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Enhance innovation in conceptual design through knowledge structuring

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THÈSE

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Délivré par

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Xin YI

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“You don’t overcome challenges by making them smaller but by making yourself bigger.”

- John C. Maxwell

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Abstract

Conceptual design plays a critical role in engineering design, as the innovation level of a final product is mostly determined in this stage. Within the conceptual design, concept generation is essential, as it allows designers to propose innovative concepts that bring value to customers. However, keep developing innovative concepts is not easy for designers. The designers are very likely to be fixed by existing concepts or solutions, which restrained them from offering new concepts. This phenomenon is called design fixation.

The thesis's objective is to enhance innovation in concept generation by helping designers mitigate this design fixation. To reach this goal, we propose to help the designers tackling design fixation through knowledge structuring.

Following clearly specified research procedures, we first take the case study of smartwatches design for phenomenon and pattern exploration. Based on the findings, we develop a knowledge-based heuristic centred methodology to guide designers in innovative concept generation. The methodology provides guidelines that lead designers along with different steps, actions and questions from knowledge identification, knowledge decomposition to knowledge structuring. This methodology is illustrated in a case study and experimented in different situations.

Résumé

Le design conceptuel joue un rôle essentiel dans la conception technique, car c'est à ce stade que le niveau d'innovation d'un produit final est le plus souvent déterminé. Dans le cadre du design conceptuel, la génération de concepts est essentielle, car elle permet aux concepteurs de proposer des concepts innovants qui apportent de la valeur aux clients. Cependant, il n'est pas facile pour les concepteurs de continuer à développer des concepts innovants. Il est très probable que les concepteurs soient figés par des concepts ou des solutions existants, ce qui les empêche de proposer de nouveaux concepts. Ce phénomène est appelé "fixation du design".

L'objectif de la thèse est de renforcer l'innovation dans la génération de concepts en aidant les designers à atténuer cette fixation sur le design. Pour atteindre cet objectif, nous proposons d'aider les designers à s'attaquer à la fixation du design par la structuration des connaissances.

En suivant des procédures de recherche clairement spécifiées, nous prenons d'abord l'étude de cas de la conception de montres intelligentes pour l'exploration des phénomènes et des modèles. Sur la base des résultats, nous développons une méthodologie heuristique centrée sur la connaissance pour guider les concepteurs dans la génération de concepts innovants. La méthodologie fournit des lignes directrices qui guident les concepteurs ainsi que différentes étapes, actions et questions allant de l'identification des connaissances, de la décomposition des connaissances à la structuration des connaissances. Cette méthodologie est illustrée dans une étude de cas et expérimentée dans différentes situations.

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CHAPTER I. INTRODUCTION

The objective of the thesis is to contribute to improving and facilitating concept generation in conceptual design to help designers mitigate design fixation and propose innovative concepts by knowledge structuring.

This introductory chapter includes four main sections. In Section I.1, the background and context of the thesis are presented with regards to understanding the importance of innovation, the importance of concept innovation and the main issue that prevents concept innovation, which is design fixation. In Section I.2, the research motivation and objective, and the related research question, are presented. In Section I.3, the methodology is designed to conduct the research is introduced. These points will later be developed in separate chapters, as it can be shown in Section I.4, that gives the thesis outline.

I. 1 Background and context

I. 1.1 The importance of innovation

With the increasingly fierce competition in the global market, succeeding in such a competitive environment is becoming more and more difficult for a company. Innovation plays a key role in this success because it influences the competitiveness of companies. As a result, companies are paying more and more attention to innovation, and some companies stand out among the fierce competition in the marketplace. What are the key factors that enable companies to innovate?

1) The individual level of innovation plays an important role to support company innovation

In a company, innovation can occur in many ways and at different levels. Within a company, innovation can occur at the individual level, team level, and organization level (Gupta et al., 2007). The individual level refers to individual employees, such as designers or engineers, who come up with creative ideas. At the team level, a group of persons exchange ideas for problem-solving (Paulus and Yang, 2000). At the organization level, a company implements innovation to provide the customers something new and unique in the marketplace (Demircioglu, 2016).

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Considering where innovation occurs at these different levels within a company, the individual level of innovation plays a fundamental role, as a new product or service begins with a new idea, and the new idea starts within the individual (Hagelaar, 2018).

Therefore, one option to enhance innovation in a company is to encourage designers to become more innovative (De Jong, 2007).

2) *Innovation: a tool to help designers to differentiate their offering*

Baragheh et al. (2009) highlighted that companies need to innovate to respond to the changing customers' needs and lifestyle. Therefore, designers are urged to innovate to meet the customers' needs by providing valuable offerings. To be more specific, they are urged to propose innovative products or services to meet the customers' needs and differentiate their final offerings with other competitors. To reach this goal, design innovation, especially concept innovation, has become an important trend.

I. 1.2 The importance of concept innovation

Conceptual design lies in the early stages of the product development process (see Figure I.1).



Figure I. 1 Product development process (Pahl and Beitz, 1988)

Innovation mainly occurs in this stage, as the principles of the solution that defines the final offering are defined there (De Bassi Padilha et al., 2017). It determines the innovation level of a final offering.

According to proposed by Koziolok and Arciszewski (2011), the conceptual design includes five main processes: problem identification, team selection, problem formulation, knowledge acquisition and concept generation, and concept evaluation (Figure I.2).

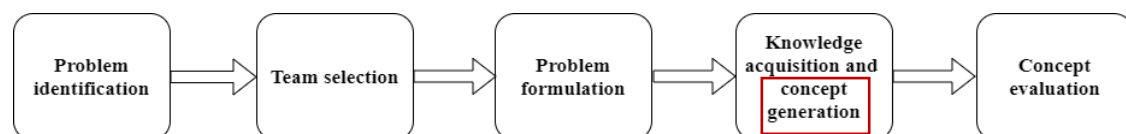


Figure I. 2 Conceptual design processes (Koziolok and Arciszewski, 2011)

Within the conceptual design, concept generation is a vital part, as it allows designers or

I. Introduction

engineers to acquire knowledge and propose innovative concepts that bring value to customers. Design activities in concept generation include two main steps: divergent and convergent, which introduce two types of design dynamics ((Liu, 2003). Divergent thinking suggests thinking out of the box to propose ideas; it encourages designers to present as many concepts as possible to expand the possible solutions. On the other hand, convergent thinking aims to zoom and select a limited set of best ideas; it focuses on reducing the number of concepts to identify the optimal ones. In general, this divergent and convergent thinking process requires several iterations to widely explore possible ideas then narrow down to the best ideas (see Figure I.3).

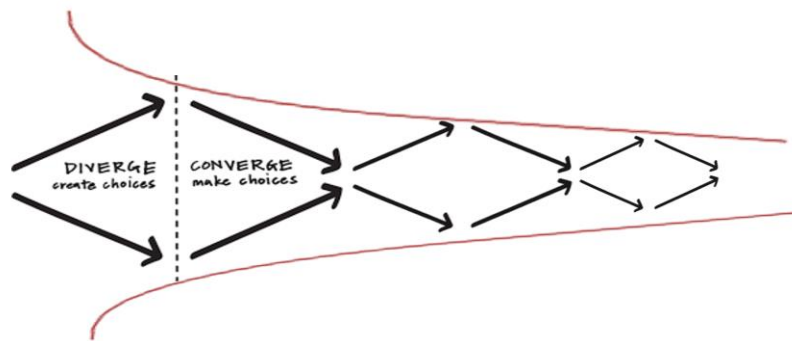


Figure I. 3: Divergent and convergent thinking (Wippler, 2018)

In conceptual design, concept generation is a process that encourages designers to come up with lots of ideas; innovation occurs a lot within this dynamic exploration process.

Therefore, to help designers propose innovative concepts, this research report naturally focuses on enhancing individual innovation in concept generation, with a particular focus on divergent thinking.

However, it is not easy for designers to cultivate innovation and constantly imagine new concepts. Designers can easily be prevented from developing new concepts in a variety of ways; existing concepts and solutions can easily encourage them to develop similar concepts. This phenomenon is called design fixation.

I. 1.3 Concept innovation obstacle: design fixation

Fixation is represented as the inability to work around the currently existing solutions or focus on developing variants of existing solutions (Moreno et al., 2015). This phenomenon frequently occurs while generating concepts in conceptual design. Design fixation often refers to a

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situation where designers are unable to propose innovative outputs because of an over-reliance on existing designs, or more generally, an overreliance on a specific body of knowledge directly associated with a problem (Youmans and Arciszewsk, 2014).

Therefore, as design fixation is the main cause that stops designers proposing innovative concepts, to successfully enhance designers innovation ability in concept generation, mitigating design fixation is a central point of this PhD thesis.

I. 2 Motivations, research objective and research question

I.2.1 Motivations

As previously discussed, conceptual design, especially concept generation, plays an important role in generating innovative concepts, which influences the competitiveness and success of a company.

However, design fixation is a major obstacle that hinders designers from innovating: designers can easily be fixed by their knowledge. To overcome this issue, some design methods (such as CK theory and design by analogy) have been proposed (Moreno et al., 2015). These theories offer an effective and reliable way to explore new knowledge and expand the knowledge space. However, to reduce design fixation, acquiring new knowledge can be useful but might not be enough. Indeed, new knowledge can be used to generate new concepts in two ways: 1) use new knowledge to directly generate a new idea (Hatchuel and Weil, 2009), 2) use new knowledge to reorder the knowledge space (Le Masson et al., 2016).

Therefore, acquiring new knowledge is not enough, and structuring knowledge is essential. However, how to structure knowledge lacks of exploration in literature.

I.2.2 Research objective and research question

With regards to the research background, the objective of this thesis is settled. It mainly aims at helping designers to propose innovative concepts during concept generation by mitigating design fixation.

Based on the research motivations, this research objective can be refined and consists in exploring how to mitigate design fixation through knowledge structuring. With regards to the

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discussion above, the ambition of this research is to propose a methodology to mitigate design fixation and therefore support innovative concept generation.

Therefore, our research question is :

“How might we help designers mitigate design fixation in order to propose innovative concepts?”

I. 3. Research methodology

To achieve the research objective and answer the research question, we need to first specify a research methodology, by referring to Saunders et al. (2011) which indicates the different choices to be made to conduct effective and efficient research, in an organised way.

We decided to adopt an interpretive research philosophy, an inductive research approach, a qualitative methodological choice, a case-study based research strategy, and a cross-sectional time horizon, as shown in Figure I.4. Explanations about these choices are provided in Chapter III.

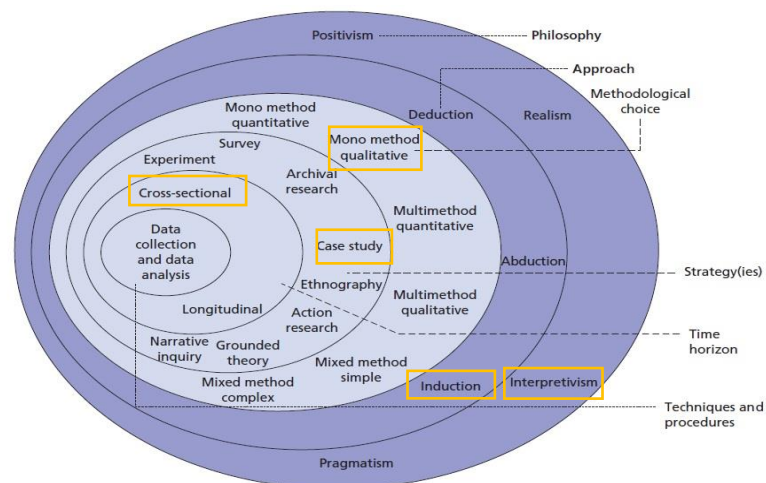


Figure I. 4 The Research Onion (based on Saunders et al. 2011)

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We also defined three main procedures that we applied chronologically: literature review, case study, a methodological proposal along with case illustration, and application of the methodology in different situations (see Figure I.5).

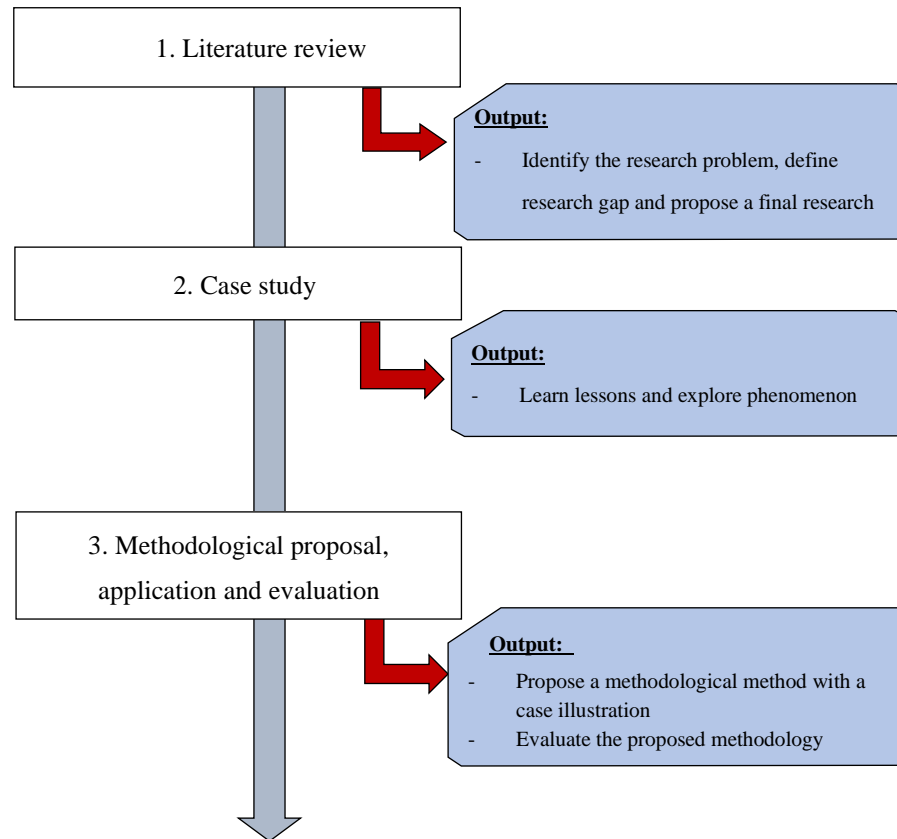


Figure I. 5: Procedures of our research methodology

I. 4. Thesis structure

The thesis is structured in six chapters that mostly follow the research procedures.

Chapter II Literature review

Chapter II reviews the literature on innovative design. It corresponds to the first procedure of research methodology (see Figure I.5).

We review literature related to design, concept generation, innovation in concept generation, design fixation and design fixation mitigation.

We highlight the importance of conceptual design, the challenges for innovative concept generation, and that design fixation constitutes the main innovation barrier in concept generation.

I. Introduction

After an analysis of the existing theories addressing this issue, mainly focusing on new knowledge acquisition, we underline that how to structure knowledge to propose concepts is not addressed.

Based on this review of the literature, we settle our research goal.

Chapter III Research methodology

Chapter III presents the choice of research methodology we made.

This chapter starts with a survey of the research methodologies from literature. We adopted the Research Onion, that illustrates the different phases of research, to guide our research journey and design our research procedures.

We detail how we adopted the research methodology to achieve our research objective, which includes research philosophy, approach, methodological choice, strategy and time horizon and procedures.

Chapter IV Case study

Chapter IV focuses on an exploratory case study. It corresponds to the second procedure of research methodology (Figure I.5).

We collect innovative cases to learn lessons, observe the innovation phenomenon, and explore the relation between design heuristics with the innovation cases. In the case study, we first explore what kind of design heuristics have been used to support innovative concept generation, then compare them with existing heuristics and analyse how heuristics affect concept generation.

The experimental findings and results from the case study lay the foundation for our methodological proposal.

Chapter V Methodological proposal

Chapter V presents a methodological proposal considering the findings from the previous case study. This chapter corresponds to the third procedure of research methodology (see Figure I.5).

It presents a methodology we propose to guide designers in innovative concept generation. The methodology includes three main steps; some specific questions are suggested for each step to guide designers on concept generation.

I. Introduction

The proposed methodology is step by step applied on a case study, so to illustrate how to follow the methodology, and then to analyse and evaluate the efficiency and effectiveness of the methodology.

Chapter VI Conclusions and perspectives

Chapter VI recalls the research objectives and concludes the achieved results. This chapter discusses the results and highlights the contributions to our research goal-mitigate design fixation and enhance concept innovation. It also discusses the limitations and underlines the future work that should be done for strengthening the proposal.

CHAPTER II. INNOVATIVE DESIGN AND RELATED ISSUES

II. 1. Introduction

The goal of this chapter is to position the research context and to review the literature related to innovation in conceptual design.

It first defines the design process, positions the design stage within the product life cycle and the system life cycle and underlines the importance of conceptual design. Then it presents the literature related to conceptual design, including the conceptual design model and conceptual design process. As in conceptual design, concept generation is an essential activity, vital to boost innovation, the literature review, therefore, focuses on concept generation and innovation in concept generation. Several types of innovation and several barriers that prevent innovation in concept generation are identified. Analysing literature highlights that, among these barriers, one major one is fixation. Deepening literature review on fixation, several types of fixation are identified. Among them, design fixation appears as a significant obstacle to generate innovative concepts. Consequently, we specifically address this issue by reviewing theories and methods to mitigate design fixation. Finally, from literature analysis, we identified limitations and defined our research objective.

II. 2. Design

II.2.1 Design definition

In a traditional understanding, design is regarded as a process to create something for the users' needs. Bonjour and Micaelli (2009) define design core competence are embedded in the designer and include five actors: 1) insights into customer's future value, needs or expectations, 2) knowledge about the weakness and strength of the firm, 3) knowledge about technological opportunities, 4) dynamic capabilities to create in time and new lines of product and 5) operational capabilities to improve the design process's efficiency. There are several viewpoints of design, such as "design as science", "design as engineering", "design as art" and "design as architecture" (Gilbert and McCarty, 1998). Different design viewpoints can apply in

II. Innovative design and related issues

different areas. For example, “Design as art” is used in the fields of fashion design. “Design as architecture” is involved in the field of construction design and interior design. “Design as science” is applied in the information system, such as computer science domain. In our research, we take the notion of “design as engineering”, which includes product, service, system design.

So, what is design? In the literature, different definitions of design can be found:

- Simon (1969) proposed design is a “*problem solving*” and “*search activities*”. He claimed that the problem-solving capability of human is deemed as a search for the possibilities.
- Gero (1990) described design “*as a goal-oriented, constrained decision-making activity*”, and designing involves exploration and learning. Gero (1990) defined design activity is characterized as “*a goal-oriented, constrained, decision-making, exploration and learning activity which operates within a context which depends on the designer’s perception of the context*”.
- Suh (1990) mentioned design is a “*mapping process*” between function or design parameters or structure.
- Schön (1992) presented “*designing as reflective conversation with the materials of a design situation.*”
- Simon (1995) indicated “*Design means synthesis. It means conceiving of objects, of processes, of ideas for accomplishing goals, and showing how these objects, processes, or ideas can be realized*”.
- Hatchuel and Weil (2003) mentioned “*Design is a heuristic process built upon a refinement model*”.
- Wang and Tang (2006) presented “*Design is a complex knowledge discovery process in which information and knowledge of diverse sources are processed simultaneously by a team of designers involved in the life phases of a product*”.
- Von Stamm (2008) defined design as a conscious decision-making process by which information (an idea) is transformed into an outcome, be it tangible (product) or intangible (service).
- Hatchuel et al., (2013) proposed “*design is about generativity which is defined as the*

II. Innovative design and related issues

capacity to generate new propositions that are made of known building blocks but are still different from all previously known combinations of these building blocks”.

- Hatchuel et al., (2017) proposed that “*design can be modelled as the interplay between two interdependent spaces with different structure and logics: the space of concepts and the space of knowledge”.*
- Hatchuel et al., (2018) indicated that “*Design is not only about idea generation, but also is about knowledge structures”.*

These various definitions reflect the different viewpoints of researchers. Even though there is no standard definition of design, some keywords can be noted, which includes: problem-solving, goal-oriented, exploration, combination, knowledge, search, reflect, generate, concept, decision making. Considering all these keywords and trying to integrate them to give our definition of design, a definition can be:

Design is a goal-oriented exploration or learning process to search suitable knowledge, and then structure the knowledge to support concept generation and decision making.

II.2.2 Design process within system development

Generally speaking, design process consists of a series of steps or activities, which lead from an initial concept proposition to a realization. It is part of system development, itself a stage of the whole generic system lifecycle (Cavalcante and Gzara, 2018).

The systems engineering ISO/IEC/IEEE 15288:2015 standard provides a common framework to describe the life cycle of systems created by humans. The Concept stage appears as the first stage, closely followed by the Development stage (see Figure II.1).

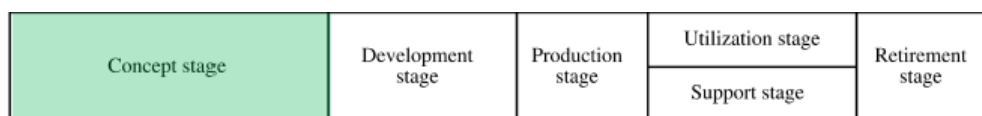


Figure II.1: System life cycle (from ISO/IEC/IEEE 15288:2015)

Brazier et al. (2018) distinguish six stages in a system life cycle, decomposing the previous Concept stage into Concept design and Preliminary; Detailed design corresponds to the ISO 15288 Development stage (see Figure II.2).

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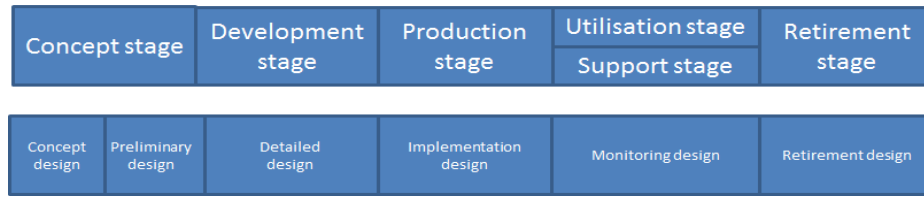


Figure II.2: System lifecycle (from Brazier et al., 2018)

Pahl and Beitz (1988) put forward that product development is a linear process, that can be broken down into six parts, which include Planning, Conceptual design, System-level design, Detail design, Testing, and Production ramp-up, as shown in Figure II.3.



Figure II. 3: Product Development Process (from Pahl and Beitz, 1988)

Product design refers to the activities that are involved in the design, which consists of a transformation process from customer requirements to a physical structure.

Therefore, the first 4 phases in Figure II. 3 correspond to product design, as shown in Figure II.4.



Figure II.4: Product design within the product development process

Among the 4 phases of design, Conceptual design is the most important one, as it determines the innovation level of the final product. Therefore, the Conceptual stage will be the main focus of our research.

II.2.3 Importance of conceptual design in design

With the increasingly fierce market competition, designers are encouraged to propose innovative products or service. The more creative products or services are proposed, the higher chance to attract more customers and occupy a bigger market. To satisfy this need, designing innovative products or services is becoming more and more crucial. Conceptual design is a vital stage to the development of successful innovative products, services or systems, as this success is related to the capability of proposing innovative concepts to meet stakeholders' needs. As seen previously, conceptual design takes place in the early stages of product design (see

II. Innovative design and related issues

Figure II.4); it focuses on the stakeholders' needs to generate a variety of concepts that meet those needs. Therefore, with this significant shift in the market, conceptual design receives greater attention than before (Wang et al., 2002), as it represents both an asset and a stake for companies to be competitive.

Based on this background, we can formulate our general research question:

How might we help designers enhance innovation in conceptual design?

Besides, decision making also has a high impact on conceptual design. As shown in Figure II 5, decisions' impact is high in conceptual design and declines in the later stages. (Hsu & Liu, 2000) demonstrates that the decisions made during the conceptual design stage significantly influence the final product, on innovation, cost, performance, reliability, safety, and environment. The central part (70–80%) of the product cost is decided by the end of the conceptual design phase (Sieger and Salmi, 1997; Li et al., 2010). (Hsu & Liu, 2000) proved that it is challenging and costly to correct or make up for poor conceptual design in a later stage.

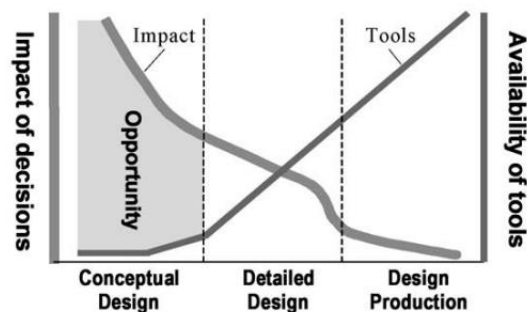


Figure II.5: the impact of decisions on different design stage (adopted from Wang et al., 2002)

Based on this background, we can state that conceptual design plays a vital role in the whole design process.

II. 3. Conceptual design

The primary purpose of conceptual design is to generate a variety of ideas, and after evaluation, to select the best one(s) to satisfy the project goal (Stump et al., 2004). Conceptual design starts with a high-level description of requirements and proceeds with a high-level description of a

solution, also named concept (Mc Nei et al., 1998). In this stage, proposing innovative concepts is a critical activity.

II.3.1 Conceptual design model

Conceptual design, in the context of product design, can be divided into two central stages: concept generation and concept evaluation (Mazani et al., 2019).

Similarly, in the context of system design, conceptual design can be divided into two main stages: concept generation and concept configuration (Jansson and Smith, 1991). A model of conceptual design is presented in Figure II.6. This model describes the movements between the two spaces, concept space and configuration space (Jansson and Smith, 1991).

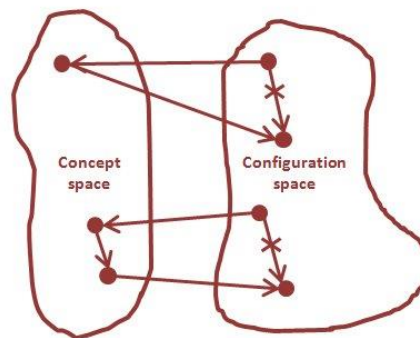


Figure II. 6: Model for conceptual design (from Jansson and Smith, 1991)

Based on this model, the conceptual design is described as a process that consists of successive exchanges between two mental space, a concept space and a configuration space (Jansson and Smith, 1991). In this model, ideas are generated in the concept space, and several configurations are made in the configuration space to see whether the selected concept meets the specifications and identified needs. So, at the end of conceptual design, the designer has explored different ideas and determined what concept can or cannot be used after the configuration (Wippler, 2018).

II.3.2 Conceptual design process

In conceptual design, several process models have been proposed. Koen et al. (2001) defined a concept development model, consisting of five processes, which are: 1) Opportunity Identification, 2) Opportunity Analysis, 3) Idea genesis, 4) Idea Selection, and 5) Idea and Technology Development.

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Afterwards, Koziolk and Arciszewski (2011) also came up with a process model in conceptual design, which includes: 1) Problem Identification, 2) Team Selection, 3) Problem Formulation, 4) Concept/Idea Generation, and 5) Concept Evaluation.

Even though these two models have slight differences, they both include concept generation as a commonality. Concept generation plays a vital role in conceptual design, as it offers the possibility for fresh and exciting ideas came up. Concept generation, therefore, is the main research focus of this report.

Research question becomes:

How might we help designers propose innovative concepts in concept generation?

II. 4. Concept generation

In the last section, a brief introduction about conceptual design model and process model are given. In the conceptual design, we found out concept generation is a very vital process, as designers are encouraged to come up with a variety of ideas or concepts. This section will go in deeper to explore concept generation, concept generation process representation, and models.

II.4.1 Concept generation process representation

A concept can be defined as a “concise description of how the product or service will satisfy customer needs (Ulrich and Eppinger, 2012). Concept generation requires a more abstract thinking style, so the concept generation consists of a series of discovery processes. At the start of the discovery process, concepts are much uncertainty; then through exploring, the process progressively converges towards the generation of a more precise concept. Newman illustrates this path of abstract and uncertainty (see Figure II.7). The uncertain starting point offers a chaotic appearance, and at this point, the designers have no idea of the form of the final offering, which means the designer is not sure about what a solution will be; it might be a product, a service, or product-service system.

This starting point is regarded as a Fuzzy Front End. It represents a situation where new business opportunities are waiting to be explored and selected for further development (J. Kim and Wilemon, 2003).

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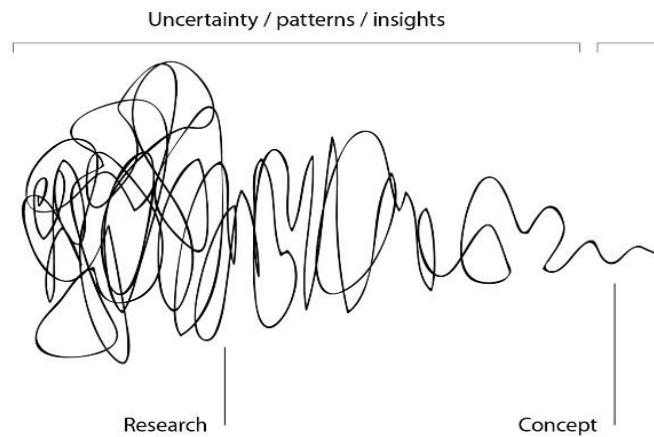


Figure II. 7: Damien Newman's "squiggle" representing the concept generation process
(adopted from Coorevits and Jacobs, 2017)

II.4.2 Concept generation process model

In concept generation, different models have been proposed to guide concept exploration and generation, such as lateral and vertical thinking, divergent and convergent thinking, or deductive and inductive reasoning.

Among them, the divergent and convergent thinking model is the most used one, involving two dynamics, divergence and convergence.

Divergence is “...the action of extending the boundary of a design situation so as to have a large enough, and fruitful enough, search space in which to seek a solution” (Wippler, 2018).

The objectives and problem boundary are unstable.

Convergence aims at reducing the uncertainties to the point where only one of the developed alternatives is retained (Wippler, 2018).

With the guidance of divergence and convergence, the concept generation process explores ideas as widely as possible in the concept space by divergent thinking, then selects the best ideas in the concept space by convergent thinking. Divergent thinking suggests thinking outside the box to propose as many ideas as possible. Convergent thinking aims at zooming and selecting the best ideas until only one of the possible alternative concepts is left. Figure II.8 shows the divergent and convergent dynamics in the concept generation process.

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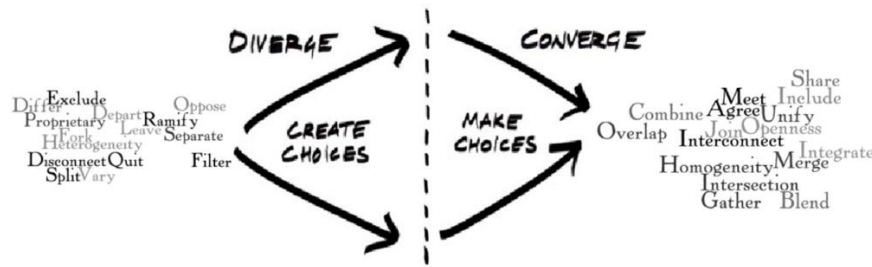


Figure II.8: Divergent and convergent dynamics in concept generation (from Wippler, 2018)

This divergent and convergent thinking process is iterative, as illustrated in Figure II.9. The best ideas selected after a convergence become at turn the starting point for a next divergence, and so on. This way, the entire process globally converges towards a final concept.

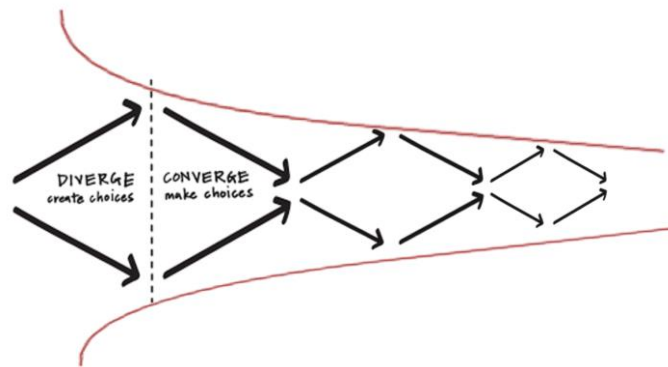


Figure II.9: Iterative globally convergent concept generation process (from Wippler, 2018)

Figure II.9 shows the iterative divergent and convergence process for concept generation. A diamond shape is used to represent divergent and convergent thinking, and each diamond shape represents a round of divergent and convergent thinking. This process relates to several iterations to explore possible ideas and narrow down to the best idea.

II. 5. Innovation in conceptual generation

Even though concept generation starts with lots of uncertainty and chaos, innovation, under different types, mainly occurs in this stage, as main functions and expected behaviours of a final offering emerge here. However, several barriers can also inhibit innovation.

II.5.1 Knowledge management and innovation

Innovation is not a new phenomenon, and it receives greater attention than before. However, the complexity of innovation has been increased due to changing customer needs, extensive

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competitive pressure and rapid technological change (Cavusgil et al., 2003). Also, as the amount of knowledge available to an organization increases, so does the complexity of innovation (du Plessis, 2007). Therefore, to enhance innovation, knowledge management deserves more attention.

Herkema (2003) defines innovation as a knowledge process that aims to create new knowledge committed to developing commercial and viable solutions. Marina du Plessis (2007) describes innovation is a process that recombines existing knowledge in new ways. From the definitions, it is not hard to see that knowledge and knowledge management play an essential role, and knowledge-based activities involve the innovation process.

Knowledge is deemed an organized group of data and information through rules and procedures (Bhatt, 2001). Knowledge management is a set of structures, methods, and technologies organized to provide strategic knowledge through the organization (Guns & Valikangas, 1998). Knowledge management occurs on three levels: the individual level, team level and organizational level (Marina du Plessis, 2007).

