博士論文

Design Support for Creative Problem Solving in Developing Countries

(発展途上国における創造的問題解決のための設計支援に関する研究)

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Abstract

In this thesis, the author proposes a design framework and a support system to assist local designers in developing countries to create problem solving products. Although there are a lot of examples of appropriate technology, most of them have been designed by the experts who have professional knowledge.

Based on the insight that local constrains can be utilized to support local designers, the author introduces a novel concept named as cultural excitation. The author defines the cultural excitation as an externalization of local contexts, in terms of a personal factor of designers, a cultural factor inherent in a local community, and an environmental factor that surrounds designers.

Following the analysis of the requirements for enhancing creative activity with the cultural excitation, the author proposes a design framework named as rapid prototyping spiral, which is a rapid iterating process of creating prototypes and getting feedback from users. In the design framework, the author defines four design spaces, such as problem space, function space, structure space, and tool-and-material space. The core of the design framework is that it enables designers to explore the design space to discover underlying issues, utilizing the interaction between each design space. The author also proposes a support system that is utilized for the design with the proposed design framework. The support system is comprised of the design space explorer, the mechanism module, and the electronic circuit module. They aim to support design and manufacturing knowledge, exploration of design space, and rapid prototyping.

The author conducts multiple experiments in Ghana to examine the effect of the proposed method, such as design of an eddy current separator to solve the e-waste problem, concurrent design of multiple artifacts to solve issues identified in an ideation workshop, and redesign of a fufu pounder to match the existing needs in a local community.

As a result, the following effects were observed in the experiments. First, transformation of the design space by rapid prototyping spiral promotes discovery of novel ideas. Second, considering superordinate concepts leads to find creative solutions.

Third, negative aspects, such as constraints of materials, can be triggers of creative problem solving.

The author also provides evaluation for the proposed method from different angles. First, the author describes the effect of following factors in the successful cases, such as facilitation, skill level of designers, personal interest in social problems, and process of collecting materials. The author also analyzes the requirements of the cultural excitation, and clarifies the fact that a specific object, which is named as cultural exciter, can promote designers to discover creative ideas. In addition, the author explains the enhancement of capability among designers, which occurred through the experiments as the side effects. Furthermore, the limit of the proposed method is also discussed. Finally, the author mentions the applicability of the proposed method for design in developed countries.

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Chapter 1

Introduction

1.1 Problem solving products in developing countries

Creating innovative products to solve daily problems gives a great impact especially to the people in the developing countries, where they are exposed to severe constraints. One of the famous activities to make these products is the appropriate technology. The appropriate technology is an application that is small-scale, labor-intensive, energy-efficient, environmentally sound, and locally controlled [1]. A well-known example of the appropriate technology is Q Drum, a plastic water tank which can be easily moved with its rotation [2]. It assists users to carry water from river to home, which is a hard and time-consuming task. Another example is a lantern named d.light, shown in Figure 1-1-[1]. The feature of d.light is that it can be charged with the solar cells, which is helpful in the areas where there is no infrastructure of electricity. In addition, a solar cooker, such as shown in Figure 1-1-[2], was also invented to be used in the unelectrifed areas to generate heat for cooking by collecting sunlight into focus of the reflector.

Although those products have challenges in practical use in terms of costs, some of those problem solving products are actually used in the developing countries. The photos shown in Figure 1-1 were taken by the author during the visit to the republic

[1] d.light [2] Solar cooker

Figure 1-1: Examples of appropriate technology

of Mali, in the western Africa.

The author points out that those products are unique in the following perspectives, compared to other products designed in developed countries.

- Regionally specific problem setting
- Singular utilization of technology

First, those products are designed for solving regionally specific problems. Such problems are generally attributed to the lack of infrastructure. For example, the Q Drum is expected to be used in the areas, where there are no water service. The d.light is an energy saving light using LED, of which the advantage is that the battery of the light can be recharged by solar cells during the daytime. It is especially convenient for users in the isolated regions without electricity, where they have difficulty to obtain replacement batteries. The problems targeted by those products are unique, since the products designed in the developed countries hardly focus on such problems.

Second, those products often utilize existing technology in a peculiar way. For example, there is a solar cooker made by a parabolic antenna. Although the parabolic antenna is obviously not designed for cooking, a designer noticed that the parabolic shape to collect radio wave can also be used for collecting sunlight. The author points out such design is attributed to the lack of resources in the locality. Such a constraint caused the consideration of alternative solutions, which is also a unique feature of the products in the developing countries.

1.2 Assisting local designers

As described in the previous section, although there are numbers of design cases of problems solving products, most of them are designed by engineers or designers who have expertise knowledge.

The difficulty of designing those products are that the designers need to understand the culture and the situation of the target area thoroughly, since they are usually the outsiders of the community. To achieve this purpose, for instance at the d.school in Stanford university, various methods were invented for the designers to discover the local needs effectively. To identify the essential needs in the developing countries, the framework of the participatory development was contrived in the field of the international development, which proceeds the project through interaction with inhabitants [3]. In addition, the inclusive design has similar concept that includes the people, such as physically challenged people, into the design process to identify socially important needs [4].

On the other hand, in terms of sustainability, it is also important to establish the environment for local designers to design products by themselves. For example, a tutorial to make some appropriate technologies is provided on the Web for the local people to recreate the products by themselves, which is called Open Source Appropriate Technology (OSAT) [5]. Moreover, recently, the platform of the fabrication for the people in the communities is developed. For example, a fab lab is a worldwide workshop which provides digital fabrication tools to the people in the community [6]. The fab labs also exist in the developing countries, where local designers have produced various useful products [7]. For instance, Fab-Fi, a low cost Wi-Fi antenna for building the Internet mesh network, was developed in the Fab lab Jalalabad in Afghanistan. Despite the increase of those platforms, the authors believe there is still room to accelerate the creation of the problem solving products in the developing countries.

1.3 Research objective

This thesis aims to propose a design method for supporting local designers in developing countries to create problems solving products. To achieve the objective, the author introduces a novel concept named as cultural excitation. The concept is unique since it takes advantage of local constraints, which are usually regarded as the negative aspects, to promote the designers to discover creative ideas.

To actualize the design with the cultural excitation, the author proposes a design framework and a support system. The design framework is important because the targeted designers in this thesis are the persons who do not have many experiences and knowledge of design. Although there are a lot of research on the design of products for developing countries, the design framework for the local designers has not been focused on. The support system is organized to cover multiple activities, such as idea generation in the knowledge level and prototyping in the physical level. To evaluate the effect of the proposed method, the author carries out experiments in Ghana.

Through the design project under real environment in developing countries, the author aims to clarify factors and conditions for successful design support.

1.4 Thesis outline

In Chapter 2, the author explains the core concept of the cultural excitation, which is expected to support the creative design by the local designers in developing countries. The author mentions the existing design research and describes the difference of the approach between the existing one and ours. Subsequently, in Chapter 3, requirements for setting the design framework are discussed. Based on such analysis, the design method and support system is proposed in Chapter 4 and Chapter 5, respectively. The experiments are described in Chapter 6, followed by the results in Chapter 7. Evaluation of the results will be given in Chapter 8. In the final chapter, the contribution of this thesis is described.

Chapter 2

Concept of Cultural excitation and Related work

2.1 Cultural excitation

As described in the previous chapter, the goal of the research is to propose the design framework and the support system to enhance the creative design of products for solving problems in developing countries by local designers. To achieve the goal, the author focuses on local contexts, in terms of personal factor of designers, cultural factor of designers and users, and environmental factor surrounding designers. The author believes what distinguishes the design by local designers in developing countries from other design problems is the strong focus on those contexts. In this research, the author especially defines the activation of those local contexts as the *cultural excitation*. The cultural excitation is desirable, in perspective of enhancing creative activity by local designers. The cultural excitation contains following aspects.

- Human excitation
- Cultural excitation (in a narrow sense)
- Constraints excitation

First, human excitation means emotionally stimulated states of designers. In short, increasing human excitation means activating the intrinsic motivation of designers. Our targeted designers are persons who spontaneously and actively take part in the design activity. Preceding research describes the significant role of such intrinsic motivation in the creative activity [8].

Second is cultural excitation. Even though the element is also called as cultural excitation, it is used in a narrow sense against the main concept of the cultural excitation. It is the state that the designers are strongly careful of assumptions or the conditions which they have been unconscious of. The author believes that all the designers are unconsciously adapted to the ways of thinking influenced by cultural assumptions in the community where they are exposed. This factor is significant for designers to reconsider preconditions and identify potentially and socially significant needs.

Third, constraints excitation is regarded as the externalization of the environmental constraints existing in developing countries, for example, lack of materials, tools, and social infrastructure. The author points out that sometimes those restrictions work as triggers to find out the unexpected use of technology. The author mentions the possibility that we can take advantage of those negative aspects to achieve creative design.

The cultural excitation is useful when discussing effective support of the discovery of underlying social issues behind communities, by the local designers. The concept of the cultural excitation is inspired by the work of the cultural probe proposed by Gaver [9]. The cultural probe is a package including materials, such as maps, postcards and cameras, to be handed to the people in the local community, in order to support the collection of data by the local people. The objective of the cultural probe is to promote deeper understanding of the local context and people, which are unfamiliar to designers and artists.

The cultural excitation also aims to observe and understand local context by the interaction with objects and users. The difference between the cultural probes and the cultural excitation is described in the following two aspects. First, our concept deals with engineering design and goals to create machines, therefore, the objects for observing local context is artificial created by local designers. Second, the observer of the interaction between users and objects are local designers, who also belong to the same community.

2.2 Related work

In this section, the author clarifies the scope of the thesis by comparing with preceding research. First, the author introduces the existing problem solving products in developing countries, of which the targets are related to this thesis. Second, the research on methodology for designing products for developing countries is described. Third, the author mentions the significance of the prototyping, in view of needs discovery. In addition, the author introduces the conventional research in the creativity support, which clarified the effect of the constraints in the creative design. Finally, based on the research on design theory and methodology, the author describes the focus of the thesis, which is the utilization of local knowledge among the designers.

2.2.1 Appropriate technology

A lot of products of the appropriate technology have been invented and currently in use [2]. For example, a solar cooker is a device to generate heat using solar power as an energy source. People can make the reflector of the solar cooker with an unused parabolic antenna, which is an example of using materials in a different way.

Other example is a hydraulic ram, a kind of water pump which can lift the water to a higher point without any external energy source. The hydraulic ram is intriguing since it is based on the water hammer, a simple principle of fluid dynamics. Each of these products is designed by the person who has expertise in a certain technical domain. However, this approach is not effective where there is small number of people who have the technical background or appropriate domain knowledge. Therefore, the author aims to involve more local people in the design of such products. In this perspective, some successful products designed by ordinary people in South Asian countries have got attention. These products are called as frugal innovation or Jugaad, which means a creative problem solving with improvised arrangements [10]. For example, a hand-made vehicle was invented by local inhabitants using the agricultural water pump.

Although there are such cases of the design by local people, there seems to be little research on the design methodology and the support system for it. In this thesis, the author attempts to clarify the requirements for supporting such local designers.

2.2.2 Design methodology for BoP

The importance of designing products for the people in the developing countries has been widely accepted in 2000s. The most influential trigger to get attention to this field is the base of the pyramid (BoP) concept introduced by Prahalad and Hart [11, 12]. They point out the possibility that multinational corporations can achieve making a profit and reducing poverty at the same time through their own business. Through the modification against criticisms, Simanis et al. eventually focused on a collaborative aspect in BoP business, which is described as working with the poor, rather than selling to the poor [13]. The BoP concept was epoch-making because it made the international business sectors turn their attention to local markets in developing countries, where the organizations of the development aid are supposed to take care.

Preceding research done by Castillo et al. proposes a framework for the development of design projects for the base of the pyramid (BoP) [14]. Castillo et al. compared several methodologies by clarifying differences between each approach as shown in Table 2.2. Although design methodologies described in Table 2.2 are useful since they utilizes multiple techniques to comprehend the needs in the community, there is still lack of perspective, which is the design by local members in the community. Based on the insight from existing methodologies, the author attempts to establish a design method that achieves discovery of the needs in the community and manufacturing the product at the same time.

2.2.3 Prototyping for creating ideas

As mentioned earlier, one of the key issues of creating problem solving products is to identify the needs of local people correctly. Some studies clarified the effectiveness of the prototyping for discovering the personal needs. Lim et al. proposed an unique prototyping method called Discovery-Driven Prototyping (DDP) that can promote discovery of underlying issues of individuality [15]. Kelly also mentioned the importance of the prototyping in the problem solving [16].

Although the prototyping of hardware has taken a long time, the recent developments of the fabrication tools drastically changed the environment around amateur creators. For example, a 3D printer enabled the production of the plastic parts with less cost and time. With a laser cutter, the creators can cut the wooden or acrylic board in precise dimensions. Moreover, the micro controller board, such as Arduino, enabled users to prototype the electronics much easily [17]. Using such micro controller boards, users can try various combinations of sensors and actuators to explore the design solution.

It is important to support both conceptualization and manufacturing in the design process, since the targets of the thesis are local designers, who usually do not have much knowledge and experience in design and manufacturing. In this thesis, the author proposes a design framework focusing on the utility of the prototyping, and implements the support system utilizing digital fabrication tools effectively.

2.2.4 Creativity support

Boden described the three forms of creativity [18]. The first one is the combination of familiar ideas in unfamiliar ways. The second and third are the exploration and the transformation of conceptual space. Gero divided the design into the three types: routine design, innovative design and creative design [19]. Their arguments seem similar if the creative design is defined as the transformation of conceptual space. Finke et al. discussed the creative activity based on the psychological experiment [20]. They proposed geneplore model, which demonstrates that the creative process is a cyclic process, which consists of generation of preinventive structure and preinventive exploration and interpretation.

Although such theoretical research and the laboratory experiments exist, there are a small number of practical studies on how to assist local designers to make the problem solving products in developing countries. In this thesis, based on preceding studies, the author proposes a design method, which promotes the exploration of the design space through the continuous prototyping.

2.2.5 Design theory and methodologies

Design theory and methodologies(DTM) have been researched according to the rising interest for understanding engineering design. Tomiyama et al. listed existing design theory and methodologies(DTM), which are utilized for the educational and industrial purpose, as shown in Table 2.1. The DTM listed in Table 2.1 are generally for the professional engineers in the industry, or the students in training to be engineers.

Table 2.1: Category of DTM by Tomiyama [21]

	General	Individual
Abstract	Design theory (GDT, UDT)	Math-based methods – optimization – Axiomatic Design – Taguchi Method Computer programs
Concrete	1. Design methodology – Adaptable Design – Characteristics-Properties Modeling of Weber – Contact and Channel Model of Albers – Emergent Synthesis – Hansen – Hubka and Eder – Integrated Product Development of Andreasen – Koller – Muller – Pahl and Beitz – Roth – TRIZ – Ullman – Ulrich and Eppinger 2. Methodology to achieve concrete goals – Axiomatic Design – Design for X – Design Decision-Making Methods – DSM – FMEA – QFD – Total Design of Pugh	Design methods

General	Individual
3. Process methodologies – Concurrent Engineering – DSM	

Tomiyama et al. mentioned that existing DTM research shown in Table 2.2 has several insufficiencies as follows.

