next step.

The framework helps companies to guide the direction of innovation. It makes the abstract concept of product innovation into a concrete and actionable thing. Companies can define how much they will innovate about the products with the framework. For instance, how many attributes they want to cover.

Suning Chen, UX Research Manager of Philip

Table 77 – Suggestions from Interview

Actionable In This Thesis	Actionable In The Future Work
1. Be more specific about target audience. 2. Provide instructions for users. For instance, before focusing on the specific opportunities, it is necessary to understand the context of use, the business model of the company, and real needs of users; use it at early stage for briefing and defining a product; use it common ground for multi-disciplinary communication and collaboration 3. Make the framework open, flexible, dynamic, and updated 4. Make it simple, efficient and easy to use 5. Test the framework with real business cases 6. Use vivid presentation methods, such as radar map, illustrative diagrams, or table	1. Determine the priority of opportunitiess 2. Determine the weighting of opportunitiess 3. Determine which opportunities are necessary, optional and additional 4. Develop the framework into an APP, a software, or an online platform (e.g., like Google Docs) as a "real" tool. The team can score the opportunitiess according to their importance. Based on the score, the tool can visualize the importance of opportunities, suggest allocation of human resources and financial resources, suggest the cost of developing each opportunity. The tool can be linked with manufacture and suppliers in Pearl River Delta.

Eight valuable questions were found from the interview, however they could not be answered at this stage (Table 78). As this research focuses on describing and explaining opportunities of intelligent products and based on which to build a framework for innovation from qualitative way, it did not aim to testify it from quantitative perspective. The questions raised need to be tested in a quantitative research in the future.

The attributes should not be isolated, but related. Is there mathematical model behind that can prove their correlation?

Is there any way to quantify the framework through algorithm? For instance, could design team with less experience and innovation capability use it to design a great product?

It is possible that different product types have different attributes. It is also possible that the same attributes can have various weighting across product categories. For instance, the sharable attributes is much more important in mobile phone than in air purifying device. How to give the weighting according to product category? Should it be given by user, innovation team or the framework itself?

If the framework becomes a tool, can it input big data and make analysis based on it? Can the product concept generated from this model (framework) based on big data become a comparatively universal product concept? Is it possible that if the data is big enough, the framework predict the radical innovation/dominant design in certain product category?

To make the product into a real tool that companies or teams can use for product development, it can be an APP, software, or an online platform (e.g., like Google Docs). The team can score the attributes according to their importance.

Xue Xue, Startup CEO

Table 78 – Questions from Interview

Actionable In The Future Work	
1.	Is there a mathematical model behind that can prove their correlation?
2.	Is there any way to quantify the framework through algorithm?
3.	Could team with less experience use this framework to create great products?
4.	How to give weighting according to product category?
5.	Who should give weighting, users, innovation team or the framework itself?
6.	If the framework becomes a tool, can it be inputed with big data and make analysis based on it?
7.	Can the product concept generated from this framework based on big data become a comparatively universal product concept?
8.	Is it possible that if the data is big enough, the framework predict the radical innovation/dominant design in certain product category?

8.3.2 Findings from Case Study

In this section, Phantom 4, an unmanned aerial vehicle (UAV) developed by DJI was selected as case study subject to demonstrate how the framework can be used for analyzing the innovation pattern of intelligent products. The selection of UAV and Phantom 4 was based on several reasons. UAV is a relatively complex product, which can be used to illustrate more opportunities innovation with the framework. Commercial UAVs have achieved higher level of intelligence till now. The selection of Phantom 4 was based on the experts' recommendation and the importance, relevance and influence in the history. It represents the most prominent innovation in its type. It is believed to play the role of redefining UAV industry with the creation of first all in one consumer UAV in the world and occupies 80% global market. It broadens the UAV market from industrial use (e.g., agriculture) to commercial use. It creates new standards for professional filmmaking, search and rescue, which makes some dangerous work safer, faster, and with greater efficiency than before.

Phantom 4 is launched in 2016. It is a UAV that can work for all users with high tech built-in, which is useful for professionals, intermediates, and beginners. The Phantom 4 is the first consumer UAV that packs advanced computer vision and sonar on-board, to not only make flying safer, but also let users do things that were beyond imagination before. With market-leading technology, user-friendly design, and excellent experience, the Phantom 4 is recognized as the Apple of consumer UAVs (Utch, 2016; Popper, 2016).

Photo 5 – Phantom 4 and its controller, exacted from the website of DJI

8.3.2.1 Appearance Innovation

DJI pays great attention to product design by inviting Apple's previous director of antenna design and Tesla's previous director of autopilot design to lead its design team. The Phantom 4 intends to transform complex technology into user-friendly commercial product with considerable design. Without propeller, the size of the drone is only 350 mm, which enables it easy to be packed and carried. Compared with its last version, the total weight is 1380g, while the net weight without battery and propellers are only 462g. The product design retains the same basic design language as its predecessors, only made it sleeker and aerodynamic with elegant line. The previous Phantoms have red, yellow, blue and silver colored stripe on the arms. The Phantom 4 is just white, with indicator lighting red and green below the arms.

The form design minimizes buffeting when flying in strong winds and against gusts from any angle. The top of the Phantom is extremely plain, and has the too-clean look of a de-badged car. The bottom, however, has the feeling of sleek integration, and makes the new Phantom look and feel extremely polished. Compared with previous version, the Phantom 4 has a larger internal space in the center for battery and electronic circuit boards. This new placement of battery lifts Phantom 4's center of gravity, improving balance, enhancing agility and adding more accuracy to how it reacts to your commands. The two-section gimbal of previous generations has been replaced with a new, cleanly mounted, 3-axis gimbal that pokes out of a composite wrap. The new gimbal anchors the camera on both sides, using two motors to control pitch. The material is magnesium to reduce weight while keeping stiffness at a maximum to minimize vibration. Other changes in design include a the body that's now better sealed and no visible sign of air vents, so the craft is both more aerodynamic and will cope better with light rain and moisture. The MicroSD card and USB card slots have also moved from the camera to the base of the body.

The hardware of Phantom 4 maintains the high craftsmanship as its previous editions with some small tweaks and improvements. The UAV is designed with compatibility and durability by using high quality materials and manufactured through serious quality control. In some cases, Casey Neistat runs some experiments of the Phantom 4 by playing the role of worst pilot with a lot of errors that new users may make. He intends to push the boundaries of technology and make it easier for everyone. In one of his test, it is found that even the Phantom 4 is crashed and lost, it can be found back again and used again with its durable quality. Testers of the Phantom 4 claims that it is can be recognized as the best overall UAV in terms of reliable flight, beautiful footage, and overall build quality. Even its package seems highly reliable with grey 157tyrofoam suitcase with key codes, which looks like a case for nuclear submarine (Popper, 2016).

8.3.2.2 Function

Photo 6 – HD video taking and gimbal System, image and data syncronization functions, exacted from the website of DJI

Phantom 4 takes aerial film making to a new highest level in the non-professional aerial film making UAVs. It can capture HD video and photos with the advanced high performance and integrated camera and gimbal system (**Photo 6**). The camera can shoot at 4k resolution at 30 frames per second (fps) and Full HD 1080p at 120fps for smooth slow motion, through a newly designed lens that dramatically increases sharpness and optical output. A hyper focal length of one meter allows users to get closer to objects while keeping them in pin-sharp focus. It gimbal system is designed in a u-frame structure and equipped with the latest in camera stabilization systems to ensure smooth footage. The control unit of the gimbal constantly communicates with its inertial measurement unit and the Phantom 4's flight controller, so that it can prepare for the Phantom 4's movements before they happen. The gimbal is designed at the bottom center of gravity to help eliminate views of the spinning propeller blades.

The Phantom 4 has many smart functions, such as Wi-Fi connectivity, compatibility, image and data synchronization, open system as well as inter-operability. The Wi-Fi connectivity was designed and incorporated into the aircraft since DJI develops its first ground station system. After that, it became the basic smart function of each DJI aircraft. DJI found that the traditional UAV is difficult to control remotely and easy to fall. After observation and research, it is found that the accidents always happen when the UAV flies out of the sight of the user. In order to solve these problems, the Phantoms can be connected with the controller as well as the smart devices with Wi-Fi.