Among these three levels of knowledge management, the individual level of knowledge management plays an essential role. Knowledge resides in each individual, and organizational knowledge is embodied in individual and groups (Sabherwal and Becerra-Fernandez, 2003). Organizational learning also takes place through individuals (Simon, 1991). Therefore, the individual level of knowledge management is central to the organizational level of knowledge management.

As innovation also occurs at the individual, team, and organization levels (Gupta et al., 2007). To enhance innovation at an organization level, the individual level, which refers to designers or engineers, is encouraged to propose more innovative concepts. In this research, we focus on the individual level of knowledge management to support concept innovation.

II.5.2 Characterizing innovation types

Innovation can be distinguished into different types. According to the authors, they are classified differently.

This way, Norman and Verganti (2014) mention different innovation categories, such as business model innovation, product innovation, service innovation, and organization innovation.

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Business model innovation refers to a type of innovation that a company to commercialize their idea through its business model (Chesbrough, 2010). Product innovation emphasizes to introduce or create a new product use new technology or combination of technologies to meet a user or a market need (Utterback and Abernathy, 1975).

In the literature, two essential resources are pointed out to support product innovation achievement, and these two resources are classified into market-related resources and technology-related resources (Danneels, 2002). Service innovation emphasizes innovation in creating value through customer experience. In general, service innovation focusses a lot on human-to-human and human-to-technology interface (Bitner et al., 2008). Organization innovation focuses on make innovation in a company or organization's context, structure and member attitudes (Pierce and Delbecq, 1977).

In this research, we mainly focus on product innovation. This section will explore more about different product innovation types by exploring different models proposed by various researchers.

(Brazier et al., 2018) proposes the FBSE model, a classification based on four categories of design, where innovation can occur: Function, Behaviour, Structure and Experience. The FBSE model extends the FBS model proposed by (Gero, 1990) from 3 to 4 categories (adding Experience).

Table II. 1 shows the four categories of the FBSE model.

Table II.1: The four categories of innovation in the FBSE model (from Brazier et al., 2018)

Function	The purpose of a system	Why? For whom? Where?
Behaviour	The way a system acts	How? When?
Structure	The components of a system and their relationships	What?
Experience	Feelings, emotions, perceptions associated with a system	With whom? By whom? With what effect?

Function represents “*the purpose of a system*”, Behavior represents “*the way a system acts or the expected behavior of a system and it's measured via key performance indicators (KPIs)*”, Structure represents “*the components of a system and their relationships*”, Experience represents “*feelings, emotions, perceptions associated with a system or the desired impact for a system in the real world*” (Brazier et al., 2018). Innovation can happen in each category of design: innovation

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in function, behavior, structure and experience.

Product innovation can be classified by two key points: applied technology, or operated market (Cooper, 1994; Song and Parry, 1997). Hence, based on these two key points, a dominant classification of innovation is introduced; they distinguish four types of innovation: incremental, radical, disruptive and sustaining innovation. These four types of innovation are classified according to two dimensions: applied technology and operated market (see Figure II. 10).

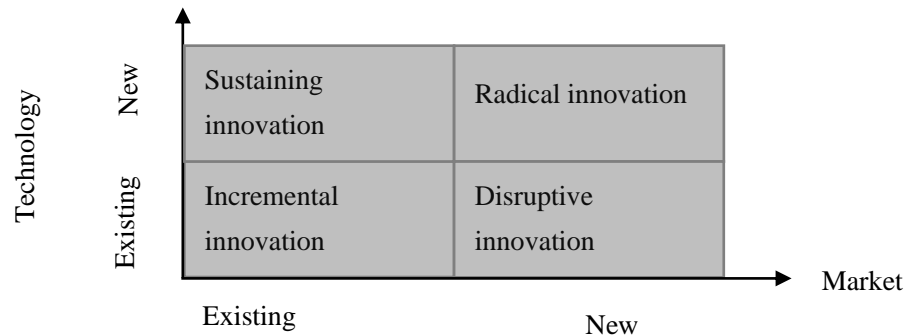


Figure II.10: Innovation types classified by technology and market

Incremental innovation aims at improving an existing product, with a low degree of novelty, less risk and cost (Norman and Verganti, 2014). Incremental innovation corresponds to continuous modification.

Radical innovation, with a high level of novelty that breaks what previously existed, is driven by technology changes (Norman and Verganti, 2014). Radical innovation can be initially targeted at mainstream or an emerging market (Govindarajan and Ramamurti, 2011). Norman and Verganti (2014) and Dahlin and Behrens (2005) define four main criteria for radical innovation: unique (dissimilar with the current product), novel (dissimilar with previous products), adopted (influence the content of the future product) and new technology-driven.

Disruptive innovation focuses on business model innovation (market innovation) to improve products or services for the most demanding customers and initially targets at an emerging/new market or low-end market (Govindarajan and Ramamurti, 2011). For Christensen et al. (2015), disruptive innovation corresponds to opening a new market.

Sustaining innovation generates growth to focus on existing markets by providing better performance (Enders, 2007). According to Enders (2007), sustaining innovation is focused on the existing market and on better performance.

II.5.3 Innovation barriers

Many factors can affect innovation in concept generation. There are different innovation barriers, such as individual, organizational, and transactional barriers.

Individual barriers include attitudes and emotional barriers, perceptual barriers and interpretive barriers, among more (Davis, 1999; Dougherty, 1992).

Organizational barriers include poor targeting of knowledge, cost management of knowledge transfer, protection of proprietary knowledge, and distance (McLaughlin et al., 2008).

Transactional barriers can also be regarded as collaborative barriers. It includes distance, different disciplines, experience (Cumming and Kiesler, 2008), and situation awareness (Belkadi et al., 2013).

In this research, we mainly focus on individual barriers. Individual barriers include attitudes and emotional barriers, perceptual barriers. Different sub-barriers influence innovation differently.

- In *emotional barriers*, temporary problems (e.g. anger, fear, upset) or permanent problem (e.g. anxiety, fear of failure, fear of rejection, or low self-esteem) can influence innovation.
- In *perceptual barriers*, habitual ways of seeing and comprehending make it difficult to see new relationship and ideas.
- In *interpretive barriers*, habitual ways of organizing their thinking and actions about innovation (Dougherty, 1992).

All these barriers, internal or external ones, can prevent innovation in concept generation. Perceptual and interpretive barriers are a habitual problem which always influences the designer's way of design. Emotional barriers, however, correspond to temporary barriers that affect the designer's way of design; it is hard to predict when they would come up. Therefore, in this research, we focus on *perceptual* and *interpretive* barriers. These barriers are referred to as *fixation* by (Linsey et al., 2010).

II. 6. Fixation

Fixation is defined as “the inability to work around the currently existing solutions or focus on

developing variants of existing solutions” (Moreno et al., 2015). Fixation also can be refined into several types.

II.6.1 Types of fixation

One main way to characterize fixation is to distinguish mental set fixation, functional fixation and design fixation.

Mental set fixation was first proposed by Luchins (1942) to describe fixation in problem-solving. It is described as an unconscious tendency to solve a problem in a particular way. For example, designers are fixed by a certain tool or approach and fail to notice other approaches or tools to solve these problems.

Functional fixation, a specific type of mental set fixation, was later introduced by Duncker (1945). It refers to the way an individual is fixed on one specific function of a product and is blocked to reinterpret the function of an object with which one is familiar.

Design fixation was first proposed by Jansson and Smith (1991) in engineering design as “a blind adherence to a set of ideas or concepts limiting the output of conceptual design”. Beitz et al. (1996) mentioned design fixation would influence designers' mental processes in the conceptual design process. Later on, Youmans and Arciszewsk (2014) defined design fixation as a situation where designers are unable to propose innovative outputs because of an over-reliance on existing designs, or more generally, an overreliance on a specific body of knowledge directly associated with a problem. They presented three sub-categories of design fixation behaviours: unconscious adherence to the influence of prior designs, conscious blocks to change, and intentional resistance to new ideas.

So, to help designers in proposing innovative concepts, we should try to help them to avoid design fixation behaviours because this would enhance their ability to propose innovative concepts.

Then the research question becomes:

How might we help designers mitigate design fixation in order to propose innovative concepts?

II.6.2 Design fixation

Concept generation, within the conceptual design, is about generating concepts to meet needs within available means (Ulrich & Eppinger, 2012). The notion of ‘available means’ is represented by knowledge and design constraints, which typically limit the designers’ ability to achieve the satisfaction of the initial needs (Levesque, 1986). Some of these constraints originate from the physical world (external world of designers), i.e. company environment, rule, policy etc. Some are related to the designers’ perceptions and interpretation of the design situation (internal world of designers) (Gero, 1994). Design fixation is used to describe a phenomenon that designers are fixed (constrained) to propose innovative ideas from the external world and the internal world.

There are different ways to characterize design fixation. Youmans and Arciszewsk (2014) divided design fixation: concept fixation and knowledge fixation.

Concept fixation occurs when a designer repeatedly considers only a limited number of concepts (Youmans and Arciszewsk, 2014).

Let us give an example of the mobile phones industry. Before the iPhone was launched, the clamshell type of flip phones and bar type of phones constituted the mainstream. Flip phones divided screen and keyboard, and these two sections fold via a hinge. Bar type of phones included keyboard and screen on a single face. Both of them included a physical keyboard. The iPhone broke concept fixation and proposed a slate type of phone with full-size touch and no physical keyboard anymore. Besides, considering functions, the iPhone improved email-checking, voicemail checking, added applications and integrated the iPod music player. Before the iPhone, the telephones were fixed by some design concepts (this is called concept fixation) in user interface and functionality; the iPhone broke this concept fixation and initiated new design.

Knowledge fixation represents a situation when a designer acquires a substantial body of knowledge in a specific area of engineering and fails to consider knowledge (and the related design concepts) outside of his or her knowledge in this area (Youmans and Arciszewsk, 2014). To illustrate the knowledge fixation, we give an example of the marathon runner and sprint runner. For example, marathon runner and sprint runner use different types of knowledge or

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strategies to train their body for running. For sprint runner, fast-twitch muscles are required to help runners quick burst their energy. In contrast, for a marathon runner, slow-twitch muscles are required to help runners maintain pace during a long-lasting race. Hence, knowledge closely related to the type of muscle training is needed. Knowledge that is not related to this training might not be considered by runners. However, unrelated knowledge might bring stimuli and help runners boost new ideas to train their muscle. The phenomenon that runners only acquire and consider a substantial body of related knowledge and not consider other unrelated knowledge is called knowledge fixation.

Figure II.11 shows all identified types of innovation barriers in concept generation as a synthesis on innovation barriers.

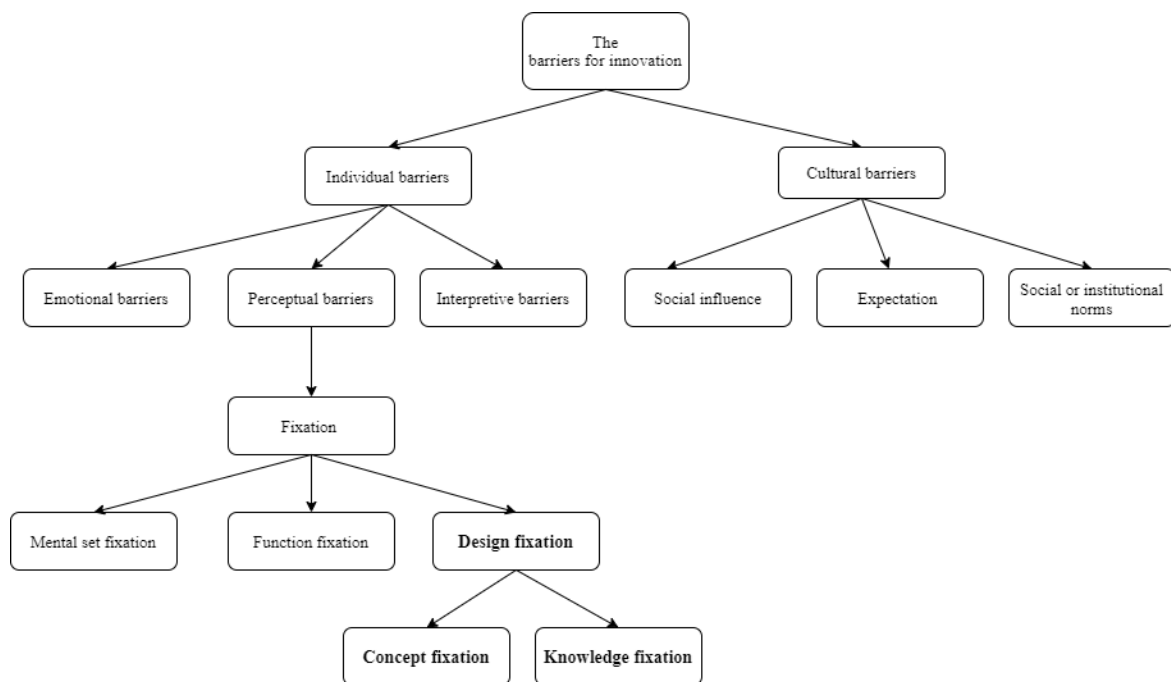


Figure II.11: The synthesis of innovation barriers

From the previous literature reviews, we conclude that several barriers might prevent innovation, among which concept and knowledge fixation, both different types of design fixation, are severe issues that constrain the designer's ability on innovative concept generation.

Hence, our research question becomes the following one:

How might we help the designer mitigate concept and knowledge fixations?

II. 7. Mitigating design fixation

Several design theories, methods and strategies have been proposed to stimulate innovation and mitigate design (either concept or knowledge) fixation.

II.7.1 Mitigating concept fixation

The different researchers have proposed various methods to tackle the issue of concept fixation, among them are morphological analysis and brainstorming.

II.7.1.1 Morphological Analysis

Morphological analysis, proposed by Zwicky (1969), is a method used to deal with concept fixation in engineering design that focuses on function categories of fixation alleviation. This method strategy is breaking down a problem into small problems. Designers first identify the main functions of a concept and decompose them into subfunctions, then propose several alternative attributes to achieve the subfunctions. In the end, designers combine attributes to generate a whole concept. The morphological analysis allows designers to use domain-relevant knowledge to reduce concept fixation.

II.7.1.2 Brainstorming

Alex F. Osborn first proposed brainstorming is first proposed in 1939 (Parker et al., 2004). It is a group idea generation technique that can help deal with concept fixation, especially closely related problem domains. This technique is used for a group of people meet to generate spontaneous new ideas as possible. There are several principles when implementing brainstorming, which includes: 1) Brainstorming instructions are essential, 2) a specific difficult target should be set, 3) Individual, not groups should generate the initial ideas, 4) use group interaction to refine an idea, 5) select final idea by individual votes, and 6) the required time should be kept remarkably short (Rossiter and Gary, 1994). The brainstorming technique allows a group of designers to generate a list of ideas to reduce concept fixation.

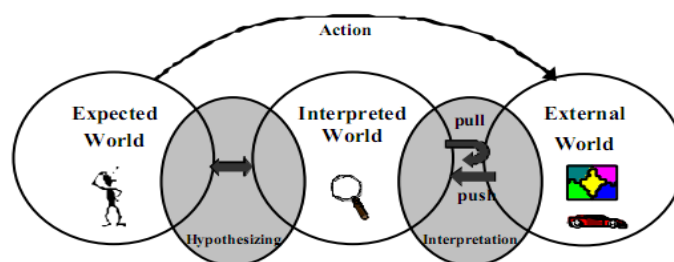
II.7.2 Mitigating knowledge fixation

Some theories and methods have been proposed to address knowledge fixation. They focus on a knowledge representation schema that allows the designer to explore knowledge. Among them, situated FBS model and CK theory are the most famous ones.

II.7.2.1 Situated FBS model

Gero (1990) proposed a knowledge schema to describe the design process, named the FBS (Function, Behavior and Structure) Framework. In this framework, he pointed out three fundamental constructs in design, which are Function, Behavior and Structure. Later on, Gero and Kannengiesser (2000) extended this model with a notion of situatedness to represent a situated design process. The new situated FBS model deals with individual mental activities of designing and the situated knowledge emerges to be obtained during the design process.

In the situated FBS framework, designers interact into three different worlds: external world, interpreted world and expected world. External world is the world that is composed of things outside the designers. Interpreted world and expected world are the worlds that inside the designer. Interpreted world which consists experiences, percepts and concepts, formed by the designer's interactions with the external world. Expected world is a world the imagined actions of the designer are expected. Figure II.12 shows the three interacting worlds.



*Figure II. 12: Three interacting worlds
(adopted from Gero and Kannengiesser, 2000)*

Among these three worlds, we also classify them into two types, which are: external world and internal world. The external world is the world outside of a designer or a design agent, whilst

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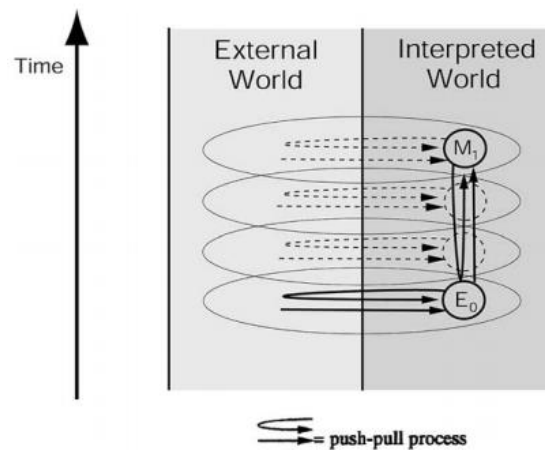
the internal world is the world inside a designer or a design agent. The internal world includes the interpreted world and the expected world.

In the internal world of a design agent, the interpreted world and the expected world with different functions.

The interpreted world with the function to “*sensory experiences, percepts and concept*”, and the expected world with the function of “*predict the effects of actions according to current goals and interpretations of the current state of the world.*”

Gero and Kannengiesser (2004) later described two processes (pull and push process) for representing an agent's interaction with its external and internal world. According to the authors, knowledge can be constructed and processed in the interpreted world from the interaction with the external world. Therefore, the interpreted world is critical, as this is a space that the agent's knowledge would be constructed and processed. However, there is a lack of a specific process of how knowledge is constructed in the interpreted world.

Figure II.13 shows the interaction between the external world and interpreted world.



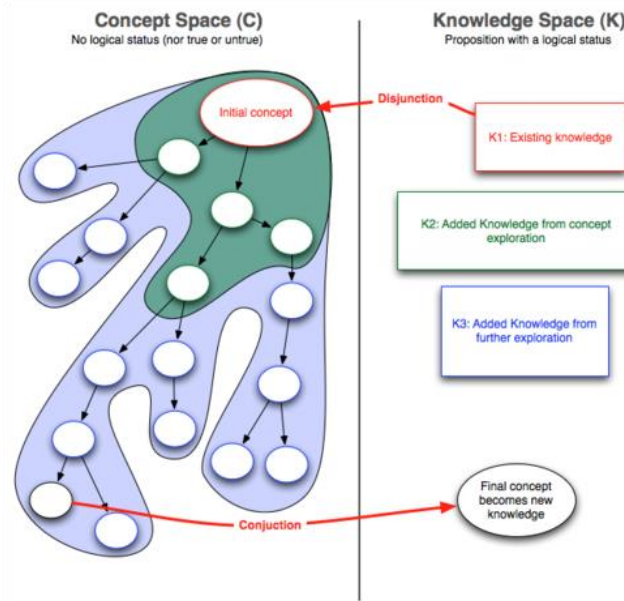
*Figure II. 13: The knowledge construction in the interpreted world
(adopted from Gero and Kannengiesser (2004))*

FBS model emphasizes the importance of situated knowledge and how it influences the final concept generation. The application of situated knowledge can deal with knowledge fixation by implementing the new obtained situated knowledge for concept generation.

II.7.2.2 CK theory

Another model of the design process is proposed by the CK (concept-knowledge) theory. This model reveals the concept generation process, which shows a double expansion of concept and knowledge in the concept and knowledge spaces simultaneously (Hatchuel and Weil, 2002).

Figure II.14 illustrates the CK theory.



*Figure II.14: Design process representation in CK theory
(adopted from Hatchuel and Weil, 2002)*

Concept space C is a generative space; it contains “concepts” which are undecidable propositions in Knowledge space K (Hatchuel and Weil, 2007). Space C is the space where “creative ideation” is explicitly organised. K space is a validation space, contains all established (true) propositions (Hautual and Weil, 2007). It is a reference space, resource space and output space that is transformed during the creative process. Concept and knowledge spaces are expandable. Hence, based on the conceptual design process models, we can see that the conceptual design process is essentially about generating undecidable proposition in C space with respect to the knowledge at the time it emerges, then transfer the undecidable proposition into a true proposition in K space. C and K space are jointly expanded through the actions in the design process.

Hence, CK theory can be used to deal with knowledge fixation. It helps new knowledge emergence in K space, which relies on the expansion of concepts in C space. Then the new

knowledge is used to deal with knowledge fixation and to support innovative concept generation.

II.7.3 Research objective

From literature analysis, we found out that new knowledge has been emphasized a lot in design theories. These theories present an effective and reliable way to explore new knowledge and expand knowledge space to deal with knowledge fixation. However, we identified some limitations.

CK theory proposes a logical way for concept and knowledge expansion. It also explains how new/unknown knowledge can be acquired in K space and how to use new knowledge to propose new concepts. However, new knowledge may generate a new concept in two ways: 1) use new knowledge to directly generate a new idea, with an immediate impact on the C-space (Hatchuel and Weil, 2009), 2) use new knowledge to reorder the knowledge space, then to impact on the C-space (Le Masson et al., 2016). CK theory only proposes using new knowledge to directly support concept generation. No guidance is provided to guide the designer in structuring the newly obtained knowledge in the knowledge space to propose innovative concepts.

Similarly, the situated FBS model (Gero and Kannengiesser 2004) emphasizes new knowledge acquisition by situated interactions during the design processes. The FBS model also emphasizes the designer's knowledge can be constructed and processed from the interaction with the external world. However, how the knowledge could be constructed in the interpreted world is not addressed.

During concept generation, knowledge plays an important role. Different types of knowledge and the amount of knowledge that can be used for concept generation are fundamental. While innovation is not only related to the knowledge type or to the amount of knowledge; how to structure this knowledge is also vital.

Brun et al. (2018) proposed one way of reordering knowledge by providing a counter example to restructure knowledge to mitigate fixation. There might be more ways to reorder knowledge for innovative concept proposition.

Therefore, in this research, we aim at exploring more ways to structure knowledge to mitigate design fixation in concept generation. Our goal is to propose a methodology that can guide the designer in structuring (newly acquired with existing) knowledge.

We propose the research objective to be:

Propose a methodology to help the designer in structuring knowledge to mitigate design fixation.

II.7.4 Heuristics for knowledge structuring

A heuristic is commonly referred to as a strategy that uses readily accessible information for guiding problem-solving (Pearl, 1984). The vital connection between design and cognitive psychology is to understand the designer's effective strategy for idea generation (Linsey et al., 2010).

Design heuristics is defined as a cognitive strategy to support designers in exploring more ideas and especially non-obvious ideas (Yilmaz et al., 2010; Daly et al., 2012). According to Yilmaz et al. (2010), design heuristics support designers in exploring potential designs' space and lead to varied and creative solutions. The purpose of design heuristics is to create a structure for the knowledge to ensure a logical route for its reuse in the future (Manuela et al., 2014).

As the research objective is to help a designer mitigating design fixation through knowledge structuring. From the fundamental of design heuristics, it shows that design heuristics can affect knowledge structuring somehow. Therefore, to reach our research goal, we focus on exploring how design heuristics affect knowledge structuring, particularly exploring how design heuristics affect knowledge structuring during the innovative concept generation.

Currently, several design heuristics exist; such as Scamper and 77 design heuristics. In the following section, we will have a look at the existing dominant design heuristics.

II.7.4.1 Scamper

Scamper is an idea generation tool to guide generating a variety of ideas. Scamper is a lateral thinking technique. Scamper is first proposed by Eberle (1971) in his book Scamper: Game for imagination development. It aims to help companies develop ideas for product or service design, and it also can turn a tired idea into something new and different.

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Scamper is an acronym formed from the abbreviation of eight design heuristics:

S—Substitute (e.g., components, materials, people)

C—Combine (e.g., mix, combine with other assemblies or services, integrate)

A—Adapt (e.g., alter, change function, use part of another element)

M—Magnify/Modify (e.g., increase or reduce in scale, change shape, modify attributes)

P—Put to other uses

E—Eliminate (e.g., remove elements, simplify, reduce to core functionality)

R—Rearrange/Reverse (e.g., turn inside out or upside down)

Scamper uses a set of directed questions to resolve a problem for concept generation. For instance, it can use a set of directed, idea-spurring questions to suggest a substitute, modify or combine, something that already exists.

Scamper has received lots of attention as a learning tool that fosters awareness, drive, fluency, flexibility, and originality (Serrant, 2017). In Scamper, the research mainly focuses on heuristics for concept generation and lacks exploring the relation between concept generation and knowledge structuring.

II.7.4.2 77 design heuristics

77 design heuristics are proposed by Yilmaz et al. (2016). It aims to extract and show concept variation evident from award-winning product designs, a solo professional design project, and protocol studies of engineers and industrial designers working on novel problems.

These identified design heuristics could offer a cognitive shortcut to guide the designer to generate more varied conceptual design concepts (Yilmaz et al., (2016).

77 design heuristics includes 77 distinct design heuristics. 77 design heuristics could help on product innovation to stimulate concept generation. Unlike Scamper, which uses the verb to facilitate concept generation, 77 design heuristics mainly use the phrase, such as “add motion”, “change direction of access” to guide concept generation.

For the existing design heuristics like Scamper and 77 design heuristics, different ways are provided to guide designer on innovative concept generation. While, how these heuristics affect concept generation, to be more specific, how does the heuristics affect knowledge space during

concept generation still lack of exploring.

Therefore, to reach our goal of guiding a designer on knowledge structuring. We determine to focus on design heuristics, explore the relationship between design heuristics and knowledge structuring, and see how design heuristics could be used as a strategy to guide knowledge structuring.

II. 8. Conclusion

This chapter reviewed the literature to refine the research focus and express a research objective. We first reviewed the definitions of design process and highlighted the importance of early stage of conceptual design, a challenging step for the generation of innovative concepts. Then we found out that design fixation constitutes the main innovation barrier in concept generation. After analysing the existing theories addressing this issue, we identified some limitations.

The existing design theories emphasize the importance of knowledge and different ways for new knowledge acquisition are proposed. Indeed, new knowledge can be directly used to generate a new idea. Meanwhile, it can be used to structure the knowledge in the knowledge space before to impact concept generation. However, how to structure knowledge, and enhance innovative concept generation is lack of exploring.

Therefore, our research goal addresses knowledge structuring, with the ambition of proposing a methodology to mitigate design fixation and therefore support innovative concept generation.

CHAPTER III. RESEARCH METHODOLOGY

III. 1. Introduction

This chapter addresses the choice of the research methodology for this study. Section 2 first surveys the different research methodologies from literature. Section 3 then explains the research methodology we adopted to achieve our research objective. We determined the most suitable research philosophy, approach, methodological choice, strategy and time horizon and procedures to guide on our research journey by positioning them with regards to the previous characterization of research methodologies. Section 5 concludes this chapter.

III. 2. Literature survey on research methodologies

The choice of a methodology is dependent on the nature of the research problem (Noor, 2009). This section surveys the different types of research methodologies from literature for us to position ourselves regarding the various methods that can be adopted and justify our choice. When conducting research, we first need to define a way to answer the research question. The Research Onion proposed by Saunders et al. (2011) (see Figure III.1) illustrates the different phases for the development of research work.

This Research Onion includes six layers, and the researcher is suggested to go from the outer layer to the inner layer, just like peeling the onion. So the first layer (the outer layer) is research philosophy, the second ring is research approach, then other rings are methodological choice, strategy(ies), time horizon, and techniques and procedures. The different layers are revealing the different phases of research design.

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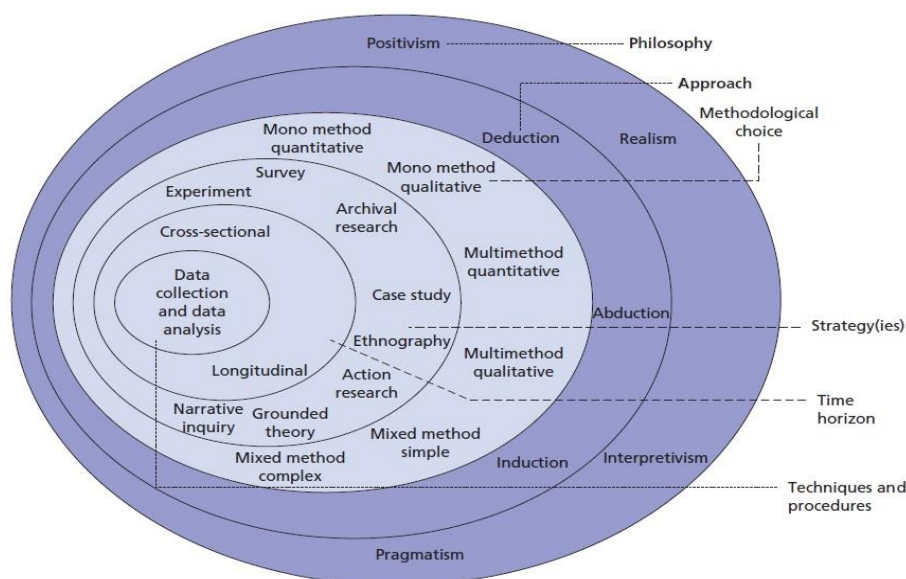


Figure III. 1: The Research Onion (Saunders et al. 2011)

According to Saunders et al. (2011), designing a research methodology starts from the outer layer to the inner layers. However, researchers often only focus on the core of the onion. After defining a research objective and research question, researchers directly try to obtain data and analyze them. But the selection of techniques for data collection and analysis is only a small part of the research; planning and designing a research methodology also is important. As it is suggested by Sahay (2016) *‘it is the researcher’s understanding and associated decisions with regard to outer layers of the onion that provide the context and boundaries within which data collection techniques, processing of data and analysis procedures should be selected. The final elements, the core of the research onion, need to be considered in line with other design elements which are contained in the outer and middle layers of the research onion’*.

In this section, let us peel the layers from the outside to inside elaborate the importance of each layer.

1. Research philosophy

The outermost layer of Research Onion is research philosophy. The research philosophy can be thought of as the assumptions about the way of the research view the world. The selected philosophy will have a significant impact not only on what the designer does but also how the designer understand what it is when they are investigating. There are three main types of research philosophy from Research Onion, which are: positivism, realism, interpretivism.

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Positivism

Positivism comes up with the research question and hypotheses that can be tested. With positivism, the researcher can find the explanations measuring the accepted knowledge of the world.

Realism

Realism is based on the idea of independence of reality from the human mind. Realism emphasizes that a researcher can revise every theory. It explains that the researcher cannot find truth without continuous research. It also encourages to use a new method in research.

Interpretivism

Interpretivism represents interested in specific, contextualized environments and acknowledges that reality and knowledge are not objective but influenced by people within that environment. Interpretivism involves researchers to interpret elements of the study. Thus interpretivism integrates human interest into a study.

2. Research approach

Once the research philosophy has been decided, the second layer of Research Onion suggests three types of research approaches, namely deductive, inductive and abductive approach.

Deductive approach

The deductive approach develops the hypothesis/hypotheses based on a pre-existing theory and then formulates the research approach to test it (Silverman, 2013). Deductive reasoning occurs when the conclusion is derived logically from a set of premises, the conclusion being true when all the premises are true (Ketokivi and Mantere, 2010).

The logic for deduction is that when the premises are correct, the conclusion must also be right.

The generalisability of the deductive approach is from the general to the specific level.

Inductive approach

The inductive approach allows researchers to create a theory rather than adopt a pre-existing one as in the deductive. Inductive reasoning occurs when there is a gap in the logic argument between the conclusion and the premises observed, the conclusion being 'judged' to be supported by the observations made (Ketokivi and Mantere, 2010). The inductive approach is characterized as a move from the specific to the general (Bell et al., 2018).

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The logic for the induction is that known premises are used to generate an untested conclusion.

The generalisability of the inductive approach is from the specific to general.

Abductive approach

Abductive approach involves collecting data to explore a phenomenon, identify themes and explain patterns, and generate a new-or modify an existing theory that is subsequently tested.

The logic for abduction is that known premises are used to generate a testable conclusion.

3. Methodological choice

The third layer of Research Onion is the methodological choice. There are three main types of research design: qualitative and quantitative or multiple methods (combining qualitative and quantitative). A way to differentiate quantitative and qualitative methods can be done by data type: numeric data (numbers) and non-numeric data (words, images, video clips and other similar material).

Quantitative method

Quantitative method is often used as a synonym for any data collection technique (such as a questionnaire) and data analysis (such as statistics) steps that generate or uses numerical data.

Qualitative method

Qualitative method is often used as a synonym for any data collection technique (such as an interview) or data analysis steps (such as categorizing data) that generates or uses non-numerical data.

Multiple methods

Use more than one data collection technique and data analysis (such as statistics) to answer the research question. It provides scope for a richer approach of data collection, analysis and interpretation than one technique.

4. Research strategy

The fourth layer of Research Onion is the research strategy. A research strategy is a plan of action to achieve a goal. It is a link between the philosophy and subsequent choice of methods to collect and analyze data. There are eight types of research strategies: experiment, survey, archival research, case study, ethnography, action research, grounded theory, narrative inquiry.