- Consideration of multiple stakeholders with different cultural and educational background
- Considerations about product complexity and multi-disciplinarity
- Consideration of increasingly complex requirements
- Management of complex product development processes
- Further integration of domains
- Integration of advanced ICT technologies for computer oriented design methodologies and better collaboration
- Consideration about globalization trends that requires advanced virtual engineering and collaboration methods

Among those challenges, the author focuses on the first one, which is the consideration of multiple stakeholders with different cultural and educational background. Especially, the author focuses on how the local knowledge of the designers of different backgrounds can be utilized. In the proposed method, local designers are expected to manufacture products with such local knowledge, collaborating with other designers.

Table 2.2: Synthesis of four different methodological approaches for the BoP by Castillo et al. [14]

Method	D4S (UNEP, 2009)	HCD toolkit (Ideo, 2009)	BoP Protocol (Hart, 2008)	Market Creation toolbox (BIDD, 2011)
Objective	Product and PSS creation for emerging markets	Creating solutions for the BoP	Co-invention and business co-creation in partnership with BoP communities	Business model development for emerging markets
Focus	Sustainability and business creation	Human centered design	Co-creation and mutual-value building	Participatory market research
Main Steps	1. Policy formulation 2. Idea finding 3. Strict development 4. Realization and follow-up	1. Preparation 2. Hear 3. Create 4. Deliver	1. Pre-field process 2. Opening up 3. Building the ecosystem	1. Rapid market assessment 2. Understanding end-users 3. Determining the distribution system 4. Pricing and financing 5. Marketing and communication 6. Service and maintenance
User context research tools		1. Individual interview 2. Group interview 3. In context immersion 4. Self-documentation 5. Community-driven discovery 6. Expert interviews 7. Participatory co-design 8. Emphatic design	1. Participatory workshops 2. Role playing 3. Group field visits 4. Action learning 5. Social and institutional mapping 6. Participatory photography	1. Deep dialogue 2. Self documentation 3. Activity map 4. Social map 5. Ranking values
Sustainability Tools	1. Benchmark 2. D4S Impact matrix 3. D4S strategy wheel 4. Life cycle assessment 5. Sustainability SWOT 6. Sustainability guidelines 7. Sustainability radar			
Design tools	1. Morphological box 2. Brainstorming 3. System maps 4. Blueprints	1. Personas 2. Brainstorming 3. Prototyping 4. Innovation pipeline	1. Prototyping 2. Brainstorming	1. Follow and observe 2. Learning by doing 3. Scenarios 4. Prototyping 5. Concept assessment
Market assessment tools	1. SWOT analysis 2. Innovation funnel 3. Bricolage 4. Business plan 5. List of specifications	1. Viability assessment 2. Implementation plan 3. Learning plan	Community contests	1. Resource flow 2. Costumer Segmentation 3. Price mapping 4. Product in market

Chapter 3

Requirements analysis

In this chapter, it is described that the requirements for supporting local designers to create problem solving products. Generally speaking, local designers in developing countries are supposed to face following issues.

- Difficulty to identify local problems
- Constraints of the environment
- Lack of design and manufacturing knowledge

The author clarifies the requirements of the proposed method, in view of solving the issues mentioned above. First, regarding the identification of local problems, the author mentions the importance of generating ideas that reflect local context. Moreover, the utilization of prototyping for discovering fundamental needs is explained. Second, the author describes the requirements of changing in mindset for handling the constraint. The author explains that the constraints of environment do not always cause problems, but also work as triggers for finding creative solutions. Third, the author mentions the importance of the knowledge base that support local designers who do not have expertise. In addition, the necessity of integrating design process is also stated.

3.1 Generating ideas reflecting local context

The significance of considering local context is apparent to achieve problem solving by local designers. In this perspective, the approach of this thesis has an advantage, because local designers are expected to be understanding their own situation much, compared to external designers.

In this section, the author introduces an example of such creative ideas identified by a person in a community. In 2013, the author conducted a workshop intended for students majoring industrial design in Bohol Island State University (BISU). At that time, a large earthquake had brought serious damage to the island. The objective of the workshop was to discuss the idea of the product, which can be utilized for the relief activity. In the workshop, the participants were divided into groups and encouraged to come up with ideas of products as many as possible. Finally, the participants chose favorite ideas and draw sketches of them. As a result, the author observed a lot of interesting outputs from the participants. Above all, an idea of a device named solar head massage vibrator was striking. The sketch of the product is shown in Figure 3-1.

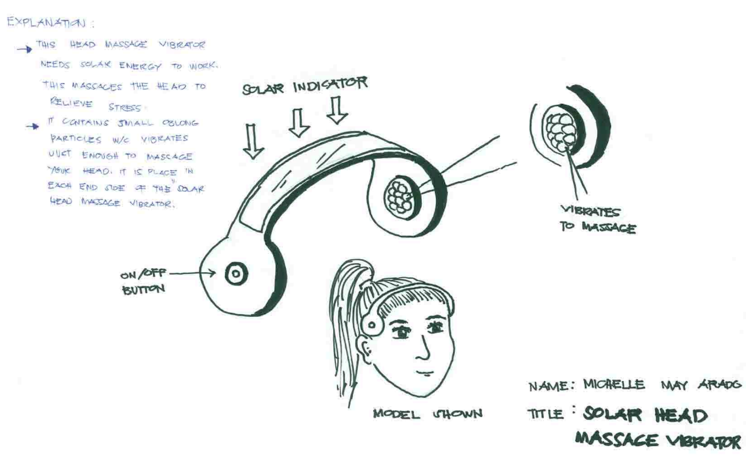


Figure 3-1: Solar massage vibrator

The female student who invented this idea explained its function as follows.

> This head massage vibrator needs solar energy to work. This massages the head to relieve stress. It contains small oblong particles with vibrating

> just enough to massage your head. It is placed in each end of the solar head massage vibrator.

It is reasonable that she proposed to use solar energy for the device, because the earthquake caused power failure in the area. Moreover, she intended to reduce stress with massage, which is a common recreational activity in the Philippines.

Although such a creative idea that reflects local context was discovered, the author points out a defect of the method used in the workshop. The process of generating ideas did not consider the actual implementation, since it was discussion-based activity. In this research, the author proposes the design framework that also considers the feasibility of manufacturing by local designers.

3.2 Identification of needs through prototyping

It may seem easy for a local designer to identify the needs in a community, and no special design method is necessary to identify the needs. However, from the experience in the past project, the author has an insight that a design method is required not only for external designers, but also for local designers. In this section, the author illustrates how the prototyping can be utilized to elicit hidden social issues.

The author engaged in a project with an educational Non-Governmental Organization (NGO) in Bangladesh for four months in 2010. The goal of the project was to enhance the educational quality at a farm area in Bangladesh. After survey including fieldwork at schools in various locations, the author decided to develop an educational material of science experiments movie for enhancing the educational quality at a farm area in Bangladesh. To test the effectiveness of the educational material, a pilot movie was shot with the help of teachers and students in a top-level high school in Bangladesh. A screen shot from the pilot movie is shown in Figure 3-2.

In spite of expectations, the quality of the movie was not acceptable, due to the lack of safety instruction by a teacher. In fact, as shown in Figure 3-2, a student was injured by dipping his fingertip into the sodium hydroxide solution. Although the result was disappointing, it was an interesting discovery in a different perspective,

Figure 3-2: Science experimental movie shot in Bangladesh

because no one in the local NGO was suspicious of the quality before shooting the pilot movie. Based on the discovery, the author gained insight that making the prototype enabled the designers to realize the hidden problem, which was the less awareness of safety education. Not only that, the author also observed another interesting event. One of the members in the NGO proposed to reuse the movie as an educational material not for students but for teachers, in order to enlighten teachers about the importance of safety instruction. Such transformation of the educational material is shown in Table 3.1.

Table 3.1: Exploration of underlying issues

Design phase	Problem	Prototype
Initial phase	Low quality of science education caused by shortage of teachers Lack of experimental facility	Science experimental movie for students in rural area to improve science education
Second phase	Lack of awareness for safety education	Educational material for teachers to enlighten importance of safety education

The observation shown in Table 3.1 is regarded as an example of the transformation of the original purpose to a different one. In this way, the author proposes to utilize the prototyping to elicit underlying issues, which are not obvious at the initial phase in the design process.

3.3 Considering limitation of materials

In general, manufacturing resources, such as materials and tools, are limited in the developing countries. These constraints sometimes make designers give up using specific material.

However, the limitation of materials sometimes promotes designers to come up with an innovative way of solving problems. For instance, the Jaipur Foot, a prosthetic foot developed in India, uses locally available rubber which satisfies various requirements from users at the same time, such as resemblance to the appearance of normal human foot, durability, waterproofness, and affordability [22]. The product diffused from India into parts of the world, which is opposite of the conventional technology dissemination. Recently, the movement of these inventions is referred as the reverse innovation [23]. This example shows that the designers can take advantage of the negative aspect, which is the limitation of materials, to find out the innovative solution.

3.4 Knowledge base of design and manufacturing

This research is expected to cover a broad range of products, since the proposed design framework lets local designers find novel issues to solve during the design. In this situation, knowledge base of design and manufacturing is required, although the targeted designers have a certain amount of engineering knowledge. The author categorizes required knowledge base as follows.

First, the knowledge base ought to provide engineering knowledge. This includes not only the design method on specific artifacts, but also the design data. As a typical example of the design data, schematics of the electronic circuit and 3D data drawn by CAD software are mentioned. In addition, it is also important to actively utilize the resources shared over the Internet. The open source software and hardware have made it possible to reduce cost, time and human resources of product development. The online platform for sharing documents of do-it-yourself projects, such as Instructables, enabled users to share the knowledge of design and manufacturing [24]. On the other hand, the author notes that providing fragmentary knowledge for local designers is not sufficient. The knowledge base also needs to support the utilization of the knowledge, such as how to combine the domain knowledge.

Second, the knowledge base for locally available resources is also required. The past experiences of the author show that it takes much time to create products, especially in developing countries. It is due to the lack of resources, such as materials, manufacturing tools and facility, and infrastructure. In order to reduce the time for prototyping, it is important to amass the information of such resources.

3.5 Integration of design process

In this section, the author explains the significance of integrating design process for the design by local designers. Pahl et al. described a typical engineering design process that is comprised of following processes: planning and task clarification, conceptual design, embodiment design and detailed design [25]. The author showed such a design process in Figure 3-3, simplifying the original figure.

The design process shown in Figure 3-3 is a basic process of engineering design. In Figure 3-3, there are feedback paths inside the design process, such as paths that return back to design specification. However, the author points out that there is no feedback to the task clarification or planning process. It is reasonable, in an enterprise for instance, the engineering department and marketing department are

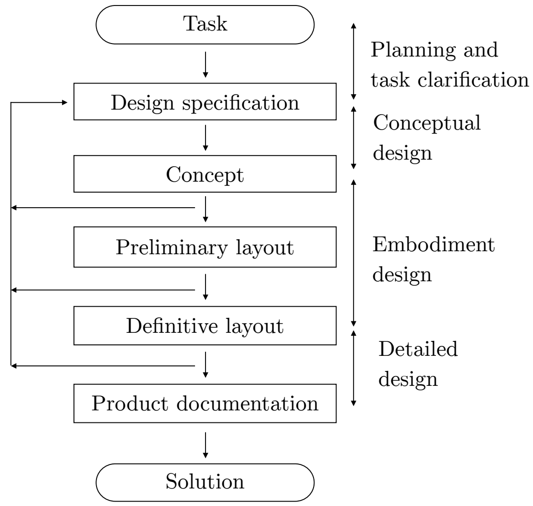


Figure 3-3: Conventional engineering design process by Pahl et al.

usually separated. In Figure 3-3, the task is supposed to be decided by the marketing department, therefore, there is no need for the engineering department to consider the given task itself.

However, the target of the proposed method is the local designers, who are supposed to both identify the problem and implement the prototype. Thus, the author argues that the integration of the prototype is required. The author shows the diagram of the integrated design process in Figure 3-4.

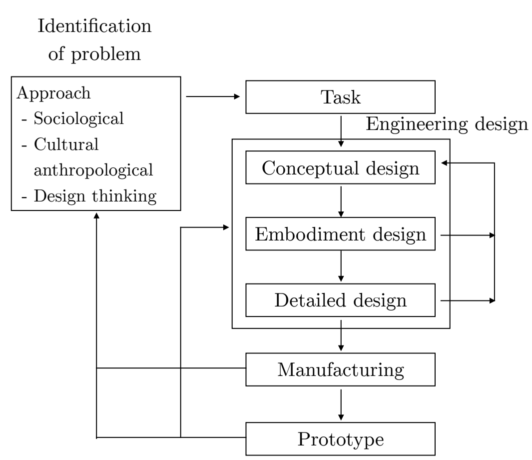


Figure 3-4: Integration of design process

Compared to Figure 3-3, the elements, such as identification of problems, manufacturing, and prototype, is added in Figure 3-4. Figure 3-4 indicates that the local designers engage in the whole activity, such as to identify the problem, design with engineering knowledge, and manufacturing a prototype. Moreover, the feedback paths are connecting each activity. That is what the integration of the design process means.

Chapter 4

Design framework

In this chapter, the author proposes a design framework considering the requirements discussed in the previous chapter.

To establish a design framework, the author starts with following hypotheses.

1. The hidden social issue can be elicited by creating a prototype and getting feedback from the users

2. The creative solution can be found by tracing back to the superordinate concept

3. The negative constraints can be triggers to find alternative solutions

First, the author focuses on the role of the prototyping, which can assist the discovery of underlying needs in the community. Second, based on the existing examples of appropriate technology, the author assumes that considering superordinate concept is helpful for finding creative solutions. In addition, as described in the previous chapter, the author notes that the designers can take advantage of the constraints to explore alternative solutions.

Based on such hypotheses, the author introduces design space model. The description of the design process with the design space model enables designers to consider the superordinate concept and constraints systematically. Subsequently, the author describes the significance of transformation of the design space, taking the cases of appropriate technology as examples. Finally, the author explains the overall process of the proposed design framework.

4.1 Definition of design space

Conventional design studies provided several ways for describing design space to discuss design process. For example, Maher et al. presented the co-evolution model, which described the design exploration as the interaction of problem space and solution space [26]. In the proposed design method, the design space is defined as the diagram shown in Figure 4-1. The author gives explanations for each design space shown in Table 4.1.

