Development of an Integrated Sustainable Design Approach for Furniture Design and Its Implementation and Application Perspectives

A Thesis submitted for the Degree of
Doctor of Philosophy

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Abstract

With increasing demand in design, most of the industrial designers or engineering designers are facing the challenge to make timely sustainable design decisions in their design practices. For instance, designers have focused and efforts towards developing to determine the best conceptual design and demands for product design with environmental consciousness are a natural result of this trend.

This PhD research aims to develop an industrial-feasible approach and tools for sustainability assessment in-process for designers in the furniture industry. The approach proposed seeks to optimize the product life cycle assessment through developing the sustainable design index (SDI). This built-in sustainable design automation which lead to comprehensive benefits of helping furniture designers directly communicate sustainability in their product design process and customers consider sustainability.

In this research, it firstly begins with the overview and characterization of the sustainable furniture design. These are four key criteria as identified in this research, modular product architecture, re-configurability, using a design structure matrix (DSM) and axiomatic design (AD). The derived sustainable design index combines all these criteria into an integrated decision-making process, an ‘embedded’ integrating SDI algorithm within the CAD design environment, using built-in Visual Basic programming codes, tool to aid the design process while assessing the design sustainability as well. SDI represents, a novel methodology for integrating sustainability considerations into the design process and working within a computer aided design (CAD) environment with the designer’s interactive design interface (Graphical User Interface).

To determine the relevant assessment criteria for sustainable design, preference analysis and analytical hierarchy process (AHP) were applied. It is which enables the industrial product designers to work with mainly the product’s sustainability performance strongly linking to the consumer’s satisfaction. The case studies further show the comprehensive and application perspectives of the SDI and associated tools, thus achieve the sustainable furniture design as the ultimate goal.

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List of abbreviations

A	Matrix
AD	Axiomatic Design
AHP	Analytical Hierarchy Process
BOL	Beginning Of Life
CAD	Computer Aided Design
CAs	Customer Domain
CBA	Cost Benefit Evaluation
CSPI	Composite Sustainability Performance Index
DFA	Design for Assembly
DFS	Design for Sustainability
DFM	Design for Manufacturing
DJSI	Down Jones Sustainability
DPs	Design Parameter/Physical Domain
DM	Design Matrix
DTT	Distance-To-Target
DSM	Design Structure Matrix
Eco	Economic
EOP	End of Pipe
EOL	End of Life
Evo	Environmental
ES	Export System
ESI	Environmental Sustainability Indicators
Feco	Factor economic
Fenv	Factor environment
Ford SDI	Ford Product Sustainability Index
FRs	Functional Requirement/Functional Domain
Fsoc	Factor social
FWM	Factor Weight Model

GDP	Green Public Procurement
GUI	Graphical User Interface
HDI	The Human Development Index
LCOP	Life Cycle Option
LCCA	Life Cycle Assessment
LInX	Life Cycle Index
MAUT	Multi attribute Utility Theory
MCDA	Multi Criteria Decision Analysis
MF	Modularization function
M&R	Modularity & Re-configurability
MOL	Middle of Life
NGO	Non-Government Association
NSA	Neighbourhood Sustainability Assessment
OCED	Organisation for Economic Cooperation and Development
OPS	Open plan System
PROSA	Product Sustainability Assessment
PV	Process Domain
PSS	Product Service system
RSP	Relevance, Stearability, Potential
R&D	Research & Development
R	Recyclability
SMI	Singular Value Modularity Index
TBL	The Triple Bottom Line
SA	Sustainable Assessment
SC	Sustainable Criteria (SCeco, SCsoc, and SCenv)
SDI	Sustainable Design Index
SMART	Simple Multi-Attribute Rating Techniques
SOMs	Self Organizing Maps
VOCS	Voltaic Organic Compounds
WCED	World Commission for Environment and Development

Author's Declaration

The work described in this thesis has not been previously submitted for a degree in this or any other university and unless otherwise referenced it is the author's own work.

Statement of Copyright

1. Introduction

This chapter presents a brief background of the problems investigated, the motivation behind this work, the aims and objectives for this research. Furthermore, the significant contributions and the research methodology to achieve them will be elaborated on. Finally, this chapter outlines the thesis structure and research scope of this PhD study.

Although furniture design is important, there is still insufficient in-depth research on furniture, particularly its sustainable design and analysis perspective. Industrial designing is the mixture of science and art which creates practical values and aesthetics in order to produce a novel design and idea (Industrial Design Society of America,2000; Tovey 1997;Slappendel, 1996). In this field product design is the first ring of the chain. Producing a new product depends on how, where and by whom it may be used. In other words, it makes the user closer to more convenience, calmness, enjoyment and efficiency. If the product has such characteristics, it will be an efficient product that can be called a green one. The requirements from end users with different interests and expectations, as well as a global market, have forced companies to manufacture products that are highly innovative and internationally competitive.

1.1 Research Motivation

Nowadays, sustainable design is one of the most primary concerns in the designing world and undoubtedly it’s one of the most significant issues that human beings have had to deal with since the commencement of their existence. Sustainable design is a general concept that is used in various fields such as architecture, industrial designing, graphic designing, agriculture, plants and anything that deals with our environment. The purpose of sustainable design is reducing environmental damages, minimizing the usage of energy sources, and being more coordinated with nature. In other words, the philosophy of sustainable design is to support and encourage points of view and decisions where every step in designing, producing, and using the product has been considered in terms of its influence on the environment and the user's health, has also considered. This study is novel research in the design field in Malaysia, especially when sustainability is the main constraint being proposed to be included into the design process of developing wooden furniture. This becomes guidance for designers in Malaysia, leading them to develop a new sustainable policy in the furniture design industries.

Determining the characteristics in the early design stage is very important. Consideration of the environmental factors, in the early design process stage on the will reduce the negative environmental impact. In past years, some methodologies have been developed to help the designer to make decisions between environmental concerns and other design requirements. According to Schwarz *et al*., (2002) putting this idea into practice needs the classification of concrete indicators of sustainability and understanding how they can be measured to determine if progress is being made. Sustainability metrics are designed to consolidate key measurement of environmental, economic, and social performance.