Experiment

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The purpose of the experiment is to explore the probability of a change in an independent variable, which causes a change in another dependent variable (Hakim, 2000). In an experiment, predictions, which is also known as hypotheses, are made rather than research questions.

Survey

A survey is typically associated with a deductive research approach, and it is common used in business and management research for exploratory and descriptive research. Quantitative data can be collected from the approach. The questionnaire also belongs to the survey strategy.

Archival research

Archival research is a type of research that make use of administrative records and documents as the principal source of data and extracting information out of it. All research that makes use of data contained in administrative records is inevitably secondary data analysis (Saunders et al., 2011).

Case study

A case study is a type of strategy that explores a research topic or phenomenon within its context or within several real-life contexts (Saunders et al., 2011). A case study strategy is most often used in explanatory and exploratory research. Meanwhile, a case study also can be considered to explore answers for some types of questions, such as ‘why?’ ‘What?’ and ‘how?’. Besides, the case study strategy would be relevant if the goal is to gain an understanding of the research context or the processes are being enacted

Ethnography

Ethnography is used to study groups. It is the earliest qualitative research strategy, with its origins in colonial anthropology (Saunders et al., 2011).

Grounded theory

Grounded Theory is a methodological approach, which involves proposing hypothesis and theories by collecting and analyzing data (Bryant and Charmaz, 2007). Grounded Theory is used to develop theoretical explanations of social interactions and processes in a wide range of contexts, including business and management (Saunders et al., 2011).

Narrative Inquiry

Narrative inquiry is from the field of qualitative research (Riessman, 1993). A narrative is a story; a personal account which interprets an event or sequence of events (Saunders et al., 2011).

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It starts with the process of gathering information for the purpose of research through storytelling. When selecting this strategy, it is generally under the situation that, the researcher believes the experiences of their participants can best be accessed by complete stories telling by the participants rather than specific interview questions to ask.

5. Time horizon

The fifth layer of the Research Onion is time horizon. Time horizon refers to the time frame of the research. There are two types of time horizons, which are cross-sectional and longitudinal.

Cross-sectional

The cross-sectional is used when all observations are for a single point of time, such as in most surveys. It is suitable for the study of a particular phenomenon at a particular time.

Longitudinal

Longitudinal implies the observations for a particular variable that is available for several years, quarters, months or days. It with the capacity to study change and development for a period of time.

III. 3. Our research methodology

Choosing an appropriate research methodology is a stepping stone, which determines the way to conduct the research and which influences the success and quality of it. To that goal, we progressed from the outside layer towards the inside one, as recommended by (Saunders et al., 2011).

This section presents this progress and the resulting research methodology. It starts by pointing out the methodological choices that have been made; it then presents the general framework of the research methodology and finally provides a detailed description of it.

III. 3.1 Methodological choices

Referring to (Saunders et al., 2011), we started by positioning our research philosophy, approach, methodological choice, strategy and time horizon from the Research Onion.

1. Research philosophy

The research philosophy lies in the most outside layer of the Research Onion, as a building block of the research. It plays a crucial role in the development of the whole study, which should

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be coherent with the research objective and research question. When selecting a research philosophy, different choices can be made depending on the research question and objective. There is no philosophy better than another.

We determined that an *interpretive philosophy* was the most suitable here. This philosophy believes outside world is not independent with the researcher, and the way of how the researcher interprets the world would enable her/him to act in one way or another. The main goal of our research is to explore a way to enhance innovation in conceptual design. One of the fundamental steps is to explore strategies from existing innovative cases, and based on this exploration, to propose a way to guide the designers structuring their knowledge to generate new concepts. An interpretive process will then be conducted regarding the needs. Hence, the research philosophy choice corresponds to interpretivism.

2. Research approach

Our research approach commences with involving a collection of cases to explore a phenomenon and explain patterns, then to generate a new theory from the learning and finding derived from the context of related cases. Therefore, it is in line with an *inductive approach* that aims at generating a new theory using reliable findings. The inductive approach is intended to allow meanings to emerge from data to identify patterns and relationships to build a theory.

3. Methodological choice

There are three main types of methodological choices, which are qualitative, quantitative or multiple methods. Quantitative methods are often used for numerical data; qualitative methods are often used for non-numerical data. In our case study, all the collected data are non-numerical ones, so it belongs to qualitative methods. Therefore, our methodological choice is a *mono qualitative method*.

4. Research strategy

Our goal being to explore an innovation strategy and how it can be used for concept generation and influence the way designers structure knowledge, a large number of existing successful innovative cases are collected to explore the phenomenon. To that goal, we try and learn lessons from case studies and pattern exploration through qualitative data collection and analysis. Hence, our research strategy choice relies on a case study.

5. Time horizon

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Two types of time horizons can be distinguished, cross-section and longitudinal. The cross-section time horizon describes the time to study a phenomenon at one time. In contrast, the longitudinal time horizon describes the time for study requires an extended period for observing or examining the changes over time.

In our case study, data are collected and observation is conducted at one time, with no need to extend the period to observe the changes. This type of research belongs to *cross-section time horizon*.

6. Techniques and procedures

In the most inner layer of the Research Onion are the techniques and procedures of the research, corresponding to data collection and analysis. This part will be detailed in the following section. Figure III.2 shows the result of positioning our research with regards to (Saunders et al., 2011) classification.

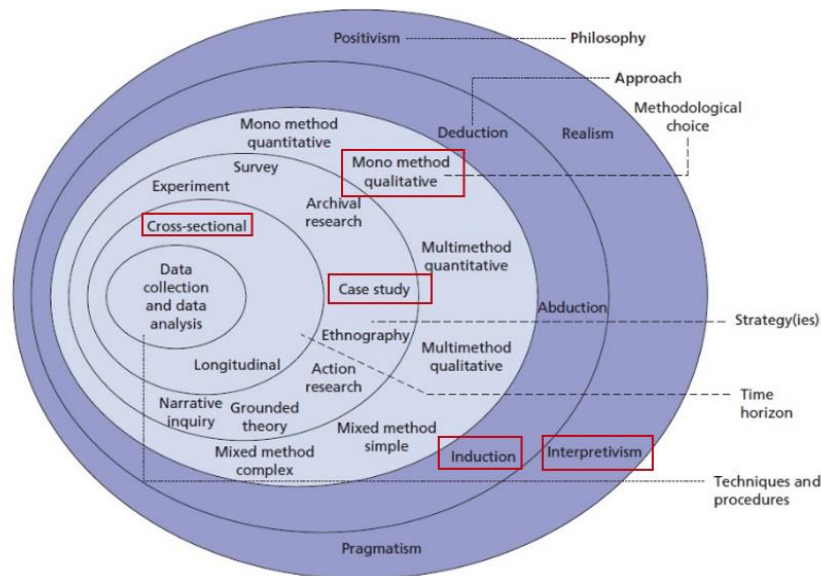


Figure III. 2: Positioning our methodological choices
(adopted from Saunders et al., 2011)

III. 3.2 Research techniques and procedures

Three main procedures are used to help reaching the research goal: 1) literature review, 2) case study, 3) proposal of a methodology, application and evaluation.

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Figure III.3 shows the general framework of the research procedures that lead this research.

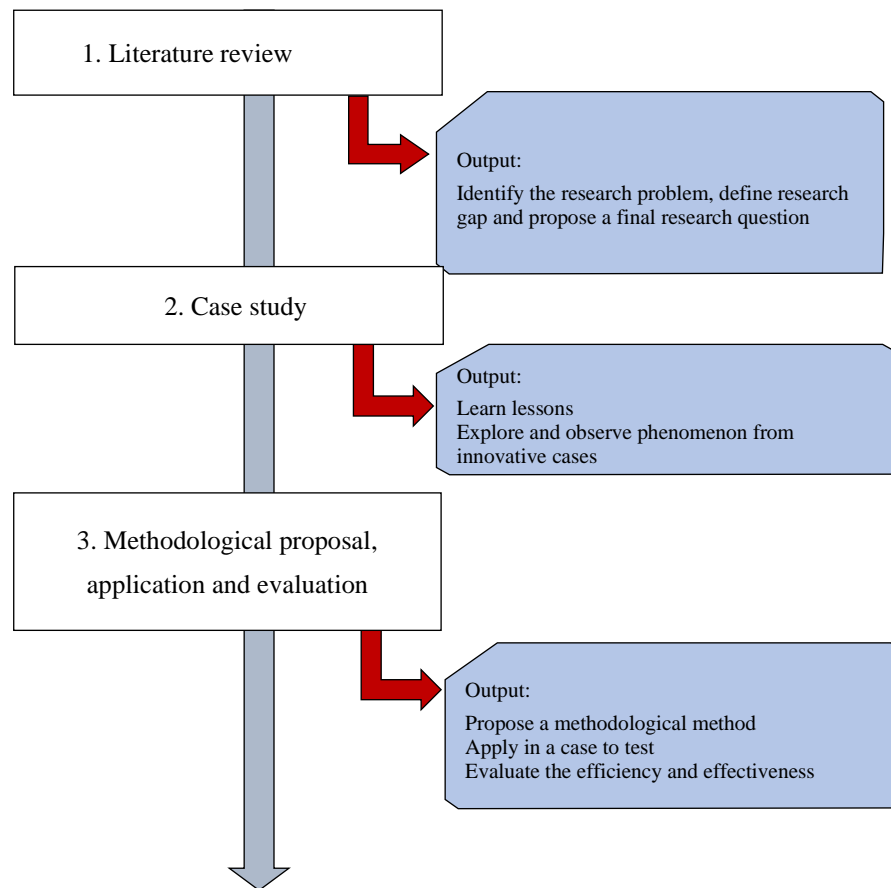


Figure III. 3: High-level framework of the research procedures

During the *literature review*, we precise the research problem, formulate the research question and develop a hypothesis of the pathway towards a solution. Thanks to an exploratory *case study*, we learn lessons and validate our hypothesis (that design heuristics can influence knowledge structuring, thus elaborating new concepts and boosting innovation in conceptual design). Based on these findings, we *propose a methodology* to support conceptual design relying on knowledge structuring, *apply* it on a case study and *evaluate its efficiency and effectiveness* for concept generation.

Below, the detailed presentation of these three procedures.

III. 3.3.1 Literature review

The literature review is the first and fundamental activity when conducting research (Creswell and Poth, 2016). It aims to obtain an overview of existing studies on a particular topic (Cornin et al., 2008).

In our case, the literature review was performed during the whole research, while with different purposes and at different stages.

In our research, we conducted three rounds of literature review.

The first round of literature review was a general literature review, to identify the research topic, understand the research problem and challenges, and to formulate the main research question.

The second round of the literature review was a systematic literature review, to identify and collect as many papers related to the research topic as possible.

The third round of literature review was a critical literature review, to analyze the existing solutions/methods, identify research gaps and proposing derived research questions.

Figure III.4 represents how we proceeded for the literature review.

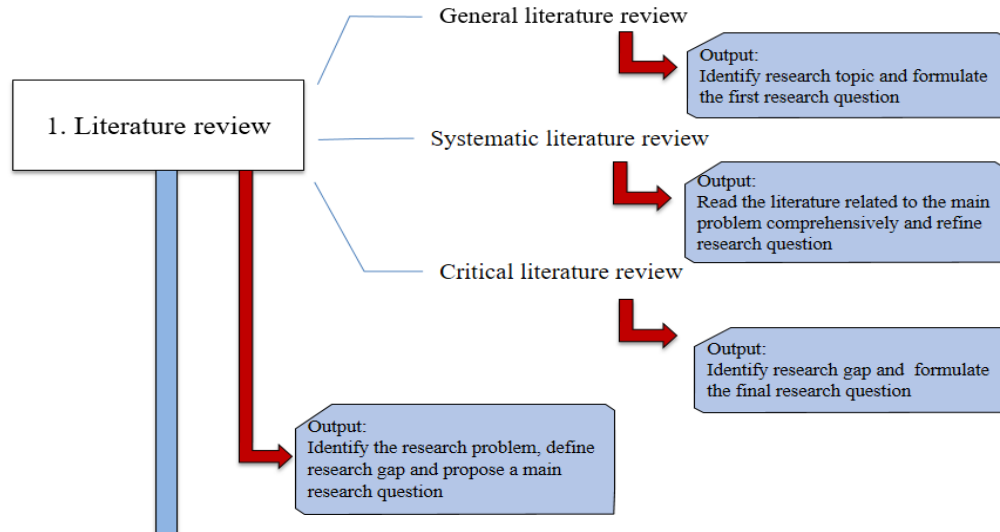


Figure III. 4: Details of procedure 1

➤ The first round of literature review

We started with defining design, the process and stage of design. As the primary goal of the thesis was to enhance innovation in design, we first proceeded to gain a better understanding of the notion of design. Next, the importance of the early design stage, conceptual design, was highlighted, and the literature related to the conceptual design was conducted. Within the

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conceptual design, as concept generation was vital to boost innovation, literature review then focused on innovation in concept generation, and the different barriers to this innovation, mainly design fixation.

➤ **The second round of literature review**

Then we did a systematic literature review to deepen the understanding of the concept of fixation and determined several types of fixation. We concluded that design fixation was deemed as a profound cause that prevents innovation occurs concept generation.

➤ **The third round of literature review**

Finally, we reviewed the literature on existing theories and methods that deal with the issue of design fixation. Among the current design theories, an emphasis was put on exploring new knowledge to deal with knowledge fixation. However, no guidance had been provided to guide the designer on how to structure the newly obtained knowledge for concept generation. Based on this finding, we formulated our research question.

In conclusion, at the end of the literature review, we identified the research problem, defined the research objective and formulated our research question:

- 1) The research problem: an important challenge is to avoid design fixation of designers while generating new ideas in conceptual design.
- 2) The research gap: some existing design theories emphasize the importance of new knowledge, and different ways for new knowledge acquisition were proposed. New knowledge can be directly used to generate a new idea. Meanwhile, it also can be used to structure the knowledge in the knowledge space before to impact concept generation. However, how structuring the knowledge, therefore improving concept generation is less explored.
- 3) The research question focuses on mitigating design fixation by exploring a way to structure previous and new knowledge to deal with design fixation and, therefore, enhance innovation.

III. 3.3.2 Case study

Studying a case is a way that allows the exploration and understanding of complex issues (Zainal, 2007). It is regarded as a robust research method, requiring a holistic and in-depth investigation. The case study enables a researcher to examine the data within a specific context closely.

Yin (1984) proposed three categories of case study: exploratory, descriptive and explanatory. In this research, we conduct an *exploratory* case study to explore the phenomenon.

The goal of the case study is to identify and explore the strategy that was used to support the innovative concept generation in the chosen case. Then to test our hypothesis, the applied strategy might influence knowledge space, thus influencing concept generation.

To reach this goal, we first analyzed the case and identified the innovation strategies that have been used. Then we compared the identified innovation strategies (design heuristics) with the existing ones to see the similarities and differences, as well as if new heuristics emerged. Afterwards, we modelled how design heuristics affect the concept and knowledge space during concept generation. In the end, we found out that design heuristics can influence knowledge structuring from knowledge space, thus influencing concept generation.

Figure III. 5 shows the main steps of the case study.

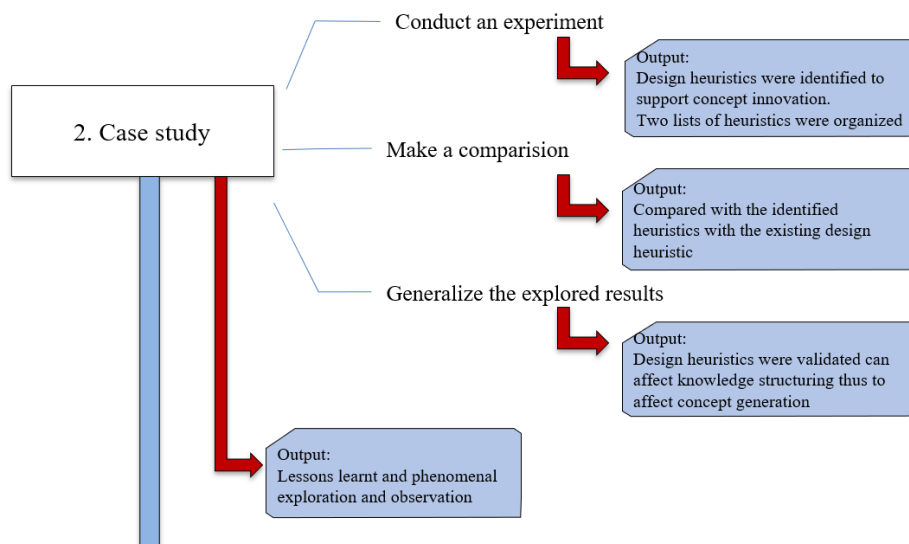


Figure III. 5 Details of procedure 2

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➤ **Conduct an experiment for innovative strategy identification**

To explore what strategy had been used for innovative concept generation, we chose the method of case study to learn the first lesson. In the case study, a number of cases were collected. Through selecting and analysing the innovative cases, many design heuristics were identified to support innovative concept generation. Then, we organised and classified the identified heuristics.

As a result, we identified that design heuristics had been applied to support innovative concept generation. Meanwhile, two lists of heuristics, that identified from innovative cases, were organised.

➤ **Compare the identified design heuristics with existing heuristics**

Then we compared the identified heuristics with the existing design heuristics. As a result, the similarities and differences between heuristics were analysed; some new heuristics were also identified.

➤ **Explore how the design heuristics affect concept generation**

To explore how design heuristics affect concept space and knowledge space during idea generation, we used the CK theory. Through the visualization of how heuristics affect concept and knowledge, we found out that design heuristics can affect a knowledge structure, thus affecting concept generation.

As a result, design heuristics was validated to be able to influence knowledge structuring, thus affecting concept generation.

III. 3.3.3 Methodological proposal and illustration

Our research aims at helping designers to deal with design fixation and propose innovative concepts by proposing a methodology based on the findings from the previous case study. The methodology is experimented, step by step, on the case study (cf Figure III. 6).

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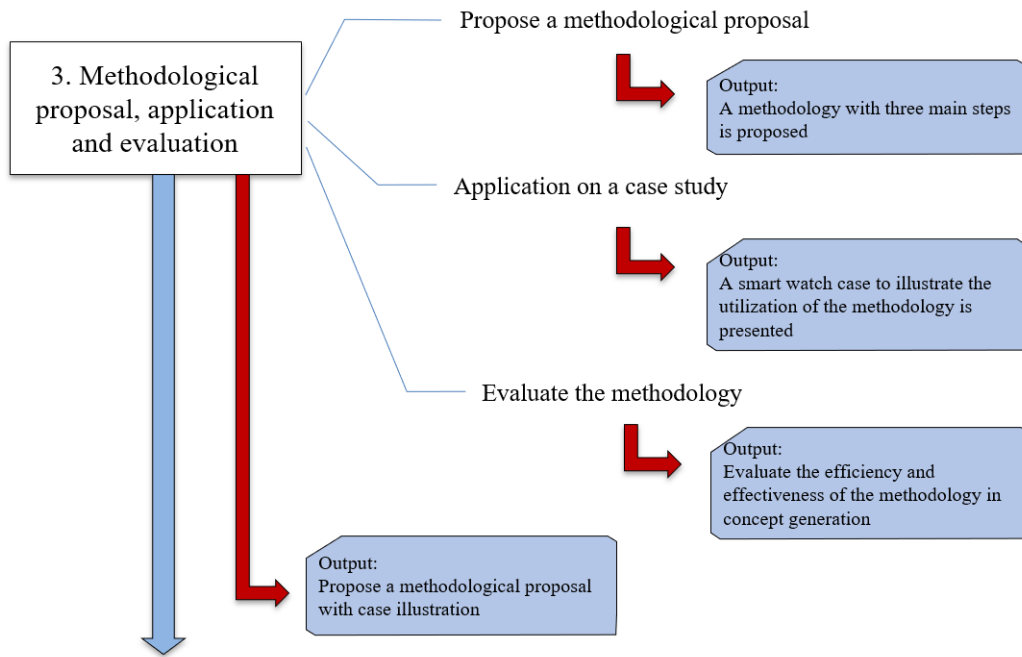


Figure III.6 Details of procedure 3

➤ **Methodological proposal**

The methodology consists of 3 main steps, knowledge identification, knowledge decomposition and knowledge structuring (see details in Chapter 4), that interactively guide the designers to identify the knowledge related to the design problem, to decompose and refine it into details. Then to structure it progressively, with the guidance of a series of questions, thanks to the support of several heuristics helping the designers in structuring knowledge.

➤ **Application on a case study**

The case study of smartwatch design is used to illustrate each step of the methodology, demonstrating how this methodology can help the designers mitigate design fixation and guide them in generating innovative concept. This proposal constitutes a new way to deal with design fixation through knowledge structuring.

➤ **Evaluate the methodology**

After applying the proposed methodology, we evaluate its efficiency and effectiveness for concept generation. We discuss the interests and current limitations of the methodology.

III. 3.3.4 Synthesis the research methodology

“Methodology is the philosophical framework within which the research is conducted or the foundation upon which the research is based” (Brown, 2006). Research methodology describes the methods, strategies, approaches throughout the study. Based on the selection of the research philosophy, approach, methodological choice, strategy and time horizon, we design our research methodology and procedures.

III. 4. Conclusion

This chapter presented and explained the research methodology we adopted to guide this fundamental research.

The next chapter presents our analysis of the case study, which correspond to the second procedure of the research methodology.

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CHAPTER IV. PHENOMENON EXPLORATION AND HEURISTICS IDENTIFICATION THROUGH A CASE STUDY

IV.1 Introduction

This chapter corresponds to the second phase of the research methodology- an exploratory case study. The first phase corresponded to the literature review. We pointed out that the main barrier for concept innovation is design fixation, which can be further decomposed into concept and knowledge fixation. We found out that many current theories and methods emphasise the importance of new knowledge and pay a lot of attention on how to use new knowledge for concept generation. Indeed, new knowledge can be directly used to generate new concepts. New knowledge can also be used to structure the knowledge space before concept generation. However, how to structure knowledge in order to enhance the innovative concept generation is not addressed.

Hence, in this research, we aim at defining a strategy that could be used to support knowledge structuring and enhance concept innovation. To this goal, we particularly explore the influence of heuristics on knowledge structuring.

This chapter aims to conduct a case study to learn some lessons, explore the phenomenon of design fixation, and observe how it could be solved in given context to determine if and what strategy can influence the knowledge space and affect knowledge structuring. To this goal, we followed an experimental based case study method.

This chapter explains the details of how we use a case study for lesson learn and phenomenon exploration. This chapter includes three main sections. Section 2 starts with introducing the case study, its objectives, and give the global outline of the process followed in tackling the case study. Section 3 details the different steps and intermediary results. Section 4 concludes with the findings resulting from the case study.

IV.2 Presentation of the case study

The case study is led with an experimental goal to explore what kind of design heuristics have been applied to support innovative concept generation in a given context, and understand how these heuristics impact concept space and knowledge space to propose innovative concepts.

For the case study, we chose the domain of smartwatches design, where innovation is relatively rapid, and it is easy to access historical data. We analyzed some innovative cases in smartwatch design to identify what kinds of design heuristics have been used to propose innovative concepts, and how the design heuristics can affect concept generation. Our objective is to derive conclusions that can be used to build a proposal to improve design fixation mitigation.

IV.2.1 Objectives of the case study

This case study's main goal is to explore a strategy that can be used to support knowledge structuring and thus affecting concept generation.

Design heuristics are known as strategies for concept generation by assisting the designer's exploring concept structuring for innovative concept generation. The concept is a representation of knowledge. Hence, our hypothesis is that design heuristics can influence knowledge structuring from knowledge space, thus to influence concept generation.

Therefore, the precise goal of this case study is to explore whether and how design heuristics can support knowledge structuring and enhance concept innovation.

To reach this final goal and test the hypothesis, the case study is divided into three sub-goals:

- **Goal 1:** determine if any design heuristics have been applied to support innovative concept generation and therefore overcome the problem of design fixation, and then identify and classify those heuristics.
- **Goal 2:** analyse the identified design heuristics to gather any useful insight, then compare those heuristics with existing ones, discuss their interests and limitations, and characterize them.
- **Goal 3:** explore how the use of design heuristics influenced innovative concept generation in this case, more precisely determine how using heuristics affected concept space and knowledge space during concept generation.

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IV.2.2 Outline of the process followed in tackling the case study

In order to reach those three goals, an 8-steps process was followed. The first four steps aimed at reaching the first goal of identifying design heuristics and gather insights. Steps 5 and 6 address the goal 2 of comparing the identified design heuristics with existing ones. Step 7 and 8 deal with goal 3 of analysing how design heuristics affect concept and knowledge space for concept generation.

To reach the first goal, there are 4 steps:

Step 1: preliminary step aiming at setting up a case base. To this goal, we collect smart watches from top 5 smartwatch companies and some other companies focusing on niches such as specific sports watches.

Step 2: we analyse the cases from each product family and select a set of innovative cases for further analysis.

Step 3: we identify if any, and what type of design heuristic has been applied to support innovative concept generation and characterize the corresponding innovation type.

Step 4: we organise the identified design heuristics to get some insights.

At the end of this step, we are able to answer the question “what kind of design heuristics has been applied to help designers propose innovative concepts?” and reached our first goal. We identified design heuristics that have been applied in smartwatch design. We classified them according to four categories. Besides, we also found out that some heuristics are applied more frequently than others.

To reach the second goal, there are 2 steps:

In order to compare the commonality and difference as well as the advantages and disadvantages between the identified heuristics and the existing heuristics, we proceed to step 5 and step 6:

Step 5: compare with identified heuristics with the existing heuristics, identify the commonly used heuristics and determine if any new heuristic emerged.

Step 6: discuss the advantages and limitations of these heuristics.

At the end of these steps, we are able to answer the question asked, “what are the difference between the identified design heuristics with the existing ones?” and reached our second goal

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to compare our identified design heuristics with other existing design heuristics. We find some common heuristics and that some heuristics are applied more frequently than others, while some heuristics have not been applied at all; we also identified new heuristics. In addition, during the discussion, we discuss the advantages and disadvantages of different heuristics.

To reach the third goal, two final steps are conducted:

In order to explore how design heuristics affect concept generation, we proceed to two last steps:

Step 7: modelling how heuristics affect concept and knowledge space during idea generation.

This step uses the CK theory to model how design heuristics affect concept space and knowledge space for concept generation.

Step 8: abstract the relationship between concept generation and knowledge structuring.

At the end of these steps, we are able to answer the question asked, “how design heuristics influence concept generation?”. We identified that some design heuristics could provide strategies for knowledge structuring, thus impacting concept generation.

Figure IV.1 shows a synthesis of these eight steps and their intermediary results.

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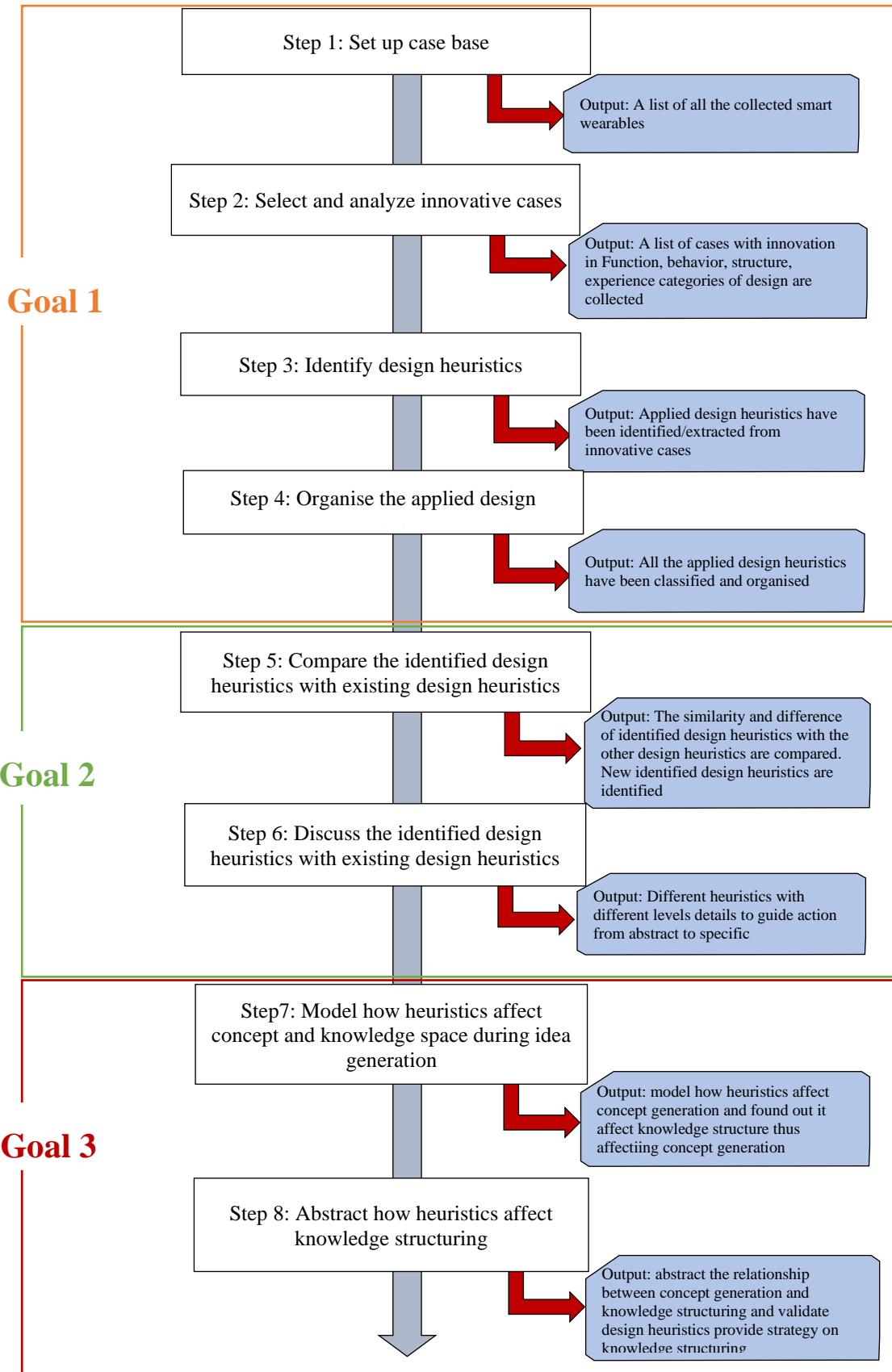


Figure IV. 1: Eight steps and intermediary results to reach the three goals

IV.3 Analysis of the case study details and results in each step

This section illustrates the details in each step to reach the goal of the case study. To reach the first goal to explore what design heuristics have been applied to support innovative concept generation. There are four steps conducted: step up a case base, select and analyse innovative cases, identify design heuristics, and organise the design heuristics.

IV.3.1 Step 1: Set up a case base

The main purpose of step 1 is to create a case base about smart watches. To create a compelling case base, we collected smart watches from different brands and with different types. To be more specific, we collected smart watches from top 5 smartwatch companies and some other companies focusing on niches, such as specific sports watches. Then we checked if enough information was available on each.

Therefore, we proceeded this way:

1. First, we selected smartwatch brands based on the market share

According to the IDC (International Data Corporation) report (Mass, 2020), Apple, Xiao Mi, Samsung, Huawei, and Fitbit are the top five companies for wearable accessories; together they form the driving force in the smartwatch market. We collected design information on smartwatches from these brands. To complete the case base, we identified some other companies, such as Suunto, Polar and Garmin, that had less market share, but focus on niches such as specific sports watches. We considered watches that won special design prizes; for example, the Suunto 7 was nominated as best fitness smartwatch of Consumer Electronics Show 2020 (Nield,2020). As a result, products from these niches have also been taken into consideration. At the end of the first round of smartwatch selection, the case base is composed of 134 cases.

2. Second, the case base was narrowed down

To increase the accuracy of the case analysis, we narrowed down the case base by two criteria:

- 1) Detailed description of the products is available on the official website, and 2) Products are still in production (discontinued products are not considered).

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At the end of the second round of case selection, there are 90 cases remained for further investigation.

3. Organise the case information

When collecting all the cases, to organise the case information, we inspired ourselves on the FBSE model proposed by (Brazier et al., 2018) so to characterise the information of the cases. The following definitions will be used in this chapter so to structure the analysis of the smart watches.

- **Function:** What functions does the watch realise?
- **Behaviour:** How are these functions realised?
- **Structure:** What physical components are used for the watch?
- **Experiential:** What experience that is expected to be perceived by the end-users?

Hence, the information of each case includes product name (series), a description of its function, behavior, structure (mainly consider components) and experience (mainly consider the experience that the expected to be perceived from system and user interface).

At the end of step 1, the case base of the smartwatch is set up.

Table IV.1 show an extract of the case base.