After connection, the real-time image or video from the Phantom 4 camera can be synchronized to a user's smartphone or smart device screen. Through it, the exact scenery captured by the camera can be seen by the user. The real-time data of the UAV can also be synchronized into DJI Go APP for data management, which enable users to monitor the aircraft's condition. The Phantom 4 has strong capability and upgraded usability, simply connecting different type of smart devices and systems. It has open source software like the immensely valuable UAVCode and UAVKit projects. The UAV can be controlled by the smartphone or Pad to realize certain functions, such as framing a shot, or simply look around, tap to fly, or tracking a person. The full manual camera controls let the user to shoot as if he/she is holding a camera in their hands.

Besides, the Phantom 4 incorporates smart functions like sensing, data management, identification sharing, customization and inter-operability. The Phantom 4 has a sophisticated sensing system consisting of sensors, sonar and four cameras on board for machine vision (not included the main 4K camera for video and photo taking). The sensing system includes Obstacle Sensing System and Vision Positioning System. The Obstacle Sensing System has front-facing cameras and sensors that allow it to spot objects and gauge their distance. Its Vision Positioning System has two cameras and two ultrasonic sensors, which enables it to identify its current position use image and ultrasonic data. The revolutionary vision positioning system of Phantom 4 enables it to fly outdoor as well as indoor where GPS cannot be received. The sensing system plays important role for the intelligent function of the Phantom 4, such as obstacle avoidance, tap to fly, or active track, etc.

The Phantom 4 has instantaneous data gathering, analysis and display functions. It can automatically and constantly record flight data from its internal mechanisms. Data recorded includes complete flight routes, duration, distance, location, flight time used, speed, number of photos taken, and recorded video time. The Phantom 4 keeps the data readily accessible for a user to playback a previous flight path, check their control stick movements, or review the moment of capturing at any time. It also manages the cached versions of any photos and videos taken during the flights for a user's future review. At the same time, an advanced flight recorder constantly records data from its internal mechanisms, which you can choose to share with the DJI support team if you ever have any questions or issues.

The Phantom 4 has accurate location identification system. It can be located precisely in an outdoor environment with quick connection to 24 satellites. It does not only rely on GPS, which other UAVs usually used, but also GLONASS. GLONASS is a space-based satellite navigation system operating in the radio navigation-satellite service and used by the Russian Aerospace Defense Forces. It provides an alternative to GPS, as the second alternative navigational system in operation with global coverage and of comparable precision. The combination of two systems enables the UAV to completely aware of its starting point, location and relation to a user during flight. With the double insure accuracy, the flight is in complete control of a user.

The HD videos or photos captured by Phantom 4 can be shared with friends and families by using the DJI GO APP. Users can edit their videos or photos with post-production function and share them with a simple tap. They can be shared among various channels, such as the world largest aerial imaging community – SkyPixel.

The Phantom 4 has strong capability of customization and personalization. Multiple flight modes are used to customize user experience. Switching flight modes to meet users' needs, whether users are looking for simplicity and intelligent navigation, speed or smooth cinematic movements is easy. The Phantom 4 is flexible enough to meet different flying demands. In normal mode, a user can use TapFly, Active Track and other functions. Sport mode adds extra agility and speed to increase its speed to the maximum of 45mph (72kph) – 25% of its normal mode speed at the cost of battery life and some stability. It brings user with ultimate thrill of speed by observing it from the smartphone screen. It also increases flying efficiency – to fly to a longer distance with shorter time than before. In both modes, satellite connection and positioning systems are maintaining to ensure safer and better controlled flight.

Besides the modes selection, the Phantom 4 enables user to customize the videos or photos taken with the advanced post-production function. Users can apply music and video templates to create productions ready with ease. For professional effect, users can select and apply 10 color profiles to create various atmospheres. As this function is essential for professional film making usage, so the Phantom 4 enables Adobe DNG RAW support as well as lens profiles built straight into to Adobe

Lightroom and Photoshop. For more customization of music, users can import their own music and clips, add filters and tweak the sound mix.

Users can personalize the course that the UAV flies with easy navigation, by setting multiple GPS points, or Waypoints. Then the Phantom 4 will automatically fly to them while the user may focus on taking video or photos with the camera.

The Phantom 4 has autonomous brake and automatic hovering function for safety consideration. Fowler (2016) describes the auto brake function of his first experience with the Phantom 4 like "the first thing I did with DJI's new Phantom 4 UAV was fly straight toward a tree… My Phantom 4 made a beeline toward a cypress, then screeched to a halt a few feet before it. But this quadcopter can do something other UAVs can't: keep you and me from being idiot pilots." The Phantom 4 has precise automatic hovering function with or without satellite positioning support. It can hover in the same place precisely and stably. Even rotating the same spot. If a hover is disturbed (e.g., pulled by wind), the position system will track the Phantom 4's movement and make it returns to its original hovering point. This function is essential for safe hovering and predictable locationalization. As in an outdoor environment, it is possible that a strong wind may blow away a hovering UAV and even lead to a crash.

The Phantom 4 has four main intelligent functions, Obstacle Avoidance, TapFly and Active Tracking, and Return Home. The missing element for truly intelligent UAV in the market is obstacle avoidance (Senese, 2016). Many advanced UAVs appeared on crowd-funding sites or tech conference in 2015 demonstrated similar concept, none of them have achieved it with reliability as the Phantom 4. Phantom 4 is the first commercial UAV that can avoid crashing into tree branches, buildings, or moving objects accurately in its pathway (Senese, 2016; Fowler, 2016). With obstacle sensors and advanced computer vision and processing, it can actively recognize and avoid obstacles in its path. In Normal Mode, when a possible collision with an oncoming obstruction is detected, Phantom 4 will stop and hover. In TapFly, ActiveTrack and Smart Return Home modes, it will intelligently adjust its path to avoid it, or hover to avoid a collision if no clear pathway is detected. This function reduces the risk of collisions, while assuring the same flight destination. Users can see from the connected screen about the image of obstacle and the UAV will push a warning so they aware of what is happening. The Phantom 4 innovates in avoiding capability by offering five times more positioning accuracy than previous systems, allowing for greater reliability and confidence for both indoor and outdoor flying.

Photo 7 – Obstacle avoidance, and active tracking functions, exacted from the website of DJI

Using control sticks to fly and maintain altitude, course and speed is not easy for new users. In order to provide astonishing user experience, the Phantom 4 has this identical function of TapFly. User can simply tap one point where the UAV is expected to go in the live view on the smart device screen. Then the UAV will take over all of the control and fly to that point, leaving the user to focus on the video or photo taking. The flying course might have surprising scenery that the users might never imagine before, which creates inspiring footage. If the user wants to change the direction, he/she can simply tap another point on the screen then the UAV will fly to. After reaching the point, the user can further set it as Point of Interest (POI) and the UAV will continuously circle around it to record more photos and videos.

The Active Track function is also a science fiction level achievement. Traditionally, the tracking function is realized with GPS or RFID, it is not to track the subject "itself" intelligently. Whether a user is running, surfing, or rafting, it is extremely hard to track his/her activity and record the movement. Circling a moving object and recording an aesthetic video used to be possible only by the professional pilots, now everyone can do it with a flick of the thumb. The Phantom 4 achieve this effect by using an advanced combination of computer vision, object recognition and machine learning algorithm to track a moving subject from a unique aerial perspective (Senese, 2016). The Phantom 4 can recognize a subject, follow naturally, and keep him/her/it in the frame, while continuing to detect and avoid obstacles without GPS bracelet, tracker or beacon required. The function can be activated with a few effortless taps. Turn on Moving POI to circle around your subject as they move or reframe the shot by dragging the subject on screen.

There are at least three mechanisms behinds the intelligent functions of Obstacle Avoidance, TapFly and Active Tracking: recognition, situational awareness and decision-making. After a user taps on the screen of what is expected to track, the Phantom 4 will save the initial images, set an expected position and trajectory for the subject tracked. With recognition of patterns, color, position, scale and other information, the Phantom 4 will anticipate where the new location of the object is. Once a large number of frames from the video have gone through this process, the Phantom 4 doesn't just look for something that resembles the initial images shown. It builds a temporary library of images for reference. It can learn what the subject looks like from different perspectives, enabling it to recognize some typical movements, such as walking, running and cycling. Even if the subject is temporarily blocked in the machine vision, the aircraft can wait until it appears and lock it again. It will lose effect only when a subject hides for a longer time.