The metrics presented are designed to meet the following criteria:

- Simple- not requiring large amounts of time of manpower to develop
- Useful for management decision making and relative to business.
- Understandable to a variety of audiences, from people in operations to finance to strategy planning.
- Cost effective in terms of data collection
- Reproducible- incorporating decision rules that produce consistent and comparable results.
- Robust and non-perverse-indicating progress toward sustainability when improvement has in fact been made.
- Stackable along the supply chain so they are useable beyond the particular fence line for which the calculation was performed.

- Proactive of propriety information, preventing the back calculation of confidential information (Schwarz *et al.*, 2002).

"The concept of sustainability in general stresses the importance of maintaining the continued capability of the natural and cultural system over time" (Telegen, 2005,p10). This term has become more significant in our lives since it entered into the definition of development in society. The first and most quoted definition of sustainable development was published by the World Commission on Environment and Development (WCED) in 1987. This document, entitled Our Common Future, says "Sustainable development that meets the needs of the present without compromising the ability of future generations to respond to their needs." (WCED,1987,p.43). To obtain a better life, and meet the requirements sustainable development must take this opportunity to satisfy all the fundamental needs.

However, the most comprehensive explanation, which is also provided by the 2002 World Summit on Sustainable Development, emphasises that sustainable development is a process of development where economic, environmental and social concerns are considered simultaneously (Kates *et al*., 2005). Sustainable development as a concept, goal, and movement spread rapidly and now central to the mission of countless international organizations, national institutions, corporate enterprise, sustainable cities, and locales (Kates *et al.*, 2005) . Since sustainable development embraces all social, environmental and economic concern, it has received considerable attention in recent years and has become widely used in policies across the world.

1.2 Research Challenge

According to (Hsu & Liu, 2000), the process of thinking the application of total design could be used to resolve a problem or to improve the system, is based on the nature and the characteristics of the design process. Being part of a team of designers, most of the Industrial Designers are facing the challenge to make a decision on determining, the right brain- storming to determine the best conceptual idea design, the selection material, and the manufacturing process. The conceptual model is the early stage in finding the best idea to generate the concrete solutions needed to meet the design requirements and specifications. The final phase is the detailed work to prepare such as the technical drawing, that is complete with all the relevant information and detail needed by professional people (Hsu & Liu, 2000). To overcome the problem of this matter, the application of concurrent engineering must be implemented during at the early stages of the product development.

Today product designers are being asked to develop high quality innovative products. To meet this requirement; various methods have been developed to help the designer in evaluating and selecting the appropriate design concept, material and manufacturing process during the design selection. Therefore, the use of a suitable tool is a prominent factor in shortening time-to-market and reducing product development costs. So far the index method is not used by designers and researchers in determining the best design concept, material and manufacturing for furniture design in the context of sustainability.

Therefore, the use of a sustainable design index for this research will be explored to determine the right selection and the appropriate design concept, material and manufacturing processes for furniture design. Hence, the problem statement of this thesis can be summarised as: How can a furniture designer determine the furniture design proposal. To produce the best design solution for the customer that demands a minimum timeline and service cost. With the highest possible product and service quality that includes the sustainability of the furniture. In the field of furniture design, the designer is a key person responsible for furniture companies achieving sustainability based on the “three triple bottom line” that is the environmental, economic, and social aspect. Furthermore, most of the designers focus is more on to the customer, manufacturing and production concerns. In an effort to change the designer thinking towards sustainable design, it needs to consider especially in the quick decision-making stage. This is because the designer makes the decision to consider the environmental impact based on their judgement, so therefore the support tool must reflect this quick process, in this study the best solution to handle this problem will be further discussed as show in Figure 1-1. On top of that, the office furniture industry much relies on their designer to produce a more sustainable product; the designer is responsible for making sure all the product development takes into account all the environmental impact of their new range of furniture products i.e. open plan system (OPS).