Table IV. 1: Extract of the smart watches case base

Name	Function (purpose of system)	Behavior (the way a system acts)	Structure (components of system)	Experience (perceived experience of system)
Apple series 3	<ul style="list-style-type: none"> • Time keeping • Health monitoring (i.e. heart rate monitoring, heart rate warning, menstrual cycle monitoring), • Safety and emergency: Emergency SOS call • Workout tracking (i.e. Yoga/cycling/swimming tracking), • Activity tracking: stand, move, exercise • Smart notification (i.e. call, text) • listen to music. • Apple pay 	<ul style="list-style-type: none"> • Show the time on the screen (by raising the wrist) • Detect heart rate, show heart rate, heart rate warning (above the default 120 bpm) • Monitor menstrual cycle and show menstrual cycle • Allow to call emergency • Show the move/exercise/stand • Show calories burned • Show workout metrics • Show the notification on the screen • Waterproof • Play music • Payment • Battery life: up to 18 hours of battery life 	<ul style="list-style-type: none"> • Watch strap (interchangeable strap, different color and materials) • Watch casing (material: Aluminum, 100% recycled) Case size: 38mm and 42mm Case color • Touch screen (flat, one screen) • Chip (Dual-core S3) • Battery system • Speakers • Microphone • Battery system • Optical heart sensor 	<ul style="list-style-type: none"> • Raise the wrist and show the display Tap the screen to see the information • Aluminum watch casing is provided • Cooperate with Nike (Nike+ aluminum model) • See health monitoring from the wrist • Know the heart health Be alerted with unusually high or low heart rates or an irregular rhythm • Call emergency from wrist Quickly call for help and alert an emergency contact • Track a menstrual cycle with a tap • Sustainable material selection (the watch case is 100% recycled aluminum) • Allow to change to different straps • Two colors for casing and different materials for watch strap

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Apple series 5	<ul style="list-style-type: none"> • Time keeping • Health monitoring (i.e. heart rate monitoring, heart rate warning, menstrual cycle monitoring, noise alert), • Safety and emergency: Emergency SOS, fall detection, international emergency calling • Workout tracking (i.e. Yoga/cycling/swimming tracking), advanced workout matrices • Activity tracking: stand, move, exercise • Smart notification (i.e. call, text) • Listen to music. • Apple pay • Navigation 	<ul style="list-style-type: none"> • Show the time on the screen (always visible on the screen) • Detect heart rate, show heart rate, heart rate warning (above the default 120 bpm) • Create ECG • Monitor menstrual cycle and show menstrual cycle • Allow to call emergency • Show the move/exercise/stand • Show calories burned • Show workout metrics • Show the notification on the screen • Waterproof (50 meters resistance) • Play music • Payment • Battery life: up to 18 hours of battery life • Provide directions (Show the bearing, elevation, incline, and coordinates) 	<ul style="list-style-type: none"> • Watch strap (interchangeable strap, different color and materials) • Watch casing (material: 100 % recycled, stainless steel, Titanium and ceramic option) • Case size: 40mm and 44mm • Touch screen (flat, different screen faces) • Screen 30% larger • Chip (Dual-core S5) • Battery system • Speaker • Microphone • Optical heart sensor • Electrical heart sensor • Compass 	<ul style="list-style-type: none"> • Always see the time and information on the watch face without touch the screen • Always on display even wrist is down (don't need to raise the wrist to wake it up) • More types of watch casing can be chosen by customers (aluminum, stainless steel, titanium and ceramic) • More than one hundred watch faces to tell the time (select by the users) • Cooperate with Nike and Hemes (Nike+ aluminum model and Hermes stainless steel model) • Know the heart health • Be alerted with unusually high or low heart rates or an irregular rhythm • See ECG • Call emergency from wrist • Quickly call for help and alert an emergency contact • Complete an emergency call while travelling abroad • Detect when a hard fall • Track a menstrual cycle with a tap • Sustainable material selection (the watch case is 100% recycled aluminum) • Customized service: more options on casing to allow customers create their own style (choose a case to pair a band) • Choose the material the customer like • With a great guidance of direction
Mi Band 4	<ul style="list-style-type: none"> • Health monitoring (i.e. heart rate monitoring, sleep tracking) • Workout tracking (i.e. Swimming tracking, cycling, running, power walking) • Activity tracking: step record, calories and distance tracking • Play music • Idle alerts • NCF 	<ul style="list-style-type: none"> • Show the time on the screen (by tapping the screen) • Detect heart rate, show heart rate, heart rate warning • Track sleep and show sleeping information • Show the exercise time and distance • Show calories burned • Show the notification on the screen • Waterproof (50 meters water resistance) • Play music • NCF to pay • Idle alerts • Battery life: up to 20 days battery life 	<ul style="list-style-type: none"> • Wrist strap (interchangeable strap, different color; silicone material) • Watch casing (Polycarbonate) • Touch screen (flat, full color AMOLED Screen) • Screen size increased by 39.9% • Chip • Battery system • Speaker • Microphone • PPG heart rate sensor 	<ul style="list-style-type: none"> • Tap the screen to see the information • See health monitoring from the wrist • Know the heart health • Be alerted with unusually high or low heart rates or an irregular rhythm • Be alerted for sitting a long time • Allow to change to different straps • Allow to change different watch face (380 watch faces are provided) • Different materials for watch strap • Low price to get a smart band (29 euros)
.....	•	•	•	•

IV.3.2 Step 2: Select and analyse innovative cases

Step 1 collected case information. The main purpose of step 2 is to select out a set of innovative cases for further analysis.

For case selection, we adopt the following strategy. We first consider every product family separately to analyse the evolution within a product family, to identify innovation and where

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innovation occurs (in functions, behaviors, structures or experience) as each case information is organised around these design categories from step 1. Then determined the corresponding innovation type of (incremental, sustaining, disruptive, or radical) and select out the cases with innovation occurs.

The innovative case selection proceeds in this way:

1. First, we select one product family to analyse.
2. Second, we compare the cases from the categories of function, behavior, structure (components) and experience.
3. Third, identify the innovation occurs in these four categories with its determined innovation type.
4. If innovation occurs in the mentioned categories, select the cases, and put the case into the innovative case list.

At the end of step 2, a list of innovative cases is selected out for further analysis.

Let us give an example of innovation cases selection. First, the product family of Apple watch is selected out for analysis. Second, we compare Apple Watch Series 3 and Series 5 from the categories of function, behavior, structure and experience. Third, we try to identify where the innovation occurs from these four categories of Apple Watch Series 3 and 5 (see Table IV. 2, where in bold is where innovation occurs).

Table IV. 2: Innovation in Apple watch design

Case	Category of design			
	Function	Behavior	Structure	Experience
Apple series 3	<ul style="list-style-type: none"> • Time keeping • Health monitoring (i.e. heart rate monitoring, heart rate warning, menstrual cycle monitoring), • Safety and emergency: Emergency SOS call (call local emergency service and share the location to your emergency contacts) • Workout tracking (i.e. Yoga/cycling/swimming tracking), • Activity tracking: stand, move, exercise • Smart notification (i.e. call, text) • listen to music. 	<ul style="list-style-type: none"> • Show the time on the screen (by raising the wrist) • Detect heart rate, show heart rate, heart rate warning (above the default 120 bpm) • Monitor menstrual cycle and show menstrual cycle • Allow to call emergency • Show the move/exercise/stand • Show calories burned • Show workout metrics • Show the notification on the screen • Waterproof • Play music • Payment • Siri for interaction 	<ul style="list-style-type: none"> • Watch strap (interchangeable strap, different color and materials) • Watch casing (material: Aluminum, 100% recycled) Case size: 38mm and 42mm Casing color • Touch screen (flat, one screen) • Chip (Dual-core S3) • Battery system • Speakers • Microphone • Battery system • Optical heart sensor 	<ul style="list-style-type: none"> • Raise the wrist and show the display • Tap the screen to see the information • Aluminum watch casing is provided • Cooperate with Nike (Nike+ aluminum model) • See health monitoring from the wrist • Know the heart health • Be alerted with unusually high or low heart rates or an irregular rhythm • Call emergency from wrist • Quickly call for help and alert an emergency contact • Track a menstrual cycle with a tap • Sustainable material selection (the watch case is 100% recycled aluminum) • Allow to change to different straps • Two colors for casing and different materials for watch strap

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	<ul style="list-style-type: none"> • Apple pay 	<ul style="list-style-type: none"> • Battery life: up to 18 hours of battery life 		
Apple series 5	<ul style="list-style-type: none"> • Time keeping • Health monitoring (i.e. heart rate monitoring, heart rate warning, menstrual cycle monitoring, noise alert), • Safety and emergency: Emergency SOS, fall detection, international emergency calling • Workout tracking (i.e. Yoga/cycling/swimming tracking), advanced workout matrices • Activity tracking: stand, move, exercise • Smart notification (i.e. call, text) • Listen to music. • Apple pay • Navigation 	<ul style="list-style-type: none"> • Show the time on the screen (always visible on the screen) • Detect heart rate, show heart rate, heart rate warning (above the default 120 bpm) show ECG • Detect fall down • Monitor menstrual cycle and show menstrual cycle • Measure the sound level and noise alert • Show the move/exercise/stand • Show calories burned • Show workout metrics • Show the notification on the screen • Waterproof (50 meters resistance) • Play music • Payment • Siri for interaction • Battery life: up to 18 hours of battery life • Provide directions (show the bearing, elevation, incline, and coordinates) • showing the direction 	<ul style="list-style-type: none"> • Watch strap (interchangeable strap, different color and materials) • Watch casing (material: aluminum made of 100 % recycled, stainless steel, Titanium and ceramic option Case size: 40mm and 44mm) • Touch screen (flat, different screen faces) Screen 30% larger • Chip (Dual-core S5) • Speakers • Microphone • Battery system • Optical heart sensor (Second generation) • Electrical heart sensor • Compass sensor (magnetometer) 	<ul style="list-style-type: none"> • Always see the time and information on the watch face without touch the screen Always on display even wrist is down (don't need to raise the wrist to wake it up) • More types of materials for watch casing can be chosen by customers (aluminum, stainless steel, titanium and ceramic) • More than one hundred watch faces to tell the time (select by the users) • A bigger screen view (30% larger screen) • Cooperate with Nike and Hermes (Nike+ aluminum model and Hermes stainless steel model) • Know the heart health Be alerted with unusually high or low heart rates or an irregular rhythm Show ECG • Call emergency from wrist Quickly call for help and alert an emergency contact Complete an emergency call while travelling abroad Detect when a hard fall • Track a menstrual cycle with a tap • Sustainable material selection (the watch case is 100% recycled aluminum) • Customized service: more options on casing to allow customers to create their own style (choose a case to pair a band) • Choose the material the customer like • Add navigation service: provide great guidance of direction • Haptic feedback

As a result of the comparison, we noticed that Apple Watch Series 5 brings several innovations in different categories of design. The following shows an organised result of identified innovation from four categories of design.

Innovation from the function category of design:

- A new navigation function is added, which corresponds to incremental innovation.
- In the health monitoring function, a sub-function of noise alert is added, which corresponds to incremental innovation.
- In the safety and emergency function, a new sub-function of fall detection is added, which corresponds to incremental innovation.
- In the safety and emergency, an international emergency call is added to complete the current national emergency call, which corresponds to sustain innovation

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Innovation from the behavior category of design:

- A new behavior of showing the direction that the top of the watch is pointing, which corresponds to incremental innovation.
- A new behavior of measuring the sound level around the users is added, which corresponds to incremental innovation.
- A new behavior of detecting fall is added, which corresponds to incremental innovation.
- ECG heart rate view is added to enhance the current heart rate visualization, which corresponds to sustaining innovation.
- The emergency call behavior is extended from the national call to international call, which corresponds to sustaining innovation.

Innovation from the structure category of design:

- Compass is added to provide navigation guidance
- Electrical heart sensor is added to provide ECG heart rate view.

Innovation from the experience (user interface) category of design:

- The user can check the direction of heading by the added compass, which corresponds to incremental innovation.
- The user would be reminded when the sound level is high, by the noise alert function, which corresponds to incremental innovation.
- The user can see the ECG from smartwatch by the newly added heart rate visualization, which corresponds to sustaining innovation.
- Fall detecting service is provided, which corresponds to incremental innovation.
- The users can always see the time and information from the watch without tap the screen by always-on display, which corresponds to sustaining innovation.
- More types of materials for watch casing are provided to extend from one type of material (aluminium) to more types (aluminium, stainless steel, ceramic, titanium), which corresponds to sustaining innovation.
- The customized service is provided to allow the customer to pair their own watch style (different watch casing and watch strap are available), which corresponds to sustaining innovation.
- The user can select their own watch face, and more than one hundred watch facing are provided, which corresponds to sustaining innovation.
- The user is provided with bigger screen view (30% larger screen), which corresponds to sustaining innovation.
- Haptic feedback is added, which corresponds to incremental innovation.

Then the innovative case-Apple Watch Series 5 is selected and put into innovative cases list.

Proceeding in the same way for innovation cases selection from the other product family, at the

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end of step 2, we obtain an innovative case list, with innovation in function, behavior, structure and experience categories of design, and the corresponding innovation types (incremental, sustaining, disruptive, radical) are determined. Table IV. 3 shows an extract of these results.

Table IV. 3: Example of characterized innovative cases

Innovative Case	Category	Innovation type			
		Incremental	Sustaining	Disruptive	Radical
Apple series 5	Function	A new function of navigation is added.			
		In the health monitoring function, a sub-function of noise alert is added.			
		In the safety and emergency function, a sub-function of fall detection is added			
			In the safety and emergency function, an international emergency call is added to complete the current national emergency call		
	Behavior	A new behavior of showing the direction, strength, or relative change of a magnetic field is added			
		A new behavior of measuring the sound level around the users is added			
		A new behavior of detecting fall is added.			
		In the heart rate monitoring, the heart rate visualization behavior is enhanced by adding ECG heart rate view			
			An extended behavior is added in the emergency call to extended emergency call from national to international		
	Structure		Add Electrical heart sensor		
		Add Compass			
	Experience	The user can check the direction of heading by the added compass, which corresponds to			
		The user would be reminded when the sound level is high, by the noise alert function			
			The user can see the ECG from smart watch by the new added heart rate visualization		
		Fall detecting service is provided, which corresponds to			
			The users can always see the time and information from the watch without tap the screen by always on display		
			There are several types of materials for watch casing are provided, that extended from one type of material (aluminum) to more types (aluminum, stainless steel, ceramic, titanium)		
			Cooperate with different companies to provide different strap		
			The customized service is provided to allow customer to pair own watch style (different watch casing and watch strap are available)		
			The user can select their own watch face and more than one hundred watch facing are provided		

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			The user is provided with bigger screen view (30% larger screen),		
		Haptic feedback is added			
...	Function		
	Behavior		
	Structure	...			
	Experience	...			
...					

IV.3.3 Step 3: Identify design heuristics

Step 2 has selected out smartwatch cases with innovation from four categories (Function, behavior, Structure and Experience) of design. The purpose of step 3 is to deepen the analysis and identify what design heuristics have been applied to stimulate innovation in different design categories (function, behavior, structure and experience).

To identify applied design heuristics, content analysis is conducted on the basis of the previous lists to identify the applied design heuristics.

The design heuristics identification proceeds in this way:

1. First, we systematically select a case from innovative case list.
2. Second, we identify the description related to the design categories (function, behavior, structure, and experience) of the innovation from the selected case.
3. Third, we identify the underlying design heuristic from the selected case.
4. Fourth, we continue the rest of the innovative cases for design heuristics identification.

At the end of step 3, design heuristics that have applied to stimulate innovation in different categories of design are identified.

To give an example of design heuristics identification from the Smartwatch case.

1. We select a case from the innovative case list; for instance, Apple Watch Series 5 is selected.
2. We identify one key description of the innovation from the function category of design from Apple Watch Series 5. For instance, in the function category, Apple watch series 5 adds a new sub-function of noise alert to extend the current health monitoring.
3. We identify the underlying design heuristics. In the function category design of Apple Watch Series 5, we found out that the designers use “add” heuristic to add more sub-function(s).
4. We select out another innovative case from innovative case list for design heuristics identification.

Table IV. 4 shows an example of identified heuristics from different categories of design.

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Table IV. 4: extract of the table of identified heuristics

Innovative Case	Category	Innovation type				Design heuristics
		Incremental	Sustaining	Disruptive	Radical	
Apple series 5	Function	A new function of navigation is added.				Add a main function
		In the health monitoring function, a sub-function of noise alert is added.				Add a subfunction to extend the current function
		In the safety and emergency function, a sub-function of fall detection is added				Add a subfunction to extend the current function
			In the safety and emergency function, the international emergency call is added to complete the current national emergency call			Complete the current function by adding a feature
	Behavior	A new behavior of showing the direction, strength, or relative change of a magnetic field is added				Add a new behavior for new function
		A new behavior of measuring the sound level around the users is added				Add a new behavior for subfunction
		A new behavior of detecting fall is added.				Add a new behavior for subfunction
		In the heart rate monitoring, the heart rate visualization behavior is enhanced by adding ECG heart rate view				Extend the way for heart rate visualization for enhancing the current behavior
			An extended behavior is added in the emergency call to extended emergency call from national to international			Add an extended behavior to complete the current function
	Structure		Add Electrical heart sensor			Add a new component (sensor) to enhance the current function and extend the way for a new way for visualization
		Add Compass				Add a new component (sensor) for a new function
	Experience	The user can check the direction of heading by the added compass, which corresponds to				Add a new user experience for showing the location and direction
		The user would be reminded when the sound level is high, by the noise alert function				Add a new user experience for noise alert
			The user can see the ECG from smart watch by the newly added heart rate visualization			Extend the way for heart rate visualization for improving the user experience
		Fall detecting service is provided, which corresponds to				Add a new user experience for fall detection
			The users can always see the time and information from the watch without tap the screen by always-on display			Revise the way of the display to improve the user experience
			There are several types of materials for watch casing are provided, that			Extend the selection of materials to improve user experience

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			extended from one type of material (aluminium) to more types (aluminium, stainless steel, ceramic, titanium)			
			Cooperate with different companies to provide a different strap			Cooperate with different companies to extend more choice for users to improve user experience
			The customized service is provided to allow the customer to pair own watch style (different watch casing and watch strap are available)			Create a customized service to improve user experience
			The user can select their own watch face and more than one hundred watches facing are provided			Create customized service to allow user to select their watch face by providing a large number of the watch face to improve user experience
			The user is provided with bigger screen view (30% larger screen),			Enlarge the screen to improve user experience
		Haptic feedback is added				Extend the feedback by adding haptic
		Sustainable material selection (the watch case is 100% recycled aluminium)				Replace the material to recycled one

IV.3.4 Step 4: Organise the applied design heuristics

From step 3, design heuristics, that are applied to enhance innovation in different categories of design from smart watches, are identified and characterized from different cases. So, the purposes of step 4 now are 1) organise the identified design heuristics and 2) gather insights from these identified heuristics.

1) Organise the identified design heuristics

In step 3, design heuristics identification, design heuristics that support concept innovation are identified from four design categories. So, we classify the design heuristics that have been applied to stimulate innovation with regard to these four categories. First, we organise all the heuristics that have been used to support innovation in the function category of design. Then, we organise the heuristics that have been used to support innovation in the behavior category of design. We iterate in a similar way to organise design heuristics that are applied in structure and experience categories of design.

Table IV. 5 shows a partial result of organised heuristics from different categories of design.

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*Table IV. 5: Extract of organised heuristics according to the four categories of design
(see detail in Appendix 2)*

Applied design heuristics in four categories of design			
Function	Behavior	Structure	Experience
<ol style="list-style-type: none"> 1. Add new function (such as a new function of contactless payment) 2. Extend the current function by adding new subfunctions or features (golf watch, add golf score etc.) 3. Enhance the current function by creating an indicator (Swim-Golf for enhancing swimming tracking by creating an indicator) 4. Enhance the current function by adding a new way (such as adding a new way for charging) 5. Improve current function by improving the accuracy of detection (Sunnto ambit 3, for running detection with 5 sec-Gps accuracy) 6. Combine several functions to a high level of function or new function (Triathlon Garmin forerunner 935/945) 7. Create new/different functions to target special users that other smart watches doesn't have (tactix series from Garmin; menstrual function for woman fitbit) 8. Magnificent one function one watch or series (Garmin swimming 2 for swim; forerunner for running; approach for golf function; D2 family for aviation; Tactix for government and defense) 9. Divide/simplified the function 10. Focus on one main function in each series (Garmin swimming 2 for swim; forerunner for running; approach for golf function; D2 family for aviation;) 11. Differentiate the function in each series 	<ol style="list-style-type: none"> 1. Add a new behaviour (such as add a noise alert) 2. Enhance the current visualisation behaviour (such as workout data) 3. Improve the accuracy of detection 4. Extend the battery life by use ultra-low power battery (Mi band) by using battery saver (automatic day life battery saver) 5. Adapt to sustainable energy for charging (such as solar energy Garmin Fenix 6x-pro solar edition) 6. Reduce the weight of watch (such as Sunnto 3) 7. Replace to a more sustainable material-recycled material (such as 100%recycle aluminium) 8. Revise the way of the display from tap the screen to always on. 9. Improve the toughness of the material to meet higher stander (Garmin) 10. Reduce the weight of the watch (Sunnto 3) 11. Extend the length of the strap 12. Revise the way of display 13. Add animated 	<ol style="list-style-type: none"> 1. Add a new sensor for a new function 2. Revise the shape of the screen 3. Adapt to different size of the screen 4. Change to the different colour of straps 5. Change to different materials of straps 6. Change to 100% material 7. Replace to the extendable strap (apple strap can wrap double in the wrist) 8. Substitute the flat screen to curved screen. 9. Replace the material (replay normal materials to a recycled one) 	<ol style="list-style-type: none"> 1. Revise the experience of checking the time 2. Improve the way for visualisation (ECG for heart review) 3. Change to different material of screen for different options (mental/ stillness/ceramic) 4. Enlarge the screen for improving the comfort level of reading 5. Improve the experience of long battery life 6. Replace to 100% recycling materials (apple 5 100% recycled aluminium) to provide a more sustainable experience 7. Replace to extra-long band 8. Create cooperation by buddle two products between users (vivofit 4 and Vivo fit JR are buddle products for parents and kids) 9. Provide lighter experience of wearing a watch: by reducing the weight of the watch (Sunnto 3) 10. Provide different strap and screen different material for the screen (mental/ stillness/ceramic); different materials and colour for strap 11. Differentiate the screen face 12. Add a new charging way (solar energy Garmin Fenix 6x-pro solar edition) 13. Add a hidden touch screen on a traditional watch 14. Add rotating dial in smart watches to change the interaction by just through a touch screen.

Table IV. 5 shows the result of identified heuristics from four categories.

The heuristics are formulated with a verb and an object. The reason why we organise the design heuristics in this way is to analyse how heuristics induce innovation. For example, the innovation occurs because of the heuristic “add a new function”, which explains how and why innovation occurs.

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We called “type 1” heuristic when heuristic is organised in a more detail manner. The complete type 1 heuristics list is given in Appendix 2.

Then based on these identified heuristics, we go one step further to abstract and refine type 1 heuristics by retrieving the verbs. The goal of refining the heuristics is to extend them to broader categories of design. Type 1 heuristics are organised in a format that includes a verb and an object. The object, however, might limit the applied situation as it specifies the specific applied condition. For example, the heuristic “add a new function” specifies the applied condition in the function category of design to the object. When we abstract the verb without object, the heuristics “add a new function” is refined to “add”, which only provides the suggested action without specifying the object. In this way, the refined heuristics can be used in a broad category of design.

This way of heuristics organisation, focusing on extracting the verb from type 1 heuristics, results in type 2 heuristics.

Table IV. 6 shows part Type 2 heuristics. The complete type 2 heuristics list is given in Appendix 2.

Table IV. 6: Partial result of refined heuristics

Type 2 Heuristics: applied in different categories of design
Add (e.g., add an existing function to a new product; add an existing service (animated workout; animated courses))
Adapt (e.g., adapt to a new way of interaction, adapt to another charging way)
Animated (e.g., animated workout; animated courses)
Bend: (e.g., bend the screen from flat to a curved shape to increase screen size and readability)
Buddle (e.g., buddle two products together; buddle a product with a service)
Create (e.g., create a new function; create new service; create a new indicator, create user community)
Change (e.g., change the materials property; change the flexibility of interface.)
Convert (e.g., add new components to reach new functions)
Customize (e.g., customize design; customize the accessory such as a strap, watch face)
Combine (e.g., combine two existing user interface design by jointing them to reach a new goal. value package)
...

2) Insights gathering after the design heuristics organization

During the process of classification and organization the identified heuristics, we found out that some heuristics have been applied more frequently than others, such as the heuristics “add” have been applied a lot. For instance, in the function category of design, add a new function and add a new feature to extend the current function. In behavior category of design, add a new behavior from the current system. In structure category of design add a new component such as a sensor. In the experience category of design, add a new user experience.

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As the first goal of this case study is to determine if design heuristics have been applied to support innovative concept generation and what kind of design heuristics have been applied to stimulate concept innovation.

At the end of step 4, we reach the first goal:

1. We identified design heuristics that have been used to support innovative concept generation from innovative smartwatch cases.
2. The identified design heuristics are classified into two ways:
 - 1) Type 1 heuristics to support concept innovation in four design categories of design.
 - 2) Type 2 heuristics to support concept innovation for broader categories of design.
3. During the organization of the applied heuristics, we found out that in the applied heuristics, some heuristics are applied more frequently than others. Such as heuristics “add” is applied more frequently than others. It suggests the designers might consciously or unconsciously apply some types of heuristics

The design heuristics that applied in smartwatch design to support concept innovation are identified and organised. At the same time, there are some existing design heuristics. The next step, we will compare the identified heuristics with existing design heuristics.

IV.3.5 Step 5: Compare the identified design heuristics with existing heuristics

At step 4, design heuristics that were applied in smartwatch design to support concept innovation were identified and organised into Type 1 and Type 2. The goal of step 5 is to compare these design heuristics with existing design heuristics from literature, the 77 design heuristics identified in (Yilmaz, et al., 2016) and the Scamper design heuristics described by (Osborn, 1953, Eberle, 1996), to gain insights of their similarities and differences.

IV.3.5.1 Compare the 77 design heuristics with Type 1 heuristics

The 77 design heuristics proposed by (Yilmaz et al., 2016) were identified from four studies of award-winning product designs, a solo professional design project, and protocol studies of engineers and industrial designers working on novel problems. These heuristics are often used in idea generation to provide ‘cognitive shortcuts’ that can help designers generate various concepts.

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They are expressed with sentences to guide designers on concept generation. As Type 1 heuristics also use sentences to trigger idea generation, this section compares Type 1 heuristics with the Yilmaz' heuristics.

Table IV. 7 shows a part of the comparison result between the 77 design heuristics and Type 1 heuristics. The entire comparison list is added in Appendix 4.

Table IV. 7: A part of the comparison result of the 77 design heuristics and Type 1 heuristics

	77 heuristics	The heuristics from the heuristics' list
Common applied/similar heuristics	Bend: (e.g., form an angular or rounded curve by bending a continuous material)	Bend: (e.g., bend the screen from flat to a curved shape to increase screen size and readability)
	Allow users to customize (e.g., giving users the customization options)	Allow users to customize (e.g., provide more than 100 watch face and allow users to choose their own watch face)
	Create service (e.g., develop a service between the user and a service provider)	Create service (e.g., create value package to allow third part to provide service).
Absent heuristic	Utilise inner space (e.g., hollow out the inner volume of the product or its parts, and use the space for placement of another component)	
New heuristics		Cooperate (e.g., cooperate with Nike, Hermes, google to provide more value)
		Reduce (e.g., reduce the weight of materials and reduce the price of the product)
		Buddle (e.g., buddle two products together; buddle a product with a service)
		Divide (e.g., divide value package and allow customers to buy when they needed)

The design heuristics comparison was performed as follows:

1. Select one heuristic from the 77 design heuristics.
2. Check whether the selected heuristic exists in Type 1 heuristics list.
3. Fill the heuristics table. If one selected heuristic from the 77 design heuristics is found in Type 1 heuristics list, then document this heuristic in the column of similar heuristic. If not, then document the selected heuristic in the column of absent heuristic. If one heuristic from Type 1 heuristics list is not found in the 77 design heuristics, then document this heuristic in the column of new heuristics.
4. Repeat step 1 to 3 for all heuristics.

This way, similar, absent and new heuristics are documented.

As an example (cf. Table IV. 8):

1. Select one heuristic from the 77 design heuristics, such as "Bend."
2. Search in the organised heuristics' list and check if "Bend" exists.

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3. The heuristic “Bend” exists in the identified heuristics’ list, then document “Bend” in the column of similar heuristic.
4. Repeat step 1 to 3 to make the rest comparison. We select another heuristic, such as “Utilise the inner space” and this heuristic does not exist in the identified heuristics’ list. Then document “Utilise the inner space” in the column of absent heuristic. We select the other heuristic, such as “Reduce”. This heuristic from the heuristics’ list while not exists in the 77 design heuristics. Then document “Reduce” in the column of new heuristics.

At the end of this step, the result of heuristics comparison between the 77 design heuristics and Type 1 heuristics are found:

1. There are some similar heuristics between the 77 design heuristics and Type 1 heuristics.
2. There are some heuristics that mentioned in the 77 design heuristics that are absent in Type 1 heuristics.
3. There are also new heuristics identified from smartwatch cases and not mentioned in the 77 design heuristics. It shows new heuristics might emerge in the different design domain.
4. In the applied heuristics, a number of heuristics is more frequently used than others.
5. There are also some existing heuristics mentioned in the 77 design heuristics have not been applied in the smartwatch design study. It might suggest that different design domains might use different design heuristics.

IV.3.5.2 Compare Scamper with Type 2 heuristics

Scamper is an idea generation tool to guide diverse idea generation that was first proposed by Osborn (1953), then further developed by Eberle (1996). Scamper is an acronym formed from the abbreviation of Substitute, Combine, Adapt, and Modify (Also magnify and minify), Put to another use, Eliminate, and Reverse. 8 design heuristics are introduced: substitute, combine, adapt, modify, put to another use, eliminate and rearrange.

Scamper is often used in idea generation for problem solving. It has also received much attention as a learning tool that fosters awareness, drive, fluency, flexibility, and originality. The Scamper stands for seven different activities:

1. S—Substitute (e.g., components, materials, people)
2. C—Combine (e.g., mix, combine with other assemblies or services, integrate)

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3. A—Adapt (e.g., alter, change function, use part of another element)
4. M—Magnify/Modify (e.g., increase or reduce in scale, change shape, modify attributes)
5. P—Put to other uses
6. E—Eliminate (e.g., remove elements, simplify, reduce to core functionality)
7. R—Rearrange/Reverse (e.g., turn inside out or upside down)

To compare our identified heuristics with Scamper, we choose Type 2 heuristics to compare with Scamper, as Type 2 heuristics also apply a verb to determine actions and trigger idea generation the same.

To obtain a view about the similarity and difference Scamper and Type 2 heuristics, a comprehensive comparison between Scamper and Type 2 heuristics was realised (cf. Table IV.8). This table classifies the heuristics into three categories: 1) the similar heuristics: the heuristics are the same or similar between Scamper with our identified heuristics, 2) the absent heuristic, the heuristics from Scamper is absent in our heuristics' list, and 3) new heuristics, the heuristics from our list are missing in Scamper.

The design heuristics comparison proceeds as follows:

1. Select one heuristic from Scamper.
2. Check whether the selected heuristic exists in Type 2 heuristics list.
3. Fill the heuristics Table. If one selected heuristic from Scamper is found in Type 2 heuristics list, then document this heuristic in the column of similar heuristic. If not, then document the selected heuristic in the column of absent heuristic. If one heuristic from Type 2 heuristics list is not found in Scamper, then document this heuristic in the column of new heuristics.
4. Repeat step 1 to 3 for all heuristics.

At the end of this step, a comparison between Scamper and Type 2 heuristics is done. The similar, absent and new heuristics and newly identified heuristics are documented. To give an example of comparing Scamper and Type 2 heuristics:

1. We first select one heuristic, such as a heuristic “substitute” from Scamper.
2. Then we check whether the heuristic “substitute” can be found in the Type 2 heuristics list. It is identified in Type 2 heuristics.
3. Therefore, the heuristic “substitute” is documented in the column of similar heuristics.

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4. Then we select another heuristic from Scamper for another comparison. The heuristic “rearrange/reverse” is selected as this heuristic not found in the Type 2 heuristics list. Then the heuristic “Rearrange/Reverse” in documented the absent heuristic.

Table IV. 8 shows an extract of the comparison result between Scamper and Type 2 heuristics.

The complete comparison table can be found in Appendix 4.

Table IV. 8: An extract of the comparison result of Scamper and Type 2 heuristics

	Scamper	The heuristics from the identified heuristics' list
Similar heuristics	Substitute: (e.g., substitute components, materials, et al)	Substitute: (e.g., substitute the materials of screen and strap, substitute the flat screen to a curved screen)
	Adapt (e.g., alter, change function, use part of another element)	Adapt (e.g., adapt to a new way of interaction, adapt to another charging way)
	Eliminate (e.g., remove elements, simplify, reduce to core functionality)	Eliminate (e.g., eliminate extra function and keep basic functions).
Absent heuristic	Rearrange/Reverse (e.g., turn inside out or upside down)	
New heuristics		Cooperate (e.g., cooperate with Nike, Hermes, google to provide more value)
		Buddle (e.g., buddle two products together; buddle a product with a service)
		Reduce (e.g., reduce the weight of materials and reduce the price of the product)

At the end of this step, the result of heuristics comparison between Scamper and Type 2 heuristics are found. There are some findings:

1. There are some similar heuristics between Scamper and the heuristics we identified.
2. Except for the heuristic rearrange/reverse, the other design heuristics from Scamper have been applied in smartwatch design.
3. There are 17 new heuristics we identified from smartwatch design and list in Type 2 heuristics that Scamper have not to mention.
4. The heuristics from Scamper more focus on helping designer improve the existing concepts, such as the heuristics substitute, adapt, modify, eliminate, reverse, and less effort on how to help designers create new concepts.

At the end of step 5, by comparing the identified heuristics (Type 1 and Type 2) with the existing heuristics (77 design heuristics and Scamper), we obtain some insights. The insights after the whole comparison are concluded:

1. Many existing design heuristics from Scamper and the 77 design heuristics have been applied in smartwatch design. Such as “Substitute” and “Adapt” from Scamper and “Bend”, “Allow users to customize” from the 77 design heuristics.