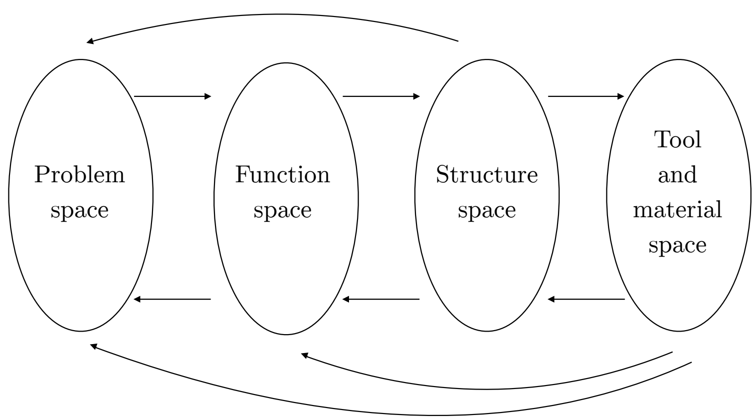


Figure 4-1: Design space

Table 4.1: Definition of design space

Design space	Description
Problem space	The problems that designers work to solve, in other words, set of the total needs of end users
Function space	Required functions of designed artifacts
Structure space	Mechanical structures and parts based on the required functions

Design space	Description
Tool and material space	Available materials and manufacturing environment, such as machine tools

The problem space consists of the needs of the product users. The function space involves the required function of the products. The structure space is the collection of the entities which materialize given functions. The tool and material space represents the whole available materials and the facility of manufacturing, such as machine tools. This separation concept is similar to the design model proposed by Suh [27]. In particular, the author focuses on the feedback from the tool and material space to the other spaces, which the author believes is the unique feature of production in the developing countries. Due to the limited resources, the exploration of the suitable structure is regulated by the locally available materials. The author uses this design space model to discuss the transformation of each space during the design process.

4.2 Dynamic transformation of design space

The main focus of the proposed design method is to transform the design space dynamically by the iteration of the prototyping. Here, the author explains how such transformation occurs with possible scenarios based on examples of the appropriate technology. First, the author takes a case of the Q Drum for example. Figure 4-2 shows the design space when the proposed design framework is applied to the design of the Q Drum.

As shown in Figure 4-2, in the proposed design framework, an issue to solve is identified in the problem space initially, which is the entry point of the design. In this case, the target problem is the accessibility to the water in an inland area. Subsequently, required functions are defined based on the problem. The function, which is carrying the water readily, is separated into the sub functions, considering

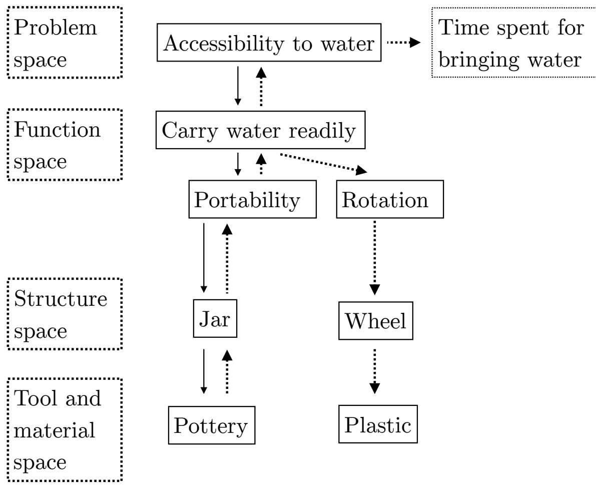


Figure 4-2: Design process of Q Drum

the correspondence with the structure space. The structure space describes entities which materialize the given functions. Finally, the materials are defined considering resources that are locally available. Such a design process is described with the solid arrows in Figure 4-2.

The dynamic transformation of the design space is triggered by several factors. For instance, to fulfill the function of portability, the water jar made by pottery is suggested. However, focusing on the superordinate concept of the portability, which is the easiness of carrying water, users can notice that the rotation can also actualize the same super function, since the revolving movement reduces the friction against the ground. When such a sub function is newly identified, the designers can explore the structure space and material space, which eventually reaches to the utilization of a plastic water tank of torus shape that can store the water and be carried by its rotation. This is regarded as the exploration of the design space by focusing on the superordinate concept in the function space. This process is shown in Figure 4-2 using dashed arrows.

Feedback from users for a prototype can also makes designers explore the problem space. If the task of bringing water becomes easy, users may notice that too much time has been consumed for the task, which causes children not to have enough time for study. With the realization of such a meta problem, the designers can start the discussion for the next design.

The author describes another example of the solar cooker. Figure 4-3 shows the design process of the solar cooker with the proposed design framework as in the previous example.

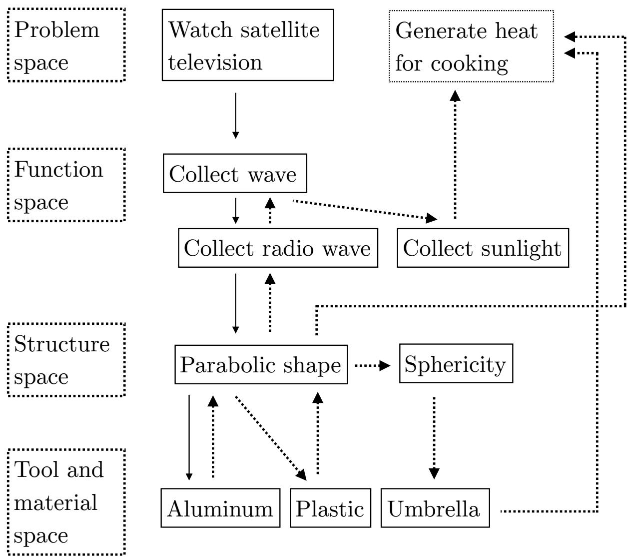


Figure 4-3: Design process that links to a solar cooker

In this example, since the author would like to show a case that the creation of a solar cooker is decided ex-post facto, the initial problem is defined as watching satellite television. Although this problem definition is based on a descriptive purpose in a way, it is common needs in rural areas in developing countries. After the definition of the initial problem, required function is identified as collecting radio waves, which belongs to the super function of collecting waves. Subsequently, the structure space is described according to the sub function, followed by the decision of material. Finally, the process shown with solid arrows in Figure 4-3 identifies an object with parabolic shape, that is to say, a parabolic antenna.

The design process in the diagram induces exploration of the design space. For instance, a designer can notice the function of collecting an electromagnetic wave includes sub function, which is collecting sunlight. This realization can bring about the novel finding that, for instance, a parabolic dish works as a solar thermal collector. The finding enables the designers consider to utilize the parabolic antenna for generating heat for cooking in the unelectrified area. The process is shown in the dashed arrows in Figure 4-3,

In addition, another type of the transformation is promoted by a focus on the constraints of resources. Interestingly, as the author mentioned the uniqueness of the tool and material space, the tool and material space can affect the problem space directly. When the appropriate material is not available, designers can notice that the frame of an umbrella may be able to be utilized for building the structure, by an analogy of the parabolic shape. In this way, the change of the design space in the lower layer makes an effect to upper layer in design space.

4.3 Rapid prototyping spiral

In this section, the author focuses on how the transformation of the design space can be achieved effectively. To promote the dynamic transformation of the design space, the author proposes the design framework utilizing quick iterations of prototyping, which is called as the *rapid prototyping spiral.*

The author uses the term prototyping in the broad sense. The prototyping in the proposed design framework is comprised of the following processes.

- Identification of initial needs
- Expansion of required functions to sub functions
- Decision of structure and material
- Manufacture of a prototype by combining functional elements
- Gain feedback from users through user test

- Discovery of a novel issue considering the feedback

The significance of the prototyping is described in the design field from various perspectives. For example, Thoring et al. mentioned that the iteration of prototyping enables designers to find the next problem, while explaining the process of the design thinking [28]. In Figure 4-4, proposed design method is compared with the process of the design thinking by Thoring et al.

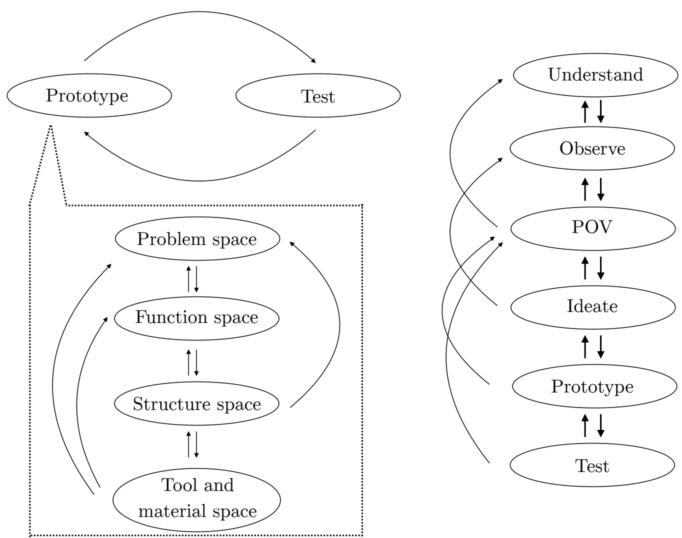


Figure 4-4: Rapid prototyping spiral compared to the design thinking (used the figure from HPI D-School as reference [28]

In Figure 4-4, the left part shows rapid prototyping spiral, and the right side represents the process of design thinking. As shown in the figure, the author proposes to start the design process from prototyping. The reason the author changed the order in the design process is that the author focuses on the following three aspects, which should be considered when assisting local designers in the developing countries.

- Limitation of materials
- Intrinsic motivation
- Production of practical products

First, due to the limitation of materials, local designers may not be able to manufacture products with the materials required in the ideal design. In the proposed method, by starting the design process from prototyping, the designers are promoted to focus on the material space, which lets the designers to explore unexpected use of materials. Second, the author expects that the continual process of the materialization motivates the local designers, and such motivation enhances the creativity in the design process as indicated in the conventional research [8]. Third, the problem solving in the developing countries requires not the conceptual but the practical outputs as materialized things. Although the prototype of the proposed design method is expected to work as a probe in the design space, it is also aimed to be used as the real solution at the same time.

Chapter 5

Support system

In this section, the author describes the detail of the support system that is utilized for the design with the proposed design framework. The author proposes an interactive system named as design space explorer, which enhances creative activity of designers. With the system, designers can organize the design and manufacturing knowledge, based on the design space model proposed by the design framework. Subsequently, the tools to enable rapid manufacturing is explained. First, mechanism module is proposed to assist the design of mechanical structure. Second, electronic circuit module is also explained, which supports the prototyping of electronic circuit boards.

5.1 Design space explorer

Design space explorer is an interactive system to support the design using the proposed design framework. The system aims to integrate visualization of design process and knowledge base of design.

Design space explorer supports the users in the following perspectives.

- Visualize design space

- Search design data and manufacturing knowledge
- Elicit underlying issues

The author implemented the system in the form of a web-based application, as shown in Figure 5-1.

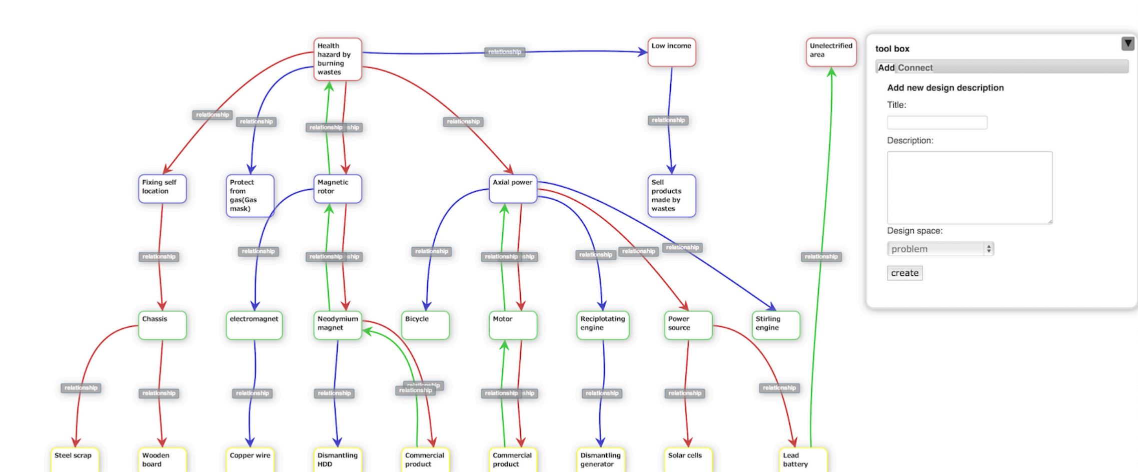


Figure 5-1: Design Space Explorer

The author describes the design flow for using the design space explorer, as shown in Figure 5-2.

First, based on the design framework explained in the previous chapter, designers start the design by defining the initial problem. Subsequently, the designers are supposed to describe sub design space, such as function, structure, and tool-and-material space. The designers are promoted to add all those description as nodes, and connect each node by arrows as edges. The designers can attach meta data to each node, such as detailed description, design data, and tags. When the designers face on a trouble for designing, such as constraints of materials, the designers are expected to explore alternative solutions focusing on the superordinate concepts. The designers can also search past design knowledge, for instance, locally available materials. For this purpose, the meta data mentioned above are utilized. The designers keep updating the description of design space through the process of manufacturing prototypes.

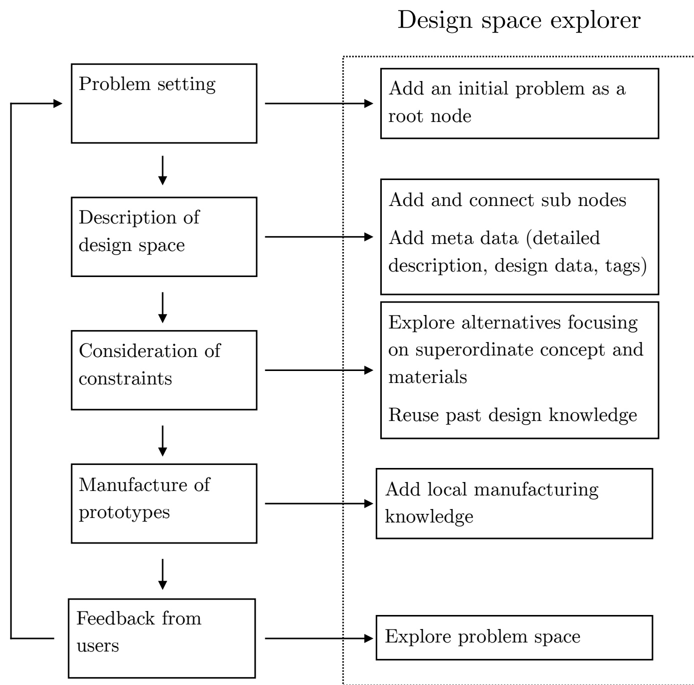


Figure 5-2: Design process with design space explorer

When manufacturing prototypes, the designers are supposed to describe local manufacturing knowledge, which will be reused in other designs. After creating prototypes, the designers observe feedback from users of the created products. According such observation, users explore the problem space to discover unnoticed problems in the beginning. In this way, the cyclic design process is iterated.

The advantage of using this system is that the designers can not only explore the design space systematically, but also create their own knowledge base that can be reused in the future design. Figure 5-3 shows how the local knowledge added by the designers can be reused.