The second important mechanism is situation-awareness, which is a kind of context-awareness. The Phantom 4 can perceive critical factors (e.g., obstacles) in the environment and understand what those factors mean. However, it didn't achieve higher level of context awareness-understanding what will happen with the system in the near future. For instance, one of the biggest stumbling blocks to widespread of UAV is how to operate it safely to avoid moving objects such as airplanes or birds on the sky. It may require a global big data and analytics system, which integrates information of flight schedule and weather and processes it in real time to support intelligent UAV flying. Besides, technology of aircraft can be used, such as automatic dependent surveillance-broadcast, which used to be pricey and heavy on-board tracking system.

The third mechanism is decision-making. For instance, when detecting obstacles, the UAV can make decision based on its speed and object distance. During the active track, it will run the obstacle avoidance function as well, and decide whether it should continue following, avoid an obstacle or simply stop. For instance, with the sensing system, the UAV can measure the distance of the object. If the obstacle within fifteen meter of an object, it will begin to slow down. When it's within two meter, the UAV will either stop and hover, fly over an object, or fly around it. When a user initiate the TapFly function, the Phantom 4 will determine the best way to navigate to that spot while avoiding collisions.

Photo 8 – Tapfly and return home functions, exacted from the website of DJI

Another essential intelligent function that ensures the safety of the flight is Return Home function. Many falling accidents occur when the UAV runs out of electricity before returning to the user. Another problem is that UAV is easy to get lost, as it fly out of pilot's sight and ascend somewhere unknown. In order to solve the problems, the Phantom 4 can record its position before ascending. When the battery reduces to low percentage, the drone will intelligently calculate an efficient path and avoid obstacle on the way towards its user. The condition of the UAV will also be shown on a map on the smart device. As this function is essential for safety, it can be manually initiated with a special button on the controller by pressing and holding. The user can also use the map on the APP to set a new home point. Even if the signal of the UAV is lost, it will return to its user. The flight controller can save critical flight data from each flight to the on-board storage device. In case of the Phantom 4 lost due to various conditions, these data can help the user to locate the position that the UAV might land or crash.

The Phantom 4 can be controlled through controller as well as smart device. The Phantom 1 is the first UAV that enables users to control an aircraft through remote controller as well as smartphone. By pushing up or pulling down the control stick, the UAV can ascend or descend. When flying in any direction, by releasing the control sticks, the UAV will immediately stop and hover in the same spot. The control sticks can control the direction and the movement of the UAV. On the controller, besides of the two sticks, there are two main buttons, the power button and Return Home button. DJI is the first UAV Company that explore to control the drone with the user's smart device method, instead of the sticks and buttons on the controller. The Phantom 4 makes more progress on the control methods. Before, the digital control button in the DJI APP displayed on the screen serves same meaning as a physical button. Users need to press the digital button to active a function. For the Phantom 4, the control through smartphone is more flexible and easier. For instance, users can designate a destination that they want the aircraft to fly to, or tap on anybody they want it to tract by just touching any place on the screen.

The performance of the Phantom 4 is safety, reliable, efficiency, with faster speed and large range. The Phantom 4 has various mechanisms to control its safety. For instance, a user can set a suitable failsafe altitude before each flight. If the UAV is flying under 20 meters and the Failsafe is triggered, when the control signal is lost, the UAV will first automatically ascend to 20 meters and return to the home point. During the FailSafe mode, the UAV can also sense and actively attempt to avoid obstacles to make the ascending process to ensure the safety. However the UAV cannot return to the home point if the GPS signal is weak or unavailable. The flight data includes the time and location of the UAV will be saved to the on-board storage device.

Normally to ensure reliability, a UAV is equipped with one set of gyro, compass and accelerometer. These sensors allow the UAV to recognize its orientation, so it can remain stable. The inconsistencies occasionally occur in these sensors can influence the performance of a UAV. In worse condition, if one of them fails, the UAV will no longer be able to stabilize itself, which causes falling. In order to enhance the reliability of the Phantom 4, the UAV is designed with dual gyros, dual compasses and dual accelerometers that allows it to constantly compare the data it is receiving through both pairs and enables double insurance in accident. Although the sensors add extra weight, they can capture more accurate data from a holistic perspective for users. The data is analyzed by advanced algorithms for accuracy. When inaccurate data is found after comparison and analysis, it will be simply eliminated from the system.

Due to its fast speed in Sports Mode and its stability, the Phantom 4 can take video and photo with high efficiency. The UAV is five times more stable than its previous version and much better than its competitors. Because of its precise hovering, there is no issue of holding its exact position that the user wants for video shooting, even in moderate winds. Therefore, when taking the same level incredible smooth footage, the Phantom 4 takes less time and efforts due to its stable and user-friendly nature. Besides, in the sport mode, the Phantom 4 enables faster flying speed, which enables its user to take more footage compared with normal UAV.

The Phantom 4 can fly at different speed to meet the requirement of new users and the professional users. The UAV can fly with the normal speed of 10 m/s. In the new sport mode it can fly at an astonishing 20 m/s. However, the Obstacle Sensing system is disabled in this mode, which makes sport mode exciting as well as dangerous. The maximum ascent speed is 6 meters per second, while the maximum descent speed is 4 meters per second. There is no official record of the maximum flying distance. If calculated by its ordinary speed 10 m/s and the maximum flight time 28 minutes, a estimated maximum flying distance can be 16.8 km. Its maximum flying altitude is 6 km.

The Phantom 4 incorporates various advanced core technology in the development of its product, including embedded technology, computational power, and better battery, etc. The Phantom 4 uses embedded vision sensors that is small enough and light enough to be incorporated into the drone without any detrimental effect on battery life. Coupled with its sensors, the Phantom 4 has a separate onboard computer for flight processing to achieve advanced intelligent functions. DJI developed a series of spatial computing and 3D depth sensing algorithms providing the Phantom 4 with its “sense and avoid“capability as well as the ability to hover in place without benefit of a

GPS signal. Other visual intelligence features include improved vision-based tracking modes and advanced mapping capabilities. The Phantom 4 has high efficiency battery with capacity of 5350mah, enabling 28-minute continuous flying. The battery has integrated power management, and smart charge and discharge protection, which is easy to charge and ready to fly at maximum capacity.

8.3.2.3 Experience Innovation

The Phantom 4 is designed and developed with the most comprehensive utilitarian experience better with almost all of the commercial drones in the market. Innovation in utilitarian experience include integrated, simplicity, consistency, user-friendly, user engagement and user empowerment. The integrated experience requires high level conformity and consistency in aspects of software, hardware, service and brand position. It means an integrated image impressed into users' mind. A principal overall experience of using the Phantom 4 is simplicity. In order to achieve it, the drone emphasizes on appearance simplicity and intuitive interaction experience. The functions are defined to solve the most important problems or meet the most desired needs of users, instead of adding more dispensable functions. When the phantom 4 is building the simplicity experience, it requires consistency in various in product design, interaction design, experience design, software engineering, and so on. It needs to build internal and external consistency, including logical coherence and accordance as well as harmonious uniformity or agreement among things or parts. It requires simplicity and user-friendly experience in each touchpoint that a user possibly interacts with, know about the Phantom 4. For instance, the aesthetic and tactile experience of the drone, the controlling experience through remote controller as well as smart devices, the interaction experience with the DJI APP and so forth should have the features of simplicity, user-friendly and so on.

The key Phantom 4 is user friendly, as it is easy to learn, to get use and to get help. The Phantom 4 is easy to learn for new users. The Phantom 4 has Beginner Mode especially for new users. The Beginner Mode limits the flying range to 30 meters up and away with camera turn-off. It aims to make a new pilot focus on the flight first without being distracted by the interesting sight captured by the camera. Compared with other UAVs, The Phantom 4 is much easier to use considering its various intelligent function, such as Obstacle Avoidance, TapFly, and Active Track. It aims to free users as much as possible from flight control and focus on the scenery they intend to take, wherever users want the UAV to go and whatever activity they want the UAV to follow and film. If a user has problems about using the DJI product, he/she can find support from forum, online support, telephone or email. There are thousands of tutorial from online channels such as DJI forum, or Youtube.