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2. Some existing design heuristics from Scamper and the 77 design heuristics have not been applied in smartwatch design. Such as “Reverse” from Scamper and “Utilise the inner space” from the 77 design heuristics.
3. There are also some new heuristics identified from smartwatch design that has not been mentioned in Scamper and the 77 design heuristics, such as “Cooperate” and “Buddle” compared with Scamper, and “Reduce” and “divide” compared with the 77 design heuristics.
4. After the comparison, we found out that Scamper provides an abstract way by using an acronym of active verbs to trigger ideas generation, such as “Substitute”. The 77 design heuristics provide a specific way by using a verb and object to boost concept generation, such as “Utilise opposite surface”. The different level of abstract might with different influence on concept generation.

During the comparison, we got an overview of the similarities and differences between the identified heuristics and the existing heuristics.

IV.3.6 Step 6: Discuss the identified design heuristics with existing heuristics

The purpose of step 6 is to discuss the advantages and drawbacks of the identified design heuristics with other existing design heuristics.

Table IV. 9 shows a discussion about the interests and limitations of several design heuristics.

Table IV. 9: discussion about the interests and limitations of several design heuristics

Design heuristics	The advantages and limitations
Scamper	<p>The advantages:</p> <ol style="list-style-type: none">1. Scamper can apply to almost all design domain as it provides an abstract form to guide designers. Such as Substitute, combine, adapt to etc.2. The description of Scamper is easy to understand, and it increases the chance to be used in the design. <p>The limitations:</p> <ol style="list-style-type: none">1. Scamper only includes 7 main heuristics.2. The heuristics from Scamper more focus on helping designers improving the existing concepts, and less effect on creating new ideas.

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(Yilmaz et al., 2016)' 77 design heuristics

The advantages:

The 77 design heuristics are based on a large database to identify the heuristics, and it can provide guidance to a broad domain.

The limitations:

1. The description of the 77 design heuristics is organised more specifically, so it might limit designers to apply it.
2. These heuristics are complex to apply, and there is a lack of guidance to suggest and guide designers to apply the 77 heuristics. As the heuristics are extracted from different domains, and if designers are not familiar with that particular domain, it might take some time to understand the heuristics before applying them.
3. These heuristics mainly target physical product innovative design and less to support innovative service design.

Heuristic identified from smart watch

The advantages:

1. They are organised the main design heuristics applied in smartwatch design domain.
2. It can provide insights for designers who work in smartwatch design and give some guidance for the later design.
3. They also can be applied to other technology-driven product design domain, such as smartphone design.
4. The other heuristics don't have a classification about the application areas of design heuristics. In contrast, we organised the extracted heuristics and classified them to different suitable applied design categories. For example, the heuristics can be applied in function, behavior, structure and experience categories. Then to bring more convenient for designers to choose the most appropriate ones according to their design focus.

The limitations:

1. The identified design heuristics from smartwatch design, and it might only sufficiently to use in some design domain and not sufficient to use in some other disciplines.
2. The case base for heuristics extraction includes 134 cases from 6 domain brands. It does not have all the smartwatches, so, it might not conclude all the design heuristics in smartwatch design.

At the end of step 6, we reach the second goal of characterising and comparison of the identified heuristics with existing design heuristics.

To reach the goal 3 'how design heuristics affect concept generation?', we perform two more steps: Step 7 'modelling how heuristics affect concept and knowledge space on idea generation', and Step 8 'Abstract the structuring process'.

IV.3.7 Step 7: Model how heuristics affect concept and knowledge space

The purpose of step 7 is to explore how heuristics affect concept space and knowledge space

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on idea generation and mostly focus on how heuristics affect designers mobilize and structure their knowledge.

We use the CK theory to model the idea generation process and to reveal the relationship between concept generation and knowledge structuring by design heuristics. The reason why we chose CK theory is that it allows representing the concept and knowledge spaces, and to visualise knowledge structuring and the concept generation process (see Figure II.14). Therefore, we can observe how heuristics affect knowledge structuring during concept generation.

This is how we proceeded to analyse and model how design heuristics affect concept and knowledge space:

1. We selected one innovative case with its corresponding heuristics.
2. We visualized the evolution of the concept generation process and how the execution of the selected heuristic structures the knowledge space to reach the concept generation

To give an example of how heuristics affect knowledge space and influence concept generation from smartwatch case.

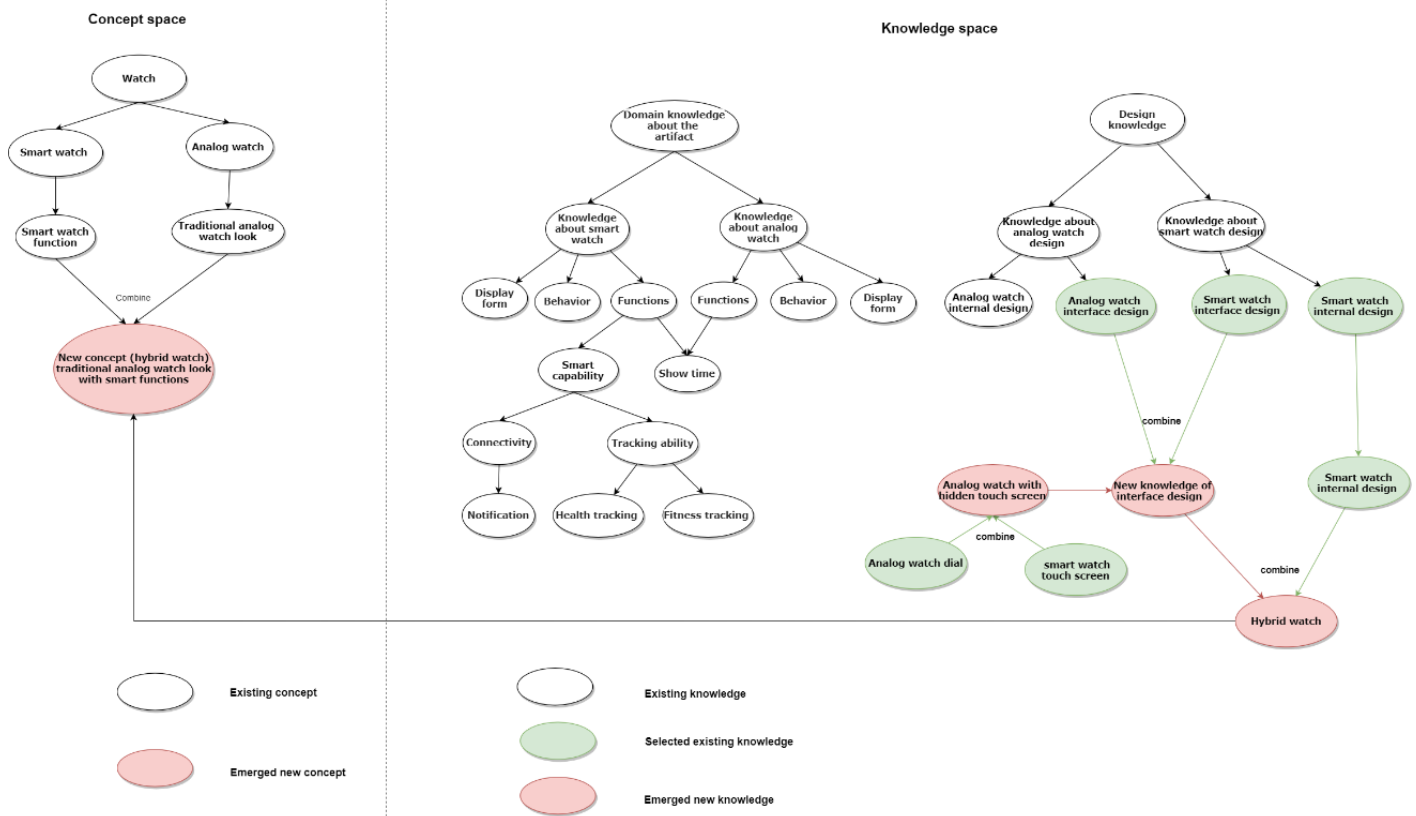


Figure IV. 2 Modelling the use of “combine” heuristics to generate a new idea

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Figure IV.2 shows how “combine” heuristic affect concept and knowledge space on idea generation.

In one innovative case of smartwatch design, a new concept “hybrid smartwatch” is proposed. Hybrid smartwatches combine the look of analog watches with smartwatches. In this case, the “Combine” heuristic was used to support an innovative concept proposition.

In Figure IV.2, we model how this concept is generated; what knowledge is mobilized and how it is structured to support its concept generation. Before reaching the new concept “hybrid smartwatch”, which make innovation in the (user) experience category, the existing knowledge about analog watch interface design and smartwatch interface design is mobilised. The analog watch interfaces with transparent screen to show the time, in contrast, the smartwatch with touch screen to show the time and notification. By structuring the previous knowledge, a new piece of knowledge of ‘analog watch with a hidden touch screen’ emerges. This new knowledge is used for a concept generation. Therefore, a new concept of the hybrid watch is proposed to innovate in user experience design.

This example shows that new knowledge emerges when structuring different knowledges and that the emergent knowledge affects a concept generation.

The goal of step 7 was to explore how heuristics affect idea generation after visualising how design heuristics affect concept and knowledge space for new concept generation; we found out that the profound reason for heuristics influence concept generation is due to the structuring of knowledge.

At the end of step 7, how heuristics affect concept generation has been analysed.

IV.3.8 Step 8: Abstract how heuristics affect knowledge structuring

The goal of step 8 is to abstract out how heuristics affect knowledge structuring and to stimulate new concept generation.

Based on the applied heuristic and the ways of heuristics mobilise and structure knowledge on concept generation, we abstract out a way of how knowledge could be structured to proposed innovative concepts.

The process of abstracting the relationship between concept generation and knowledge

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structuring proceeds in this way:

From the case of using “combine” heuristic in smartwatch design, we use CK theory to modelling the mobilisation and combination of the previous knowledge, and the emerging of new knowledge to propose a new concept. Figure 1 shows the use of ‘combine’ heuristics for new concept generation. Based on the visualisation of the structuring in knowledge space and concept space, we abstract how knowledge is (re)structured to propose innovative concepts.

The figure below shows the example of abstract one heuristic affect concept generation and knowledge structuring.

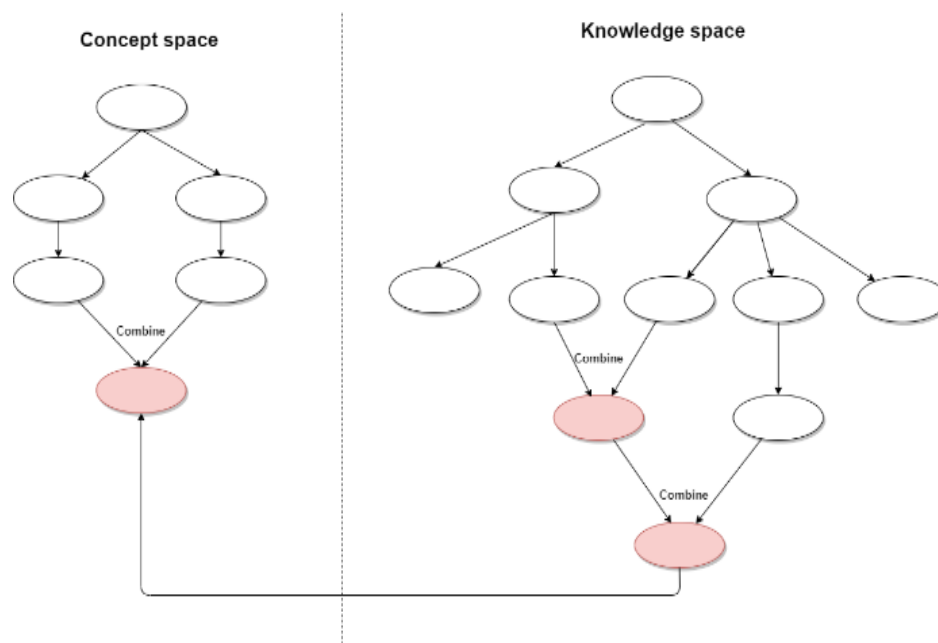


Figure IV. 3: How do the heuristic “combine” affect concept generation and knowledge structuring

At this step, we get inspirations and conclusions that allow answering goal 3 “Explore how design heuristics affect concept generation”. We found out that design heuristics provide a strategy on knowledge structuring (structuring a hierarchy among the knowledge components to cause effects on knowledge structures) and therewith impact concept generation.

IV.4 Conclusion

To reach our main research goal of exploring how design heuristics affect concept generation and the influence of heuristics on knowledge structuring, a case study is conducted for lesson learn, phenomenon exploration, and observation.

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To reach this goal, we first to identify design heuristics, then organise and analyze the identified design heuristics for insight gathering. As a result, we confirmed design heuristics could help on innovative concept generation. Meanwhile, we organised and classified the identified heuristics into two types: Type 1 and Type 2 heuristics.

Following that, we compared the identified heuristics (Type 1 heuristics and Type 2 heuristics) with the existing heuristics (the 77 design heuristics and Scamper). As a result, we found out that: 1) there are some common heuristics between the identified heuristics and existing one, 2) some heuristics mentioned in the existing design heuristic are not identified from the smartwatch cases, 3) existing heuristics does not mention some new heuristics that identified from smartwatch design cases. 4) depend on the domain where the heuristics are extracted; new heuristics might emerge, and there might be an infinite list of heuristics, and 5) different heuristics with different levels of details to guide designers/engineers on concept generation.

In the end, we explore how the heuristics influence innovative concept generation, to be more specific how heuristics influence concept space and knowledge space to affect innovative concept generation. At the end of this case study, we found out that design heuristics can influence knowledge structuring from knowledge space, thus influencing concept generation. That is to say, design heuristics could provide strategy on knowledge structuring.

In the next chapter, based on the case study's findings, we propose our methodology to help and guide designers to deal with design fixation and present innovative concepts.

CHAPTER V. METHODOLOGICAL PROPOSAL, ILLUSTRATION AND EVALUATION

V.1. Introduction

Our research aims at helping designers to deal with design fixation and to propose innovative concepts. As we saw in Chapter 2, design fixation can be classified into concept and knowledge fixation. Therefore, in order to reduce design fixation, we focus on reducing concept and knowledge fixation. Concept fixation occurs when a designer repeatedly considers a limited number of concepts. Knowledge fixation occurs when a designer is fixed to consider or apply a substantial body of knowledge; knowledge plays an important role in concept generation. In this research, we mainly deal with knowledge fixation to mitigate design fixation. By dealing with knowledge fixation, we can help designers propose innovation concepts, and reduce the effects of concept fixation.

A number of theories and methods have been developed to deal with knowledge fixation. Most of them focus on using new knowledge to mitigate knowledge fixation, especially on using new knowledge immediately for concept generation. New knowledge can also be used to (re)structure in knowledge space for concept generation. In this research, we try to explore how to help designers structure their knowledge to mitigate design fixation and enhance innovation. The case study presented in Chapter 4 has shown that design heuristics can help with creating innovative concepts by knowledge structuring. It was also noticed that several heuristics are applied more frequently than others. It might indicate the designers consciously or unconsciously repeatedly applied some types of heuristics. Chapter 4 also identified new heuristics and organised the heuristics that are used to promote innovation.

Based on these findings, this chapter proposes a knowledge structuring methodology so to address knowledge fixation during concept generation. The methodology provides guidelines that lead the designers along with different steps, from knowledge identification to knowledge structuring.

V. Methodological proposal, illustration and evaluation

The first goal of this chapter is to introduce the framework of the methodology and illustrate its step by step application. A second goal is to practice the methodology and evaluate a case study its efficiency by experimenting its application and its effectiveness by evaluating the resulting concept(s). To these goals, we continue on the smartwatches design case study to determine if, thanks to the methodology, new concepts could be proposed considering new needs and a new context, the one of the Covid-19 pandemic.

This chapter first introduces the case study, then it details the framework of the methodology and illustrates its step by step application on the case study (*text appears in blue color*). Then the efficiency and effectiveness are discussed.

V.2 Introduction to the case study

V.2.1 Context and objectives

On 30 January 2020, the World Health Organization declared the outbreak of Covid-19 as a public health emergency of international concern (World Health Organization, 2020, January 30). Compared with the SARS virus that caused an outbreak in 2003, Covid-19 has a stronger transmission capacity. The rapid increase in confirmed cases makes the prevention and control of Covid-19 extremely serious (World Health Organization, 2020, March 3).

At the time this report is written, the Covid-19 outbreak continues to evolve (World Health Organization, 2020, March 17). Rigorous hygiene routines have been prescribed to reduce the chance of getting infected, such as wearing a mask and cleaning hands over 2 minutes with soap frequently. Beyond these basic recommendations and the prohibition of individual gatherings, the global strategy to try to slow down the pandemic consists in early detecting symptoms, isolating individuals that may be infected and those who were likely to have been in contact with, and treat people with the most severe symptoms.

Early detecting Covid-19 appears as crucial in this strategy. From CDC (Centers for Disease Control and Prevention), two types of tests can be performed (Centers for Disease Control and Prevention, 2020, October 21). First there are antibody tests; as antibodies usually start developing within 1 to 3 weeks after infection, these blood tests can only tell you if you had a past infection with the virus. Then there are screening tests, which are used to determine

whether a person is carrying the virus at the time of testing, using a nasal or salivary swab. This test allows better collective prevention by an early containment of contact people and an anticipated medication of infected individuals. In complement, some online tests allow each person to autonomously evaluate whereas she/he is likely to be infected with regards to the symptoms she/he has, most frequent and common ones being fever, dry cough and fatigue. Connecting on the internet to these dedicated websites requires a conscious and voluntary approach by individuals. Another option would be to alert them automatically when the first symptoms appear.

In connection with the example that we took in Chapter IV on smart watches' design, we have chosen in this chapter to continue on this case study, investigating the possibility of proposing new concepts for smart watches addressing a self-detection of the Covid-19 symptoms.

V.2.2 Drawbacks of current detection tools

The best way to slow down the spreading of Covid-19 is to know as quickly as possible when a person becomes infected. Then proper actions can be taken to stop the spreading of Covid-19. Based on the information from CDC (Centers for Disease Control and Prevention, 2020, October 29), the incubation period of Covid-19 is on average 5-6 days up to 14 days; during this “pre-symptomatic” period, the spread can occur. Therefore, the sooner a person knows or suspects having the virus, the sooner she/he can take actions to stop spreading it to others and the sooner she/he can receive proper treatment.

Currently, except the medical tests performed in medical centres or hospitals, some (a few) tools are available for self-detection, which do not need support from any medical personnel. We identified an online survey for Covid-19 self-detection with the guidance of symptom questions (Centers for Disease Control and Prevention, 2020, September 10).

However, according to the option chosen, these available tools for Covid-19 self-detection have several defaults:

- A single and unique use of the kit
- Lack of accuracy and guidance of the online survey
- Lack of convenience of the Covid-19 kit that needs to be bought
- Lack of sustainability of the kit

V. Methodological proposal, illustration and evaluation

- Risk of hurt, at least uncomfortable, of the nasal test
- Inability to detect potential infection at early stages of contamination

So, is there any and what other options can we consider to answer the need of Covid-19 self-detection?

V.2.3 Objective and requirements of the case study

Therefore, the objective of this case study is to explore “How can people be helped for self-detecting Covid-19 symptoms or even pre-symptoms?”

Naturally, the market trend leads us to consider health-monitoring solutions such as intelligent clothing or watches to answer this question. We focus here on smart watches design as a use case of the application of our methodology.

Our goal is to practice the methodology on this use case, to evaluate its efficiency and effectiveness.

With regards to the customer's expectations (being able to early self-detect a potential Covid-19 infection) and the drawbacks of the market current self-detection solutions, requirements for the case-study are to find a concept that leads to a solution:

- Multiple usages
- Accurate prediction
- Easy to use: no risk of hurt, convenient, available and comfortable
- Sustainable
- A long term monitoring
- Real-time monitoring

V.3 Framework of the methodology and application on the case study

The methodology consists of 3 main steps (see Figure V.1): knowledge identification, knowledge decomposition and knowledge structuring. These three steps interactively guide the designer to identify the knowledge related to the design problem, decompose and refine it into details, and structure it progressively, with the guidance of a series of questions.

In the first step, the designer is first encouraged to identify and characterize the different knowledge that is considered relevant to tackle the design problem and acquire more knowledge

V. Methodological proposal, illustration and evaluation

if needed and possible. In the second step, the designer is encouraged to decompose each identified relevant knowledge into details and to prepare knowledge structuring. The third step aims to guide the designer in structuring the decomposed knowledge by experimenting with different proposed heuristics and exploring different concepts. Each step includes a set of actions that are detailed hereafter.

At each step, examples of questions that are suggested to the designer to guide her/his progress are given as an example; the entire list of questions is provided in Appendix 1.

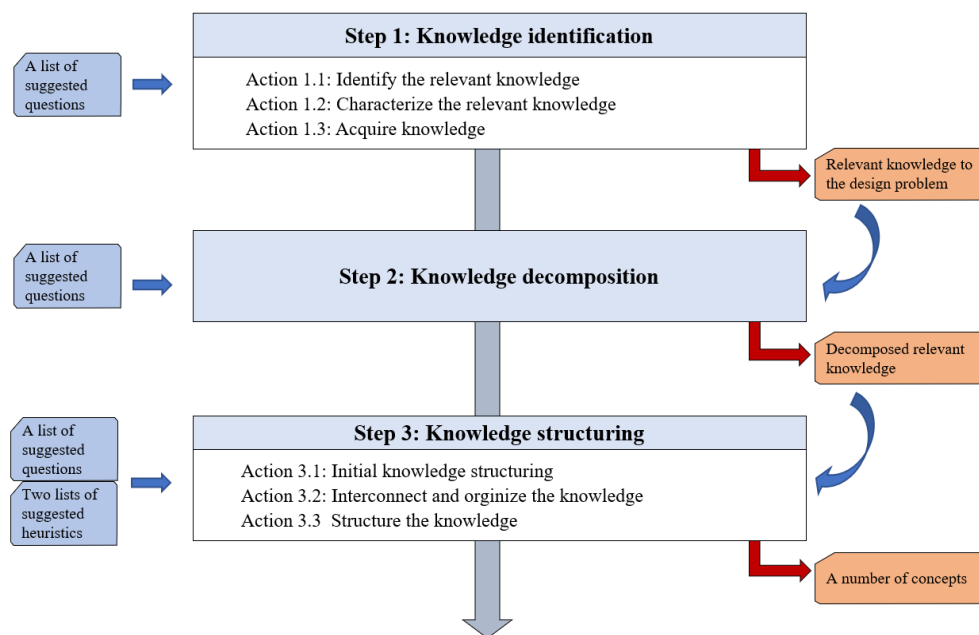


Figure V.1 Framework of the methodology

V.4. Step 1: Knowledge identification

Step 1 aims to help a designer identify the relevant knowledge for a design problem or a task. Knowledge identification consists of performing 3 successive actions: Identify the knowledge that is relevant to the design problem, Characterize the identified knowledge and Acquire the identified unknown knowledge.

V.4.1 Action 1.1: identify the relevant knowledge

It starts with helping the designer identify the knowledge that might be useful for the problem, that we will call ‘relevant knowledge’ in the following.

Even though we cannot specify exactly what knowledge might be needed in the context of a given problem, we can indicate some general pathways to identify what knowledge could be relevant, for instance, knowledge about the different aspects of design, knowledge about commercial strategy, knowledge about the market, knowledge about the technology, etc.

Note that knowledge identification can be subjective and depends on the designer.

As an example, let us consider that we want to imagine innovation in the next generation of smart watch design. With the guidance of question Q1.1 “*Do I know any knowledge that might be helpful on this design problem/task?*”, the designer is encouraged to identify the relevant knowledge for smart watch design. As a result, the designer could get relevant knowledge from 1) already existing smart watches 2) feedbacks from different users 3) new technology (see Table V.1).

Table V. 1: An example of relevant knowledge in smart watch design

Number	Relevant knowledge
1	Knowledge about the already existing smart watches
2	Knowledge about the feedbacks from different users
3	Knowledge about new technology
...	...

Identifying the different knowledges related to the problem helps the designer determine the current scope of her/his knowledge and be clear with what knowledge helps support concept generation and tackle the design problem. The more relevant knowledge the designer has, the more efficient she/he will be in concept generation.

V.4.2 Action 1.2: Characterize the relevant knowledge

Then the designer characterizes the type of the identified relevant knowledge. To reach this goal, the designer can refer to the knowledge type classification by Rumsfeld (2011). The knowledge type is classified into four main types: known knowns, known unknowns, unknown knowns, or unknown unknowns. For instance, the designer can aware that she/he has that

V. Methodological proposal, illustration and evaluation

relevant knowledge (known knowns) or that she/he does not have (known unknowns), or the designer is not aware of the existence of knowledge however this knowledge might be relevant to the design problem (unknown knowns or unknown unknowns).

Note that this characterization of knowledge can be subjective and depends on the designer.

For example, in the smart watch design, for one designer, and with the guidance of question Q1.2 “*What is the knowledge types of each relevant knowledge?*”, the knowledge type of the relevant knowledge is characterized. Based on the identified relevant knowledge from Table V.1, the designer considers that ‘knowledge about the feedbacks from different users’ and the ‘knowledge about new technology’ are ‘known unknowns’: the designer is aware that they are relevant but doesn’t have those knowledge currently. Note that another designer might characterize those knowledge differently.

Table V.2 shows the result of knowledge characterization in the example of smart watches.

Table V. 2: An example of characterizing knowledge type

Number	Relevant knowledge	Knowledge type
1	Knowledge about existing smart watches	Known knowns
2	Knowledge about the feedbacks from different users	Known unknowns
3	Knowledge about new technology	Known unknowns
....	

This action aims to help the designer characterize the type of knowledge based on the designer’s current knowledge scope. However, different designers might characterize the identified knowledge differently.

Characterizing knowledge helps the designer be aware of the knowledge she/he has or doesn’t have. Then the designer needs to acquire more knowledge if possible.

V.4.3 Action 1.3: Acquire knowledge

Then the designer is encouraged to think about the possibilities for acquiring more knowledge (such as known unknowns), and some questions are suggested to guide the designer to turn the ‘known unknowns’ knowledge into ‘known knowns’.

V. Methodological proposal, illustration and evaluation

There are several reasons to encourage the designer to consider the possibilities of obtaining more unknowns knowledge. First, the current known knowns might not be sufficient for the concept proposition, and new knowledge may need to be required. Second, even if the current known knowns were sufficient, reusing these known knowns might lead to similar and repetitive concept generation.

Note that, based on design time and available resources, the possibilities to acquire knowledge might vary for different designers and with different projects.

From the previous example, the ‘knowledge about feedbacks from users’ and ‘knowledge about new technology’ were characterized as ‘known unknowns’. With the guidance of the question Q1.3 “*Can I obtain the known unknowns?*”, the designer thinks about the possibility of the known unknown acquisition. As a result, the designer considers the ‘knowledge about feedbacks from different users’ is hard to obtain, as it is difficult to contact the different end-users and collect information from them. However, for the ‘knowledge about new technology’, the designer considers it possible to obtain this through online resources.

If any known unknowns is considered as possible to be acquired, with the guidance of question Q1.4 “*How can I learn those known unknowns?*”, a learning process is conducted. Once a knowledge that is initially characterized as ‘known unknown’ has been acquired, then its type is changed to ‘known known’. In this way, the knowledge scope of known knowns is increasing. In the example, Table V.3 shows updating knowledge types from Table V.2 after acquiring knowledge.

Table V. 3: An example of updating knowledge type

Number	Relevant knowledge	Knowledge type
1	Knowledge about existing smart watches	Known knowns
2	Knowledge about the feedbacks from different users	Known unknowns
3	Knowledge about new technology	Known unknowns Known knowns
...	

Then the designer needs to think about the current knowledge scope and assess whether the current known knowns are sufficient for concept generation. With the guidance of question

V. Methodological proposal, illustration and evaluation

Q1.5 “Are these known knowns sufficient for concept generation?”, the reflection process is conducted. If the current known knowns are considered sufficient, then the designer stops at step 1; otherwise, the designer continues exploring more knowledge types, such as unknown knowns and unknown unknowns with more suggested questions (see Appendix 1).

Table V.4 shows an example of a final characterization of relevant knowledge.

Table V. 4: An example of final identified knowledge from known knowns

Number	Relevant knowledge	Knowledge type
1	Knowledge about existing smart watches	Known knowns
2	Knowledge about new technology	Known knowns
3	Knowledge about already target market and users	Known knowns
4	Knowledge about the trend of smart watch design	Known knowns
...	

At the end of Step 1, the different knowledge that might be relevant to the problem has been identified characterized, and acquired. Therefore, the knowledge scope of known knowns has been extended, as illustrated in Figure V.2.

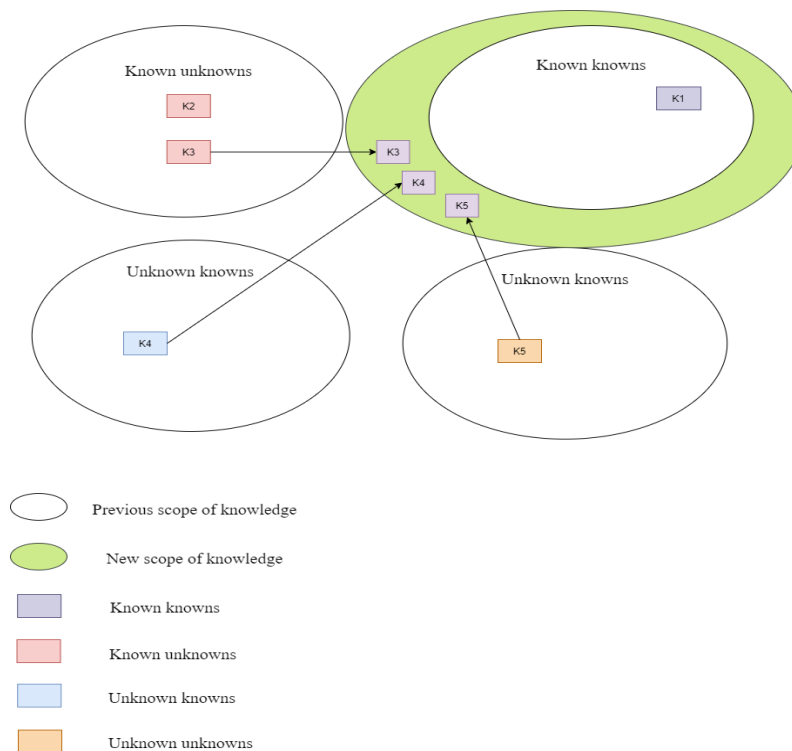


Figure V.2: Extension of the scope of known knowns knowledge

However, note that some knowledge might not evolve to known knows. Only the knowledge from known knows can be regarded as applicable knowledge in later steps.

For example, in the case of smart watch design, knowledge about the feedbacks from different users was characterized as ‘known unknown’ (see Table V.2) and remained ‘known unknown’ because of the difficulty to collect feedbacks (see Table V.3).

V.5 Step 2: Knowledge decomposition

Steps 2 aims at helping designers gradually and progressively decompose the knowledge that has been identified as relevant for the design problem (resulting from Step 1, as illustrated in Table V.4). It constitutes a transition step towards knowledge structuring (performed in Step 3).

The goal is to help the designer in decomposing the relevant knowledge into details. Note that the depth level in knowledge decomposition is subjective and depends on the designer.

For example, question Q2.1 “*Can I gradually decompose each relevant knowledge?*” helps the designer to consider relevant knowledge resulting from Step 1 one by one for potential further knowledge decomposition. Let us first select out knowledge Number 1 from Table V.4. This knowledge can be first decomposed into: knowledge about existing functions, knowledge about existing behaviors, knowledge about existing architectures (mainly components), and knowledge about existing experience. Proceeding the same way, knowledge about the new technology (second line of Table V.4) can be decomposed into: knowledge about new sensor technology and knowledge about new technology for long battery life (see Table V.5).

Table V.5 An example of knowledge decomposition

Number	Relevant knowledge	Knowledge decomposition
1	Knowledge about existing smart watches	knowledge about existing functions
		knowledge about existing behaviors
		knowledge about existing components
		knowledge about existing experience
2	Knowledge about new technology	knowledge about new sensor technology
		knowledge about new technology for long battery life
3	Knowledge about the already target market and users	knowledge about kid smart watch market
		knowledge about adult smart watch market

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		knowledge about women smart watch market
4	Knowledge about the trend of smart watch design	knowledge about the trend of new function design knowledge about the trend on different material replacement

Then the designer can gradually deepen the knowledge decomposition if needed, according to the interest or value of it from the designer's point of view. The interest of knowledge decomposition is to show the details of each relevant knowledge and lay the foundations for knowledge structuring.

Note that, for different designers, interest or value for decomposing a same relevant knowledge can vary.

In our example, with the guidance of question Q2.2 “*Can I continue decomposing the knowledge into more details?*” the knowledge about existing functions could be further decomposed into: fitness function, entertainment function, health function, safety function and alert function, etc. Proceeding the same way, knowledge about existing behaviors can be decomposed into: monitoring behavior, connection behavior, wearing behavior, physical item behavior, privacy behavior and interaction behavior. The result of this succession of decompositions is shown in Table V.6.