As shown in Figure 5-3, the designers can describe the design knowledge found in the design process, as the annotation for each node. For reusing such local knowledge, the designers can utilize tags for attaching meta data to the description. The system of reusing knowledge is explained with the following example. The author supposes that a designer designed a solar cooker, and he left the description for the finding in

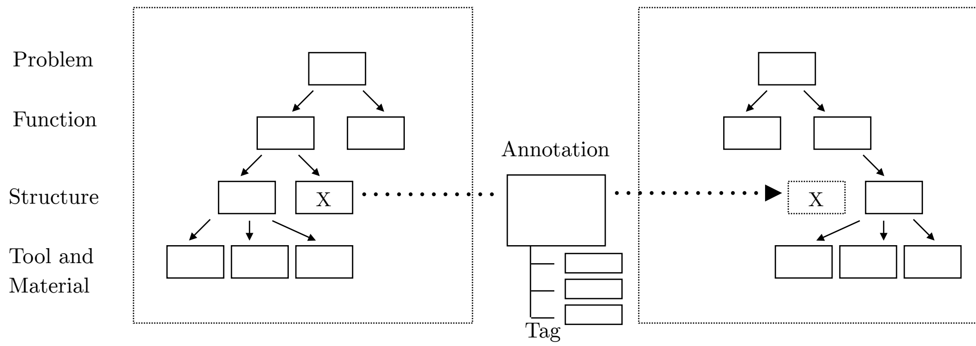


Figure 5-3: Reuse of knowledge

the design, which the parabolic antenna can be utilized for generating heat. In the next project, when the designer considers to design a Stirling engine as the power source of a generator, the designer results in realizing the necessity of heat source to operate the Stirling engine. In this situation, the designer can come up with the idea of combining the solar cooker and the Stirling engine, by searching the knowledge base using the associated tags, such as heat.

5.2 Mechanism module

The core concept of the mechanism module is a design by combination of prepared units associating with specific functions. Each of the modules is implementation of a mechanism, such as link mechanism and crank mechanism. The primary objective of preparing mechanism module is to enable the designers to create prototypes rapidly.

A mechanism module is represented by a 3D drawing data created with 3D CAD software, considering the rapid manufacturing. The mechanism module is prepared as the 3D data, since the designers are expected to utilize digital machine tools, such as a laser cutter and a CNC milling machine. The designers are supposed to use such data as templates, and modify the data to adjust the dimension and the detailed structure to be suitable for each situation. The author selected a CAD software for creating mechanism modules, which is used in a technical high school in Ghana, where the experiments are carried out.

The typical mechanisms are shown in Table. 5.1

Table 5.1: Category of mechanisms

Category	Example
Fastener element	Screw, key, spline, cotter pin, rivet, snap ring
Transmission element	Shaft, shaft coupling, link gear, friction wheel, gear wheel, cam, belt drive system (plain belt, V belt, rope, chain), hydraulic cylinder, fluid coupling
Seal element	Static seal (gasket), dynamic seal (packing, reciplocating seal, rotary shaft seal)
Buffer element	Brake, dumper, flywheel
Fluid transmission element	Pipe, pipe coupling (screw coupling, flange coupling, welding coupling, valve (flow control valve, direction control valve, pressure control valve)
Lubrication element	Bearing (ball bearing, plain bearing, oiling device)

As one of examples of mechanism modules, a 3D data which represents a lead screw mechanism is shown in Figure 5-4.

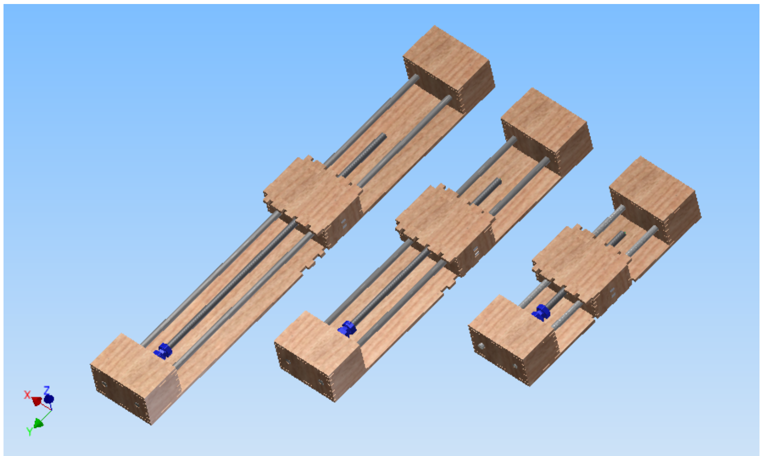


Figure 5-4: Example of lead screw mechanism module

In addition, a three-axis slide table which is made by the mechanism module is shown in Figure 5-5.

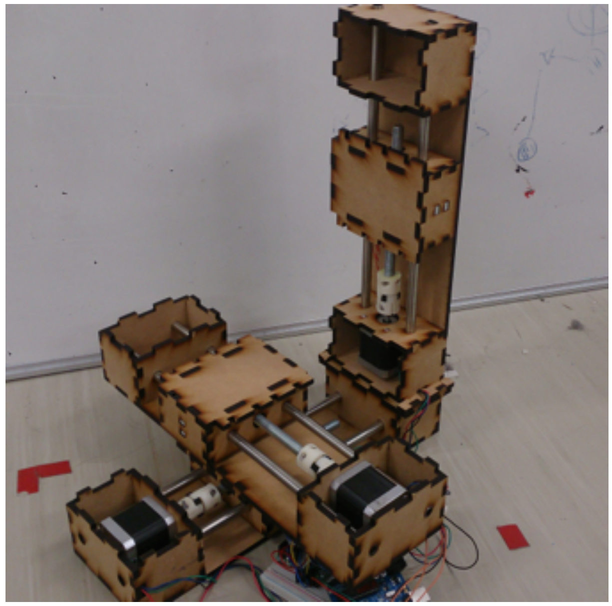


Figure 5-5: A prototype created with mechanism module

The prototype shown in Figure 5-5 was designed for creating a small Computer Numerical Control (CNC) milling machine. This example expresses the feature of design using mechanism modules. As seen in Figure 5-5, the three-axis traverse mechanism is achieved by combining the same mechanism modules of lead screw. In fact, the shape of the prototype is different from the gantry-type CNC machine, which is the ordinary design of the CNC machine. Although the design is redundant in the perspective of achieving required function of the CNC machine, it has an advantage of reducing time spent on design and manufacturing. Moreover, the design by combination of mechanism module enables designers to reuse the component to other design. The mechanism module of a lead screw can be used for other products that require the function of reciprocating movement.

It is difficult to choose and prepare all the modules for any situations in advance. Therefore, the author aims to increase the kinds of modules, during the design process, considering a reusability in the future design.

The process of adding new modules is also significant for the design of products that can adapt to the situation in developing countries. It is explained compared to an idea of bricolage, which is introduced in the cultural anthropology [29]. Bricolage is defined as the process of developing novel solutions by making use of previously unrelated knowledge or resources that already exist in the society. Such activities are often seen in developing countries, where the designer faces severe limitations of resources. In this context, the author also introduces the finding of a curious manufacturing activity reported by Morita, based on the fieldwork in the small factories in Thailand [30]. Morita mentioned the farm truck called as *rot i-taen*, which was a locally-made vehicle produced by local engineers utilizing the farm engine. The rot i-taen was unique since it could change its own shape into several machines depending on the situation, such as a tractor, an irrigation pump, and a generator. From such a feature, Morita defined those machines as the *fluidic machines*. The author analyzes that the local engineers could design such a multi-purpose machine focusing on the reusability of the component. Similarly, the author believes that the design by mechanism module enables the designers to try various combination of the modules, which can finally lead the solution that adapts to the local context.

In addition, the utility of the mechanism module is explained compared to the concept of liquidization and crystalization in the creative activity, proposed by Hori [31]. The liquidization process is to decompose the information or knowledge into the pieces, and crystalization process is combining those separated knowledge to create a novel value. In the liquidization process, the knowledge is released from the contexts which constrain it, and restructured dynamically in the crystalization process. On the other hand, in the design process of mechanism modules, a mechanism is extracted being separated from original contexts. In this way, the design by mechanism module also aims to release the designers from initially addressed problems, and promote to find unexpected usage of the products.

5.3 Electronic circuit module

The design by electronic circuit modules has a similar concept to the design using mechanism modules. In this case, the core units are the circuit boards, which have specific and minimal function. In the design using the electronic circuit modules, designers are promoted to create a prototype combining those circuits according to the required functions.

Figure 5-8 shows an example of combining circuit modules.

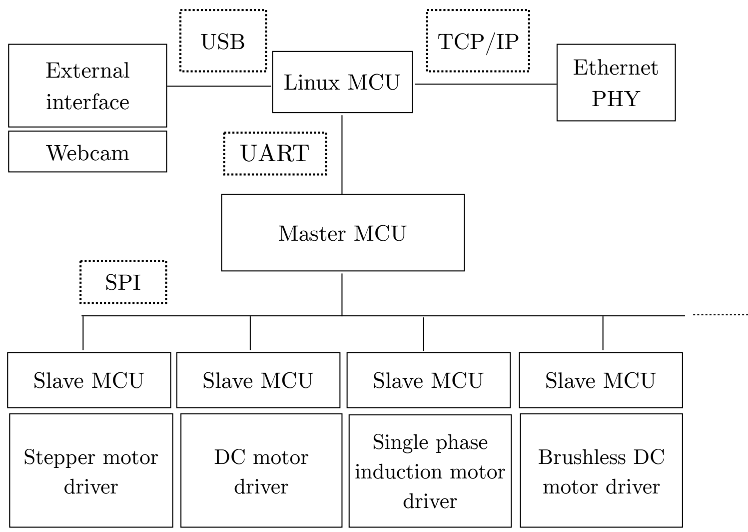


Figure 5-6: Combination of electronic circuit modules

In Figure 5-6, two types of circuit boards are described. As shown in the figure, some circuit modules are connected around a central module, which is called as a central Micro Controller Unit (MCU). The central MCU controls peripheral circuit boards around it. Those peripherals are named as slave MCUs. which have one micro controller board on it, As mentioned above, various functions are expected when designing slave MCUs, such as driving a motor, obtaining a value from a sensor, send a signal to communicate with other circuits, and supplying power. However, in the experiment, the author will focus on motor drivers, such as a stepping motor driver or a DC motor driver, considering the priority and necessity in experiments.

The unique feature of this circuit modules is that each board has a micro controller on it. This seems redundant in terms of a number of required parts, however, the author uses this method because this system enables rapid customization of the modules. One of the problems of the electronic components, such as sensors and motor driver ICs, is that the communication protocol differs depending on each component, When customization of the modules, it is troublesome for the designer to check the protocols in each case. On the other hand, in the proposed method, once a circuit module is developed, the designers can concentrate on modifying the firmware of the micro controller. In particular, the designers only have to modify the part of serial communication with other boards. In this sense, the micro controllers on each board provide common interface of the communication.

An example of implementation is shown in Figure 5-7. In this example, eight bit micro controllers are used as MCUs.

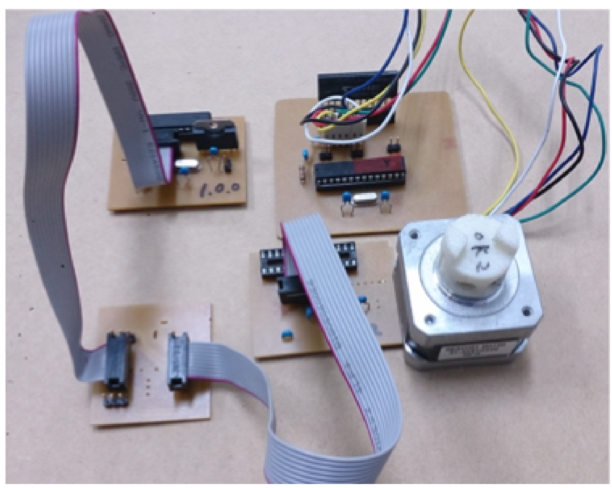


Figure 5-7: Example of circuit module

The actual design process using circuit modules is shown in Figure 5-8.

As shown in Figure 5-8, the design process has two branches. When the required function can be achieved by the existing modules, the designers only have to select the appropriate modules and implement them. On the other hand, if the existing modules do not cover the required function, the designers are supposed to design the

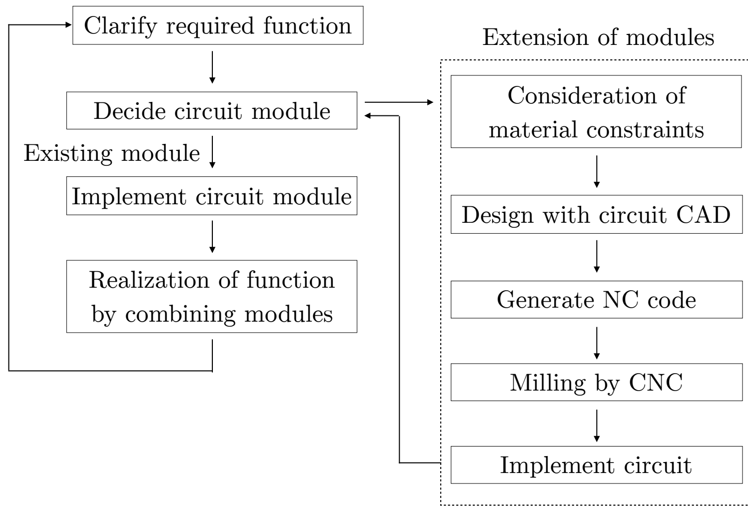


Figure 5-8: Design process using an electronic circuit module

novel modules.

Another feature of the proposed module is that it utilizes the single sided circuit board. If the designers use double sided board or multi-layer board, it enables the designers to implement complex circuit compactly. However, the focus of the method is to support the manufacturing by local designers. Considering the local situation, to manufacture circuit modules, the proposed method utilizes a small CNC milling machine at the school in Ghana, where the experiments are conducted. Since there is difficulty for milling double sided boards with the milling machine, the circuit modules are manufactured using single sided boards.

There are numbers of research for module-based design of the electronic circuit. For example, Villar et al. proposed .Net Gadgeteer to support prototyping to enhance the creative design of gadgets [32]. Bilkstein et al. invented Go go board to support the students to learn electronics through the prototyping [33]. The differences between such existing research and the proposed method are as follows.

- Feasibility of manufacturing by local designers
- Extendability of modules

First, the preceding cases do not take notice of the aspect of local manufacturing, since those studies focus on the process of combining products. The proposed method guarantees the designers to manufacture the circuit boards by themselves. This is particularly important in developing countries, where the commercial products of the circuit modules are not available. Second, although it is related to the former, the proposed method aims to support the designer to extend the modules by themselves. As described earlier, by putting a micro controller on each board, the proposed method enables the flexible customization of the modules.

Chapter 6

Experiment

To evaluate the proposed design framework and support system, the author carries out three experiments. The experiments are listed in Table. 6.1.