The Phantom 4 is convenient to use. As the UAV is designed with high level of integration, users can install and pack it in a very convenient way. The components that need to be installed are only the propellers and the battery. The propellers use a clip-on/off mounting structure, which can be mounted quickly and securely than before, requiring a simple push and twist to attach or release of each propeller. While other UAVs still use the screwing down method. This efficient, secure and convenient design allows the Phantom 4 to fly with more overall agility. This specific feature is commends by the UAV tester Casey Neistat (2016) as "the single best feature of the Phantom 4", as there is no need for additional tools. Besides, the propeller-off UAV is small and durable enough to be put into a backpack directly without extra protection.

Users of the Phantom 4 can engage in a lot of online and offline events, such as Welcome the Future in Seoul, SDK developer Challenge 2016, DJI Games in 2015, or Redefine creativity in 2015. Besides, users are passionate to generate contents and upload to the website, such as high school football game, natural exploration, sports. The engagement helps to build trust, make better communication, and build a stronger relationship between users and the DJI.

The Phantom 4 empowers users to capture images that once were out of reach. These high quality videos and photos can only be viewed by eyes or recorded by professionals shooting from helicopters before, which is difficult and expensive. Now, the Phantom 4's high quality camera and stabilization system can redefine camera placement and motion, which empowers every user to take high quality videos or photos. Users can record, share and remember their treasured personal experience, in every corner of the world. As DJI claims in its conviction, the technology does not empower creators, but also push visionaries to go beyond the limits of what is thought possible, inspiring users to inspire the world.

The interaction experience has basic interaction experience as well as intuitive interaction experience. Basic interaction experience is that user needs to learn first then to know how to interact with the drone, such as user manual, tutorials from official website, or from friends. Users need to learn and practice the remote control of the Phantom 4 through controller. For instance, try several times to figure out the relationship between moving the control sticks and the direction and altitude it changes.

In comparison, intuitive interaction means that users can know or understand how to use some functions immediately without reasoning or being taught. The intuitive interaction is designed in the DJI APP and controlled through connected smart device. For instance, the TapFly and Active Track are two functions with intuitive interaction experience. After initiate the function, users can only need to tap on the screen of the place they want the drone to fly to or a subject they want the drone to track, then the drone will go accordingly. To achieve the intuitive interaction experience, the interface of the DJI App visualizes functions with icons and symbols that deliver message and indicate meaning based on what are commonly understood and accepted by users. The logics of information hierarchy can easily guide users through a natural comprehending way. Besides, the algorithms to achieve the intelligent functions are based on human behavior. For instance, the

behavior of tapping on the screen means to target a subject or a destination, or emphasize its importance.
DJI is the pioneer in the technology-driven drone industry, in creating in-depth and diverse emotional experience, such as trust, free of anxiety, sense of belonging, confident, enjoyable, and interesting, etc.
Trust relates to emotion and a user's attitudes regarding how the Phantom 4 can fulfill promised task commitments. The reliability, durability, user-friendliness, intelligence, interaction experience, and transparency of information of the Phantom 4 make it trust-worthy. Many users and reviewers express their trust by referring it as "anti-collision" UAV during normal flight (e.g., Wöber, 2016; Guarino, 2016). However, due to the limitation of technology, the concept of trust is a comparative concept as the UAV cannot guarantee one hundred percent security and reliability.

The using experience of Phantom 4 is free of anxiety due to its user-friendliness, simplicity and intuitive interaction. The appearance is designed with less aggressive and accommodating style with simple, smooth and round shape and white color, which alleviates the "forbiddingness'" of high-tech product. Besides, as the Phantom 4 is easy to learn, use and get help with intelligent functions, it is not hard for new user to adapt to the control system. So not only young generation, but also elders can learn to fly. A user describes how his father-an amateur photographer learns to use the Phantom 4 with ease quickly.

The DJI creates a sense of belonging with social media (e.g., Facebook or Twitter) and social fun groups of amateur (e.g., DJI Academy). Users feel a connection to all the people share the same interests and value of adventure and discovery over the world. Even in the loneliest journey, they can share with each other and gain courage and acknowledgement.

The using process of the Phantom 4 brings users with confident emotional experience. Many users describe when they are using the Phantom 4 in the field, many passersby are curious about the UAV and attracted to approach them. It is much easier to build a conversation with strangers by demonstrating the UAV. Users feel they are more popular, cool and confident, because they build a tech-savvy and cool image of themselves.

The Phantom 4 can capture images from the perspective that cannot be captured by normal means with enjoyable emotional experience. Users can easily and conveniently create astonishing and surprising images of various exciting activities, such as sports and adventure, which brings enjoyable experience. Besides of activities and events, users can also record and appreciate the beauty of nature, wildlife and cultural heritage, which may extend knowledge. In both ways, the UAV can help to deliver a better life experience.

The emotional experience of the Phantom 4 is not only fun, but also interesting and astonishing. As it is easy to learn, the learning curve is not too long to be boring. New users can enjoy the intelligent functions and have fun of flight. Experienced pilots can add horsepower and agility for the thrill of speed. Professional camera operators can film dynamic chasing, rotation or hovering shots to tell stories (e.g., high speed races). The Phantom 4 has higher level of complexity that allows different kinds of users to explore or the same user to have different experience when making progress of flying.

The emotional experience is created through various ways. For instance, the Phantom team invites users to tell their own story of using the Phantom 4 to create emotional resonation among users. One of the stories is about Andy Lewis, who is one of the world's best slackliners, known for incredible feats of balance high up in the air. The Phantom 4 is emotional connected with him, because it is the product that records and witnesses the most dangerous and exciting adventure of him in the lonely wilderness. Before it is hard for people to see slacklining from the same perspective of him, how high it is, how scary it is, how committing he is, how focus he has to be, and how much efforts it takes. With the Phantom 4 he can explain what he is doing and how fearless he needs to be, which is hard to describe with static image or words before.

Photo 9 – Andy Lewis's slacklining, exacted from the website of DJI

The aesthetics of the Phantom 4 are derived from its appearance, such as the composition of color, shape, proportion and material, etc.

The product design of the Phantom 4 considers about various things. The appearance of the drone has three kinds of colors without slight contrast and less kinds of materials. By eliminating any unnecessary decoration, the main form of the drone is enforced. The craftsmanship of the drone is exquisite and high quality

The Phantom 4 has simplicity style because of its almost same color glossy coating and aerodynamic body. Compared with the design of previous versions, the Phantom 4 does not have its signature – colored bands and keeps the whole body in an integrated white color. The exposed motors are made of shiny grey metal, while its belly is lighter grey. The small proportion of grey makes a nice break from the all-white design, which increases flexibility and elegance. The overall industrial design ensures consistency with its previous versions as well as advanced and professional impression. This impression is not boring and rigid, but dynamic and intimating, because the Phantom 4 uses more smooth curves and rounder "belly" to expand more internal space for large battery and circuit boards. Therefore the overall impression is reliable and advanced, but not in an extreme high-tech and aggressive way.

8.3.2.5 Meaning

The product identity of the Phantom 4 is left to its users to define with far more expandable possibility. Besides, it totally subverts the traditional product identity of civilized drone, which are usually radio controlled toy aircraft for players. Many users mention that when they are using the Phantom 4, it can express their cool, adventurous, and fun character and attract similar people. By sharing the videos or photos with global audience, users demonstrate their social-identity as well. By using the Phantom 4, they can express their interest to discover natural beauty and human civilization, opinions and perspectives of how to see the world, and behaviors of discovering known beauty and free and meaningful life style.

The economic meaning of the Phantom 4 is to apply the intelligence with more acceptable price for civilized use. The Phantom 4 costs $1,399. Although the price is much higher than its last version, considering of its breakthrough technology and experience, the drone is still cost efficient.

8.3.3 Findings from Workshop

Among the seven groups, two groups chose speakers; two groups chose air conditioners; two groups chose drones; one group chose socket. The socket group provides the highest voted presentation. Compared with traditional socket, 30 opportunities were identified and developed in the intelligent socket within the four sectors.

All of the 35 participants fulfilled and submitted the questionnaires, which reflects the strength and weakness of the framework.