Table V.6: An example of gradual knowledge decomposition

Number	Relevant knowledge	Knowledge decomposition	
1	Knowledge about existing smart watches	knowledge about existing functions	Fitness function
			Entertainment function
			Health function
			Safety function
			Alert function
		knowledge about existing behaviors	Monitoring behavior
			Connection behavior
			Wearing behavior
			Physical item behavior
			Privacy behavior
		knowledge about existing components	Interaction behavior
			Watch casing
			Watch strap
			Smart module
knowledge about existing	Battery system		
	Be alert for notification		

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		experience	Raise wrist to show notification
2	Knowledge about new technology	knowledge about new sensor technology	Sensor to detect air quality
			Sensor to detect glucose level
			Sensor to detect blood pressure
			Sensor to detect hydration
		knowledge about new technology for long battery life	New sensor to extend battery life
			Using sustainable energy such as solar energy to charge the smart watch
3	Knowledge about the already target market and users	knowledge about kid smart watch market	Suitable function for kid
			User experience design for kid
			Cute exterior design attracts kid
		knowledge about adult smart watch market	Suitable functions for different adults
			User experience design for adult
			Exterior design to attract adult users
		knowledge about women smart watch market	Customised function for woman users
			Special user experience only for woman
			Fashion exterior design to attracts woman users
4	Knowledge about the trend of smart watch design	knowledge about new trend on function design	New function about Covid-19 self-detection
			New function about pressure detection
			New function about depression detection
		knowledge about the trend on material replacement	Ferroelectric material
			Energy-harnessing smart fabrics
			Graphene

As a result, at the end of Step 2, the knowledge that identified and characterized at Step 1 has been potentially decomposed into several levels.

V.6 Step 3: Knowledge structuring

This step aims at helping the designer in interconnecting and structuring knowledge to generate new concepts. Our goal is to prevent the designer from using or reusing some fixed way of structuring decomposed knowledge during this exploration.

Step 3 starts with selecting one initial knowledge, of high potential or value, among the decomposed knowledge resulting from Step 2. Note that, there might be more than one decomposed knowledge with high potential and value. However, it is suggested to select one at a time in the beginning to keep the approach manageable. Then the designer looks for other

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knowledge that could support this initial knowledge (called supportive knowledge) and progressively connects them with the initial knowledge, to determine if the initial knowledge can be achieved or not and in which ways. Finally, the relevant knowledge and initial knowledge are structured to provide several pathways towards the generation of new concepts, thanks to the guidance of a set of different heuristics.

This step consists of 3 actions: Initiate knowledge structuring, Interconnect and organise the knowledge, and Structure the knowledge.

V.6.1 Action 3.1: Initiate knowledge structuring

Step 3 starts with guiding the designer to select one knowledge with high potential and value from the designer's point of view or according to the company's strategy (called initial knowledge here after) to initiate knowledge structuring.

For example, in the case of smart watch design, with the guidance of the question Q3.1 "*What knowledge is the most valuable?*", the designer decides to take 'Knowledge about new trend' as initial knowledge, as from the designer's view, it can point out a new direction for smartwatches industry, and it also might attract new users.

At the end of action 3.1, one decomposed knowledge from 'knowledge about new trend' is selected out as initial knowledge, which is 'new function about Covid-19 self-detection'. Therefore, the designer is convinced that the new concept he/she is looking for should integrate, if possible, the function Covid-19 self-detection because it is of high value considering the current potential market trends. Is this initial knowledge achievable?

V.6.2 Action 3.2: Interconnect and organise the knowledge

The designer selects several pieces of knowledge and evaluates their ability to support initial knowledge; this knowledge is referred to as supportive knowledge here after. This action is to select, sort and organise the supportive knowledge with the goal of evaluating the achievability of the initial knowledge.

In this way, the designer can start establishing connections between the initial knowledge and each potential supportive knowledge to start organizing them, as illustrated in Figure V.3.

Figure V.3 provides a graphical representation of how Action 3.2 starts establishing these

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connections. The initial knowledge is at the core. Then a first set of supportive knowledges, which can directly support the initial knowledge, are connected with this initial knowledge and forms the first layer around it.

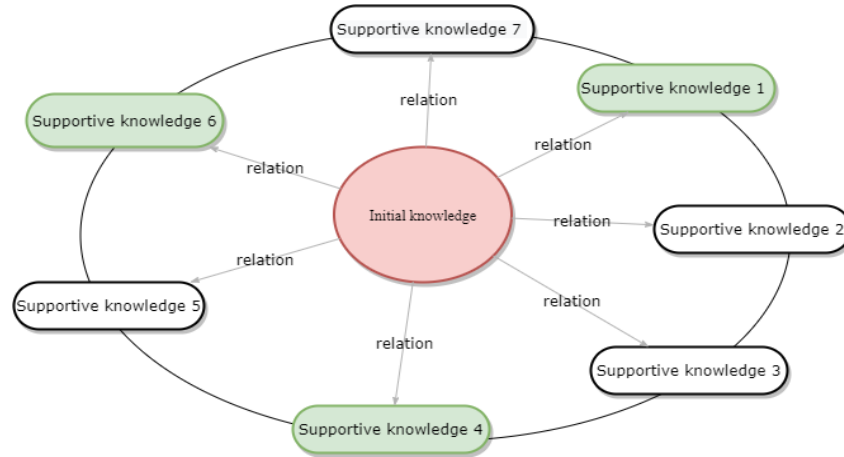


Figure V.3: First layer of supportive knowledge around the initial knowledge

Expressing these connections brings intuitive insights about whether supportive knowledge is sufficient to support the initial one. Progressively interconnecting supportive knowledge with regard to the initial knowledge helps to structure the knowledge. This lays a foundation for evaluating the achievability of initial knowledge (the goal is to connect supportive knowledge with the initial knowledge in order to progressively evaluate the achievability of initial knowledge). Referring to Figure V.3, if an initial knowledge has 7 direct supportive knowledges, then the initial knowledge is regarded with 7 possible ways to be achieved.

As the process is recursive, it is then applied to the knowledge that appears in the first layer: if at their turn, the directly supportive knowledge (from the first layer) can themselves be potentially supported (this corresponds to an indirect support to the initial knowledge), then connections are established, and other layers are gradually defined. This process contributes to developing a net of interconnections between the knowledge from different layers. Figure V.4 shows how the action progresses; knowledge with the possible expansion is noted in green; other knowledge appear in white. The process iterates until no more supportive knowledge can be found.

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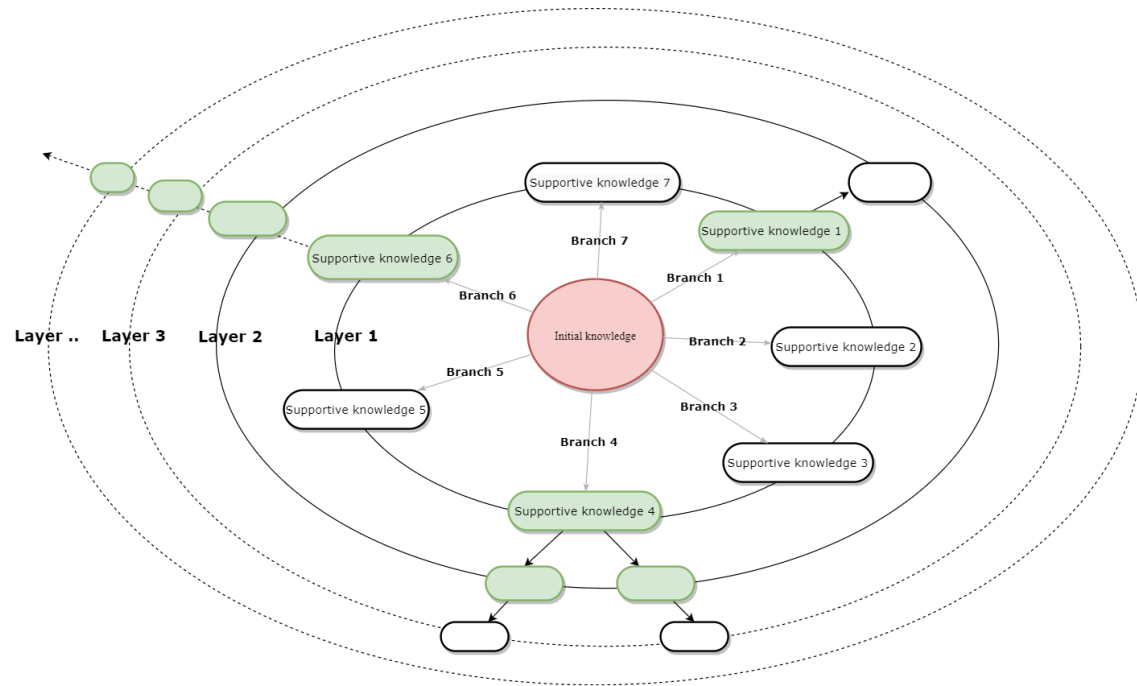


Figure V.4: Expansion into several layers and connections between supportive knowledge

Once the expansion stops, the evaluation starts. In this onion-like structure, we progressively developed several branches (a branch consists of a path that starts from the initial knowledge and crosses different layers by following interconnections between supportive knowledge). Each branch corresponds to a possible way to achieve the initial knowledge. The designer checks the supportive knowledge of each branch. If a supportive knowledge on the most external layer (at the leaf of a branch) can be executed, then this branch of supportive knowledge (such as the supportive knowledge from branch 4) is regarded as an option to support the achievement of the initial knowledge. Once the branch(es) that can support initial knowledge is determined, the designer needs to evaluate the achievability based on all the optional branches. To support the achievement of an initial knowledge, one or several branches will be needed to support the initial knowledge.

In this way, the achievability of the initial knowledge is determined.

As a result of this action, the possibility of these selected knowledge to support the initial knowledge is evaluated, and the feasibility of initial knowledge is determined.

Note that, for different designers, and in different cases, the selection of supportive knowledge might vary. Also, if no existing knowledge can be selected to support the initial knowledge, the

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designer can rapidly iterate step 1 and 2 to find supportive knowledge through knowledge identification and decomposition.

This is precisely the case in our example: answering question Q3.2 “*Can I select any decomposed knowledge that is relevant to support the initial knowledge?*”, the designer realizes that no existing knowledge can support Covid-19 self-detection because this initial knowledge has been selected at the last level of knowledge decomposition (last column in Table V.6). For instance, if the initial knowledge had been ‘knowledge about new technology for long battery life’, then we could have selected ‘New sensor to extend battery life’ and ‘Using sustainable energy such as solar energy to charge the smart watch’ as direct supportive knowledge. Therefore, with the currently selected initial knowledge related to Covid-19 self-detection, the designer has to rapidly iterate step 1 and 2 to identify more relevant knowledge to support it. The details of these rapid iterations for supportive knowledge identification are presented in Appendix 3. In this way, a number of decomposed knowledges that can support the initial knowledge are found. Table V.7 shows the three pieces of knowledge that can be relevant to support Covid-19 self-detection, resulting from an iteration on Step 1: knowledge about the symptoms of Covid-19 (sorted according to the percentage of appearance of symptoms), knowledge about the ways for Covid-19 symptoms detection, and knowledge about relevant existing sensors that might be applied for Covid-19 assessment. Then, after a fast iteration of Step 2, the identified relevant knowledge is decomposed (third column of Table V.7).

Table V.7: An example of supportive knowledge selection

Initial knowledge	Relevant knowledge	Knowledge decomposition
Covid-19 self-detection	Knowledge about the symptoms of Covid-19 (from https://www.who.int/docs/default-source/coronaviruse/who-china-joint-mission-on-covid-19-final-report.pdf , page 12)	Fever (87.9%)
		Dry cough (67.7%)
		Fatigue (38.1%)
		Sputum production (33.4%)
		Shortness of breath (18.6%)
		Myalgia or arthralgia (14.8%)
		Sore throat (13.9%)
		Headache (13.6%)
		Chills (11.4%)
		Nausea or vomiting (5.0%)
		Nasal congestion (4.8%),
		Diarrhea (3.7%)

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		Hemoptysis (0.9%)
		Conjunctival congestion (0.8%)
	Knowledge about the detection of Covid-19 symptoms	Detect fever
		Monitor cough
		Measure fatigue
		Test sputum
		Measure blood oxygen saturation
		Measure respiratory frequency detection
		Detect sore throat
	Knowledge about relevant existing sensors that might be applied for Covid-19 assessment	Temperature sensor for fever detection
		Cough monitor sensor for cough detection
		SpO2 sensor for blood oxygen detection
		Infrared sensor for respiration frequency detection

Table V.7 contains all potential supportive knowledge, but these are not sorted, nor organised. The next operation consists in defining what knowledge can directly support the initial knowledge (first layer) and what knowledge can indirectly support it (second layer).

With the guidance of question Q3.3 “*What knowledge could support the initial knowledge and how could they be organised?*”, the designer considers that, to support Covid-19 self-detection, ‘Knowledge about the detection of Covid-19 symptoms’ (cf. Table V.7) can be regarded as direct support (such as detect fever, monitor cough, etc.) and will constitute the first layer of supportive knowledge.

Among the different symptoms, Fever, Dry cough, Fatigue, Sputum production, Shortness of breath, Headache, Myalgia or arthralgia, and Sore throat are the most frequent ones. As detecting Myalgia or arthralgia is not currently possible by a smart watch, then we only address the remaining 7 symptoms.

Figure V.5 shows the resulting connections between Covid-19 self-detection and the first layer of supportive knowledge.

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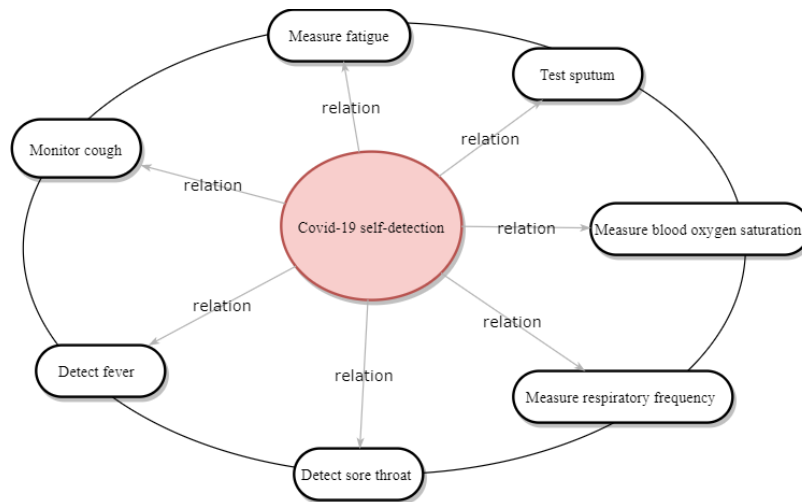


Figure V.5: The connection between the first layer of supportive knowledge and initial knowledge

Then the designer reflects on the means to detect these 7 symptoms, and therefore considers the ‘Knowledge about relevant existing sensors that might be applied for Covid-19 assessment’ (from Table V.7). These four pieces of knowledge (about existing sensors) that appear in Table V.7 could be useful to support the knowledge from the first layer (about detecting symptoms): ‘Temperature sensor’ can be used to support the ‘Detect fever’, ‘Cough monitor sensor’, ‘SpO2 sensor’ and ‘Infrared sensor’ can be used to respectively support ‘Monitor cough’, ‘Measure blood oxygen saturation’ and ‘Measure respiratory frequency’. The result of this analysis is shown in Table V.8.

Table V.8: Progressive selection and organization of supportive knowledge

Initial knowledge	Decomposed knowledge could support the initial knowledge	Decomposed knowledge that could support the first layer
Covid-19 self-detection	Detect fever	Temperature sensor
	Monitor cough	Cough monitor sensor
	Measure fatigue	No existing sensor
	Test sputum	No existing sensor
	Measure blood oxygen saturation	SpO2 sensors
	Measure respiratory frequency	Infrared sensor
	Detect sore throat	No existing sensor

These pieces of knowledge will constitute a second layer of supportive knowledge, as it appears in Figure V.6.

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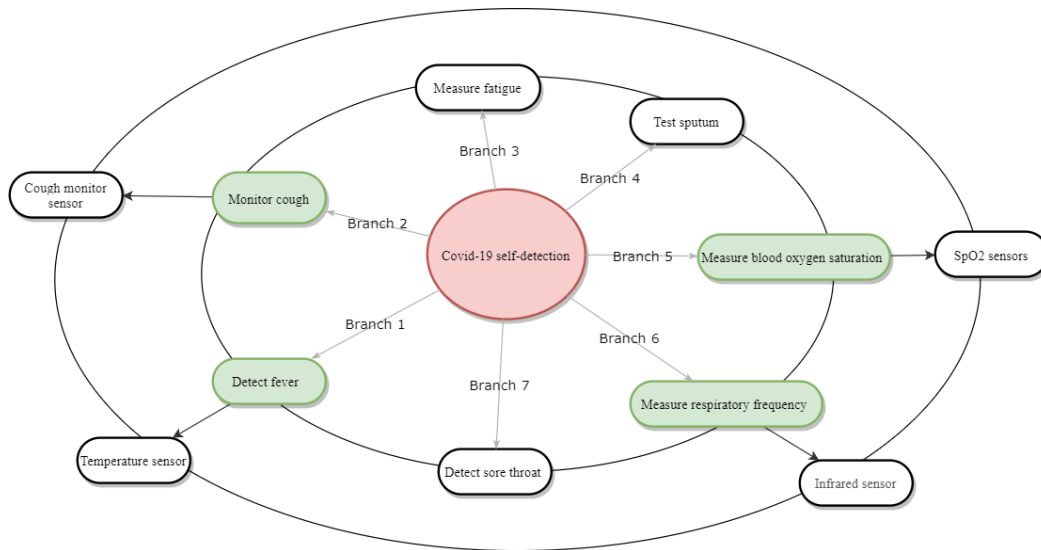


Figure V.6: The different layers of supportive knowledge and their interconnections

We note on this figure that some pieces of supportive knowledge (that remain in white instead of green) from the first layer have no supportive knowledge themselves in the second layer. For example, ‘Measure fatigue’ without any supportive knowledge from the second layer is a lack of existing technology (sensor) for directly measuring fatigue.

Hence, only four branches (1, 2, 5 and 6) of supportive knowledge from the first layer can be extended to the second layer. Then the process can stop because the designer estimates the knowledge to achieve Covid-19 self-detection is enough.

In the end, with the guidance of question Q3.4 “*Is the selected knowledge sufficient to support the initial knowledge realization?*”, the designer confirms the achievability of ‘Covid-19 self-detection’.

In this case, the designer concludes that Covid-19 self-detection is achievable by exploring the four extended branches of supportive knowledge that have been identified.

As a result, Action 3.2 determines whether the initial knowledge can be achieved in a way or other, and how, thanks to the supportive knowledge. If the initial knowledge is evaluated to be achievable, it then provides some directions for new concept generation.

V.6.3 Action 3.3: Structure the knowledge

Action 3.3 aims at elaborating a whole innovative concept. To that goal, the initial knowledge and its supportive knowledge can be regarded as a part of a broader concept. Other relevant knowledge might be needed to build a whole concept.

Action 3.3 consists in determining these pieces of knowledge (from the results of Step 2, as shown in Table V.15), organise and structure them with results from Action 3.2 (cf. Figure V.4).

These pieces of decomposed knowledge can indeed be structured in different ways for concept generation.

Note that, in order to explain the knowledge structuring process, we will use a tree representation (cf. Figure V.7), which is completely equivalent to the previous table representation (cf. Table V.9) but easier to visualize.

Table V.9: Decomposed knowledge

Number	Relevant knowledge	Knowledge decomposition		
1	Relevant Knowledge 1	Decomposed Knowledge 1.1	Decomposed Knowledge 1.1.1	...
			Decomposed Knowledge 1.1.2	...
		Decomposed Knowledge 1.2	Decomposed Knowledge 1.2.1	...
			Decomposed Knowledge 1.2.2	...
2	Relevant Knowledge 2	Decomposed Knowledge 2.1	Decomposed Knowledge 2.1.1	...
			Decomposed Knowledge 2.1.2	...
		Decomposed Knowledge 2.2	Decomposed Knowledge 2.2.1	...
			Decomposed Knowledge 2.2.2	...
.....

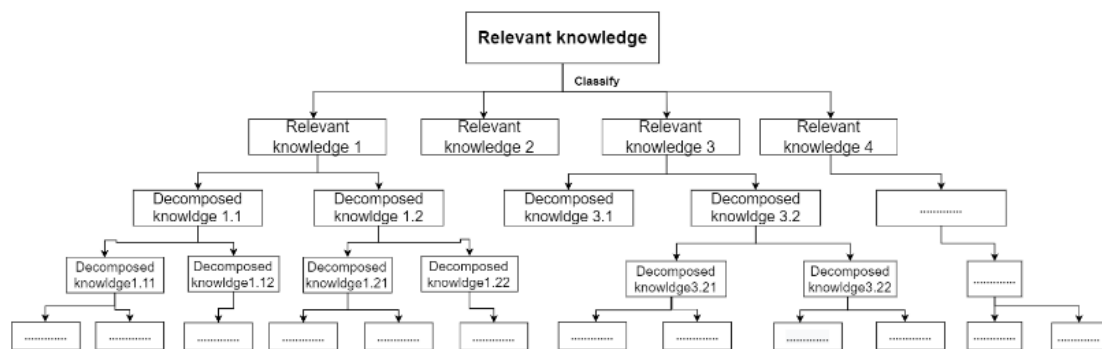


Figure V.7: Representation of decomposed knowledge with a tree

In the previous example from action 3.2, it determined that Covid-19 self-detection could be

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achieved by four branches of supportive knowledge, which include ‘Detect fever’ by ‘temperate sensor’, ‘Monitor cough’ by ‘cough monitor sensor’, ‘Measure blood oxygen saturation’ by ‘SpO2 sensor’, and ‘Measure respiratory frequency’ by ‘infrared sensor’. However, to get a whole innovative concept, the designer needs to determine, for instance, if this function should replace an obsolete one, or to add this function to the current functions, or eventually combine this function with other health monitoring functions.

So, apart from the supportive knowledge that determined the achievability of this function (the 4 branches), the other knowledge that is related to smart watch concept generation is also needed. For example, from the designer’s point of view, the ‘knowledge about existing smart watches’ is regarded as needed knowledge, as it can provide insights to the designer how the current smart watches operate. This ‘knowledge about existing smart watches’ has already been identified in Table V.6, and decomposed into ‘knowledge about existing functions’, ‘knowledge about existing behaviors’, ‘knowledge about existing components’ and ‘knowledge about existing experience’. Among them, the designer evaluates that ‘knowledge about existing functions’ is closely relevant to the function Covid-19 self-detection. Therefore, he decides to focus on this knowledge to generate a new concept. Note that, the design also can return to Step 1 to identify more relevant knowledge.

At the end of this process, the initial knowledge and the relevant knowledge are available.

To structure knowledge resulting from Step 2 (cf. Figure V.7) and Action 3.2 (cf. Figure V.4), the designer is encouraged to apply different heuristics. To this goal, two lists of heuristics, extracted from innovative cases (cf. Chapter 4) is provided to guide the designer for different concept proposition.

Let us remember that heuristics are classified into two types:

- *Type 1:*

Type 1 heuristics mainly focus on supporting knowledge structuring within four categories of design, which includes function, behavior, structure, and experience. To give an example, “add a new function” supports knowledge structuring in function category of design. They are under the form of a short phrase, which includes a verb and an object. The detail of how we identify

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and extract these heuristics is given in Chapter 4, with examples of Type 1 heuristics (see Table IV.5); the complete list of heuristics can be found in Appendix 2.

- *Type 2:*

Type 2 heuristics can be more generally applied. They are formulated with a single verb, without any object. These verbs provide guidance to the designer to structure knowledge, so that she/he that encounters no limitation on case background nor the category of design. To give an example, “add” heuristic can support knowledge structuring in abroad categories of design. Such as in function category, to add a function. In the service category to add a service etc. The detail of how we identify and extract these heuristics is given in Chapter 4, with examples of Type 2 heuristics (see Table IV.6); the complete list of heuristics can be found in Appendix 2.

In Action 3.3, the designer first determines the type of heuristics that suits best according on the initial knowledge. For instance, if the achievement of the initial knowledge is related with function, behavior, structure or experience categories, then Type 1 heuristics are recommended. Then the designer randomly selects one heuristic from the corresponding list to try to structure knowledge.

For example, if the initial knowledge is related to the function category of design, so Type 1 heuristics will be chosen. Then the designer randomly picks one heuristic from the heuristics list of function categories (first column of Table V.9). Among the various functions related heuristics, the designer can pick one, such as ‘combine several functions’. Then, with the guidance of this heuristic, the designer will try to combine the related knowledge with the initial knowledge for new concept generation.

When experimenting with a heuristic, the designer first selects a branch (initial knowledge and its supportive knowledge) from Figure V.4 (one branch or more can support the initial knowledge). Then, by applying the selected heuristics, for instance “add”, the designer selects relevant decomposed knowledge that can be ‘added’ to the existing knowledge to structure with initial knowledge. Note that, according to the selected heuristics, the selection of relevant knowledge and decomposed knowledge might vary. Also note that, according to the heuristic that has been selected, the structuration of knowledge can be different.

At the end of this process, the designer obtains a set of innovative concepts.

Figure V.8 illustrates the structuring process in Action 3.3.

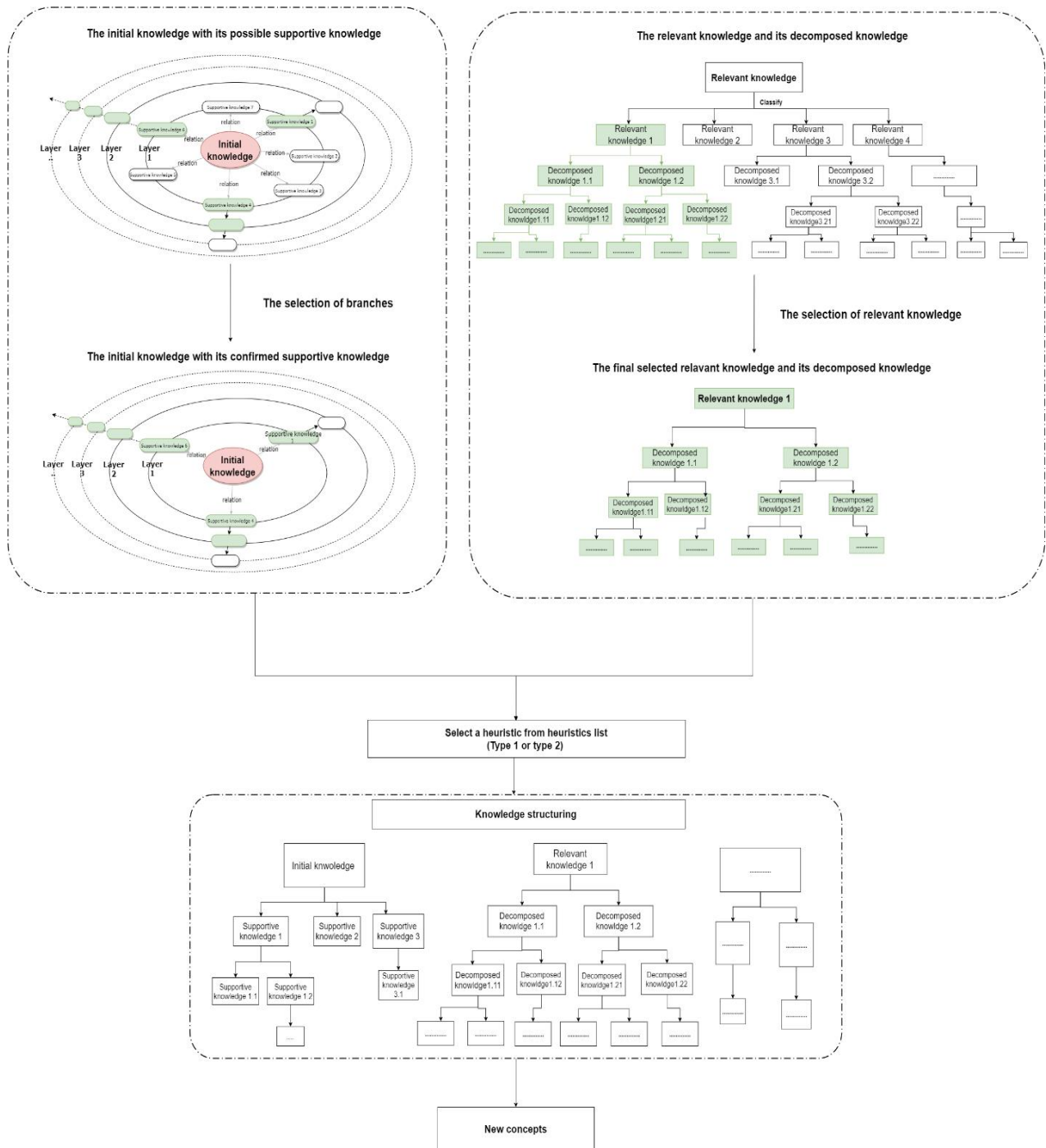


Figure V.8: Illustration of the process followed in Action 3.3

By iterating on this process, from the same initial knowledge but with trying different heuristics, the designer will obtain different options to develop the initial knowledge towards new concepts. Besides, the designer can also go back to Action 3.1 and select another initial knowledge, then follow the same process, to get more concepts. In the end, the designer will arbitrate between the several generated concepts.

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With the guidance of question Q3.5 “*Can I structure the decomposed knowledge for concept generation?*” the designer starts to choose heuristics and try to propose different concepts.

In the example, let us suppose that the designer decides to select Type 1 heuristics as a try, as this type of heuristics focuses on function categories of design. Table V.10 synthesizes the heuristics that can be applied in the function category of design.

Table V.10: Example of heuristics for function category of design

Heuristics for function category of design
<p>– Add new function (e.g., add contactless payment function)</p>
<p>– Combine several functions (e.g., combine several functions to a high level of function or new function; such as Triathlon function)</p>
<p>– Create new functions (e.g., create new functions to target special users; such as menstrual function and target for woman users)</p>
<p>– Decompose a function (e.g., decompose the functions into sub-functions; such as health-related function is decomposed into heart health monitor, stress monitor)</p>
<p>– Differentiate the function to each series (e.g., differentiate functions to different series; such as approach mainly for golf function; D2 family mainly for aviation)</p>
<p>– Emerge a new function with an existing function of sub-function (e.g., emerge a function with a current function)</p>
<p>– Extend the current function by adding new features (e.g., extend the current function by adding new features. Such as golf watch, add golf score.)</p>
<p>– Enhance the current function by creating indicator (e.g., enhance the current function by creating indicator. Such as enhance swimming tracking by adding Swim-Golf score)</p>
<p>– Improve the current function’s accuracy (e.g., for run detection Sunnto ambit 3 improve to 5 sec accuracy)</p>
<p>– Magnificent one function (e.g., magnificent one function of a watch; such as Garmin swimming series mainly for swim; forerunner series mainly for running)</p>
<p>– Simplify the function (e.g., simplify the function with main features)</p>
<p>– Separate the function (e.g., separate a function as an independent function and not a sub-function of other)</p>

From the suggested heuristics, the heuristic “Add a new function” is first selected by the designer to try structuring knowledge. By using this heuristic, the initial knowledge “Covid-19 self-detection” is regarded as a separate function to add to the existing functions of smart watch design. Figure V.9 shows an example of using this heuristic “add a new function” for knowledge structuring.

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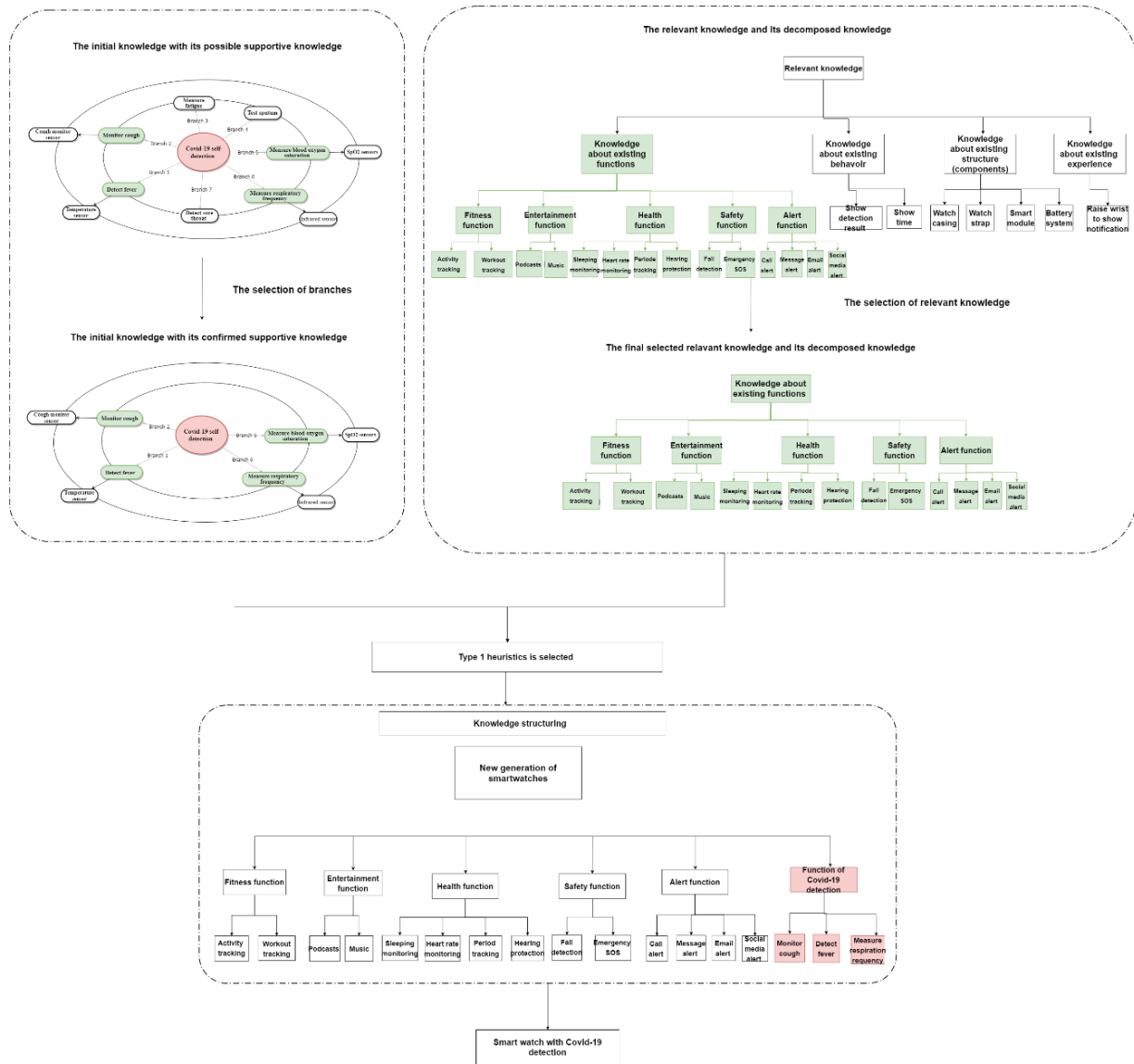


Figure V.9: Example of using the heuristic “add a new function” for knowledge structuring

As a result of using this heuristic, a new concept for the next generation of smart watches appears. It simply consists of adding a new function to meet a current new trend of smartwatch design.