Table 6.1: Comparison of experiments

	Period	Target	Summary	Prototype
Exp.1	August - September, 2012	Teachers in the Takoradi Technical Institute	Design of an eddy current separator to solve e-waste problem	Eddy current separator Alarm clock
Exp.2	May - June, 2014	Students in the Takoradi Technical Institute	Evaluation of prototyping comparing with ideation through workshop	Metal detector Power meter Water meter CNC plasma cutter IP camera
Exp.3	July - August, 2014	An engineer in the Kumasi Polytechnic	Modification of a fufu pounder	Fufu pounder

The author clarifies that there are two kinds of objectives in the experiment. The first one is the objective of the author. The primary objective of the author is to test the following hypotheses with the design framework and support system.

- Transformation of the design space by rapid prototyping spiral promotes discovery of novel ideas
- Considering superordinate concepts leads to find creative solutions
- Negative aspects, such as constraints of materials, can be triggers of creative problem solving

The second one is the objective of local designers. Each experiment has a different objective of the designers. In the following section, the detail of each experiment is described.

6.1 Experiment1: Design of eddy current separator

6.1.1 Introduction

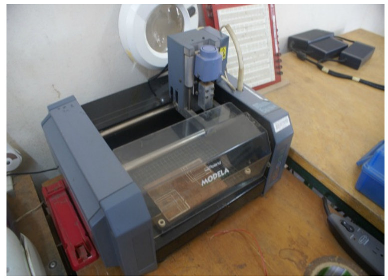
This experiment was conducted by the author in August and September in 2012. The targeted designers were mainly the instructors of the fab lab, which was established in Takoradi Technical Institute. Takoradi Technical Institute is one of the largest educational facilities located in Sekondi-Takoradi, the capital of the Western Region of Ghana. Fab lab in Takoradi Technical Institute was established mainly for the educational purpose. Students in Takoradi Technical Institute use the fab lab as after-school activities, to create their own products or make experiments.

The fab lab provides various kinds of tools, such as a laser cutter, a CNC milling machine, a vinyl cutter, an oscilloscope, and electronic components. The example of such tools are shown in Figure 6-1.

6.1.2 Objective

In this experiment, the initial problem was set as the e-waste problem in Ghana. The e-waste problem is a problem caused by the illegally-dumped electronic waste,

[1] Laser cutter



[2] CNC milling machine

[3] Oscilloscope

Figure 6-1: Available tools in fab lab

such as printers and computers. Those wastes had been thrown away mainly from European countries. Such wastes were gathered in a large waste dump in Accra, the capital of Ghana, where laborers are burning those wastes in order to extract copper or golds to gain an income. In this situation, health problems among inhabitants around the waste dump had been reported, since the burning process generated the harmful smoke [34].

In this context, the experiment was intended for designing an eddy current separator, in order to solve the e-waste problem. An eddy current separator is a machine that can separate metals from non-metal objects, such as plastics, using the electromagnetic force generated by a magnetic rotor. The eddy current separator is useful, since it can separate metals without burning the scrap.

6.2 Experiment 2: Concurrent design of multiple artifacts

6.2.1 Introduction

The experiment 2 was conducted by the author in May and June in 2014. In this experiment, the designers start the design by identifying the local problems by themselves. To help generating the ideas, the author provides workshop for the designer.

Primary purpose of the experiment is to observe the advantage of prototyping, compared to the workshop. Since the author assumes that the hidden issue can be elicited by the prototyping spiral, it is aimed to observe the unexpected design change during the design process.

In this experiment, around ten students were selected, who use fab lab on a daily basis. The background of the students were diversified, such as mechanical engineering, electrical engineering, and welding. In contrast to the experiment 1, the targeted designers in this experiment had less experience of design and manufacturing.

6.2.2 Objective

The objective of this experiment is to observe how the problem space will be extended through the rapid prototyping spiral. In addition, the designers are supposed to design multiple artifacts at the same time. The experiment is set in this way, since the author expects the interaction between each prototype will promote designers to come up with novel issues. In other words, the author intends to observe the generation of the ideas by combination of the object.

6.3 Experiment 3: Modified design of fufu pounder

6.3.1 Introduction

The experiment 3 was conducted by the author in June and August in 2014. The objective of this experiment was set according to a proposal by an engineer in Kumasi Polytechnic. The proposed idea was to create a food processor, named as fufu pounder.

Fufu is a staple food of the western and central African countries [35]. The ingredient of fufu is food crops, such as cassava, yams or cooking plantains. Fufu is made by pounding the boiling starch of the ingredient into a dough-like consistency.

The proposal of the engineer was to modify the design of a fufu pounder originally designed by him. The author shows the fufu pounder in Figure 6-2.

Figure 6-2: Fufu pounder

As shown in Figure 6-2, the fufu pounder is composed of following parts, such as a chassis, a mallet, and a mortar. The working principle of the fufu pounder is simple. The mallet is periodically upheaved and dropped as the rotation of the motor. What is interesting of the fufu pounder is that it considers multiple local aspects. First, it uses a lead battery as a power source, which can be charged by solar cells. The reason of using battery is that the machine is expected to work as a standalone device, because power supply is frequently interrupted in the area. Second, it is driven by a wiper motor extracted from an automobile. The choice of a wiper motor is suitable because it is not only a DC motor, but also available in the local market.

The engineer was planning to diffuse this machine, and he had already taken user research for the customer, such as a staff in a neighbor restaurant. The user test had pointed out several issues to be improved. In this experiment, the modification of the fufu pounder is set as a initial problem.

6.3.2 Objective

According to the user test, improvements of the current design of the fufu pounder was clarified as follows.

- Compact chassis
- Adjustable pounding force

First, the user indicated that the fufu pounder should be miniaturized. As shown in Figure 6-2, the first prototype is uselessly bulky and heavy. It is also a problem in terms of portability. Second, the user demanded that the pounding force of the fufu pounder should be variable. It is not possible for the the first prototype to change the pounding force, since the mallet of the fufu pounder is just dropped with gravity.

At first glance, those two improvements can be solved by modifying the mechanism, since current design is not utilizing the theoretical knowledge of the mechanism. In this way, this experiment attempts to modify the design of the original fufu pounder, considering the improvements clarified by the users.

Chapter 7

Result

7.1 Experiment 1

7.1.1 Designed prototypes

In this experiment, an eddy current separator was designed based on the proposed design framework described as following design process.

1. Define the main function as separation of metal from non-metal using eddy current
2. Split the root function into sub function and specify the required components, such as a magnet rotor, a motor for driving the rotor, and a conveyor belt
3. Decide material for manufacturing, considering local availability
4. Manufacture a prototype and execute a test
5. Get a feedback from users and redefine the problem

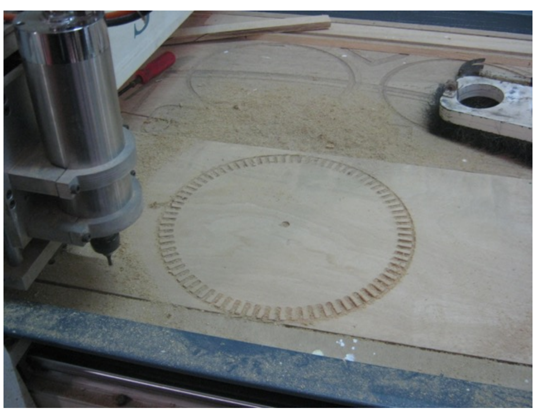
The author mentions the place where designers collected materials. The electronics components to create a motor driver, such as capacitors and transistors, were obtained in the local electronics store shown in Figure 7-1-[1]. The mechanical parts, such as pulleys, bolts and nuts were obtained in the local market shown in Figure 7-1-[2]. In particular, the place is called as kokompe, in the local language.

[1] Electronics store


[2] Kokompe: local market

Figure 7-1: Places for collecting material

In the manufacturing process, the designers utilized digital fabrication tools. For example, as shown in Figure 7-2-[1], the designer used a CNC milling machine to cut the plyboard. The electronic circuit boards were milled by a small milling machine. Figure 7-2-[2] shows the milled circuit board.


[1] Cutting with CNC milling machine

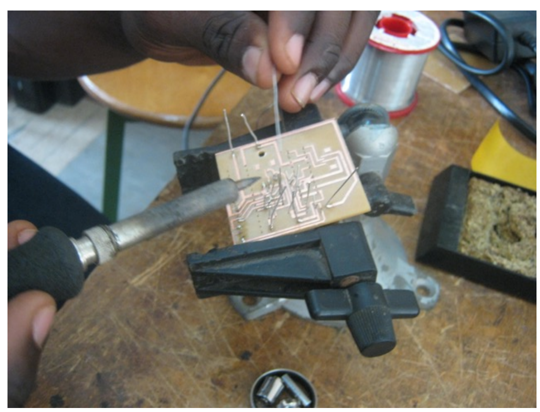
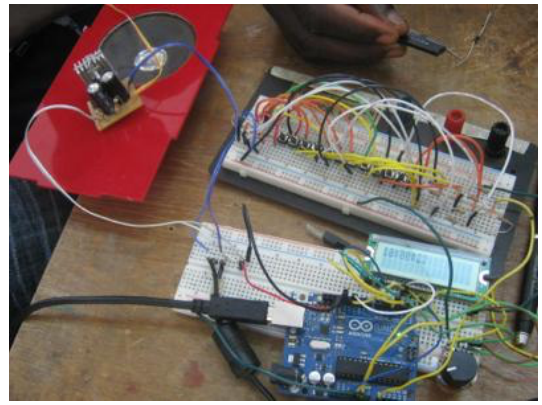

[2] Implementation of motor driver

Figure 7-2: Manufacturing process

The prototype of the eddy current separator is shown in Figure 7-3-[1].

[1] Eddy current separator



[2] Alarm clock

Figure 7-3: Designed prototypes

In this experiment, another prototype was also created. When the designers were creating the eddy current separator, the principal of the school suggested to create an alarm clock, which announces the beginning and end of the class to teachers and students. Behind this proposal, there was the fact that the school did not have an automated school bell. Instead, a school janitor was supposed to ring a handbell, walking around the school. The proposal was recognized as one of the result by the prototyping spiral, since the idea was evoked by the principal, when he was looking at prototypes of electronic circuit. Such prototype is shown in Figure 7-3-[2].

7.1.2 Discussion

The result in this experiment is summarized in Table 7.1.

Table 7.1: Result of experiment 1

Designed prototype	Design change and discovered issue by feedback	Factor of design change	Clarified constraints and conditions	Category of constraints
Eddy current separator	Changed material rotor from metal to wood	Difficulty to obtain a flywheel Difficulty of drililng small hall to a metal disc	Better availability of wood compared to metal Suitability of wood or creating a prototype	Material Manufacturing method

Designed prototype	Design change and discovered issue by feedback	Factor of design change	Clarified constraints and conditions	Category of constraints
	Extract neodymium magnets from HDD	Unavailability of magnets	Distribution of magnets Situation of local manufacturing industry	Material
	Consideration of manufacturing using a CNC milling machine	Difficulty to achieve required function by lack of accuracy while using manual machine tools	Technical skills of local engineers	Manufacturing method Material
	Necessity to decrease manufacturing time	Restricted use of machine tools caused by frequent power failure	Constraints for manufacturing facility Situation of power supply	Environment
Alarm clock	Modification of sound from melody to alert	Discrepancy from users expectation	Preference for sound Implicit assumed function	Function

In the following sections, the author describes the detail of the result for each prototype.

Eddy current separator

The main focus of the proposed design method was to transform the design space dynamically by the iteration of the prototyping. The description of the design space in the initial phase is shown in Figure 7-4 .

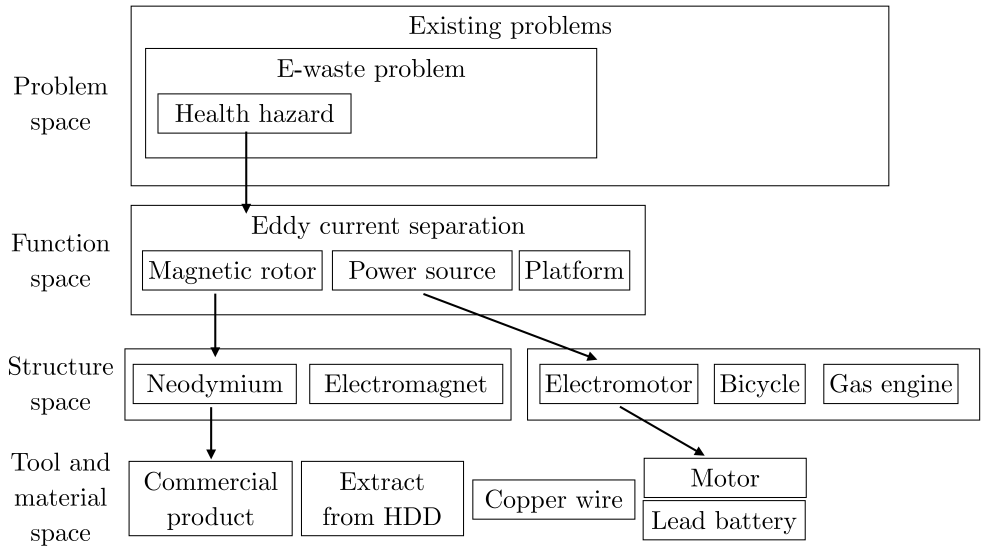


Figure 7-4: Initial design space

In Figure 7-4, the solid arrows represent the initial flow of the designers' thoughts. In this experiment, the designers initially targeted to solve the e-waste problem. The problem was associated with the health hazard among the laborers, who were burning the wastes to extract metals, such as gold and copper. To solve the problem, the designers defined the required function as the eddy current separation, which could separate the metals from plastics without burning the wastes. Subsequently, the designers picked up the sub functions of the eddy current separation as follows:

- Magnetic rotor to generate the electromagnetic field by the rotation of the magnets
- Power source for driving the magnetic rotor
- Platform to hold the magnetic rotor, a drive shaft, and bearings

First, the designers started designing the magnetic rotor. At the beginning, the designers expected to use the neodymium magnets, however, the designers noticed there were no neodymium magnets available in the local stores. After discussions, the designers decided to dismantle hard disk drives to extract the neodymium magnets.

This transition of the design can be regarded as the extension of the tool and material space, because the designers were able to discover the availability of the particular material through the design process. Such transformation is shown in Figure 7-5.