8.3.3.1 Example of Intelligent Socket Innovation

The socket group worked on an intelligent socket for home use, targeting young users who have already gained knowledge of intelligent products. They identified the problems of traditional sockets and discussed how to solve them as following (Table 79):

Table 79 - Problems and Needs

Problem	Needs
1. Each year a lot of electricity and money to pay the electricity is wasted, as users forget; don't want to be	1. Is there a better way to turn on and off electricity; or remind users how much electricity is wasted and the

bothered; or don't know the importance to plug off devices when not using them.	money they paid for it?
2. At each location, only one or two sockets are installed at home. On one hand, many users feel that the sockets are not enough to use, but on the other hand, they don't want to install more to keep the room tidy.	2. Is there a better way to install more sockets, and hide them? When they are not used and show they when necessary?
3. The traditional socket is hard to plug in at dark.	3. Is there an easy way to plug in?

Considering these problems and needs, an intelligent socket, which can manage the home use of electricity systematically and effectively was proposed by the participants. In appearance sector, the socket has simple style, white color, cubic form and plastic material. In total, five outlets are located at the top and four sides. The surface of each side is not flat, but with a gradual slope reaching towards the center of the surface. The outlets of each side are located at the end of the slope, which enable users to reach it easily without looking at it. When press the socket, only one outlet can be seen. By pressing it again, the other four sides appear. The structure needs to enable this pop up function.

Considering the function innovation, the socket is innovated with main function to calculate energy consumption and energy generation. It has a screen to display current time when it is not used. When the socket is using, the screen will display the real-time electricity used, which informs users and reminds them to save energy. The screen can use e-ink screen, which requires low energy for daily use compare with LED screen. In China, some families have installed solar panels. They can fulfill the home use of electricity, while the extra can be sold to electrical companies. The socket can be used to transfer electricity and calculate how much electricity and profit they generate. The socket can be connected and networked with other intelligent sockets at home and exchange data of energy consumption. The synthesized data can be gathered, transferred to the mobile phone of the user, analyzed, and displayed through an APP. Users can know how much electricity is used at home each day, month and year; which electronic devices cost the most electricity; and how much money needs to pay for running each device; how much electricity the solar panels generate; and how much money they earn. A more environmental-friendly plan can be calculated by the APP based on the behavior of the users, the time they use or do not use certain devices, or the necessity to keep certain devices working all the time. For instance, to turn on an air conditioner before a user comes back home or turn off the electricity of computer when it is turned off. Users can control electronic devices through the intelligent socket remotely and at home through APP.

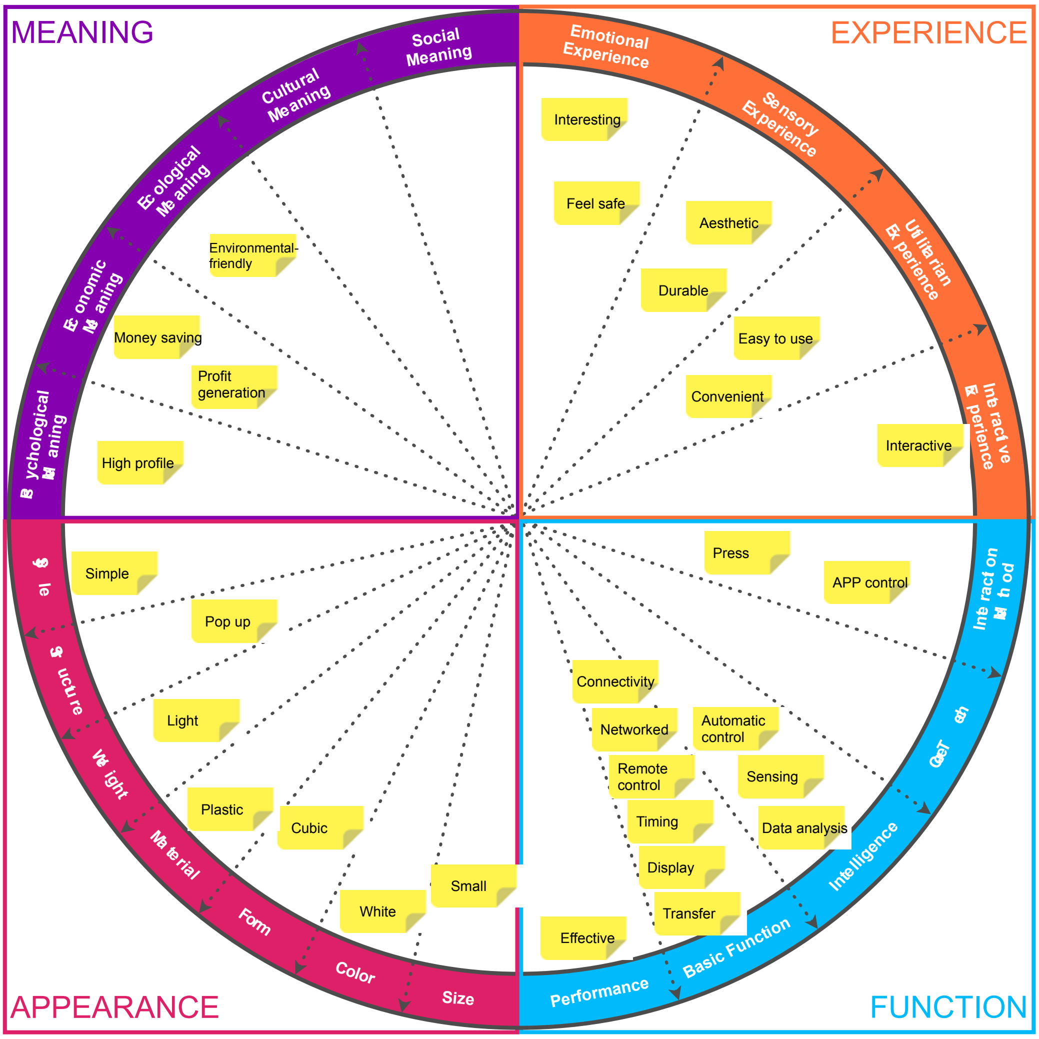


Figure 24 - Intelligent Socket Innovation

In experience sector, instead of being a “silent” and “invisible” device, the socket enables interactive experience with users by providing more helpful information. It is more convenient and ease to turn on and off. The product will be designed with aesthetics and durability. With its “high-tech” functional innovation, it is interesting to use. When the socket is not used, the electricity will be cut off. This is especially helpful when some families have babies. Even if babies touch the socket, they will not be shocked.

In meaning sector, with its advanced functional innovation, the intelligent product can help users to change their current behavior, reduce carbon footprint, and live a more environmental-friendly life. The more electricity they save, the more money they save. The changing of the life style will reward users with financial benefits.

8.3.4.2 Evaluation of The Framework

The questionnaire is designed with seven-point likert scale from totally agree (point 7) to totally disagree (point 1). Fourteen close questions were asked in total considering four aspects: the overall experience of using the framework, the comprehension and experience of the sectors, vectors and opportunities (Table 80).

Table 80 - Questionnaire Results

About	Question	MD	SD	Majority
1. The overall framework	helps you to understand intelligent product innovation.	5.83	0.57	6 (71%)
	helps you to generate innovative ideas.	5.97	0.66	6 (63%)
	is easy to understand.	5.40	0.74	5 (43%)
	is easy to use.	5.11	0.68	5 (51%)
	is effective to use.	5.37	0.69	5 (51%)
2. The four sectors	are comprehensive.	5.83	0.79	6 (60%)
	are clear.	5.54	0.66	6 (51%)
	are simple.	5.71	0.71	6 (60%)
3. The 22 vectors	are comprehensive.	5.74	0.66	6 (60%)
	are clear.	5.26	0.78	5 (46%)
	are simple.	5.26	0.78	5 (46%)
4. The 168 opportunities	are comprehensive.	5.51	0.85	5 (51%)
	are clear.	5.00	0.84	5 (51%)
	are simple.	4.97	0.95	5 (37%)

From the results of questionnaire, it was found that the average points of the four aspects are around 5 out of 7. Majority participants agree that the framework can help participants to understand intelligent product innovation and generate innovative ideas. It is easy and effective to understand and use. Majority participants agree that the sectors, vectors and opportunities are comprehensive, clear and simple to understand and use.

8.3.4.3 Comments of the Framework

Two open questions are asked:

- If you are required to develop intelligent products, are you willing to use this framework?
- Please comments and give suggestions about the framework.

71% of the participants agree that they are willing to use the framework if necessary. Comments about the framework are like following:

- The workshop is interesting and inspiring.
- The opportunities are too complicated and hard to fully comprehend at short time.
- If the workshop was held for longer time, participants have more time to get familiar with the framework and use it.