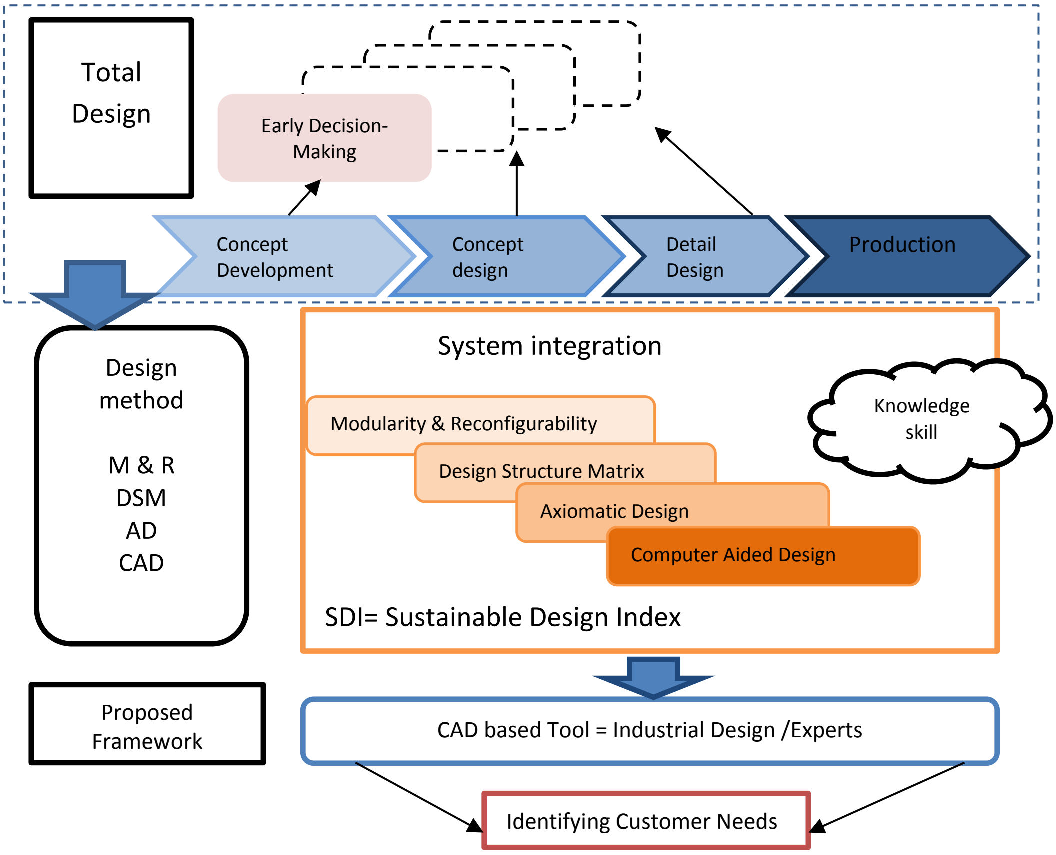


Figure 1-1: The motivation for implementation and research gap in this study

Assuming that everyone will not come to a decision regarding an indicator sustainable development, the manufacturing industry can continue to move in another direction by creating a standard indicator (Hussey *et al.*, 2001). Creating a standard indicator would enable the following: (Azapagic & Perdan, 2000)

a) Comparison of similar products made by different companies

b) Comparison of different processes producing the same product

c) Benchmarking of units within corporations

d) Rating of a company against other companies in the (sub-)sector

e) Assessing progress towards sustainable development of a (sub-)sector (Azapagic & Perdan, 2000).

1.3 Research Approach

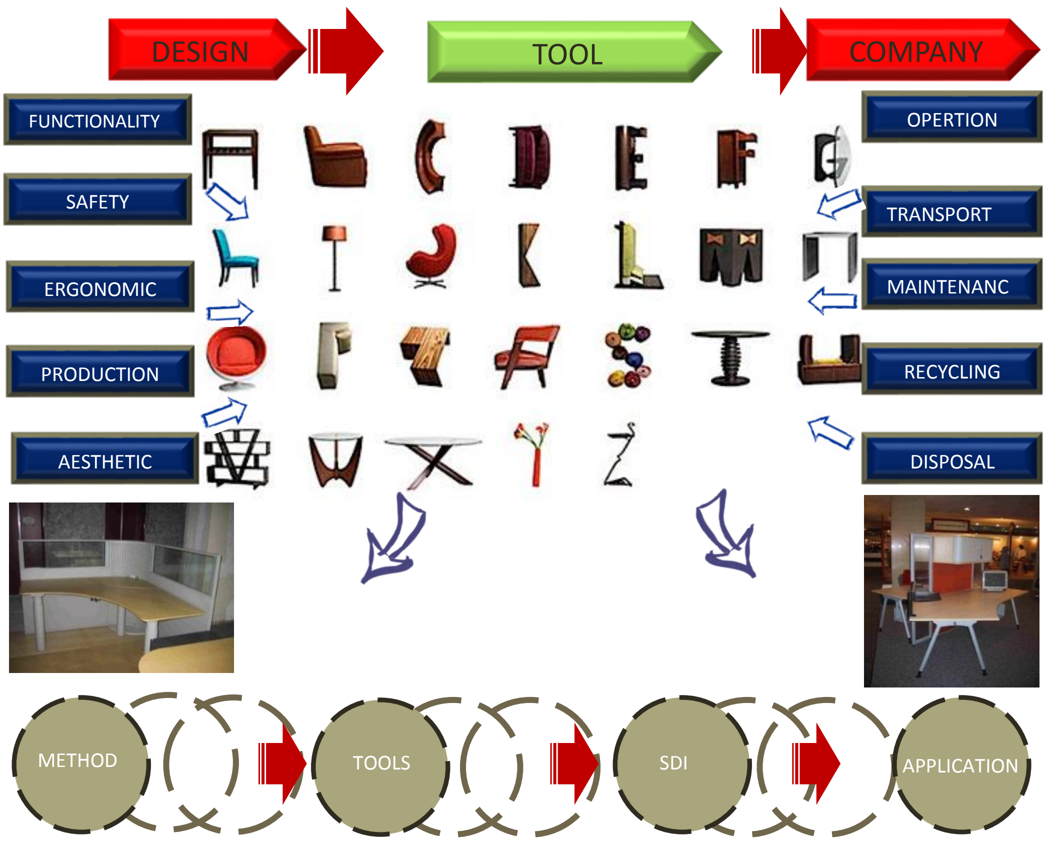


Figure 1-2: The mechanism for sustainable design furniture

As shown in Fig 1-2 design is an important mechanism for the company, at the same time designers play a crucial role in determining the properties of the product in terms of functionality, safety, ergonomic, production process, transportation for delivery, operation, maintenance, recycling, and final product disposal. The furniture designer works as a function to implement the sustainability in all stages of the design process, such as a practice start with a redesign, creating a new product and designing a new system of furniture as follows the open market demand and trend. A tool to enable the furniture designer or industrial designer to measure the sustainability of furniture design and development is needed. The transition from a traditional product orientation towards a new approach is needed, which includes looking at different directions, such as using technologies to manage the complex system consisting of the products, manufacturer, and users.

Meanwhile, in this research study under the same team one of our college developed the sustainable design index and associated algorithm for furniture design based on the material costing data and dynamics. According to Zhao et. al. (2015) the (SDI) formulation of the SDI combining with the existing CAD tool enable the designer to undertake sustainable products design and development in an industrial-feasible and effective manner.

Due to that, in this research the development of a new tool that are embedded in a CAD based environment are introduce, that enable the designer make the decision in the early design stage to fulfil the end user requirement towards environmental manner.

1.4 Aim and Objectives of the Research

Due to that the aim of the research presented in this thesis is to develop a sustainable design index that is applied to office furniture in the early decision-making process. The research aims to examine, identify, and analyse office furniture both quantitatively and qualitatively, and through which the sustainable design and analysis can be implemented in an industrial feasible manner.

The distinct objectives of the research are:

1. To gain a global understanding of sustainable design applied to furniture design through a scientific analytical manner.

2. To analyse the criteria of sustainable design selected by a design team and develop the sustainable design index (SDI) applicable to furniture design
3. To develop tools for supporting sustainable design and decision making for any design stage across the (preliminary) furniture design process.
4. To discover the challenge in applying sustainable furniture design by focusing on methods, tools, analytics, SDI, innovation and industrial implementation.