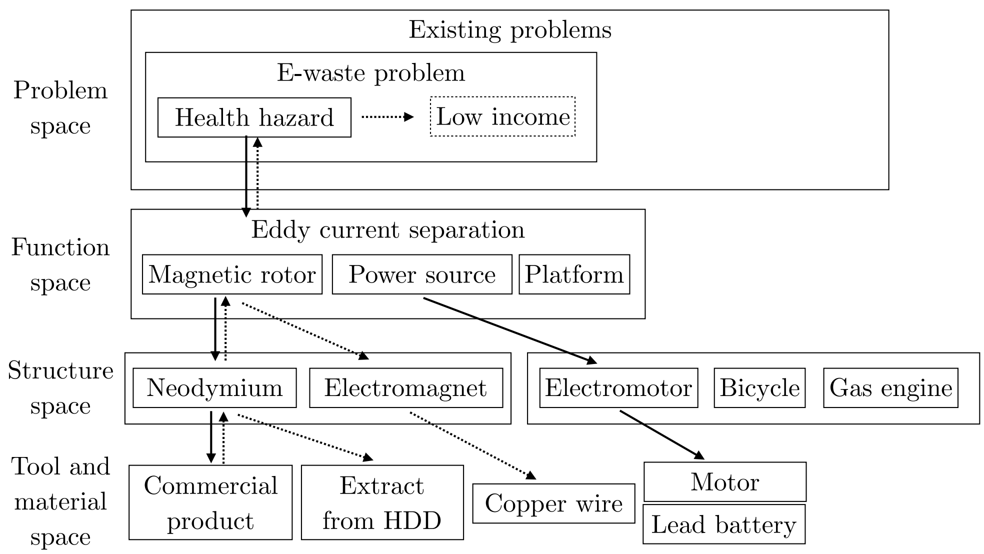


Figure 7-5: Exploration of structure space and material and tool space

In Figure 7-5, the dotted arrows show the flow of the induced thoughts through the prototyping process. In a similar way, each design space reflects on other design spaces, which triggers the transformation of the design space. Interestingly, the tool and material space could affect the problem space directly, which the author considers the uniqueness of the proposed method. For example, as indicated in Figure 7-6, when a designer comes up with the idea of using the electric motor and the lead battery to drive the magnetic rotor, it signified that the designers were aware of the local availability of the lead battery. After that, the designers started the discussion on the possible product made with the lead battery, which led the use of the product to supply the electricity in the unelectrified area.

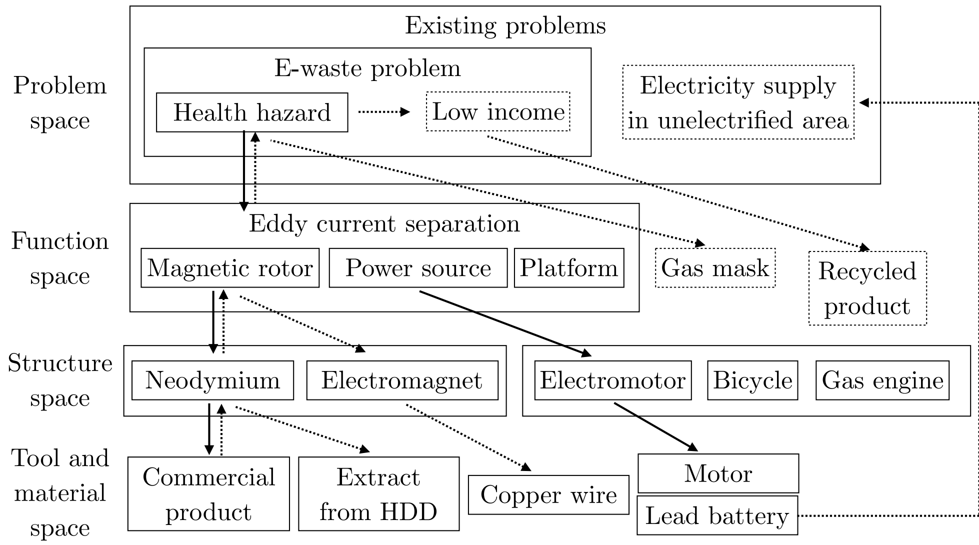


Figure 7-6: Exploration of function space and problem space

Alarm clock

The designers made the prototype of an alarm clock, which played the melody at a scheduled time with electronic sound generated by the micro controller. The initial reaction of the teachers in the school to the prototype was surprising, at least for the author. The teachers demanded that the the electronic sound should have been changed to much louder and noisier siren. The feedback made the author realize that the implicit assumption was restricting the mind of the author. That is to say, based on the circumstances the author was raised, the author had believe that the school bell was supposed to play the melody, not the louder siren. The finding is regarded as one of the example that the prototyping spiral externalized the cultural context.

7.2 Experiment 2

7.2.1 Problems identified in workshop

In the beginning of this experiment, the designers participated in a workshop provided by the author. In the workshop, the designers discussed about local problems and encouraged to identify as many issues as possible. The problems identified in the workshop is shown in Table 7.2.

Table 7.2: Problems identified in the workshop

Category	Example
Infrastructure (electricity, gas, water, road, communication)	Unstable power supply (power failure, surge voltage), communication disconnection (mobile phone, the Internet), flood from a gutter, suspension of the water supply, traffic jam, lack of personal mail delivery, storage (unavailability of refrigerator by blackout), improper layout of plumbing, gas leakage inconvenience of paying a fee for electricity undesirable action of water meter
Sanitation, wastes	Recycling, waste disposal
Disease, medical service	Malaria caused by mosquitoes
Agriculture	Irrigation, incubator, storage, combine harvester, bean sheller
Social norms	Mobile phone usage in public space, infelicity of students in school Noise on the street (megaphone, loudspeaker), shortage of public officer in rural area, insufficient facility in school
Others (personal)	Expensive computers, remote control of light switch

It is observable that many ideas concentrate on the issues about the infrastructure. This result is reasonable because the designers are always exposed to the limitation caused by lack of infrastructure. However, the advantage of the proposed method is to externalize the implicit local context. In the following sections, the author describes how the initial problem space was extended.

7.2.2 Designed prototypes and Discussion

Based on the result of the discussion, the designers selected following prototypes to design: metal detector, electric power meter, water meter, CNC plasma cutter, and

IP camera. The result in this experiment is summarized in Table 7.3. In the following section, the author describes the detail of each design and discuss the result.

Table 7.3: Result of experiment 2

Designed prototype	Design change and discovered isssue by feedback	Factor of design change	Clarified constraints and conditions	Category of constraints
Metal detector	Addition of a relay circuit	Consideration for combining conveyer belt to create industrial machine	Absence of industry for waste disposal	Environment
Power meter	Paying a fee via short message service	Constant availability of the paying service	Inconvinience of payment with prepaid card Demand for paying a fee in a small amount	Social infrastructure
Water meter	Measure usage of only water	False recognition of water meters that reacts to air	Operation of the water company after power restoration Situation of distribution	Social infrastructure
CNC plasma cutter	Using a CNC platform for a CNC sewing machine	Indifference of non-engineering students to computers	Necessity of education about information technology for all the students	Educational situation
IP camera	Utilization of Wi-Fi router as single board computer	Searching local market Open source embedded operating system	Infelicity of students in school	Material

Metal detector

In this experiment, the designer who pointed out the problem of waste disposal designed a metal detector. The objective of the device was to separate the metal from other non-metal objects. The designer decided to design the prototype that utilizes the principle of beat frequency oscillation (BFO).

A normal BFO circuit is comprised of two coils. The first one is called search head coil, and another one is called reference coil. The search head coil changes its inductance when the metal object approaches to it, interacted with a magnetic field generated by an eddy current on the surface of the metal object. This change of the inductance generates a beat caused by the different inductance of each of coils.

On the other hand, the designer attempted to detect the change of the inductance using an interruption of a micro controller. By this design, the circuit became much simpler than the usual BFO circuit. The created prototype is shown in Figure 7-7.

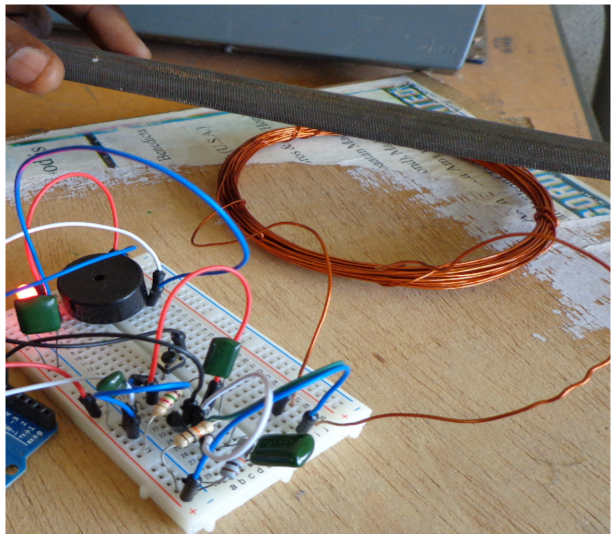


Figure 7-7: Metal detector

After creating the prototype, the designer proposed to combine a relay circuit with it. The intention of the designer was to create a machine to separate the wastes which flow over a conveyor belt. In fact, a conveyor belt had been already designed in the experiment 1, since it was a part of the eddy current separator. The proposal by the designer was interesting, since the designer reused past design knowledge to create the novel product.

Electric power meter

Some students pointed out that the most of the household in Ghana used prepaid system for paying for the electricity bill. People were supposed to go to stores to buy a prepaid card, when they used up the decided amount, depending on how much paid in advance. An example of the electric power meter used in households is shown in Figure 7-8.

Figure 7-8: Electric power meter used in households

Because most of the users were paying a small amount of money in each time, they often used up the decided amount even in the evening, which caused sudden shutoff of the electricity. Since the stores were closed in the evening, such users had to wait for the stores to open, without electricity.

In the context, students proposed to create a digital power meter which enabled the payment via short messaging service, so that users could pay the bill during night. The reason why the designers chose short messaging service was that both the Internet connection and the smart phones were not available in most of the households. In the beginning of the design, one of the students proposed to utilize a mobile phone, which works with the GSM network. The designer suggested to attach the mobile phone to a micro controller, and use the micro controller as an interface to control the existing power meter. After such consideration, the designers started to get around the local market to look for secondhand mobile phones. Fortunately, the designers found an old type of the mobile phone made by Nokia, which can communicate with the micro controller.

Behind this discovery, there was a background that hobbyists had analyzed the communication protocol used in the old phones, called as F-bus, and published the information on the Internet. The designers started to create a prototype that utilized an old mobile phone and a micro controller, as the first step of controlling power meter via short messaging service.

Water meter

Another problem about the meter was specified during the discussion. Near the school, the water supply had been frequently interrupted caused by the power failure. A designer pointed out that, the water company flows the pressurized air when it resumes to supply the water. The water meter in the households also measures the air, which causes the overestimation of the usage of the water. The designers clarified the requirements of the water meter, which can only react to the water and measure the usage of it.

First, the designers considered to attach the electrode to the water pipe, which could detect the water flow. However, the designers had trouble to obtain flow sensors, since most of the sensors were not available in the local electronics stores. After taking a survey in the local market, the designers found out that rotary encoders were available, which were embedded in a ball mouse sold in a local store. Finally, the designers started to design a digital water meter to measure the water flow with those electrodes and rotary encoders.

CNC plasma cutter

During the experiment 2, the designers found a CNC plasma cutter in the school, as shown in Figure 7.4. It had been left unused for years, because some parts were broken.

Since the CNC plasma cutter could be utilized for cutting a sheet metal, the designers decided to redesign the machine. During the design, a mechanism module of rack-and-pinion mechanism was utilized. The 3D drawing data of the designed

		
[1] Main unit	[2] Compressor	[3] CNC platform

Table 7.4: CNC plasma cutter

CNC plasma cutter is shown in Figure 7-9.

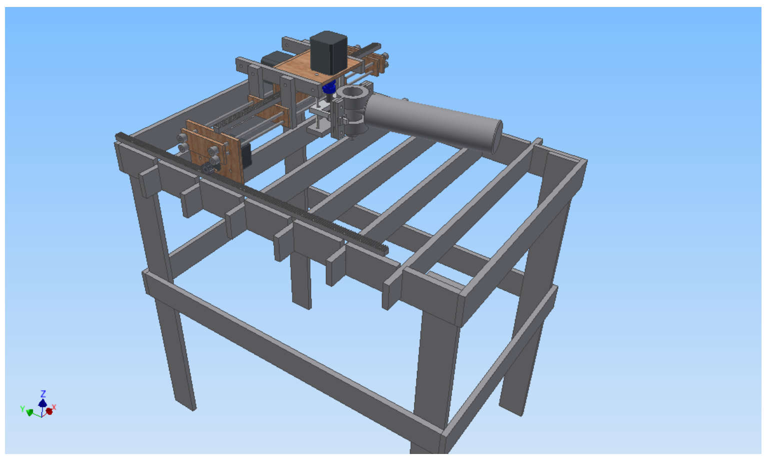


Figure 7-9: Redesigned CNC Plasma cutter

During the design of a CNC plasma cutter, an interesting idea was given by a teacher in the school, who taught information technology. Although the school was a technical school, it also included non-engineering departments, such as fashion department and catering department. The teacher suggested to create a CNC sewing machine, utilizing the core structure of the CNC plasma cutter. According to his proposal, the CNC sewing machine was supposed to do embroidery automatically, controlled by the data created on desktop computers. The objective of the CNC sewing machine was to provide the experience of using drawing software for the students in the non-engineering departments. When the author asked the intention to the teacher, it was clarified that the teacher desired those non-engineering students get more interested in information technology. The teacher also mentioned his educational belief, which all the students including non-engineering students should learn to use computers. This observation also identified the reality of the education in Ghana, which is the indifference among students to the subject that is not related to their major.

IP camera

In the workshop, some students mentioned necessity of a device that could stream moving images captured by a camera. The problem behind this proposal was surprising to the author. The students proposed that the school should have monitored the misbehavior of students, although the proponents were also the students of the school. In fact, the proponents had been harassed by some delinquent students in the school.

According to the interesting proposal, the designers started to create the prototype. The designers decided to use the webcam for capturing moving images, since they could find a webcam sold at a low price in a local electronics store. However, during the design, the designers regarded it difficult to create the prototype since they faced some difficulties in terms of collecting material. First, the designers had difficulty to make the webcam communicate with eight bit micro controllers, which were only available micro controllers in fab lab. Second, although the designers attempted to use a desktop computer to acquire the data from the webcam, they eventually realized it was not only expensive but also redundant. In addition, most kinds of integrated circuit chips were not available. Although the designers considered to utilize TCP/IP for streaming the data, the integrated circuit chips that works as the Ethernet controller were not available in the local market.

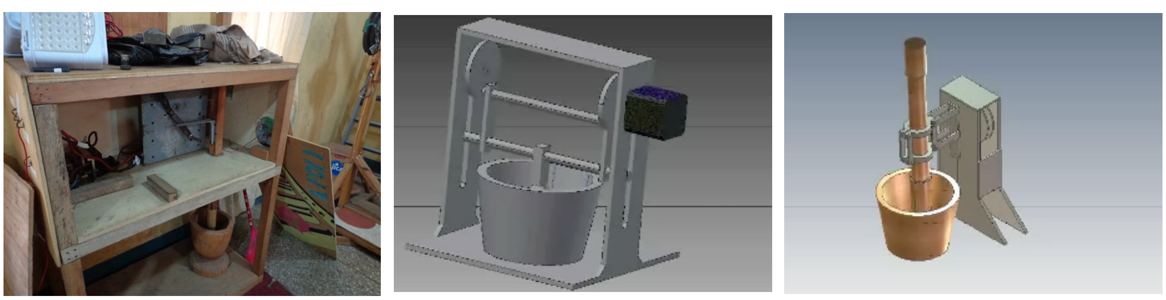
Meanwhile, the designers unexpectedly found a Wi-Fi router in an electronics store, of which the firmware can be customized. In fact, OpenWRT could be installed on the Wi-Fi router, which was an open source embedded operating system specialized for devices to route network traffic. In addition, the webcam was supposed to work with the Wi-Fi router.