8.4 Discussion

8.4.1 Discussion of Expert Interview

After summarizing the comments, suggestions and questions, it was found that framework was further improved in the following ways:

8.4.1.1 Target Audience

The target audience includes researchers and practitioners that interested in and related to intelligent product innovation. There is no specific requirement for the backgrounds of the audience, as intelligent product innovation requires multidisciplinary collaboration. The way to use the framework could be different according to the audience's needs.

Table 81 - The target audience of the Framework

Audience	Way to Use The Framework
Researchers	1. Analyze the intelligent product's innovation pattern 2. Diagnose the weakness of intelligent products
Practitioner	1. Inspire innovative ideas and stimulate brain storming at early stage 2. Define product opportunities that the team needs to develop at early stage 3. Compare and analyze competitor's products 4. Evaluate product innovation results

8.4.1.2 Suggestion of the Framework

Before using the framework, some suggestions can be given to the users, like the followings:

1. Before focusing on the specific opportunities, it is necessary to understand the context of use, the business model of the company, and the real needs of users.
2. The framework can be used as common ground for multi-disciplinary communication and collaboration.
3. Users can adjust the space of sectors, vectors and opportunities freely according to their own needs.

8.4.1.3 Stable and Flexible Structure

In order to make the framework easy, efficient, open, flexible, dynamic to use, the framework has been designed into fixed part and flexible part. Four sectors and 22 vectors are the fixed part.

While the opportunities are flexible with more open space. When development team makes brainstorming, they can determine which opportunities they want to focus.

The framework was recognized as a comprehensive, practical, helpful, and effective from interview results. It could help companies to save time and resource. It could help develop teams to avoid misunderstanding among different parties. It could help them to guide the direction of innovation, and change abstract concept into concrete and actionable schedules.

Based on the suggestions of interviewees, the framework was further improved to be an open, easy to use, flexible, and efficient to use framework.

8.4.2 Discussion from Case Study

After studying the case of Phantom 4, an innovation pattern was created with the framework as following (**Figure 29**). It demonstrates how Phantom 4 was innovated in different sectors; how the innovation activities were distributed; what is the advantage and disadvantage of the product; what opportunities can be discovered and developed in the future.

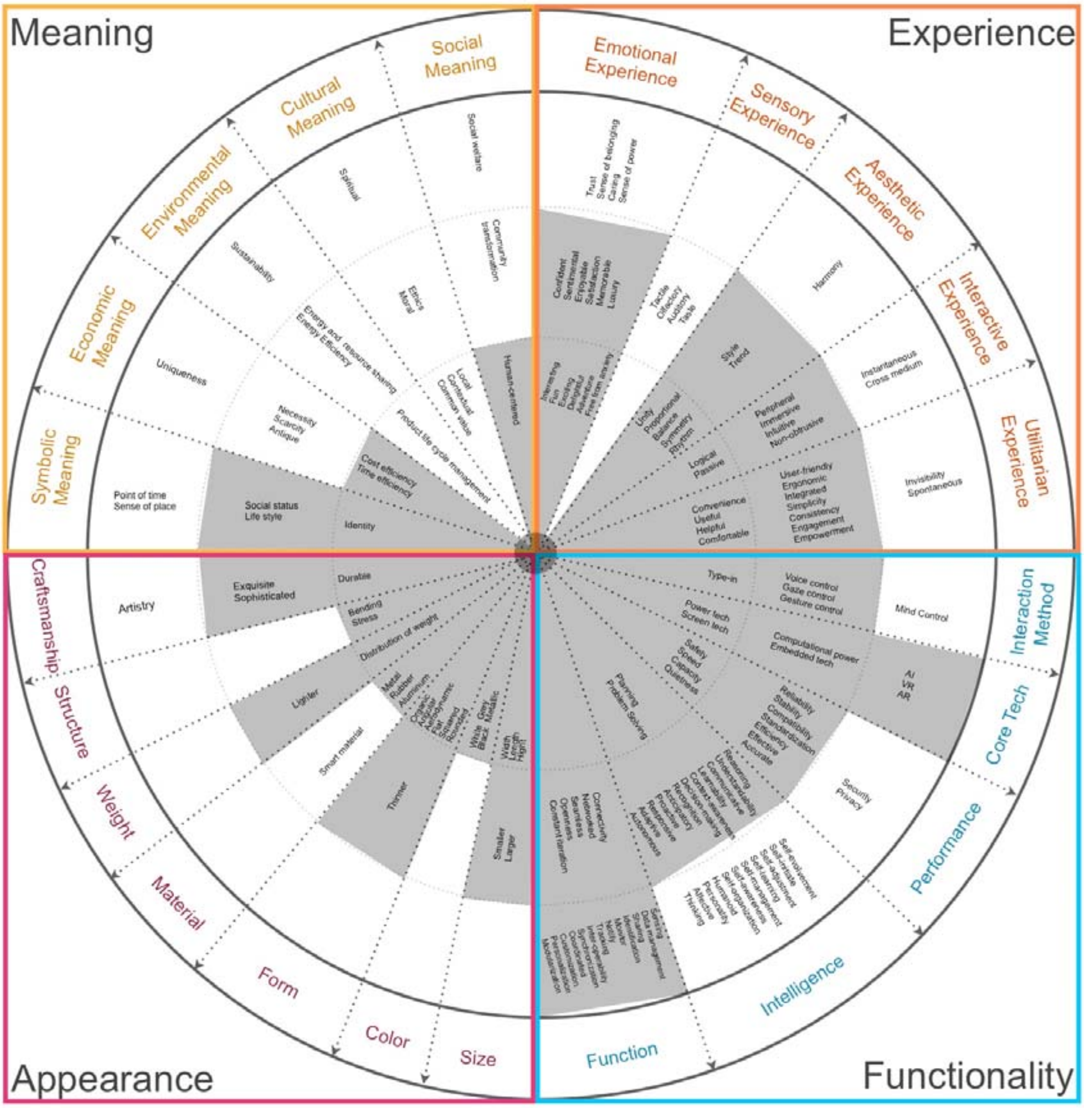


Figure 29 - Innovation Pattern of Phantom 4

8.4.2.1 Appearance Innovation

Phantom 4 innovates in the four sectors. In appearance sector, the size has changed to 350mm, which is incredible considering of its powerful functions. Two colors are provided, including white and silver, which has not changed much compared with its previous version. The form is designed into aerodynamic for aesthetics as well as the reduction of air force. Only normal material is used. It innovates in structure with the application of magnesium skeleton. The weight of it is 1380g (with battery and propellers) and 462 g (net weight). The craftsmanship of the product is very exquisite and sophisticated.

8.4.2.2 Function Innovation

In function sector, Phantom 4 has Wi-Fi connectivity, compatibility with various mobile phones. The photos and videos that it takes can be synchronized with mobile phones or shared with others. It has multiple sensing functions, such as obstacle sensing, vision sensing, and ultrasonic sensing. The data can be instantaneously managed and displayed, such as altitude, distance, or flying speed. It can be tracked with identification of GPS and GLONASS. The UAV enables inter-operability, such as frame a shot, look around, tap to fly or track an object with mobile phones. It enables users with certain level of customization, such as the switch between normal and sport modes, video and photo customization and personal course setting.

What makes Phantom 4 an intelligent product is its innovation in “intelligence” vector. The product can learn and recognize obstacle, aware its surroundings, and make basic decisions, such as hovering decision to avoid obstacle. Currently, the intelligence of Phantom 4 is still limited to technology development. For instance, Obstacle Avoidance function can only recognize obstacles like trees or mountains, but not the glass wall. It develops certain levels of autonomous, such as auto brake, or automatic precise hover. In the future, the development of the product can be on opportunities like anticipatory, pro-action, communication, understanding, or adaptive.

The interaction methods of Phantom 4 includes remote hand controller with 3.5-5km and smart device control. Other interaction methods could be developed, such as gesture control, voice control, gaze control or even mind control in the future.

The product has stable performance. It presents certain level of reliability with functions like return home. It increases its efficiency by enhancing the battery with longer time to use as well as providing different modes of flight with different battery consumption. However, the security and privacy of the Phantom as well as all the UAVs attracts great concern, which are challenges and opportunities at the same time.