This research will be focusing on qualitative and quantitative research approach to elicit data. These will include a group of expert interviews with authorities and designers from furniture industries, as well as government bodies (e.g., Forest Research Institute, Furniture Technology Centre, Malaysian Design Council, etc.).

The methodology engaged in this research will consist of a combination of a few methods. Literature searches involving a thorough review of current and previous research in the area of environmental evaluation and project appraisal will be discussed. The exploration and understanding of the issues related to the development of sustainable design index in the early decision making will also be investigated.

The research work focuses on the office furniture namely open plan system (OPS). Even in office furniture, there are various categories of furniture, but for this research, the open plan system is the primary subject matter. Open plan system will include work surfaces, panel, pedestal, drawer, leg, etc.

The study focuses on four scopes including: (1) Modularity and Re-configurability (2) Design Structure Matrix (3) Axiomatic Design and (4) CAD-based Environment, as depicted in Fig 1-1 and Fig. 1-3.

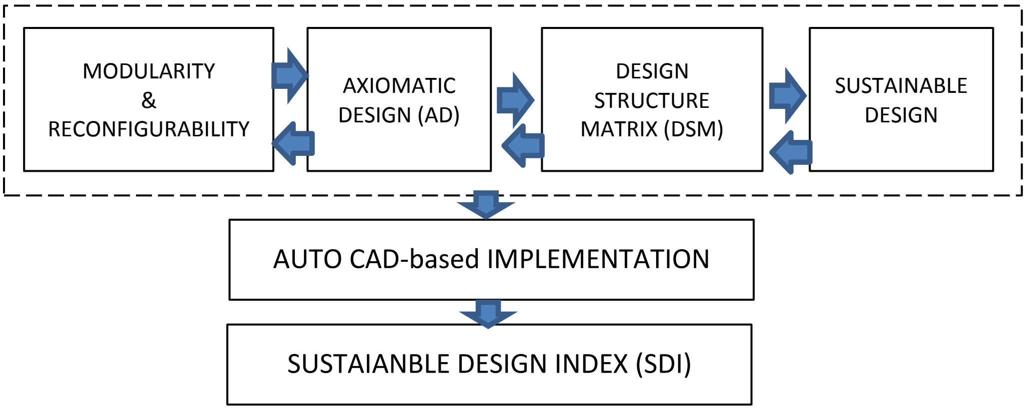


Figure 1-3: The study focus of the research

1.5 Organisation of the thesis

This thesis consists of eight chapters,

Chapter 1 represent with the introduction of the study, its motivation, the chapter which provides a brief synopsis of the whole argument. It also explain the significant of this research to the furniture industries especially in office furniture i.e. open plan system (OPS).

Chapter 2 discusses the literature and previous research and the challenge in today's environmental impact. It then briefly explains the needs of SDI and the collaboration between the methods used in this research. The researches also investigate the nature and extend of environmental, economic, and social in relation to multi-criteria approach for project appraisal. The review can classify the state of the art to know and understand the method that is used in this research.

Chapter 3 provides a detailed overview describes the approach and methods to achieve the objective. This chapter describes and proposed the development of the SDI framework for sustainable design index. The main research contribution in the SDI is the development of the tool that imbedded in CAD environment, which is then applied to the office furniture i.e. open plan system.

Chapter 4 discusses the characteristics of furniture products. Furthermore, some of the furniture industry, even academic has discussed and studied in deeply in the furniture concept and category of sustainability. This chapter discusses the application of the proposed approach is presented in the context of modularity and re-configurability of open plan system.

Chapter 5 involves the development of a Sustainable Design Index (SDI) formulation. This chapter aims to identify the sustainable design index that is important to the decision making process when assessing the environmentally concern to the office furniture in early design process.

Chapter 6 involves the development of a Graphical User Interface (GUI) is using Visual Basic. The Visual Basic is a microprogramming that should run in the computer aided design (CAD 2014). The chapter details the questionnaire sent to the designer and expert in furniture industries. The main purpose is to obtain the important and opinions from expert, in order to fulfil the need for transition towards the sustainability concern.

Chapter 7 implementation and the application of a Sustainable design Index (SDI) with office furniture design. The integration of the three pillars of sustainability, i.e. the economic, environmental, and social aspects. The comprehensive application of integrate and obtain the information to make office furniture in open plan system more sustainable.

Finally, Chapter 8 concludes the research findings of the thesis and suggests future work that may be carried out in connection with the research presented in this thesis.