The finding was important because the designers realized that a specific type of Wi-Fi routers could be utilized as a single board computer with the customization. With the finding, the designers could come up with the creative solution for creating the IP camera.

7.3 Experiment 3

7.3.1 Designed prototypes

This experiment was intended for modifying the design of fufu pounder. In this experiment, the designer repeatedly changed the design by the feedback from users. The author shows the transition of the design in Figure 7-10. The detail of the modification in each design is shown in Table 7.5.



[1] Original design [2] First modified design [3] Second modified design

Figure 7-10: Transition of design of a fufu pounder

Table 7.5: Detail of modifying fufu pounder

	Original design	First modified design	Second modified design
Feedback from users	Compact chassis Adustable pounding force	Power output	Proposal of a solar car using alternator
Change of Structure	Slider-crank mechanism	Space to put hands Change of dimension Removable mallet	
Change of Materials	Milling plywood by CNC Stepping motor	Alernator for driving pounder	

First, the improvements of the original design were downsizing of the chassis and adjustable pounding force. Based on such needs, the designer started design by changing its structure. The designer designed first prototype utilizing the slider-crank mechanism module. For the motive power, the stepping motor was selected, considering the availability. The first prototype is shown in Figure 7-10-[2].

The feedback from the user to the first prototype was about the mallet. The user demanded that the mallet should be the traditional one and removable. Although the original design was using the traditional mallet, the first prototype replaced it with the newly designed one. The reason of changing the mallet by the designer was the heaviness of the traditional mallet. Since the designer wanted to use a stepping motor, he redesigned the lightweight mallet, considering the torque of the motor. The feedback about the mallet was reasonable, since the user wanted to preserve the same quality as the handmade fufu. In addition, the user demanded that there should be the space over the mortar. It is understandable because fufu is usually prepared by multiple persons, who pound and knead it. Such a space is required for the person who kneads fufu.

According to the feedback, the designer was forced to rethink the motor. The decision process of the motor is described in the following section. Finally, the designer could come up with an idea to use an alternator as a motor. The second prototype is shown in Figure 7-10-[3].

After creating the second prototype, a local engineer provided unexpected feedback. It was a proposal to create a solar car utilizing alternators. The detail of this finding is also described in the following section.

7.3.2 Discussion

The author describes how the design space was transformed by the design framework. In particular, the author highlights the decision process of the motor, which brought interesting finding by the interaction between material space and functional space. The initial design space in this experiment is shown in Figure 7-11.

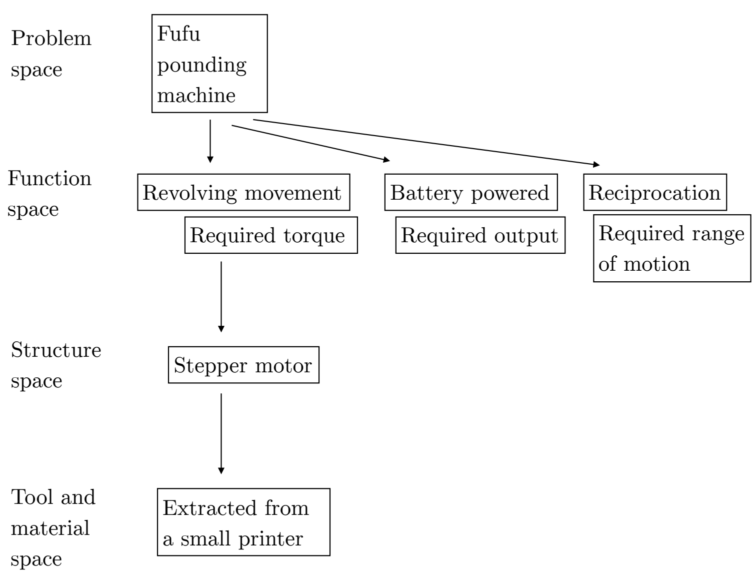


Figure 7-11: Initial design space

As shown in Figure 7-11, the designer initially considered to use a stepper motor, which was extracted from a small printer. However, the design change of the mallet by user's feedback increased the required torque of the motor. Since the designer realized the generated torque by the stepper motor was not enough to drive the load, the designer started to look for alternative solution to fulfill the novel requirement. The design process of exploring alternative solution is shown in Figure 7-12.

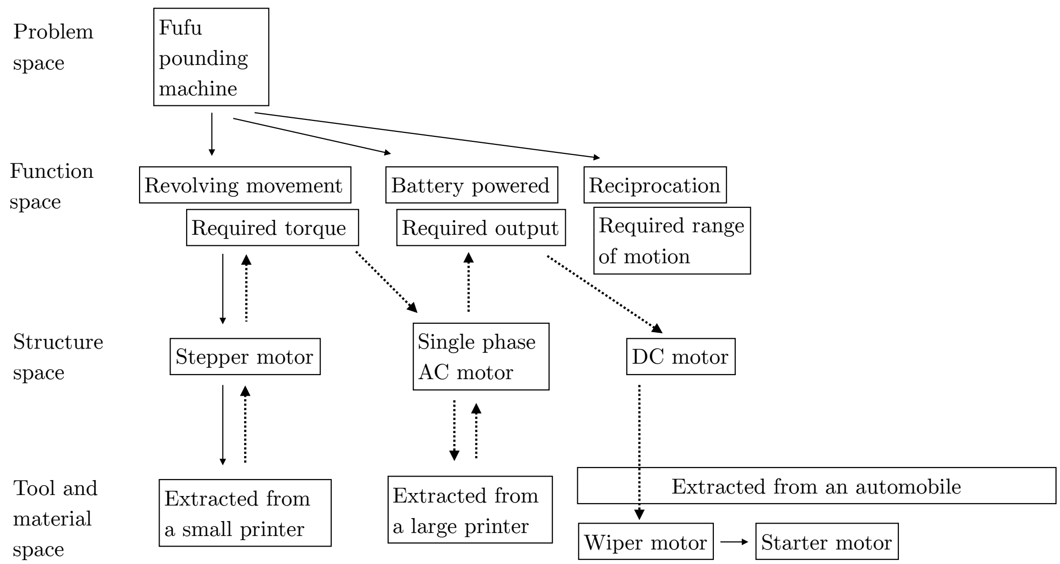


Figure 7-12: Exploration of design space by interaction between function space and material space

Based on the change of requirements, the designer considered to use a single phase induction motor that was extracted from a second-hand printers. In the local market, second-hand printers were widely available, since some store owners were importing those second-hand printers from other countries, such as the United Kingdom. The idea of using a single phase induction motor seemed favorable, since it could fulfill the requirements of power output. However, this idea was also rejected by a user, because batteries could not be used with it. Although the designer considered to use an inverter to convert direct current from the battery to alternating current, the capacity of the battery was not enough to generate required current.

Under the restriction, the designer focused on the automobile. The automobile was a treasure-trove, since it had various kinds of reusable components built-in. First, the designer considered to use a wiper motor and realized that the torque generated by a wiper motor was fundamentally weak. Second, the designer focused on a starter motor, which has higher torque compared to the wiper motor. However, the starter motor could not be run continuously because it was not designed to be driven for a long period.

Eventually, the designer noticed the potential of an alternator. Returning to the principle of the alternator, the designer found that an alternator could be converted to the motor, by regarding it as a synchronous DC motor whose primary magnet is substituted for a coil. The central coil of an alternator can become an electromagnet by flowing the direct current. The outer coils could be excited with a rotating magnetic field. This principle is quite similar to synchronous motors, such as a stepper motor. Such consideration from the first principle enabled the designer to find a way to use an alternator as a DC motor. The process that led this finding is shown in Figure 7-13.

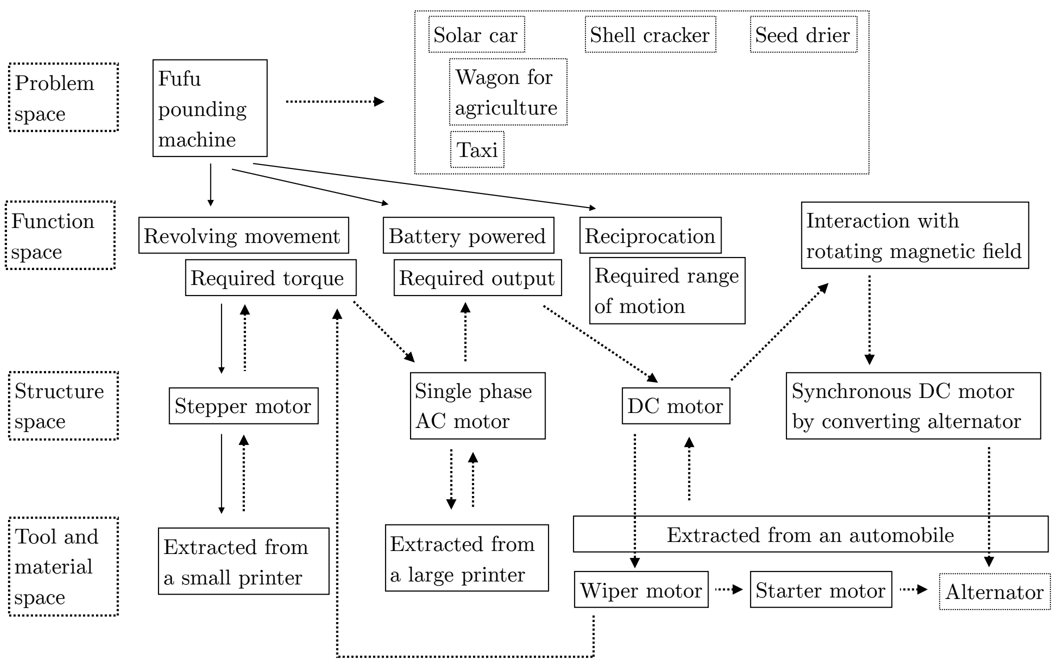


Figure 7-13: Discovery of a creative solution and exploration of problem space

In addition, the finding of novel utilization of alternator enhanced the designer to come up with a creative idea. Based on the finding, the designer proposed an idea of a solar car, which used two alternators. According to the idea, one alternator is converted to the motor to power the vehicle and another is used as normal alternator to charge the battery. The idea was noteworthy because it was different from most of the proposal by the local designers in the experiments, which were usually attributed to the lack of infrastructure. The author mentions that is one of the successful example of the rapid prototyping spiral, which enables local designers spontaneously explore the design space and discover a creative concept.

Chapter 8

Evaluation

In this chapter, the author evaluates the effect of the design framework and support system based on the results of experiments. First of all, the author describes the effects of the proposed method observed in the experiments, followed by the analysis of the causal relationship. Subsequently, the author states the requirements of the cultural excitation that were specified by the implications acquired in the experiments. In addition, the author explains the enhancement of capability among designers, which occurred through the experiments as the side effects. Furthermore, the limit of the proposed method is also discussed. Finally, the author mentions the applicability of the proposed method for design in developed countries.

8.1 Observed effects of proposed method

In this section, the author describes the finding in the experiments that backs up the assumptions in this research. The author has stated three major hypotheses in Chapter 4. The cases that support those hypotheses were observed in the experiments, as shown in the Table 8.1

Table 8.1: Examples to support hypotheses

Hypothesis	Observation
Transformation of the design space by rapid prototyping spiral promotes discovery of novel ideas	Proposal of a CNC sewing machine, to enlighten the importance of information technology for students (Exp.2)
Considering superordinate concepts leads to find creative solutions	Conversion of an alternator to a motor for generating driving force, which also triggered to come up with an idea of a solar car (Exp.3)
Negative aspects, such as constraints of materials, can be triggers of creative problem solving	Design of an IP camera using a Wi-Fi router as a single board computer (Exp.2)

First, the author has pointed out that there are unapparent problems in developing countries, which are difficult to recognize even for the local designers. Those underlying issues were supposed to be found out through the transformation of the design space in the rapid prototyping spiral. The author could observe an example that sustained this assertion. As described in Table 8.1, after the prototyping spiral process in the experiment 2, a designer could propose to create a CNC sewing machine to enlighten the importance of information technology for students. Since the issue was not identified in the workshop, the author concludes that the proposed design method elicited this latent issue.

Second example is a conversion of an alternator to a motor that was observed in the experiment 3. When designing a fufu pounder, a designer was confronted with a problem that an appropriate motor was not available locally. Through the design process, by exploring the design space focusing on the principle of the motor, the designer could come up with an idea to use an alternator for generating driving force. The idea to utilize an alternator is suitable for the situation in the region, since it has multiple advantages in terms of cost, power output and easiness of control. Such creative solution was found out because the designer could notice the structural similarity of a motor and an alternator, by focusing on the superordinate function of the motor. In this way, this example indicates that considering superordinate concepts leads to find creative solutions. Furthermore, the example also shows that such exploration of the design space can promote the designer to discover the hidden needs, which have not been identified initially. In this example, the focus on the alternator let the designer to come up with a novel idea, which is a solar car made by the converted alternator. Eventually, the proposal implied a great demand for improving public transportation.

Third example is the IP camera observed in the experiment 2, which utilizes a Wi-Fi router as a single board computer. Although local designers initially proposed to create an IP camera to monitor students in the school, the constraint of the material was impeditive. In this example, the designers faced the problem that they could not obtain specific integrated circuit chips in the local market. However, this shortage of material let the designers focus on alternative solutions. Through the survey in the market, the designers could find a specific type of Wi-Fi routers that can be customized by reinstalling the operating system to communicate with a webcam. In other words, the designers found out that the Wi-Fi router could be used as a single board computer. This finding is interesting because it implies that such a Wi-Fi router can be used not only as a part of an IP camera, but also as a general-purpose computer. Although inexpensive computes are not available in the region, by converting such a Wi-Fi router, local designers will be able to create diversified products that processes more complex tasks. This example indicates that the negative constraints of materials worked as a trigger of finding a creative solution.

In addition, the author also observed that the proposed method has the following effect: breaking through the synchronicity. The author defines the *synchronicity* as the phenomenon that similar concepts are simultaneously proposed by the people who share the same local context in different areas. Although a concept of the fufu pounder designed in the experiment 3 was proposed by an engineer in the Kumasi Polytechnic, the author have observed that a similar food processor had been created in the Takoradi Technical Institute. Moreover, students in the Takoradi Technical Institute and an engineer in Kumasi Polytechnic proposed the same idea of an electric power meter, whose users can complete electric bill payment via the short messaging service. This synchronicity happened in spite of no explicit communication between those two places. The author argues that the coincidence has occurred because they were sharing the same local context, such as social issues, forms of perception, and constraints. The author believes that those implicit common sense unconsciously restricts the minds of the local designers. The significance of the finding in experiment 3 was that, a designer was able to reach to the totally new idea of the solar car, although he started the design from an ordinary idea of a fufu pounder. The author states that the designer was able to be released from the local context by the proposed method.