The product advances in the core technology. With great computational power, multiple intelligent functions can be realized instantly and accurately. With battery tech, it can last for 28 minutes flight. With embed sensors, it can achieve multiple types of sensing to ensure its safety. However, how new technologies like AI, VR and AR can be applied in the UAV product is still an issue under discussion.

8.4.2.3 Experience Innovation

In experience sector, the product innovates in various vectors. It is user-friendly, easy to learn, to get help, and easy to use. It provides convenience for its users, including convenient to install, to carry and to fly. It presents integrated, simplicity and consistent utilitarian experience. Users can engage with the product in various ways, such as attending online and offline events. It empowers uses with capability of record and share personal experience. People share similar dreams and interests gather and create new vision and break the boundary of imagination. In the future, the product can be further developed with capabilities like invisibility and spontaneous action.

In interactive experience, the product achieves basic level of intuitive interaction. It could be further developed in the opportunities like peripheral interaction, instantaneous interaction, immersive interaction, and cross medium interaction.

In emotional experience, the product gains great trust from the market and its users. It basically frees the anxiety of its users with simple and easy ways of use. Users by using the products feel more confidence about themselves. They have an enjoyable and interesting experience. It also helps users to build sense of belonging with its online and offline community.

In aesthetic experience, the phantom 4 is designed with high-tech style with simplicity and elegance following the trend of modernist. In the future, the product design can explore different styles or trends to make the product more interesting, such as limited edition of pop or retro style drone.

The product did not innovate in the sensory experience, which could be an interesting attempt in the future.

8.4.2.4 Meaning Innovation

The meaning innovation of Phantom 4 is limited. In symbolic meaning, it represents the identity of users, such as cool personality or hi-tech person. The life style it symbolizes can be passionate for wildness and adventure. It makes making movies by individual more easily with time efficiency and cost efficiency. The products, events and activities that DJI launched all consider the pursuit of human beings. It tackles the basic desire of humans to explore the boundary of the world. However, it did not develop in the cultural and environmental meanings.

The innovation pattern identified in the framework shows the existing innovation activities and proposes the future opportunities. Generally speaking, the Phantom 4 emphasizes on the function sector. In the future, it can develop more in the other sectors. The case study demonstrated that the framework could be used for describing innovation patterns, stimulating new ideas and analyzing the advantage and disadvantage of products.

8.4.3 Discussion from Workshop

The framework intends to be heuristic, open and flexible. Its aim is to inspire innovative ideas and to encourage cognitive and creative thinking. From the results of workshop, it was found that the framework could facilitate users to generate innovative ideas and to stimulate innovation in intelligent products. From the feedback of the participants, it is interesting to notice that:

- The explanation of sectors and vectors are comparatively easy to be understood and used. While the meaning and usage of opportunities are harder to grasp within short period of time due to its large numbers.
- Two version of the framework can be provided depending on the time duration and background of participants in the future workshop. If the workshop was held for more than three hours with professionals as target users, the full version of the framework can be introduced. If the workshop lasts for about one hour, only sectors and vectors can be introduced, especially for layman participants.
- The introduction of the framework can be conducted in several steps, instead of giving all of the inforamtion at once. For instance, the cylce of learning can be: introduction of sectors > brief design > introduction of vectors > exploration of design > introduction of oppportunities > reflection of design. The learning cycle can encourage participants to think in-depthly about the issue.

However, this workshop only tests one possible application of the framework: ideation - to translate diffused innovative sparks into an innovative product description. Whether the framework can be effectively facilitate collaboration among multidisciplinary experts in real business; and whether the framework can help to transform traditional electronic products into intelligent products can be tested in future work.

Chapter 9 – Conclusion

9.1 Key Findings

The aim of this research is to propose a comprehensive conceptual framework for innovation in intelligent product design. The framework can be used to inspire and facilitate innovation activity, analyse product innovation pattern, diagnose advantages and disadvantages of products brought to market, evaluate innovation outcomes, and tackle new opportunities for product innovation.

Prior to developing the framework, it was necessary first to clarify the definition of intelligent products, as this was found to be only vaguely explained in the literature due to different semantic interpretation (Gutierrez et al., 2013). The lack of any specific, generally accepted, and well-recognised definition hampered attempts to build a design theory. The literature review on intelligent products uncovered eight definitions with 34 characteristics. Most of the characteristics discussed in these definitions were functional and oriented to technology, despite the centrality of non-technological aspects to product success. As the majority of developments in intelligent product design occurred after 2010, the most important non-technological characteristics of such products may not have been thoroughly incorporated into definitions or characteristics of 'intelligence'. The insufficiency of the literature required examination of related concepts, which shed light on studies of intelligent products. Nine concepts adjacent or closely related to intelligent products were thus reviewed, including smart products, IoT and robotics; these were compared with intelligent products to examine how boundaries are drawn around the category of intelligent products. After comparison, a definition of intelligent products was provided.

In addition to providing a specific definition, it was also necessary to review the legacy of frameworks for product innovation. After reviewing this literature, it was found that frameworks for studying product innovation can be categorised according to four perspectives: product, process, user, and organisational. The literature review revealed that most frameworks for studying innovation adopted a process-based perspective, considering how products can be developed and designed to meet users' needs. However, the analysis revealed that the most promising perspective was the product perspective. Different from the others, the product perspective seeks to decode product innovation 'internally' from the 'constructs' or attributes of a product. This approach was found to be especially useful (e.g, Holbrook, 1999; Cagan & Vogel, 2001; Boztepe, 2007), as product innovation could be understood as a manipulation of individual attributes. Product innovation can proceed by changing, increasing, improving or creating certain attributes. The overall framework thus adopted the product perspective to evaluate specific product attributes.

When examining studies that could be used to generate intelligent product attributes, three approaches were found. One originated from technological backgrounds within disciplines like manufacturing, engineering, information technology, and computer science (e.g., Shackel & Richardson, 1991; Keinonen, 1998; Konradt, Ubalazs, & Christopherensen, 2003; Mashal et al., 2015). Research conducted in these domains focused mainly on functional innovation, performance optimisation or new applications of advanced technology, with attributes like sensing, connectivity, decision-making or learnability understood as most important (e.g., Wong et al., 2002; McFarlane et al., 2003; Kärkkäinen et al., 2003; Ventä, 2007; Kim & Han, 2008; Meyer et al., 2009; Kiritsis, 2011; Leitão et al., 2015). Very few of these studies discussed how traditional, non-intelligent attributes could be redefined and recreated in the context of intelligent product innovation.

Another approach originated with consideration of non-technological attributes, including design, marketing, business or economics (e.g., Geistfeld, Sproles and Badenhop, 1977; Eckman & Wagner, 1994; Zhang, Li, Gong & Wu, 2002; Reid, Frischknecht & Papalambros, 2012). This approach focuses more on innovation in non-intelligent attributes, such as appearance, aesthetics, experience or meaning (e.g., Horváth, 2001; Snelders & Schoormans, 2004; Ashby & Johnson, 2014). There was very little overlap between these studies and those that focused on the innovation of technical attributes, including the discovery of any new attributes brought by technological change. Despite massive social, cultural, economic, and technological paradigm shifts, the focus in the main stream of this research remained centred on the investigation of human-oriented attributes, such as psychological or behavioural mechanisms (e.g., Lee, Ha and Widdows, 2011; Mugge & Schoormans, 2012; Ashby & Johnson, 2014).

A third approach, which addresses products as an integration of technological and non-technological or intelligent and non-intelligent attributes, was also considered (e.g., Chin, Diehl & Norman, 1988; Hassenzahl, 2004; Ryu and Smith-Jackson, 2006; Jandaghi & Hashemi, 2010; Valencia et al., 2015). This integration is not merely a 'one plus one' process, but rather is dynamic and iterative, involving a continuous examination of whether and how technological factors affect non-technological attributes through the lens of human-centred design (Norman, 2005) and an exploration of new possibilities for non-technological innovations deriving from multiple social, cultural, economic and technological paradigm shifts.