Resulting concept from the use of Type 1 heuristic:

At the end of applying the proposed methodology, a concept for Covid-19 self-detection watch is proposed through knowledge structuring of using a Type 1 heuristic. To better describe this concept, we use functional architecture to show the new concept's functions (the next generation of smart watches) and its functional flow block diagram to show a scenario of how it works.

Figure V.10 show the functional architecture of a final concept (Covid-19 self-detection smart

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watch).

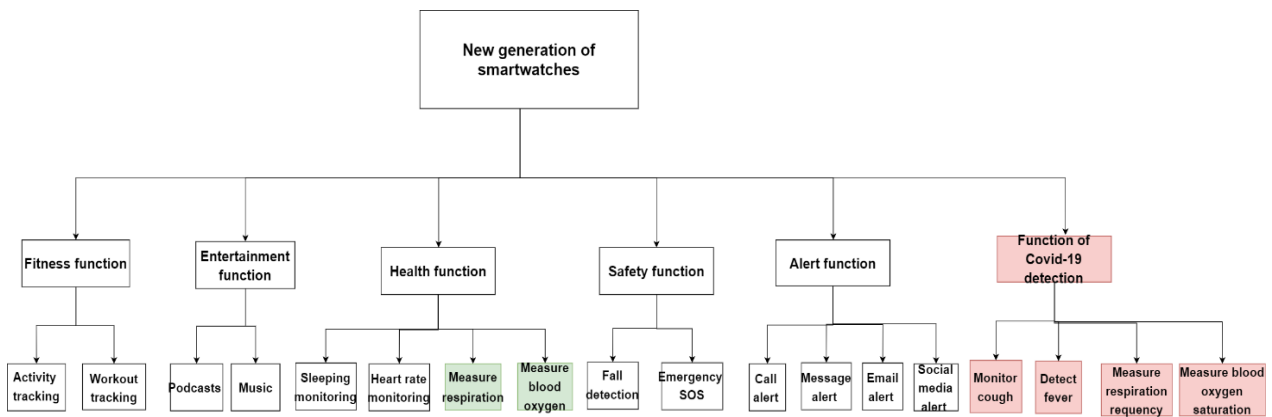


Figure V.10: Functional architecture of a final concept (Covid-19 self-detection smart watch)

By applying the heuristic “add a function”, the function of “Covid-19 self-detection” is added to a new generation of smart watch design with a function innovation. The function flow block diagram gives a quick view of how the new concept works.

Figure V.11 illustrates a scenario of Covid-19 self-detection by using a smart watch.

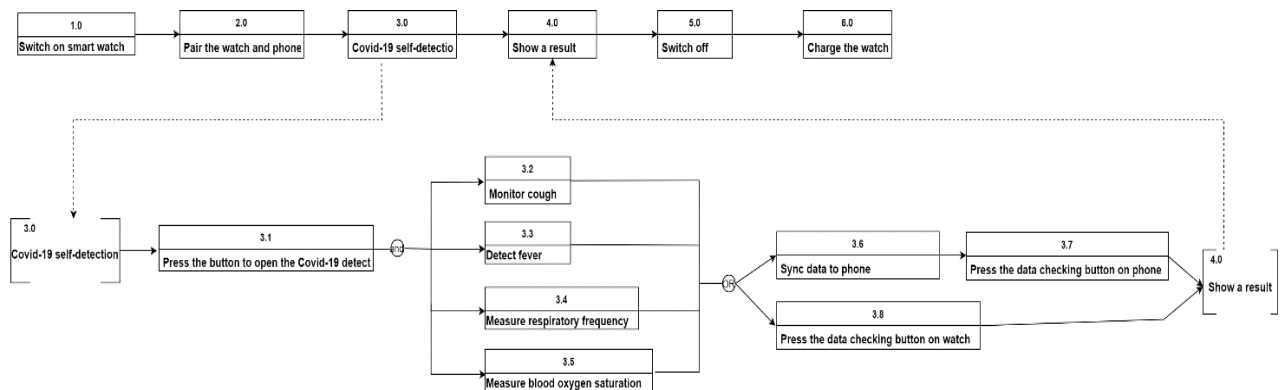


Figure V.11: A scenario of a final concept (Covid-19 self-detection by using smart watch)

Now, let us suppose that the designer decides to experiment a Type 2 heuristic, ‘bundle’. Then, among the several branches that can support “Covid-19 self-detection” (cf. Figure V.6), three are selected by the designer: ‘Detect fever’, ‘Monitor cough’ and ‘Measure respiration frequency’. Then the designer selects ‘Energy-harnessing smart fabrics’ from Table V.6, which results from the decomposition of ‘knowledge about the trend on material replacement’. Then by applying the ‘bundle’ heuristic, the designer bundles ‘Covid-19 self-detection’ with ‘Energy-harnessing smart fabrics’ for concept generation.

The current smart watch materials include aluminium, stainless steel, ceramics, stainless,

titanium and polycarbonate. All of these materials are hard materials and suitable for smartwatch design. But bundling the ‘Covid-19 self-detection’ with ‘Energy-harnessing smart fabrics’ to achieve ‘Covid-19 self-detection’ with smart clothes is suggested. As energy harnessing smart fabrics is a soft material which is not so suitable for watch design, but with potential application for smart cloth in real-time tracking of the vital sign of the wearer. Hence, by applying this heuristic ‘bundle’, the ‘Covid-19 self-detection’ can be achieved with smart clothes.

Resulting concept from the use of Type 2 heuristic:

After applying the methodology, a concept of Covid-19 self-detection smart cloth is proposed through knowledge structuring. To better describe the new concept, we use functional architecture to show the new concept's functions (a new generation of smart cloth for Covid-19 self-detection) and its functional flow block diagram to show a scenario of how it works. Figure V.12 show the functional architecture of Covid-19 self-detection smart clothes.

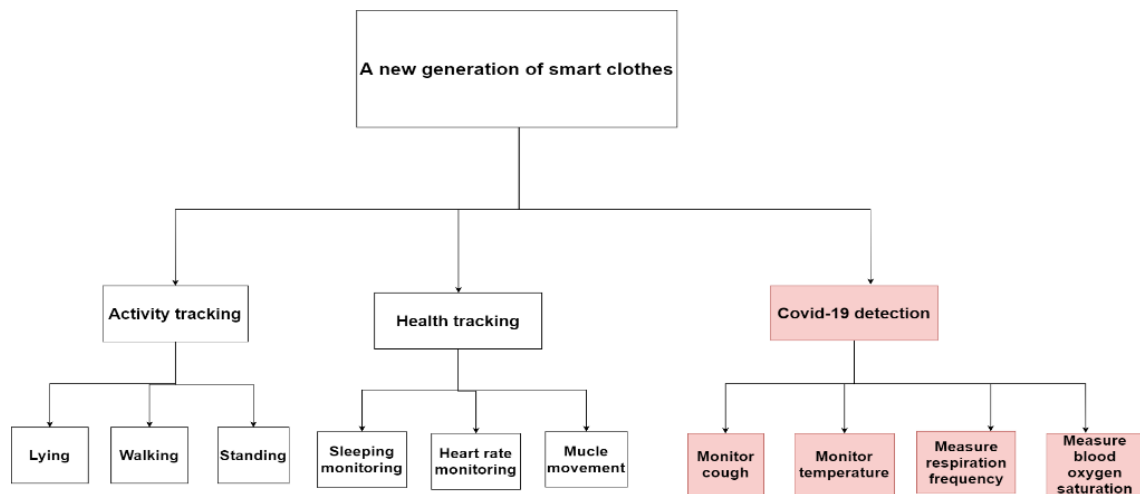


Figure V.12: Functional architecture of a concept (Covid-19 detection smart cloth)

The function flow block diagram is used to describe how the new concept works. Figure V.13 illustrates a scenario of Covid-19 self-detection by using smart cloth.

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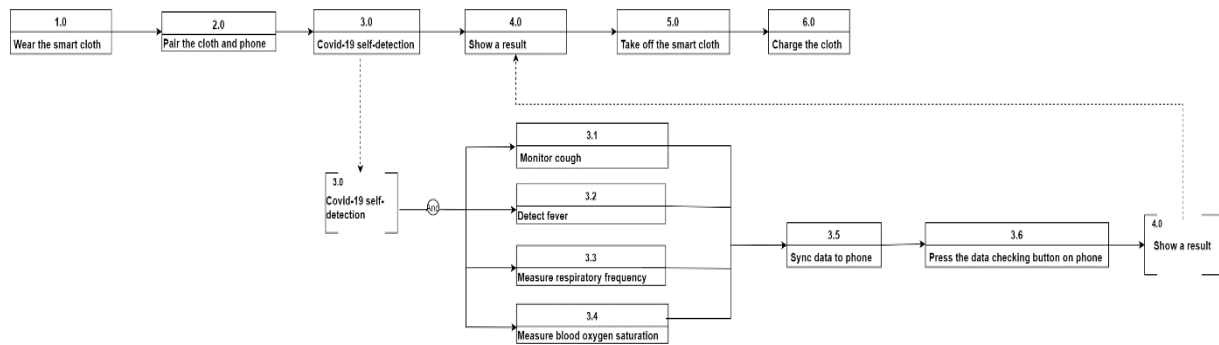


Figure V.13: A scenario of a final concept (Covid-19 self-detection by using smart watch)

After one round of knowledge structuring, the designer can either rapidly iterate Action 3.3 to select other heuristics for other concept generation for the same initial knowledge, or rapidly iterate from Action 3.1 to select another initial knowledge for more types of concept proposition. As a result, at the end of step 3, a variety of new concepts can be proposed.

V.6.4 Synthesis on the method and obtained results

This chapter detailed the methodology and how it can be used to guide concept generation. Its main goal was to illustrate the application of the methodology and evaluate it on a use case.

The methodology starts with an identification of relevant knowledge, followed by a decomposition of it, and ends with a structuration of knowledge. These three steps play different roles; they are applied iteratively. The first two correspond to divergent processes aiming at expanding task-related knowledge through intentional or incidental learning. The third one is a convergent process consisting in selecting an initial knowledge to start knowledge structuring, thus influencing concept structuring. Processes are supported by the logical and systematic guidance of questions and lists of heuristics. At the end of implementing the methodology, different concepts can be produced depending on the different selections of initial knowledge, the supportive knowledge and the heuristics. In the use case we took, by selecting one initial knowledge and using two different heuristics, two different concepts were found. If we iterated the third step to chose another initial knowledge, and/or tried different heuristic, more concepts would be found; however, finding a large panel of concepts was not the purpose here.

V.7 Discussion

In this section, we discuss the results obtained on the use case when applying the methodology. The goal is to evaluate the efficiency (“Can the methodology be easily practiced and does it produce results?”) and effectiveness (“Does the methodology lead to the emergence of new smart watches concepts answering the market needs in the Covid-19 context?”) of the proposal, by answering several questions.

V.7.1 Evaluation of the methodology efficiency

1) Is the methodology easy to apply?

Due to a lack of time, we could not deploy the methodology and have it experimented by a panel of designers. However, we got the first feedback from its use on the case study, on its interests and on different difficulties that could occur during its application.

Interests:

This methodology provides a systematic approach to guide the designer, especially a novice designer, on idea generation. Compared with other idea generation strategy which provides an abstract way to show idea generation, this methodology provides a structured framework, clear steps, specific questions to progressively guide a designer to take actions towards concept generation.

The methodology iteratively follows divergent and convergent steps to support knowledge structuring. Initiating convergent processes is usually a challenging point; we propose a smooth transformation from divergence to convergence. We introduce a notion of “initial knowledge” to guide the designer to select the most promising and valuable piece of knowledge. Once the selection of initial knowledge is settled, a direction for a new concept generation is suggested, and a convergent process of knowledge structuring is conducted to reach a final concept.

In addition, the knowledge structuring process is also guided; to that goal, two lists of heuristics that provided to the designer. By applying various heuristics, different concepts can emerge.

Difficulties:

Through applying the methodology on the case study, we noticed some difficulties that might be improved. The three main steps of the methodology indicate a globally linear process;

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however, several iterations are locally recommended. The number of iterations to perform and the stage where the designer should stop might be difficult to determine.

2) Does the methodology produce results?

During the application of the methodology, some factors can impact concept generation and the innovation level of the final concept.

The identified knowledge has a huge impact on concept generation. If it comes from prior knowledge, and no new knowledge is acquired, the designer might be quickly fixed. The designer decides when to start and stop acquiring knowledge.

Besides, the choice of the initial knowledge and supportive knowledge also affect concept generation and especially influences the level of innovation. The choice of the initial knowledge, performed by the designer, decides the concept starting point and the direction to develop a final concept. Then, without enough supportive knowledge, the initial knowledge is hard to be further developed.

Therefore, several data influence concept generation's efficiencies: the identified knowledge, the selected initial knowledge and its supportive knowledge. The designer's experience plays an important role in applying the processes.

3) What does the time spent depend on?

In general, when applying this methodology, the first two steps of exploration (divergent process) require more time, and the last step (convergent process) less. It mostly depends on whether the designer experiments or not, and whether he/she is familiar with the methodology.

The designer's knowledge and mastery of the methodology will help not to waste time in applying the steps, and to ask the right questions; the designer's experience in her/his job and her/his knowledge of the company's strategy will help her/him to quickly determine which initial knowledge is interesting to choose, as well as determine the supporting knowledge and the need to acquire more.

4) When is the methodology most useful?

According to the situation (whether the design problem is very similar or not to a previous

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problem, therefore inducing a more or less high risk of fixation), the interest of this methodology will vary. The most similar the problem is, the most interesting it is to use the methodology.

Whatever the novelty of the design problem, acquiring knowledge remains essential, to avoid fixation and to have a higher chance to be innovative.

Situations differ by the structuration of the knowledge, according to the ratio of anterior and new knowledge: the less similarity the problem has with the previous problem, the newer the knowledge is.

Whatever the situation considered, the implementation of the method requires finding a compromise between the expected level of innovation and the time spent to achieve it.

5) Can we be sure of the exhaustiveness of the knowledge?

In this research, we feel there is no standard for the exhaustiveness of the knowledge, and it subjectively depends on the designer. A designer determines knowledge scope and the details of the decomposed knowledge based on their own needs. This decision may rely on project time and resources. Therefore, in the methodology, we help a designer evaluate the knowledge's scope relies on the sufficient instead of comprehensive.

For example, under the same problem solving or concept generation and for different designers, the knowledge scope may diverse at the end of step 1, and the decomposed knowledge may vary with different levels of details. So, a designer evaluates the knowledge scope by himself/herself. Once the existing identified knowledge that can support the initial knowledge and concept generation, then knowledge scope could be defined as enough by the designer. If not, the designer always can iterate the methodology for new knowledge acquisition. Once, concepts are proposed, the knowledge is regarded as sufficient.

6) Can we imagine pathways for improvement?

The methodology aims to help designer on concept generation. The concept generation process is challenging to visualize and formalize, as it is a cognitive process that occurs in the mind of the designer. It is often difficult for designers to identify and describe their mental process, as it is somehow unconscious and intuitive, and consequently challenging to articulate. With the

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help of adapted tools, the proposed methodology would be helpful to trace and formalize concept generation.

In knowledge identification and decomposition, tables, that collect all identified relevant knowledge, could be recorded in databases.

In knowledge structuring, several computerized tools could be used to help to evaluate the initial knowledge and progressively build the structure. For instance, using drag-and-drop actions to manipulate decomposed knowledge.

The proposed methodology also has the potential to be adapted for group ideation. The current methodology aims to help an individual designer. With a smart system, a group of people can join the ideation at the same time and focus on their knowledge structuring and concept generation path. After that, the documented results from each step can be easily shared with others.

V.7.2 Evaluation of the methodology effectiveness

1) What is the quality of the results with regards to the innovation level?

Based on the problem context and how the designer applies the proposed methodology, the innovation level of a final concept may vary. For example, for a situation of a new problem is very similar to a previous problem, similar concepts with a higher chance to be proposed if the designer mainly relies on prior knowledge on concept generation. On the contrary, for the same situation, if more new knowledge is applied, the proposed concept might come with a higher innovation level.

2) What does the performance of the methodology depend on?

The proposed methodology aims at helping designers to come up with different innovative concepts. To enhance its performance, one can iterate from the first action of step 3 to select different initial knowledge or iterate on the last action of step 3 to try different heuristics based on the same or different initial knowledge. It depends on the designer's needs and allowable time.

3) Could we have obtained different concepts?

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The proposed methodology aims to guide the designer to propose a variety of concepts. As mentioned above, there are several parameters that can influence the concept generation. Each variation of the parameters will lead to different concepts. Therefore, a variety of ideas can be proposed when implementing this proposed methodology.

4) Could we have obtained the same results without applying the methodology?

This methodology provides a systematic approach to guide the concept generation. Some concept generation methods are provided by literature, such as brainstorming and brainwriting. Compared with other idea generation tool, our methodology provides the designer with more precise, systematic and structured guidance on concept generation. The less experimented the designer is, the more useful the methodology can be.

5) Are the initial requirements on the use case satisfied?

The concepts obtained in the use case meet the initial requirements of Covid-19 self-detection and overcome the drawbacks of existing Covid-19 self-detection tools. The first concept targets adult users; the second targets kids. The two proposed concepts address the detection of Covid-19 symptoms to provide people with real-time monitoring and detection. They are sustainable and convenient to use, especially for kids and induce not hurt.

V.8 Conclusion

In this section, we presented and experimented our methodology for Covid-19 self-detection of early symptoms in the objective to find new concepts that answer this need. This experiment was an opportunity to evaluate the efficiency and effectiveness of our proposal.

Through this application, we found out several interests and also some limitations of the methodology:

The interests

1. The potential of a final concept is evaluated in concept generation, not after it.

In the first action of step 1, a designer is encouraged to select out one initial knowledge with the highest potential to develop. Following that is the supportive knowledge selection and

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connection. That is to say; if an initial knowledge has not enough supportive knowledge, the initial knowledge will not be further developed as well.

2. Time-saving on concept generation

During the concept generation, two lists of heuristics are provided on guiding knowledge structuring. It helps the designer accelerating concept generation

3. A systematic approach to guide concept generation

Compared with the existing methods on ideation, a systematic approach is provided to guide designers, especially on idea generation, step by step.

4. The proposed methodology can help to visualise the process of concept generation

It is often difficult for designers to identify and describe their mental process, as it is somehow unconscious and intuitive, and consequently challenging to articulate. The proposed methodology, with the help of adapted tools, would be helpful to trace and formalize concept generation.

The limitations

1. Need to learn before applying the methodology

Compared with other idea generation methods, which focuses on providing strategies, this methodology offers detailed steps to guide idea generation. In contrast, the new users may need time to understand and learn it before applying it for concept generation.

2. Lack of a complete visualization toolkit to support the application of the methodology

The proposed methodology requires lots of tools to help designers document their findings in each step. For example, the designer needs to document the identified knowledge in step 1, record all the decomposed knowledge in step 2, visualize the connection between initial knowledge and its supportive knowledge, as well as knowledge structuring in step 3. Currently, we suggest some tools and the designer can collect these tools and apply them separately when needed. There is a lack of toolkit that includes all the needed tools for implementing this proposed methodology.

This above analysis of the efficiency and effectiveness of the methodology, however, results from a unique application on the case study detailed in the report. Before deploying the method, a few additional pilot cases would need to be dealt with, in order to gather broader feedback. It

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would also be necessary to define an appropriate computer tool to make it more operational. Such a small-scale deployment, to begin with, would make it possible to better identify areas for improvement in the methodological proposal.

CHAPTER VI. CONCLUSION AND PERSPECTIVES

In this chapter, we first remind the research issue, how we addressed them, and the main contributions. Then, we discuss how this work could be continued.

This chapter has three sections. Section 1 reminds the challenge and issue. Section 2 synthesizes our research methodology and the intermediary conclusions obtained at the end of each procedure. Section 3 discusses the limitations of this research. Section 4 indicates some pathways for future work.

VI.1 Challenge and issue

The general goal of our research is enhancing innovation. Innovation plays a vital role for companies or organizations, as it helps them get ahead of their competitors. Successful innovation is related to propose new products or services to meet the customers' need and change market conditions. Design is a process of transforming customer's requirement to a final offering. During the transformation process, the stage of conceptual design is the most important one.

Conceptual design defines the innovation level of a final offering by producing innovative concepts. Concept generation is a critical process that can boost innovation, as designers are encouraged to generate a lot of ideas.

However, designers can be stuck by design fixation. Design fixation refers to a situation when a designer has a blind adherence to a set of ideas or concepts that limits the output of concept generation.

Therefore, to enhance innovation, our research goal focuses on helping designers to mitigate design fixation.

VI.2 Research methodology and intermediary results

To reach the research goal, we defined and followed a dedicated research methodology, decomposed in 4 procedures (cf. Figure VII. 6).

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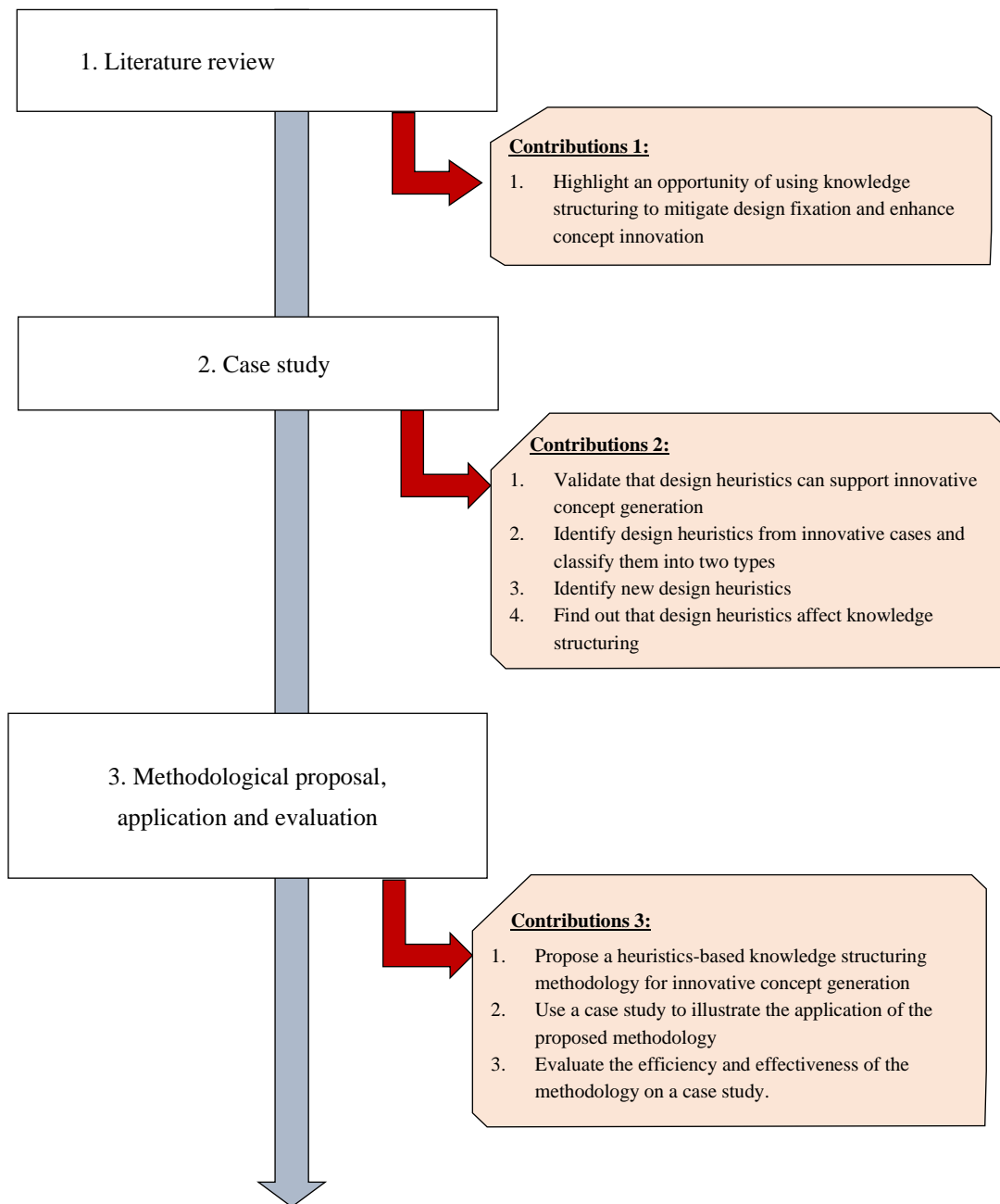


Figure VII. 7: Intermediate contributions

VI.2.1 Literature review

We first reviewed the literature to have a comprehensive understanding of the research background and to position the research context and objective: enhance innovation in concept generation.

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Then, we deepened our knowledge about the research problem, design fixation, and existing solutions. Current design theories emphasize the importance of using new knowledge to overcome design fixation but have some limitation: they do not indicate how to structure knowledge. We, therefore, specified our research question, exploring strategies to guide knowledge structuring, in order to mitigate design fixation and support innovative concept generation.

Contributions 1:

Highlight an opportunity of using knowledge structuring to mitigate design fixation and enhance concept innovation

VI.2.2 Case study

In this procedure, an exploratory case study was conducted to observe the phenomenon and learn lessons. We particularly explored the influence of heuristics on knowledge structuring.

We analyzed the case of smart watches design and identified the design heuristics that have been final used to support the innovative cases. Then we compared them with the ones existing in the literature to analyze the similarities and differences, as well as if new heuristics emerged.

We determined how the design heuristics can have different impacts on the concept and knowledge space during concept generation. In the end, we found out that design heuristics can influence knowledge structuring, therefore influence concept generation.

Contributions 2:

Validate that design heuristics can support innovative concept generation

Identify design heuristics from innovative cases and classify them into two types

Identify new design heuristics

Find out that design heuristics affect knowledge structuring

VI.2.3 Methodological proposal and application on the case study

Abstracting and extending the findings from the case study, we proposed a methodology based on the use of heuristics to support knowledge structuring. The proposed methodology consists of 3 main steps (see Figure VII.2): knowledge identification, knowledge decomposition and knowledge structuring.

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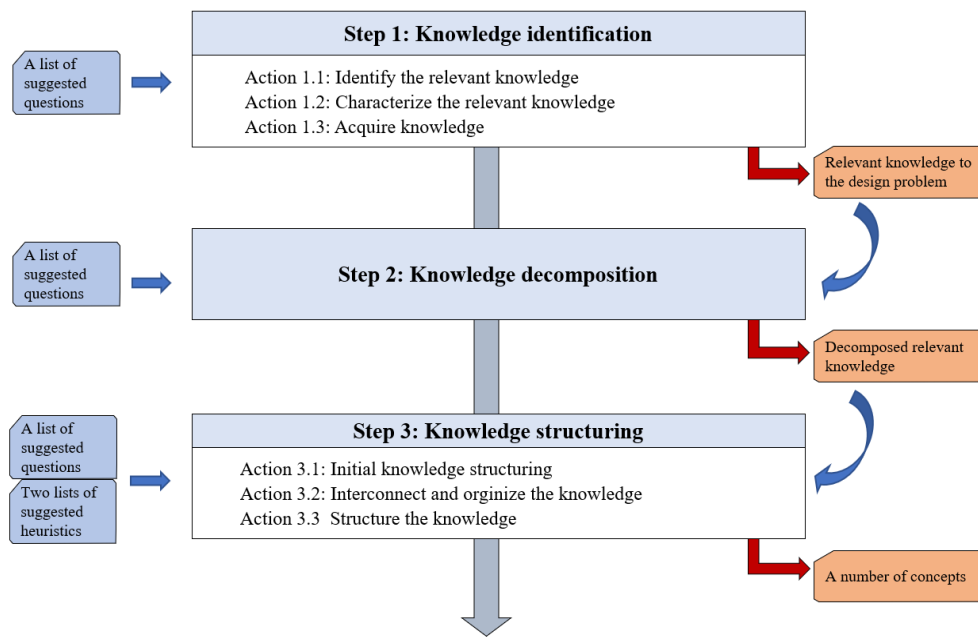


Figure VII. 2: Our methodological proposal

These three steps interactively guide the designers to identify the knowledge related to the design problem, decompose and refine it into details, and then structure it progressively, with the guidance of a series of actions, questions, and heuristics.

Heuristics are used in knowledge structuring help to connect and structure knowledge to explore several opportunities for generating concepts.

Contributions 3:

Propose a heuristics-based knowledge structuring methodology for innovative concept generation

Use a case study to illustrate the application of the proposed methodology

Evaluate the efficiency and effectiveness of the methodology in a case study.

VI.3 Discussion

A posteriori, we noted some limitations in our research methodology and also some limitations in the proposed methodology.

The limitation of the research methodology:

1) Our research methodology follows an inductive process, starting from a case study to learn

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lessons, explore phenomena and patterns, to develop a theory based on the findings. We then use a case study to illustrate the proposed methodology's application and evaluate its efficiency and effectiveness. However, we could only proceed to this evaluation from a single application. The proposed case more illustrates the application of the methodology. With more case studies, we could more accurately evaluate its interest and limitations.

- 2) For design heuristics identification and extraction, we were forced to identify the applied heuristics by analysing the final innovative products. However, final concepts only show a part of used heuristics; there might be more heuristics that have been applied during the concept generation. Joining a design team to observe their concept generation process and identify the applied design heuristics in this context would bring more benefits for more first-hand design heuristics identification. Moreover, we were obliged to identify heuristics by interpreting final products and chose to analyse the final successful innovative concepts. Therefore, we cannot certify that the identified heuristics were the ones precisely used in practice.

We use content analysis for heuristics observation and identification to ensure the identified heuristics with higher certainty from available sources. Content analysis is a widely used qualitative research technique to interpret meaning from the content of text data.

The process of using content analysis for heuristics identification follow this way:

We compare existing products to observe and identify innovation or innovative cases by analyzing four critical categories of design (function, behaviour, structure, and experience). Once innovative cases are identified and collected, we interpret the applied heuristics based on the collected information.

Through this exploratory case study, we try to collect information as comprehensive as possible. Meanwhile, we also attempt to interpret the observed heuristics as accurately as possible. But, the identified heuristics can not be totally certified.

The limitation of the proposed methodology

- 1) The proposed methodology aims to help a designer to propose more innovative concepts. The current methodology mainly targets on designer on individually concept generation, and it is less efficient on a group idea generation.

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- 2) The proposed methodology includes three main steps to guide on concept generation. Concept generation is a cognitive process, and it is usually hard to visualize. To support the designer document his/her concept generation, some tools are recommended in each step, such as Table is used for documenting the identified knowledge; Table or tree structure can be used to show knowledge decomposition. While, all the current tools are separate to use. If a whole toolkit accompanies this methodology, it will bring more convenience for a designer to use and better support his/her concept generation process.
- 3) The proposed methodology guide the designer on relevant knowledge identification. A designer determines knowledge scope and the details of the decomposed knowledge based on their own needs. This decision may rely on project time and resources or some other factors. So it subjectively depends on the designer to evaluate the knowledge's scope. Therefore, in the methodology, we help a designer evaluate the knowledge's capacity relies on the sufficient instead of comprehensive.

VI.4 Future work

Based on the discussion on the interests and limitations of the methodology, we identify further investigation pathways of this research:

- 1) Applied the proposed methodology in different idea generation situation to better evaluate it.
- 2) Update the current methodology from supporting individual idea generation to support group idea generation.
- 3) Develop smart tools to accompany the proposed methodology to enhance the convenience for sharing concept generation with its knowledge structuring process.