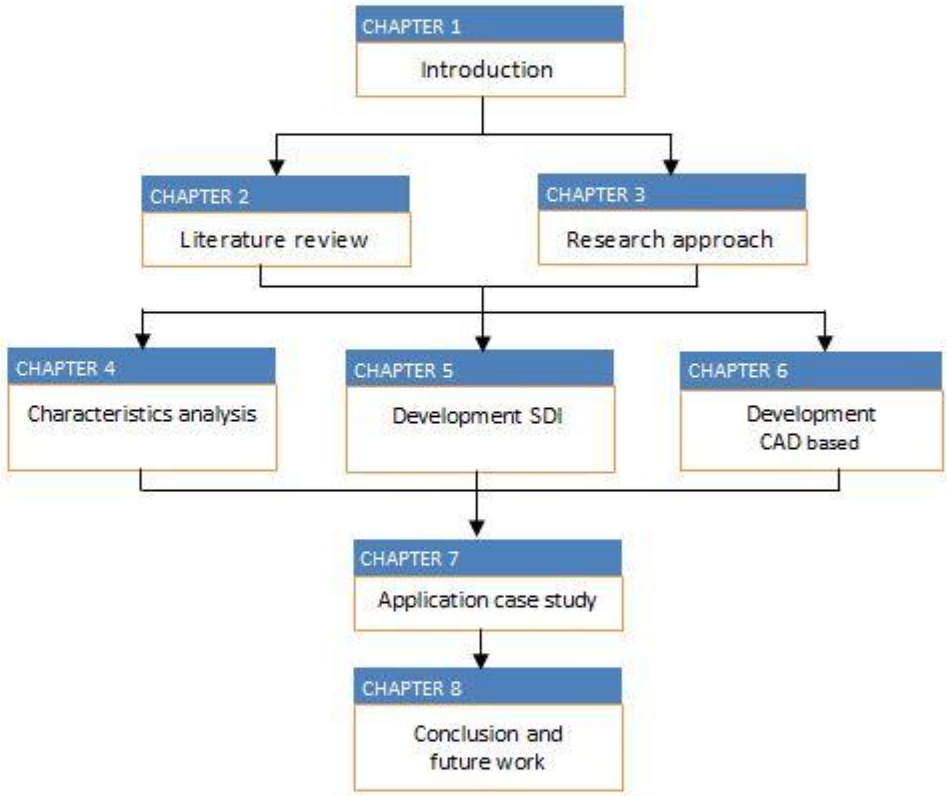


Figure 1-4: Structure of the thesis

2 Literature Review

This chapter investigates and outlines the relevant issues in this research context which is to addresses for first objective to gain a global understanding of sustainable design applied to furniture design through a scientific analytical manner. This chapter begins with a review of the concept of sustainability, and its importance to the designer as the decision maker, before discussing what exactly is needed when talking about sustainability especially for office furniture industries. An elaborate the modularity and re-configurability, design structure matrix and axiomatic design as well the computer-aided design (CAD) environment that helped adopt the relevant method for this research perspective. Finally, a summary of the literature review of the proposed research study will be provided.

2.1 Fundamental Concepts of Sustainability

"Sustainability" is defined in various ways depending on the context and area of interest. The term "sustainable" from an ecological point of view, means the maintenance of the integrity of the ecology. From a non-ecological point of view it means how to continue to sustain the supply of raw materials when existing sources of raw material run out (Harger & Meyer 1996). This specific connotation of sustainability originated from the context of renewable resources such as fish and forests; most proponents of sustainability would define it as the existence of the ecological conditions necessary to support human life at a specific level of well-being through future generations (Lélé, 1991).

The concept of sustainability has been developed, and now is the time to urgently address what being unsustainable actually means. These pressures require urgent attention due to the increasing global population and the fact that natural resources are decreasing. Sustainability has become increasingly important and it is now utilised in several fields. The challenging and complex responsibility is making sustainability meaningful, in order to balance human activity while incorporating economic and environmental societal objectives (Rosen & Kishawy 2012). Changing the way people think is a challenge when moving towards sustainability. The present generation should contemplate the impact of their activities and take action to protect the environments. A decision that is being now, and that will be made in the future, depend on technological change and climate change as well as social trends and attitudes (Harding 2006).

Numerous studies have attempted to define sustainability. The study of environmental issues is a hot topic and of increasing importance to manufacturers and academics. According to Handfield et al., (1997) without a proper framework and understanding of theoretical environmental issues, people in high levels of management face pressures when addressing the importance of sustainability. Government regulation has made consumers conscious of environmentally friendly products and they have also encouraged manufacturers to realise the importance of integrating environmental concerns into the value chain process. Handfield et al., (1997) analysed the furniture industry using methods of qualitative analysis, and they developed the taxonomy of managerial responses to enhance further theory testing.

The word sustain the means to support, hold, or bear up from below; to keep up or continue moving, to provide with the needs concerning survival (Farrell 1995). It is especially important in this interpretation to understand what is being backed up (human life) and what is doing the supporting (the biosphere, and a host of human institutions). At the core of concern about sustainability are the ideas that the support for human life should last indefinitely, while current human activities may prevent the biosphere from doing so (Farrell, 1995). In its literal rudiments, sustainability means a capacity to maintain some entity, outcome or process over time (Jenkins, 2003). Sustainability has been (until now) beyond our knowledge, and its meaning beyond our full understanding. Thus an appropriate path forward would be to demand small, evolutionary steps in what we consider to be the right direction from our present position.

A popular definition of sustainability is by the Brundtland Commissions using their statement from Our Common Future (Paper 2012), Here, sustainable development is described as ”development that meet the needs of the present without compromising the ability of future generations to meets their own needs”. It is usually accepted that sustainable development is an experienced improvement; it covers the three pillars of economic improvement, social fairness, and environmental prevention, as shown in Figure 2.1. A popular way of expressing the three pillars of sustainable development is that the people represent the social pillar, the planet represents environmental pillar, and profit represents the economic pillar as shown in Figure 2-1 (Heijungs et al. 2010)

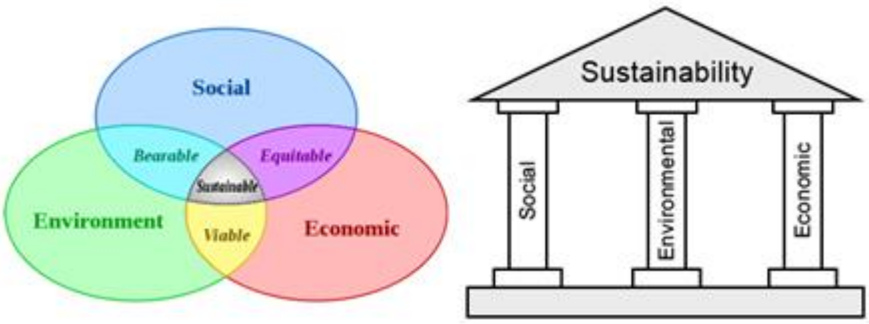


Figure 2-1: The three pillars of Sustainable Development (Heijungs *et al.,* 2010)

According to (Elkington 2001), the triple bottom line (TBL) not only refers to the achievement of economic profit; in order to succeed, a company must also meet environmental and social needs as a bottom line. The term ‘triple bottom line’ also helps to establish the principle of sustainability. Furthermore, the term TBL is recognised in the business worlds as the gold that creates long-term value economically, socially environmentally, and in particular, sustainable. The importance and ultimate aim of the TBL is to identify negativity and to create healthier communities and natural environments. The concept of sustainability (Quinn & Baltes 2009) refers to the research and development of new designs that do not contain toxins or non-renewable materials.

Due to a long period of promotion, and much effort from its advocates, sustainability is progressively more likely to happen in communities that have an interest in discovering useful and efficient solutions to the sustainability issues, using novel methods such as innovative materials, new technologies, new energy, and new services (Liu *et al*., 2010). Hence, the field of design very much linked to the connection between human beings and the ecological environment, and has proposed the idea of 'sustainable design' as well as seeking to change and find new methods of solving problems through research and practice (Liu *et al.,* 2010).