When generating attributes specific to intelligent products, it is important to better understand the classification of attributes, as this makes it easier to grasp attribute development systematically. Theoretical and empirical attribute classifications were reviewed, analysed, and summarised. Based on the review, four sectors of intelligent product attributes were proposed, including appearance, function, experience and meaning. The appearance sector involves attributes that are captured visually. The function sector involves a product's capacities to solve problems or finish tasks. The experience sector concerns feelings, ideas, emotions or memories that were created in moments when users interacted with a product. Finally, the meaning sector refers to social, cultural and psychological messages that attach to and are delivered by a product. Each sector is distinguished by its underlying process, but they are also all associated with one another. A hierarchical relationship was discerned among the four sectors. Appearance and function attributes describe how a product is constructed tangibly and intangibly; these can be understood as objective and concrete attributes; experience and meaning attributes concern how a product is perceived and interpreted, which can be categorised as subjective and abstract. In the process of product realisation, concrete attributes were considered as actionable. Appearance and function sectors could thus be recognised as basic sectors, upon which the experience and meaning sectors are built. These relationships determine why the framework is structured in certain ways and has important implications for product innovation.

After exploring these sectors, the attributes of intelligent products were then generated from systematic literature review and expert interviews. The results were compared, integrated and analysed. These attributes could then be further categorised into two levels: vectors and attributes. 22 attributes were identified, including size, colour, form, material, weight, structure and craftsmanship in the appearance sector; function, performance, core technology, and interaction method in the function sector; utilitarian experience, interaction experience, aesthetic experience, sensory experience and emotional experience in the experience sector; symbolic meaning, economic meaning, environmental meaning, cultural meaning and social meaning in the meaning sector. 168 attributes belonging to the 22 vectors were also demonstrated. The attributes could then be further classified into different levels according to their innovation capacity. An expert interview was conducted to categorise these attributes into three layers. Following this, the sectors, the relationships within sectors, vectors and attributes were constructed together to form an overarching conceptual framework for understanding innovation in intelligent product design.

A small-scale validity test was conducted with expert interviews and case studies. Based on feedback from the interviews, the framework was improved further, considering generalisation, stability and flexibility. These evaluations revealed that the four sectors and 22 vectors existed independently, with exclusive meaning, confirming their stability and validity as product constructs. However, the framework also remains open to further innovation; as intelligent products evolve, new attributes or attributes may emerge and can be incorporated into the framework.

9.2 Contributions

The framework was developed considering the paradigm shift ushered in by the era of intelligent products. The framework should bring inspiration for academic fields by introducing a comprehensive conceptual framework with different levels, layers, and aspects of attributes. The framework is important and necessary as it brings a new perspective for intelligent product innovation, analysis and evaluation. It fills the gap between a design theory of product attributes and the practice of product innovation, linking the two together.

The framework is a step forward compared with previous research. In contrast with Holbrook (1999) and Boztepe (2007)'s frameworks, the framework presented here includes more levels of attributes, numbers of attributes, and layers of attributes for innovation. Compared with Cagan and Vogel (2001)'s 'value opportunity' model, the framework not only includes traditional electronic attributes, but also information-oriented and decision-oriented attributes. Compared with other similar models and frameworks, this framework is more comprehensive, systematic, integrated and synthesised.

The research was conducted by reviewing both theoretical and empirical approaches. It utilises data triangulation, which facilitates validation of data through cross-verification, considering both systematic literature review and expert interview. It is expected to overcome the disadvantages or intrinsic biases that could result from the use of a single method.

The research adopts insights from different fields and disciplines. There is a benefit to sourcing information from a heterogeneous group of experts, in terms of diversity of geographic location, professional and academic backgrounds, position, age, and the nationality of interviewees.

The research is beneficial for practitioners as well as academic researchers interested in intelligent product innovation, such as researchers, designers, engineers, marketing specialists, managers, and strategists.

One of the aims of the framework is to reduce the paradoxical elements in innovation research. For product development teams, as the experts' background may vary from engineering, designing, marketing or business, misunderstanding and confusion happen easily in the process of communication, which may undermine innovation results. Thus, the framework is intended to provide a common platform upon which different parties can work toward unified goals.

The framework can help to generate ideas of intelligent product innovation and evaluate innovation more efficiently and effectively. This will aid in the brainstorming stage, which is typically conducted without precise direction; of course, this can be an advantage and a disadvantage, but the goal with the framework is to minimize unproductive confusion as ideas generated in this way can be loose, inefficient, and hard to achieve. In a similar vein, when assessing the innovation of intelligent products, the framework can be used to establish certain 'rules' that make evaluation more comprehensive and efficient – for instance, to design questionnaires for evaluation based on the framework. However, it should be noted that the application of the framework should not constrain creativity. The balance between 'principle' and 'freedom' should be handled by the users of the framework.

The framework provides more possibilities for idea generation and more angles for assessing innovation results. With four sectors, 22 vectors and 168 attributes, the framework can provide inspiration from both technological and non-technological perspectives.

9.3 Limitation

As the study was qualitative and inductive, bias is a risk. Although based on literature, the classification of attributes requires judgment that is limited by the researcher's knowledge and experience, which may be neither objective nor comprehensive. Because the coding of attributes was a manual process, it is possible that some implicit attributes were missed. To reduce this possibility, however, iterative coding and analysis process were undertaken to ensure the objectivity of the process.

The selection of attributes could have also been influenced by the background of the researcher. The researcher is from a design background. It is thus possible that attributes associated with design domain, such as appearance, aesthetics, experience, and function, were selected more preferentially. Similarly, the researcher may not be familiar with technological knowledge, which may have limited her recognition and adoption of technological attributes.

It is possible, too, that the attributes of intelligent products were not thoroughly reviewed, due to limited time and resources. Additionally, as the researcher is not familiar with Japanese, German and Korean, only search results in English were considered. The numerous valuable studies written in these languages were not included in the literature review. An additional problem is that the domain of intelligent product innovation will always be dynamic, with new insights, comments, and literature appearing regularly. New attributes may emerge in the future, which were not included in this research currently.

Validity of the framework was only tested only on a small-scale and limited case study. Due to time and resource limitations, testing of the framework was conducted through expert interviews. More suggestions, comments and questions could be generated if the sample size were larger. Further, in demonstrating the framework on only one case, one must take caution not to generalise conclusions to other product types.

The versatility of the framework was not thoroughly tested. In this study, the framework was only tested for its functional analysis of innovation patterns, advantages and disadvantages. Its utility in facilitating innovation has not been tested.

It is not the intention of this research to predict and design an impeccable, universal framework that, if followed, would ensure a company success. As the market success of a product is no trivial task, requiring close collaboration between experts, appropriate business models, in-depth understanding of users, and far-reaching insights, no single framework will be able to guarantee success; its goal is merely to provide greater probability of innovation.

9.4 Future Work

The research shares a vision of intelligent product innovation in the future. Future research, such as how products evolve with the creation, modification or changing of its attributes, or how particular attributes evolve over time, should be conducted to better understand product development.

This paper has barely scratched the surface of the vast topic of intelligent product innovation and has raised more questions than it has answered. Having a subject as complex and as multidimensional as innovation and intelligent product design, and a research discipline so young, the questions that deserve future research attention are many. For example, future research could shed more light on the testing of priorities and the weighting of product attributes. Are there different priorities among attributes for product innovation? Is it possible to assign weighting to the attributes for product innovation?

It is hoped that future research will examine the versatility of the framework to other product categories. Did the same attributes have different weightings across product categories? Did the attributes from the same product category have similar weightings? Who should assign weightings – the users, the innovation team or the framework itself? Which attributes are necessary, optional or additional?

Similarly, further research should pursue these questions using quantitative approaches. Is there a mathematical relationship among attributes? Is there any way to quantify the framework through algorithm design? Could a team with less experience use this framework to create successful products? If the framework becomes a tool, could it be imputed with big data and conduct analyses based on machine learning or artificial intelligence modelling? Can the product concept generated from this framework become a comparatively universal product concept? Is it possible that, given enough data, the framework could predict where and how radical innovation might take place, or whether a certain product will become the dominant design in a given product category?

Further development of this framework could be motivated by its application in industry. How could design consultancies use it? How could the framework be developed as an API, a software, or an online platform (e.g., like Google Docs) as a ‘real’ tool? If this were the case, teams would be able to use the tool to score product attributes according to their importance. Based on this score, the tool might then visualise the importance of attributes, suggesting the allocation of human and financial resources, or the costs of developing each attribute. The tool could even be linked with manufacturers and suppliers in the Pearl River Delta.

In sum, the framework opens an arena for extensive future research on intelligent product innovation. This research provides a framework for intelligent product innovation, which could be used to analyse innovation patterns, forecast innovation opportunities, and evaluate innovation results.

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