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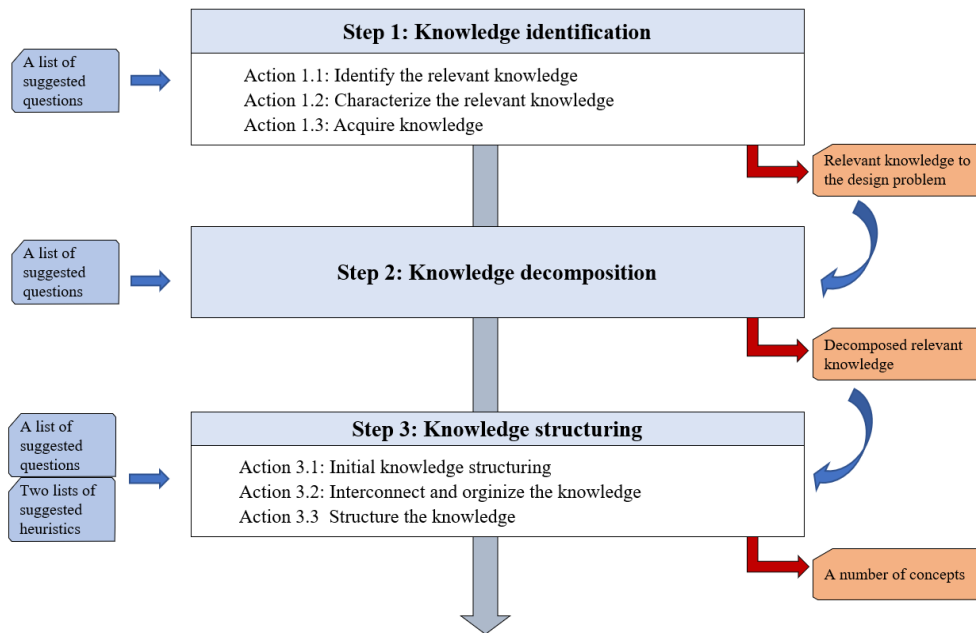
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Appendix 1: Suggested questions at each step



Framework of the methodology

Step 1: Interactive knowledge identification

In step 1 of interactive knowledge identification, there are three main actions and some suggested questions in each action.

Action 1.1: Identify the relevant knowledge

Q1.1: Do I know any knowledge that might be helpful on this design problem/task?

Action 1.2: Characterize the relevant knowledge

Q1.2 What is the knowledge types of each relevant knowledge?

Action 1.3: Acquire knowledge

Q1.3: Can I obtain the known unknowns?

Q1.4: How can I learn those known unknowns?

Q1.5: Are these known knowns sufficient for concept generation?

Q1.6: Am I know what other knowledge might be needed?

Q1.7: Can I obtain the unknown unknowns?

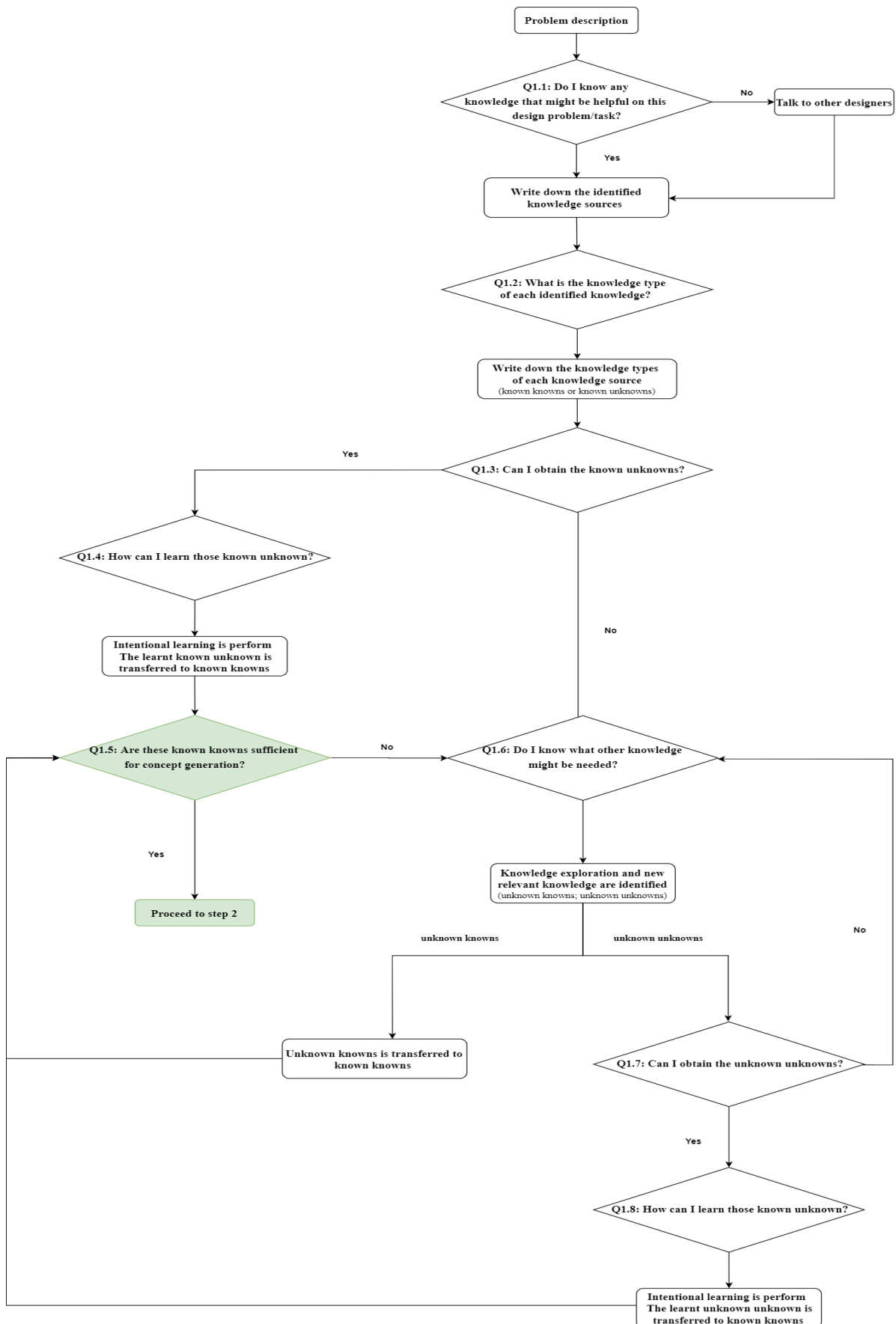
Q1.8: How can I learn those unknown unknowns?

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Step	Action	Suggested questions	
1: Interactive knowledge identification	1.1 Identify the relevant knowledge	Q1.1: Do I know any knowledge that might be helpful on this design problem/task?	
	1.2 Characterize the relevant knowledge	Q1.2: What is the knowledge types of each relevant knowledge?	
	1.3 Acquire knowledge		Q1.3: Can I obtain the known unknowns?
			Q1.4: How can I learn those known unknowns?
			Q1.5: Are these known knowns sufficient for concept generation?
			Q1.6: Do I know what other knowledge might be needed?
			Q1.7: Can I obtain the unknown unknowns?
			Q1.8: How can I learn those unknown unknowns?

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The algorithm for step 1:



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Step 2: Interactive knowledge decomposition

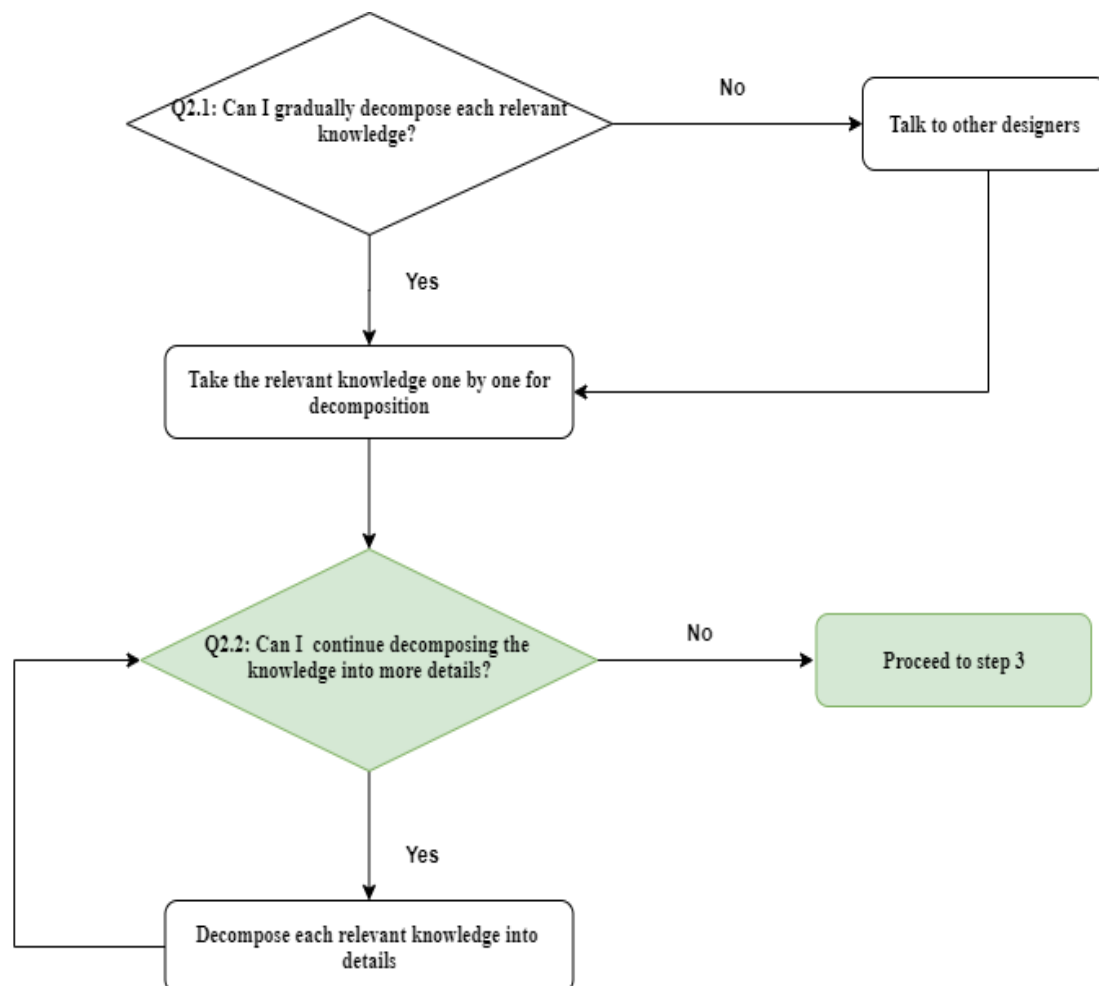
There are 2 questions are suggested to guide knowledge decomposition.

Q2.1: Can I gradually decompose each relevant knowledge?

Q2.2: Can I continue decomposing the knowledge into more details?

Step	Action	Suggested questions
2. Interactive knowledge decomposition	2.1 gradually decompose each relevant knowledge	Q2.1: Can I gradually decompose each relevant knowledge?
		Q2.2: Can I continue decomposing the knowledge into more details?

The algorithm for step 2:



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Step 3: Interactive knowledge structuring

In step 3 of interactive knowledge structuring, there are three main actions and some suggested questions in each action.

Action 3.1: Initiate knowledge structuring

Q3.1: What knowledge is the most valuable?

Action 3.2: Develop the knowledge structure

Q3.2: Can I select any decomposed knowledges that is relevant to support the initial knowledge?

Q3.3: What knowledge could support the initial knowledge and how could they be organised?

Q 3.4: Is the selected knowledge sufficient to support the initial knowledge realization?

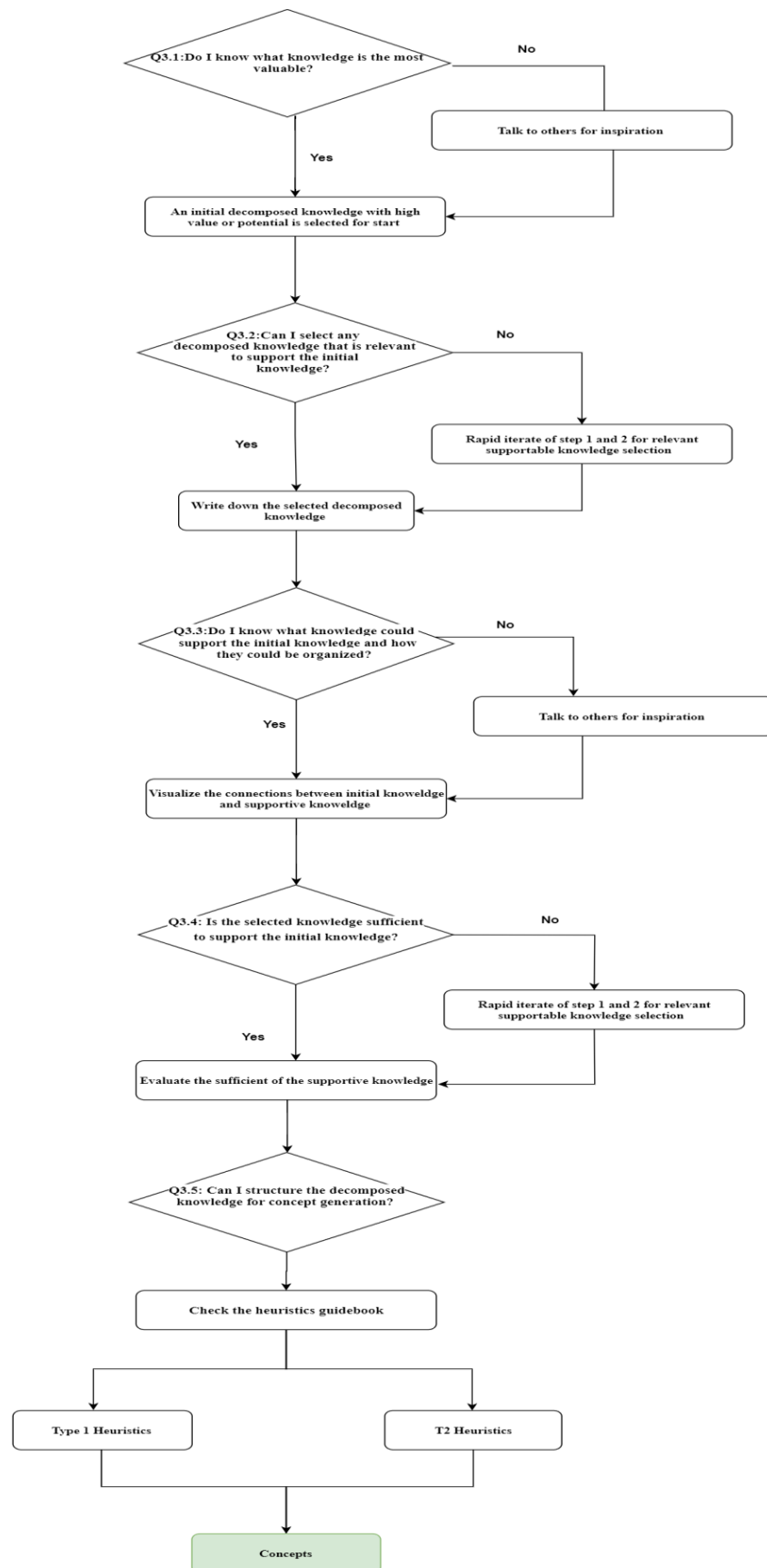
Action 3.3: Structure the knowledge

Q3.5: Can I structure the decomposed knowledge for concept generation?

Step	Action	Suggested questions
3: Interactive knowledge structuring	3.1 Initiate knowledge selection	Q3.1: What knowledge is the most valuable?
	3.2 Iteratively connect more knowledge to support the initial knowledge	Q3.2: Can I select any decomposed knowledges that is relevant to support the initial knowledge?
		Q3.3: What knowledge could support the initial knowledge and how could they be organised?
		Q3.4: Are these selected knowledges are sufficient to support the initial knowledge realization?
3.3: Structure the decomposed knowledge	Q3.5: Can I structure the decomposed knowledge for concept generation?	

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The algorithm for step 3:



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Appendix 2: The list of heuristics

Type 1 Heuristics: the heuristics can be applied in FBSE categories of design

Type 1 Heuristics for four categories of design			
Function	Behavior	Structure	Experience
<ul style="list-style-type: none"> – Add new function (e.g., add contactless payment function) – Combine several functions (e.g., combine several functions to a high level of function or new function; such as Triathlon function) – Create new functions (e.g., create new functions to target special users; such as menstrual function and target for woman users) – Decompose a function (e.g., decompose the functions into sub-functions; such as health related function is decomposed into heart health monitor, stress monitor) – Differentiate the function to each series (e.g., differentiate functions to different series; such as approach mainly for golf function; D2 family mainly for aviation) – Emerge a new function with an existing function of sub-function (e.g., emerge a function with a current function) – Extend the current function by adding new features (e.g., extend the current function by adding new features. Such as golf watch, add golf score.) – Enhance the current function by creating indicator (e.g., enhance the current function by creating indicator. Such as enhance swimming tracking by adding Swim-Golf score) – Improve current function's accuracy (e.g., for run detection Sunnto ambit 3 improve to 5 sec accuracy) – Magnificent one function (e.g., magnificent one function of a watch; such as Garmin swimming series mainly for swim; forerunner series mainly for running) – Simplify the function (e.g., simplify the function with main features) – Separate the function (e.g., separate a function as an independent function and not a sub-function of other) 	<ul style="list-style-type: none"> – Add a new behavior (e.g., add a sleep monitoring; add stress monitoring) – Adapt to a new behavior (e.g., adapt to a new charging way) – Change the behavior (e.g., from tap the screen to check information to raise the wrist) – Enhance a current behavior (e.g., enhance swimming tracking by adding tracking indicator) – Extend a behavior battery life (e.g., extend the battery life) – Make it lighter (e.g., change the materials to make it lighter) – Reduce the weight (e.g., reduce the weight of smartwatch) – Improve the toughness (e.g., change to a tougher material) – Improve the security level (e.g., add falling down detection and noise reminder) – Improve the accuracy of detection (e.g., add sensor or indicator to improve the accuracy of the detection) – Sustainability (e.g., replace to 100% recycling material) 	<ul style="list-style-type: none"> – Change casing color and size (e.g., provide different color and size of casing) – Change strap color and size (e.g., provide different color and size of strap) – Differentiate materials for casing (e.g., provide different materials of casing) – Differentiate materials for strap (e.g., provide different materials of strap) – Replace battery system (e.g., change from the other types to sustainable battery system) – Revise the shape of screen (e.g., from flat screen to curved screen) – Revise size of the screen (e.g., differentiate the size of screen) – Revise to durable materials (e.g., revise to a material meet military standard) – Revise to sustainable materials (e.g., replace to 100% recycling material) – Reduce the materials (e.g., reduce the class of materials) – Update the sensor (e.g., update the sensor to make it smaller, faster) 	<ul style="list-style-type: none"> – Add a new service (e.g., add service to allow customer gain more value) – Add package service (e.g., add service package and bring value to customers) – Ask customers to assembly (e.g., ask the customers to assemble the product) – Add animation (e.g., add animation to guide the user do Yoga and another course) – Adapt to a new user experience (e.g., from tap the screen to check information is adapted to wrist the hand) – Create cooperation (e.g., create a service to enhance cooperation; such as Vivo fit 4 and Vivo fitJR build a cooperation between parents and kids) – Create competition (e.g., create competition between different users) – Create reward (e.g., create reward experience and keep the users are motivated) – Create interaction (e.g. Cooperation service between users) – Create challenge (e.g., create challenge service to boost motivation by users) – Extend the strap choice (e.g., provide a variety of strap with different color and materials) – Improve the external design (e.g., some smartwatch with best design award) – Provide visual service (e.g., provide visual caddie) – Provide customized service (e.g., provide customized strap, screen etc.) – Provide SOS service (e.g., provide emergency call) – Provide interchangeable service (e.g., interchangeable strap and screen) – Update the service (e.g., update the service)

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Type 2 Heuristics: the heuristics can be applied in different categories of design

Type 2 Heuristics: applied in different categories of design
Add (e.g., add an exist function to a new product; add an exist service (animated work out; animated courses))
Adapt (e.g., adapt to a new way of interaction, adapt to another charging way)
Animated (e.g., animated work out; animated courses)
Bend: (e.g., bend the screen from flat to a curved shape to increase screen size and readability)
Buddle (e.g., buddle two products together; buddle a product with a service)
Create (e.g., create a new function; create new service; create new indicator, create user community)
Change (e.g., change the materials property; change the flexibility of interface.)
Convert (e.g., add new components to reach new functions)
Customize (e.g., customize design; customize the accessory such as strap, watch face)
Combine (e.g., combine two existing user interface design by jointing them to reach a new goal. value package)
Create (e.g., create a new design/function to target special users)
Differentiate/distinguish (e.g., differentiate the design; differentiate the function; differentiate the prices)
Deduce (e.g., deduce the components; deduce the using of materials)
Extend (e.g., Extend the battery life; extend the material life time)
Enhance (e.g., Enhance the current function by creating an indicator; keep using the current material by strengthen the toughness)
Eliminate (e.g., eliminate extra function and keep basic functions).
Expand or collapse (e.g., expand the component surface of the user interface)
Focus on (e.g., focus on one main function in one series)
Improve (e.g., improve the current functions by adding features; improve the current function by improving the accuracy)
Magnify (e.g., magnify the battery capacity; magnificent one function from a watch series)
Modify (e.g., modify the screen from flat to curved)
Reduce (e.g., reduce the weight of materials and reduce the price of the product)
Replace (e.g., replace the original material to recycled materials)
Remove (e.g., remove material from the user interface by eliminating unnecessary components or change the structure)
Segment/divide (e.g., segment the product into several parts for easy assembly)
Substitute (e.g., substitute the materials of screen and strap, substitute the flat screen to a curved screen)
Scale up/down (e.g., change the physical dimensions, such as change the screen size and the shape)
Separate (e.g., separate functions and service; separate functional components such as separate sensors to meet different functions)
Simplify (e.g., remove unnecessary components or function, simplify the design to make the product more concise and easier to use)
Substitute (e.g., replace another component to accomplish or enhance the same function. Such as different sensor. Replace another way to charging)
Synthesize (e.g., combine two or more functions to reach a new function)
Twist (e.g., twist the strap into two circles and provide a different wearing experience like wear a bracelet)
Update (e.g., update the hardware such as ship; update the service; update the design; update the visualization)
Visualize (e.g., use different visual representation to distinguish different function visualization)

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Appendix 3: The details of rapid iterations for supportive knowledge identification

The section presents the detail results of fast iterates step 1 and 2 for supportive knowledge identification. Note that, this section may not be needed if current supportive knowledge is enough to support initial knowledge.

In our example, to supportive an initial knowledge: knowledge about Covid-19 self- detection, no existing supportive knowledge can be selected to support this initial knowledge. Hence, a fast iterates of step 1 and step 2 for supportive knowledge selection.

Step 1: Knowledge identification

It starts with aware some knowledge that might be relevant to the start point by asking “*Do I know any knowledge that might be helpful on this design problem/task?*”

By asking this question, some relevant knowledges are identified and shown in the Table below:

Table: Relevant knowledge identification

Number	Relevant knowledge
1	Knowledge about the symptoms of Covid-19
2	Knowledge about the ways for Covid-19 symptoms detection
3	Knowledge about existing tools could support (a single) symptom detection of Covid-19
4	Knowledge about already applied laboratory assessment for Covid-19 testing
5	Knowledge about already applied for self assessment tools for Covid-19
6	Knowledge about relevant sensors that might could be applied for Covid-19 assessment

The designer is encouraged to characterize the types of identified knowledge by asking the suggested question “*What is the knowledge types of the identified knowledge?*”. Then the identified knowledges are characterized and show in Table below.

Table: characterizing knowledge type of identified relevant knowledge

Number	Relevant knowledge	Knowledge type
1	Knowledge about the symptoms of Covid-19	Known unknowns
2	Knowledge about the ways for Covid-19 symptoms detection	Known unknowns
3	Knowledge about existing tools could support (a single) symptom detection of Covid-19	Known unknowns
4	Knowledge about already applied laboratory assessment for Covid-19 testing	Known unknowns
5	Knowledge about already applied for self assessment tools for Covid-19	Known unknowns
6	Knowledge about relevant sensors that might could be applied for Covid-19 assessment	Known unknowns

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Following that, the designer needs to wonder about the possibility of learning that knowledge, especially for the known unknown by asking “*Can I obtain the known unknowns?*”. The results of possibility of known unknown acquisition is show in Table below.

Table: the possibilities of knowledge (known unknowns) acquisition

Number	Relevant knowledge	Knowledge type	Possibility for unknown acquisition
1	Knowledge about the symptoms of Covid-19	Known unknowns	Can be obtained by online exploring and learning
2	Knowledge about the ways for Covid-19 symptoms detection	Known unknowns	Can be obtained by online search and ask from the others
3	Knowledge about existing tools could support (a single) symptom detection of Covid-19	Known unknowns	Can be obtained by oneline exploring and learning
4	Knowledge about already applied laboratory assessment for Covid-19 testing	Known unknowns	Can be obtained by oneline exploring and learning
5	Knowledge about already applied for self assessment tools for Covid-19	Known unknowns	Can be obtained by oneline exploring and learning
6	Knowledge about relevant sensors that might could be applied for Covid-19 assessment	Known unknowns	Can be obtained by oneline exploring and learning

Then the learning process is conducted, to obtain the known unknown. After learning, an updating knowledge type of the identified knowledge shown in Table below:

Table: an updated knowledge type of identified relevant knowledge

Number	Relevant knowledge	Knowledge type
1	Knowledge about the symptoms of Covid-19	Known unknowns Known knowns
2	Knowledge about the ways for Covid-19 symptoms detection	Known unknowns Known knowns
3	Knowledge about existing tools could support (a single) symptom detection of Covid-19	Known unknowns Known knowns
4	Knowledge about already applied laboratory assessment for Covid-19 testing	Known unknowns Known knowns
5	Knowledge about already applied for self assessment tools for Covid-19	Known unknowns Known knowns
6	Knowledge about relevant sensors that might could be applied for Covid-19 assessment	Known unknowns Known knowns

The current identified knowledge is deemed to sufficient, then the designer enters to the step 2 knowledge decomposition.

Step 2: knowledge decomposition

The designer needs to gradually and progressively decompose identified knowledge. By asking

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the question “*Can I gradually decompose each relevant knowledge?*”

Table: a high level of relevant knowledge decomposition

Number	Relevant knowledge	Knowledge decomposition
1	Knowledge about the symptoms of Covid-19	Fever (87.9%)
		Dry cough (67.7%)
		Fatigue (38.1%)
		Sputum production (33.4%)
		Shortness of breath (18.6%)
		Myalgia or arthralgia (14.8%)
		Sore throat (13.9%)
		Headache (13.6%)
		Chills (11.4%)
		Nausea or vomiting (5.0%)
		Nasal congestion (4.8%),
		Diarrhea (3.7%)
		Hemoptysis (0.9%)
		Conjunctival congestion (0.8%)
2	Knowledge about the ways for Covid-19 symptoms detection	Detect fever
		Monitor cough
		Measure fatigue
		Test sputum
		Measure blood oxygen saturation
		Measure respiratory frequency detection
		Detect sore throat
3	Knowledge about existing tools could support (a single) symptom detection of Covid-19	Thermometer for fever detection
		Cough frequency monitor to monitor cough
		Fatigue can be measure individual's sustained attention and reaction time.
		Sputum testing by lab technician
		Oximeter for blood oxygen saturation measurement
		Capnography monitors for respiratory frequency detection (hospital)
		Sore throat can be detected subjectively
Headache can be detected by questionnaire and headache diary		
4	Knowledge about already applied laboratory assessment for Covid-19 testing	Nasopharyngeal swabs
		Oropharyngeal swabs
		Sputum testing
		Nucleic acid testing
		CT scans
5	Knowledge about already applied for self assessment tools for Covid-19	Online questionnaire based on CDC (Centers for Disease Control and Prevention) guideline
6	Knowledge about relevant sensors that might could be applied for Covid-19 assessment	Temperature sensor for fever detection
		Cough monitor sensor for cough detection
		SpO2 sensor for blood oxygen detection
		Infrared sensor for respiration frequency detection

After a high level of decomposition of every relevant knowledge, the designer is encouraged to think about are these decomposed knowledges can be used to support the initial knowledge.

As the main goal of the rapidly iterative the methodology is to explore new function that can be add to smart watch for Covid-19 detection. After a high level of decomposition, there are some decomposed knowledge might can bring insights for the designer. After the reflection, the decomposed knowledge that can be used to support initial knowledge are organised and classified.

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Table below shows the three knowledges that can be relevant to support Covid-19 self-detection.

Table: An example of supportive knowledge selection and classification

Initial knowledge	Relevant knowledge	Knowledge decomposition
Covid-19 self detection	Knowledge about the symptoms of Covid-19 (from https://www.who.int/docs/default-source/coronaviruse/who-china-joint-mission-on-covid-19-final-report.pdf , page 12)	Fever (87.9%)
		Dry cough (67.7%)
		Fatigue (38.1%)
		Sputum production (33.4%)
		Shortness of breath (18.6%)
		Myalgia or arthralgia (14.8%)
		Sore throat (13.9%)
		Headache (13.6%)
		Chills (11.4%)
		Nausea or vomiting (5.0%)
		Nasal congestion (4.8%),
		Diarrhea (3.7%)
		Hemoptysis (0.9%)
	Conjunctival congestion (0.8%)	
	Knowledge about the detection of Covid-19 symptoms	Detect fever
		Monitor cough
		Measure fatigue
		Test sputum
		Measure blood oxygen saturation
		Measure respiratory frequency detection
Knowledge about relevant existing sensors that might be applied for Covid-19 assessment	Detect sore throat	
	Temperature sensor for fever detection	
	Cough monitor sensor for cough detection	
	SpO2 sensor for blood oxygen detection	
		Infrared sensor for respiration refrequency detection

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Appendix 4: Compare the identified heuristics with the existing heuristics

Compare the identified heuristics with Scamper

	Scamper	The heuristics from the identified heuristics' list
Similar heuristics	Substitute: (e.g., substitute components, materials, et al.)	Substitute: (e.g., substitute the materials of screen and strap, substitute the flat screen to a curved screen)
	Combine (e.g., mix, combine with other assemblies)	Combine (e.g., combine two existing user interface design by jointing them to reach a new goal. value package)
	Adapt (e.g., alter, change function, use part of another element)	Adapt (e.g., adapt to a new way of interaction, adapt to another charging way)
	Magnify/Modify (e.g., increase or reduce in scale, change shape, modify attributes)	Magnify/Modify (e.g., magnify the battery capacity, modify the screen from flat to curved)
	Put to other uses	Put to other uses (e.g., can be used as a GPS, compass with the GPS, and compass function)
	Eliminate (e.g., remove elements, simplify, reduce to core functionality)	Eliminate (e.g., eliminate extra function and keep basic functions).
Absent heuristic	Rearrange/Reverse (e.g., turn inside out or upside down)	
New heuristics		Cooperate (e.g., cooperate with Nike, Hermes, google to provide more value)
		Segment/ divide (e.g., segment the product into several parts for easy assembly)
		Buddle (e.g., buddle two products together; buddle a product with a service)
		Reduce (e.g., reduce the weight of materials and reduce the price of the product)
		Differentiate/distinguish (e.g., differentiate the design; differentiate the function; differentiate the prices)
		Animated (e.g., animated work out; animated courses)
		Simplify (e.g., simplify the design, simplify the color)
		Focus on (e.g., focus on one main function in one series)
		Customize (e.g., customize design; customize the accessory such as strap, watch face)
		Update (e.g., update the hardware such as ship; update the service; update the design; updata the visualization)
		Sustainable (e.g., use sustainable material, use sustainable energy for charging)
		Add (e.g., add an exist function to a new product; add an exist service (animated work out; animated courses))
	Create (e.g., create a new function; create new service; create new indicator)	

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		Extend (e.g., Extend the battery life; extend the material life time)
		Enhance (e.g., Enhance the current function by creating an indicator; keep using the current material by strengthen the toughness)
		Improve (e.g., improve the current functions by adding features; improve the current function by improving the accuracy)
		Replace (e.g., replace the original material to recycled materials)

Compare identified heuristics with the 77 design heuristics

Common design heuristics between the 77 heuristics and the heuristics in smart watch design	77 heuristics	The heuristics from smart watch design
Adjust functions for specific users	Design functions around a user population based on age, gender, education, and diverse abilities; allow each user to adjust functions	Cooperate with other companies to provide customized products to meet different users' needs from different gender and different wearing situation.
Apply existing function in new way	Consider how function is accomplished in other products and determine how they can be applied to your product when adapted to its new use.	Combine two existing user interface design by jointing them to reach a new goal.
Bend/curved design	Form an angular or rounded curve by bending a continuous material in order to assign different functions on the bent surfaces.	Substitute the flat screen to a curved screen and increasing the size to increase the readability
Build user community	Consider how two or more users can work together to operate the product, or how one user's operation affects another.	Add connecting function to allow users competing or cooperate with other users.
Change the materials	Change material properties with different or modified material; Consider durability, collapsibility, function, and adjustability	Add different straps (leather, sportive, aluminium) to meet different wearing situations.
Create service	Develop a service by defining interactions between the user and a service provider.	Create value packages (service) provide by their partners.
Offer optional products	Provide additional components that can change or adjust function, purchased separately or included, and where they are stored.	Bundle two products (smart watches with optional sensors) to increase the accuracy of monitoring
Use recycled or recyclable materials	Explore the use of recycled or recyclable materials within the product.	Replace the materials to recyclable materials
Change product life time	Consider the assumed lifetime of a product or its parts and alter the number of times it can be used	Magnify the battery capacity, modify the screen from flat to curved

New identified heuristics	The example from the cases
Cooperate	Cooperate with other companies to provide more value (cooperate with Nike, Hermes, google)
Change to a sustainable energy for charging	Charging by solar energy
Extend the current function by adding new service	For hiking function, suggest best route for hiking
Enhance the function by creating indicator	Create indicator to improve the accuracy of monitoring Swim-Golf for enhance swimming tracking
Enhance the current function by enhance the feature	Enhance the durable for the material by adopting to a more tough material
Reduce weight	Reduce the weight of material
Create cooperation and competing to allow users more involved	Parents give tasks to child through smart watch
Divide to sell the product and service to allow users buy the thing/service whenever they need to reduce original selling price and waste	Provide value package service to allow customers to buy when they need
Buddle two products together	Buddle smart watch with sensor to increase detection ability