The sustainability concept, therefore, includes an innovative set of moralistic issues, with several factors that need to be taken into consideration such as: a) Something needs to be sustained b) should advantages mean jeopardising with specific exciting development about social ways; c) should some benefits be preserved; d) Which need to be preserved (Jenkins 2003).

Elkington (2001) developed the 3P's, 'people, planet, and profit'. These were first adopted by Shell (Shell Report) and are now broadly applied in the Netherlands, using the following seven drivers a) markets b) value c) transparency d) life-cycle technology e) partnerships f) time and g) Corporate governance. Bhamra & Lofthouse (2007), in their book 'Design for Sustainability', identified three waves in the evolution of the era of sustainability. The first wave began due to a growing awareness of environmental problems in the 1960s and 1970s, through the effort of an environmental NGO, which focused on radical change via governmental policies and regulations.

The second wave occurred in the 1980s and early 1990s, when consumers demanded an eco-friendly process due to concerns over further environmental crises. In contrast with the 'green' design that describes a process of dealing with individual environmental impacts, an eco-design deal with the environmental impact over a product's entire lifespan.

The third wave was prompted by the publication of 'our Common Future' by the Brundtland Commission in 1987; introduced the term 'sustainable development'. The Sustainable design was more effective than green or Eco designs as it went beyond just making a 'green' product, as shown in Figure 2-2.

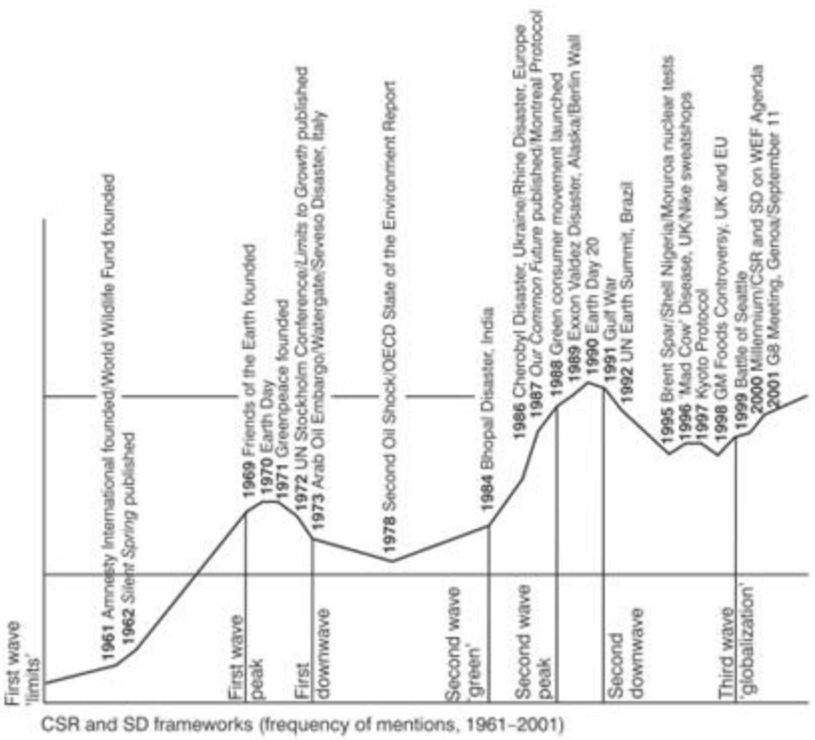


Figure 2-2: Pressure waves, 1961-2001 (Elkington 2001)

2.2 Sustainability Assessment Methodologies

Sustainability assessment (SA) is an important tool in increasing the shift toward sustainability. SA is often described as a process by which the implication of an initiative on sustainability are evaluated, where the initiative can be a proposed or existing policy, or a recent practice, programme, strategy, or a part of the law (Pope *et al.,* 2004). Interpretations of sustainability are also important when deciding which assessment approach to employ. In some cases assessment tool practitioners and decision-makers have the choice to use a tool or specific assessment results that most closely reflects their political viewpoint and their broader interpretation of sustainability (Ness *et al*., 2007). According to Singh *et al.*, (2012) for sustainability indices, assessment methodologies are needed in order to make an appropriate decision, and also to evaluate the integrated system from a sustainability perspective.

According to Seevers et al., (2013) designers and engineers find it hard to create a valuable products that meet profit requirements and are beneficial to the end of their life. In the product design process, product assessment focuses on sustainability as a way of creating a new value for the end user. According to Kates (2001) often presents the decision-makers with the opportunity to such evaluate the worldwide impact of interaction between environment and society. As a result, they can use short and long term points of views to help them to select the measures must (or not) be used in an effort to create an environmentally friendly society.

In product manufacturing, it is necessary to focus on recent trends and their future implementation in product design in order to develop an advanced engineering programme that will involve the sustainability principle for environmental, social and economic benefit. Jawahir & Rouch (2007) mention that it is often difficult to measure and quantify product performance in terms of its environmental performance, economic and social effect. As shown in Figure 2-3 from their research, there are six factors used to evaluate the sustainability of a manufactured product. The Product Sustainability Index (PSI) is expected to represent the 'level of sustainability' Jawahir & Rouch (2007). The sub-elements contributing to the sustainability element are as follows:

a) Product Environmental impact (life-cycle factor, environmental effect, ecological balance, regional and global impact)
b) Product Functionality (operational safety, health and wellness effect, ethical responsibility, social impact)
c) Product Societal Impact (safety, health, and ethics)
d) Product Resource Utilization and Economy (energy, material usage, purchases, training cost, operational cost)
e) Product Manufacturability (assembly and manufacturing method, packaging, transportation, storage)
f) Product's Recyclability/Remanufacturing (disassembly, material separation, recycle ability, disposability, remanufacturing/reusability).