8.2 Examination of causal relationship

As described in the previous section, several cases that support the hypotheses were observed in the experiments. However, the author also points out that the favorable effects were not always observed. In this perspective, successful cases were assumed to be also affected by other conditions. In this section, the author analyzes such conditions based on the results of experiments.

8.2.1 Facilitation

Originally, the author has expected the support system interacts directly with the local designers. However, actual design process has been carried out with the form indicated in the diagram shown in Figure 8-1.

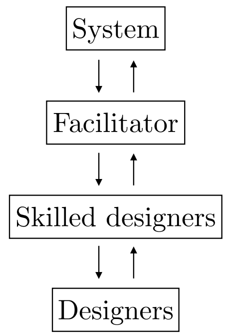


Figure 8-1: Actual usage of the proposed method

Figure 8-1 shows there were the layer structure among the actors. In Figure 8-1, the system means the design space explorer described in Chapter 5-1. The facilitator is the provider of the support system, namely the author. Other designers engaged in the experiments, interacting with a facilitator, who interprets the intention of the system.

The core of this separation is the intermediation of the facilitator. The author analyzes that there were three key factors of the facilitation while the experiments, described as follows.

1. Intermediate the system and the local designers to follow the proposed design framework

2. Support of detailed design knowledge

3. Promote the designers to provide feedback to prototypes

First, the proposed design framework expected the designers to follow the design framework, which is the design with the interaction between separated design spaces. It also expected the designers to categorize the design knowledge into each design space by themselves. However, because it seemed difficult for the local designers to utilize the system by themselves, the author ended up playing a role as the interpreter by intermediating the system and the local designers. The author supported to update the description of the design space, interacting with the local designers. The reason of the difficulty for using the system is considered to be that the proposed design framework was too different methodology to follow, from the usual one for the local designers. The author notes that the case of designing a fufu pounder was an example that this type of facilitation worked. A designer could reach to the idea of converting an alternator to a motor, by considering superordinate concept in the function space, with the facilitation by the author.

The second facilitation, the support of detailed design knowledge, was required to create prototypes, even when the required information was almost provided. For example, when creating a prototype of the metal detector, almost all the required design knowledge was available through the Web. In this case, the design data, such as the circuit diagram and the firmware was provided by the knowledge base. However, manufacturing a prototype has not been completed by a local designer independently. The author analyzes this reason as the lack of basic design knowledge and experiences. For example, the designer who proposed to make the metal detector needed an explanation for compiling a firmware and flashing it to a micro controller, as he was the beginner for using the micro controller. Another technical advice was also required by the facilitator, for example, when the designer slightly changed the design to add a LED to indicate that the device is in operation, the modification of the circuit diagram was done with the help of the facilitator. Although this may seem to be a very simple modification, the designer with less experiences had a trouble to complete this customization. In addition, the author mentions that if the electronics components specified in the knowledge base are not available locally, supporting the knowledge about equivalent parts will be also required.

The third factor is required when obtaining feedback for prototypes. Although this is related to the first factor as difficulty of following the proposed design framework, it seemed difficult for the local designers to give feedback to prototypes spontaneously.

In the experiments, the facilitation for obtaining feedback was done as the query to the designers by the author, in the form of conversation.

All those facilitation was done by the author, because neither the current system considered those factors of the facilitation, nor the local designers knew how to facilitate the design by themselves. However, it would be possible to implement the functions of the required facilitations in the future system. The author confirmed with the results of the experiments, which the facilitation mentioned above, whether by the system or by the human, are required for deploying proposed design framework.

8.2.2 Skillful designers

In the experiments, skills and knowledge of the designers varied from person to person. Among those designers, contribution by senior members was noticeable, such as teachers and instructors, who were relatively skilled persons. The author points out that the crucial ideas were often proposed by such designers. For example, the idea of a CNC sewing machine was identified by a teacher in the technical high school. Besides, the proposal of a solar car using two alternators was provided by a skilled engineer in the university. The author observed that such skilled designers could come up with much options during the design process, compared to the other designers. The author infers that the reason is skilled designers have good intuition based on the past experience of the design. In addition, the skillful designers comprehended the intention of the facilitation better. In fact, such designers have nicely led the discussion, considering the suggestion by the author. In this sense, those skillful designers seem to have much potential to be a facilitator. Therefore, in the light of the significance of the facilitation described in the previous section, the importance of team building is also pointed out. That is to say, to include such skillful designers into the project was one of the factors for enhancing the creative activity.

8.2.3 Awareness of social problems

Although several cases were observed that the proposed method promoted designers to discover underlying problems, there would be an argument that the designers have already aware of the issues in advance of the design project. The author accepts such an argument because the discovery of the problems was affected by the personal experience of the designers. The point is, even supposing that the designers have already aware of the issues, they recognized those issues as their own problems, through the design process. For example, a teacher who pointed out the importance to instruct the information technology to non-engineering students did mention the problem only after the prototyping.

The author gives an explanation for the observation in the following manner. First, based on the educational situation at the school, the designer was subconsciously aware of the issue, which is the indifference to the information technology among non-engineering students. The designer did not recognize the issue as his own agenda, since he took it for granted. However, the prototyping process provided different angle for the designer to see the issue. The design of a CNC machine made the designer focus on the process of using the machine, which let him notice that such a process involves creation of data with the computer. He linked this finding to his own experience and found out that such a process can be utilized for the education. In this way, the author concludes that the proposed method can elicit the issues that have subconsciously existed in the designers.

8.2.4 Process of collecting material

The proposed method was supposed to take advantages of negative aspects, such as the constraints of the material. In other words, those constraints were expected to be triggers to find creative solutions. The author has observed cases that support the hypothesis, for instance, a designer discovered a way to convert an alternator to a motor when designing a fufu pounder.

The author mentions the significance of the process of getting around the local market to collect materials. In the example described above, when the designers faced a trouble for obtaining an appropriate motor, what led the creative finding was the activity of searching an automotive repair shop to find alternative materials. The importance of the process is reasonable considering the situation in the developing countries. Through the experiments in Ghana, the author found that the distribution of products was under a fluid situation. In a store where the electronics components are sold, the stock of the products varied at different periods. As for the outdoor bazaar, selling system was not sophisticated since there were no inventories. In such a situation, it was significant for designers to get around the local market to update the latest information of available resources. The author points out that the exploration of the design solution was not possible without such a process of collecting materials. Therefore, the author concludes that such a process works as a significant part of the design to find creative solutions.

8.3 Requirements of cultural excitation

In Chapter 2, the author introduced the concept of the cultural excitation. In this section, the author summarizes the requirements of the cultural excitation, considering the results of the experiments. To come right to the point, the cultural excitation can be achieved by the prototyping spiral process with the *cultural exciter*.

Through the experiments, the author have found that specific objects which emerged in the design process could promote designers to discover creative ideas. For example, finding of converting alternator to a motor let a designer to come up with an idea of the solar car. In addition, the combination of a micro controller and a mobile phone made designers to conceive of an idea of the remote control of a gate.

The author names such an object as the cultural exciter, since it enhances the cultural excitation.

The author points out the cultural exciter has multiple functions that enhances all the three aspects of the cultural excitation. The association of the functions and each aspect of the cultural excitation is shown in Table 8.2.

Table 8.2: Functions of cultural exciter

Category	Function of cultural exciter
Human excitation	Stimulate the interest of the designers
Cultural excitation (in a narrow sense)	Recall information which the designers are subconsciously aware of
Constraints excitation	Visualize local constraints of resources

The author explains the functions with the result of the experiment 3. In the experiment 3, the utilization of an alternator was caused by the constraint of material, which was the lack of an appropriate motor. Viewed from the opposite side, the alternator was considered to be visualizing the local constraints. Simultaneously, this finding enabled a designer to focus on the problem and function that the designer had not focused on, due to the constraints. In this case, a designer could consider the possibility to create a machine that requires higher motive power, which finally resulted in the idea of a solar car. In addition, there was another factor that the designer had subconsciously aware of the local problem, which is the improvement of public transportation. The author explains that the finding of the alternator worked to recall such subconscious information in the designer. The author also states that the designer was literally excited with the idea of utilizing an alternator as a motor. The finding of unexpected usage of technology stimulated the interest of the designer, since it had multiple advantages, such as cost and power output. Finally, the finding directed the designer to consider the possibility for using the customized alternator to another application.

8.4 Enhancement of capability among designers

In this section, the author describes side effects observed through the experiments, which is the enhancement of the capability of the designers engaged in the design project.

First, the local designers, especially among students in the technical high school, educational effects have been observed. Through the experiments, the students started to focus on how the design knowledge in the current design can be applied to the next design. For example, a student who got interested in programming the micro controller, started to apply a code of driving a DC motor to a circuit that opens and closes the window remotely. An interesting point is such a design consideration simultaneously triggers the exploration of the problem space. In this case, a newly identified function as controlling the window with a micro controller, clarified a demand of local enterprises that have air conditioners, which is to open windows automatically when the power supply is stopped, and close the windows by detecting the recover of the power supply. In addition, such a focus on solving problems around them motivated students to master novel skills and organize engineering knowledge to design activities. In contrast to classes at school, for the students who does not have many experiences of engineering design, considering how the engineering knowledge is applied to solve real problems provided opportunities to put learned skills and knowledge in practice. For those reasons, proposed design method is also useful for educating engineering design to the local designers in the developing countries.

Another perspective of the side effects is the improvement of the design strategy of the facilitator. The design strategy specifically means how to collect appropriate materials to create prototypes quickly. The participation to the design project provided the deep comprehension of the local situation for the author. In particular, the author got confused about the fact both domestic and international distribution system in Ghana was much severe than expected.

In such a situation, the author realized the significance of fundamental engineering knowledge for accelerating collection of materials, described as follows. The designers in Ghana had been usually using a small CNC milling machine to create a Printed Circuit Board (PCB). However, some circuits could not be made precisely, because they had much smaller trace width. Therefore, we started to consider creating the PCB with chemical etching. Nevertheless, we had difficulty to obtain the ferric chloride etchant, which is normally used for chemical etching. Considering the superordinate concept of the etching, which is oxidization of copper, the author decided to look for hydrochloric acid and hydrogen peroxide in the local market. Finally, we found antiseptic solution which included hydrogen peroxide in a pharmacy, and hydraulic acid in a local store offering chemical materials. In this experience, the author analyzes that the PCB manufacturing has been achieved considering fundamental engineering knowledge. In this case, with the knowledge of chemical reaction, the author could come up with a way of etching instead of using ferric chloride. The proposed design framework has an advantage since it promotes the designers to consider a superordinate concept. In this way, the proposed method could also improve the design strategy of the facilitator.

8.5 Limit of proposed method

In this section, the author discusses the limit of the proposed method. Main argument for the proposed method are the reproducibility and the dependency on the actors.

First, although the author clarified the requirements of the cultural excitation by analyzing the finding in the experiments, there is no guarantee of reproduction of the similar phenomenon for the designers in the different situation. Second, the effect of the proposed method depends on the individual, since the cultural excitation is essentially person-oriented. For example, the skillful engineer and the designer who pay much attention to the social problems are more likely to achieve creative problem solving.

On the other hand, one potentiality of the cultural excitation is that it focuses on the utilization of the object, which is the cultural exciter. In the conceptual design, abstraction of the concept depends on the meaning of the language. Contrary to this, the cultural exciter is expected to reflect the knowledge that cannot be verbalized.

8.6 Applicability to design in developed countries

In this section, the author mentions the applicability of the proposed method to the design in the developed countries. As indicated in the experiments, local designers in the developing countries could discover the underlying needs in the community by exploring the design space with the proposed method. The author believes that the proposed method can bring the similar effect for the designers in the developed countries.

Generally speaking, the difference of the situation between the developing countries and developed countries is the explicitness of the constraints. Those constraints, such as lack of infrastructure and shortage of material, are not relatively crucial in the design in the developed countries. However, the other factors of the cultural excitation, the human excitation and cultural excitation in a narrow sense, also play an important role for the design in the developed countries.

Since the societies became complicated and diversified, the author believes there are a number of underlying issues in the developed countries. To elicit such issues, the proposed method which externalizes local context can be utilized.

Chapter 9

Conclusion

9.1 Thesis contribution

This thesis attempted to propose a design method to support local designers in developing countries to create problem solving products.

To enhance the creative problem solving by local designers, the author introduced a novel concept named as cultural excitation. The cultural excitation aimed to support designers to discover underlying issues by externalizing the local context.

The author proposed a design framework with the approach that focuses on prototyping. The main feature of the proposed design framework is to promote the designers to discover underlying issues by the iteration of the prototyping.

Moreover, a support system was proposed to assist the local designers who have less experiences of design and manufacturing. The support system included following sub system: the interactive system for promoting users to explore the design space, the 3D data to support quick prototyping of mechanical components, the electronic circuit module to support rapid implementation of the electronic circuits.

Through the experiments in Ghana, the author confirmed that the proposed method has following effects. First, transformation of the design space by rapid prototyping spiral promotes discovery of fundamental issues. Second, considering superordinate concepts leads to find creative solutions. Third, negative aspects, such as constraints of materials, can be triggers of creative problem solving.

Furthermore, the author observed that the specific object named as cultural exciter enabled local designers to discover creative solutions. The author finally concluded that the requisites of the cultural exciter is the following: to stimulate the interest of the designers, to recall information which the designers are subconsciously aware of, and to visualize local constraints of resources.

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List of Publications

Papers, international conference

[1] Shohei Aoki and Koichi Hori, "Rapid prototyping spiral for creative problem solving in developing countries," in *ACHI 2014, The Seventh International Conference on Advances in Computer-Human Interactions*, pp. 172–177, 2014.

[2] Shohei Aoki, "Prototyping spiral in fablab to solve local problems," in *Proceedings of the 10th Fab Lab International Conference (FAB10)*, 2014. to appear.

Poster presentation, international conference

[3] Shohei Aoki and Koichi Hori, "A novel design framework for enhancing creative production in developing countries," in *OHS2013, Open Hardware Summit 2013*, 2013.

Domestic conference

[4] 青木 翔平, 堀 浩一, "創造的問題解決のためのプロトタイピング手法と設計支援システムの提案," 2014 年度人工知能学会全国大会, 2014.

[5] 青木 翔平, 堀 浩一, "プロトタイピングサイクルによる潜在的なニーズの発見に関する考察," 2013 年度人工知能学会全国大会, 2013.

[6] 青木 翔平, 堀 浩一, "適正技術の設計・製作支援のための UPC プラットフォーム," Design シンポジウム 2012, 2012.