Figure 2-3: Factors affecting product sustainability (Jawahir & Rouch 2007)

Jawahir & Rouch, (2007) present the sustainability indicators of the six major elements as shown in Figure 2-4 to identify the sub-elements that are used as a basis for developing product sustainability. They also highlight their interactions in order to indicate the relationship between the elements and sub-elements, where the application of equal weight ratings is needed (Jawahir *et al.*, 2006). Moreover, SA is an ideal solution as the public interest inspires researchers to provide practical guidance for designers in order to make a product more sustainable. For design improvement, most designers or project managers make a comparison between selections of designs after the final stage of the design process. In their decision-making they must ensure that the product is appropriate and that a suitable design has been applied for a better life (Chang *et al*., 2014).

A common assessment method is life cycle assessment (LCA), which is employed in the automobile industry and in a variety of other products and applied (Shuaib *et al.*, 2014). To evaluate and rate the performance criteria and themes in relation to sustainability goals, the scale is measured using neighbourhood sustainability assessment (NSA). There are two broad categories in the neighbourhood sustainability scale: 1) the existing third-part building assessment and 2) the embedded decision-making tool within the NSA scale planning (Sharifi & Murayama, 2013) . The SA tools are developed to determine any final results regarding ideas and as a technique to generate an ideal factor towards sustainability and formulate the ability to help analyse a particular task (Pope *et al.,* 2004).

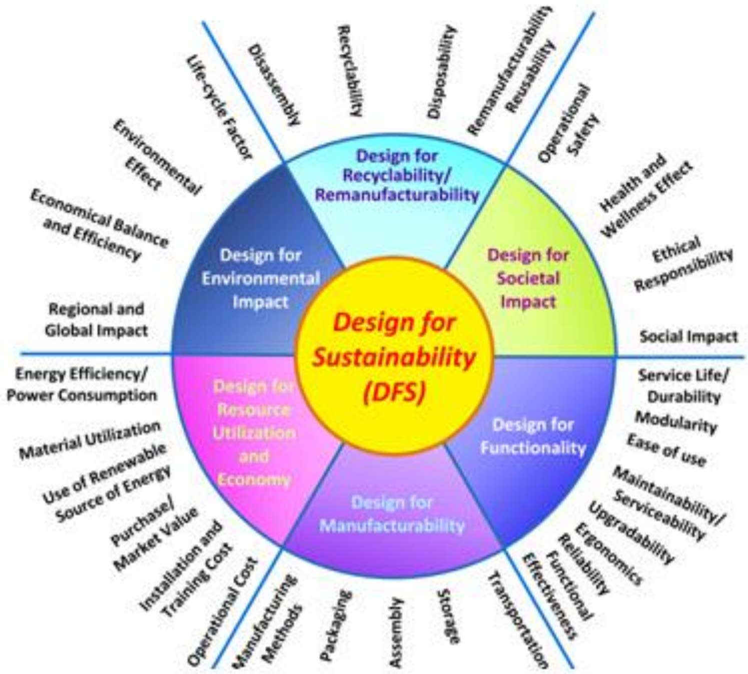


Figure 2-4: The element of product design for Sustainability (Jawahir & Rouch 2007)

2.2.1 Sustainable Design

According to Cooper (2002), sustainable means capable of being maintained indefinitely within limits, while development implies the pursuit of continuous growth. The concept of sustainable design developed initially from sustainable development, and it is an important measure of humanity's response to global environmental change at present (Huang & Zhang 2008). Sustainable design leads to the development of a product whereby the process considers the environmental impact. Any form of design that emphasises environmental impact by incorporating itself into living practice is called sustainable design. Sustainable design helps us to review our designs and people's daily life cycles and behaviours. The success of sustainable design is due to a collective effort among designers, suppliers, manufacturers, sales and service professionals, and consumers (Chen *et al*., 2011).

To participate in sustainable design, engineers have to evaluate and apply information from multiple disciplines such as economics, public policy, environmental science, social sciences, etc. Sustainability is always surrounded by uncertainty and ambiguity. Hence, engineers need knowledge and skills in order to be able to make decision and manage uncertainty (Chandu 2012). The basic challenges of sustainable design can be summarised by the old business management adage: “if you do not measure it, you do not manage it.” Such tool are particularly important at the product design level to predict the environmental effects associated with the different design options, and to be able to compare them with established targets (Skerlos *et al*., 2006).

According to Huang & Zhang, (2008), in order to create the design process more creative and successful the designer must follow the idea of sustainable design methods of conceptual product design. We must be more comprehensive when integrating modern design methods using all the kinds availabe science and tecnhology. Chen *et al.*, (2011) states that, the principle of sustainable design is the implemented throughout the life cycle of a product, including design, manufacturing, marketing, distribution, consumption, and disposal. The three general goals of sustainable design are a) the use of non-renewable resource should be reduce or minimised; b) sustainable design reflects a new ideal of human beings, and new aesthetics and values; and c) sustainable design without any cultural meaning or aesthetics will not be acceptable to society. Sustainability can be consolidated into product design. An in this process the environmental impact of the product improves with an LCA tool (Rosen & Kishawy 2012).

2.2.2 Sustainability Concerns

The world faces many alarming problems regarding water, the environment, foods, energy, health and etc., and these problems are becoming increasingly evident. Engineers and technology are problem solvers and these issues should be in sustainable ways. Sustainability should reach many disciplines, including but not limited to design, engineering, manufacturing, technology, and management (Fox *et al*., 2009).

A satisfactory level of sustainability in product design and development requires an appropriate tool in the early phase of the design process. The crucial part of this process is the decision making on uncertainties and the need to reflect the knowledge and experience of the designer's. The goal in this interactive process is to reach at satisfactory solution using multi-objective criteria. Normally in the design process, designers try to find the best solution using a trial-and-error approach. It is impossible for designers to pass on their knowledge to new designers without reasoning process of the decision-making support (Inoue *et al.,* 2012). Sustainability is increasingly important in human development and should be addressed in the development of social, economic, and environmental concerns. The success of sustainability is dependent on the decision-making practice, that is, metrics are needed to measure sustainability factors (Rosen & Kishawy 2012).

2.2.3 Sustainability Product Conceptualisation

Sustainable product conceptualisation using design knowledge was studied by Bei & Yan (2011), They highlighted the fact that the consideration of environmental impact in sustainable product design is a complex task compared to traditional approaches. The early involvement in the design process of sustainable product design means that decisions can be made about the product's life cycle in order to improve its environmental impact.

With a rapidly expanding market for new furniture, the level of waste can rise to a worrying level. People make use of many furniture items in order to obtain a higher standard of living, and new items are constantly when created to meet the growing demand. Furniture goods become unwanted for many reasons, for example, due to malfunction, the fact that they are outdated, or even because new innovative designs come along that bring many benefits. Technological improvement is unavoidable; the peaks in the never-ending technological cycle are becoming more rapid, as technology quickly advance. One question that arises is what exactly happens to outdated, unwanted furniture?

Figure 2-5 illustrates the furniture life-cycle and the sustainable life-cycle, beginning with the process of furniture design, and moving through development and use until the end of the life cycle, where materials can possibly be re-used in the manufacture of new products.

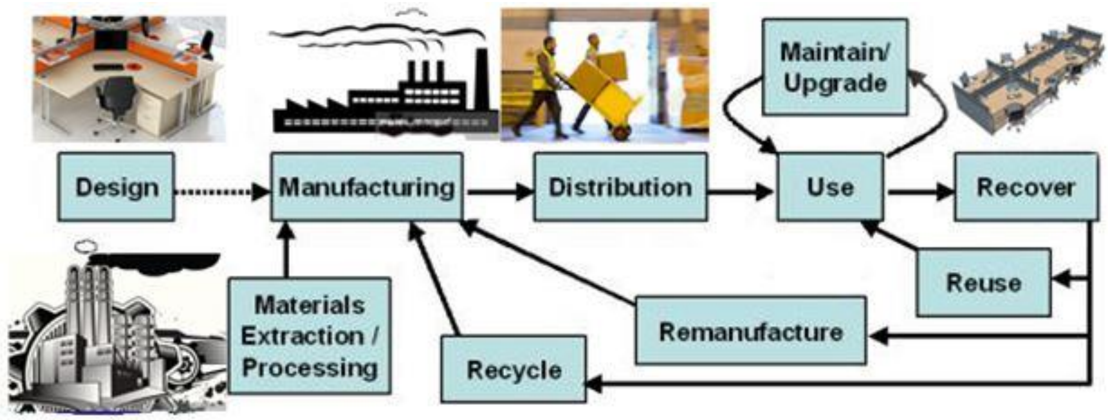


Figure 2-5: The Life-cycle of Furniture

Fiksel *et al*., (2013) as illustrated in Figure 2-6, below, developed a type of interconnection concept framework. The framework, known as a Triple Value Model (3V), describes the links between the industrial, societal, and environmental systems. This model is based on his previous studies for the Organization for Economic Cooperation and Development (OCED) (Fiksel 2006). In order to overcome the challenge faced, Fiksel, (2006), proposed this new concept of an integrated framework. It gives options for reducing the amount of material used, and illustrates the material flow between three types of capital: economic, human, and social, and natural. These three systems are interconnected. The Ecological system contains renewable resources (e.g. forest) and non-renewable resources (e.g. petroleum). The industrial system describes the type of ecological resources that may be depleted and use in manufacture, and cannot be re-used. The societal systems use the end products supplied by the industrial sector, and the consumer products generate waste; this can either be recycled or drawn back into the biosphere. There are two types of product categories: durable consumer products such as automobiles and non-durable products such as food items.

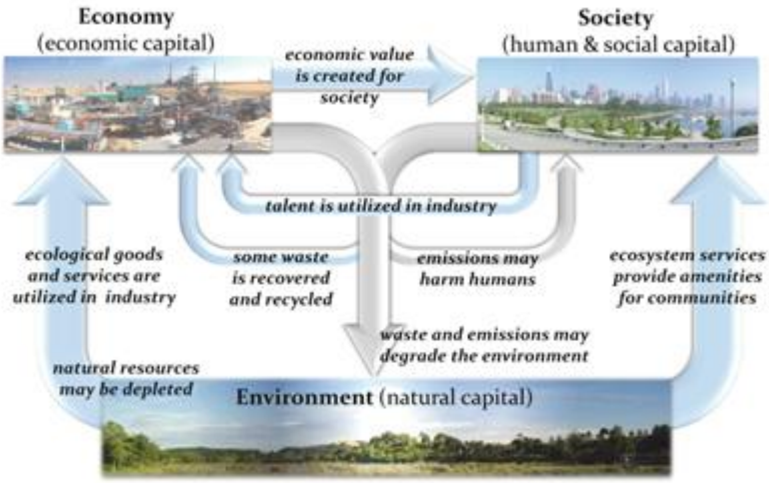


Figure 2-6: The Tripple Value Model (Fiksel et al. 2013)

Jawahir *et al.*, (2006) in their keynote paper, mention the importance of product design for sustainability and how it is important to achieve sustainable products, in order to achieve the needs of society and the, economy, along with environmental improvements. Their new framework was developed to evaluate the level of product sustainability and it involves a new methodology divided into different life-cycle stages: pre-manufacturing, manufacturing, use, and post-use. It covered the three pillars of sustainability - the environment, the economy and society. The life cycle is shown in Figure 2-6.

According to Nasr & Thurston, (2006), material, supply is necessary for closing the loop and matching consumer demand. Products remanufacturing has emerged as an essential element of the product enhancement practice. As a result, a product developer can reap the benefits of sustainable design by maintaining product responsibility throughout the product’s life cycle. The detailed product design issues include:

- Design for disassembly (and separation).
- Design for multi life-cycle (product reliability, durability, restoration and cleaning).
- Modular design: functional cluster and components with similar technical properties (durability) and market life (technology change rate).

- Product support for take-back decision (embedded conditions or usage monitoring) (Nasr & Thurston, 2006).

Further enhancing the ideas of Nasr and Thurston, Jawahir *et al*., (2006) proposed the closed loop process known as “cradle to cradle “ (see in Figure 2-7). In order to achieve sustainable product development, at least three criteria must be meet: a) reduction of materials and power sources necessary to fulfil product functionality and customer desire b) maximisation of the use of consumer resources and c) minimisation of undesirable impacts of waste products and pollutants.

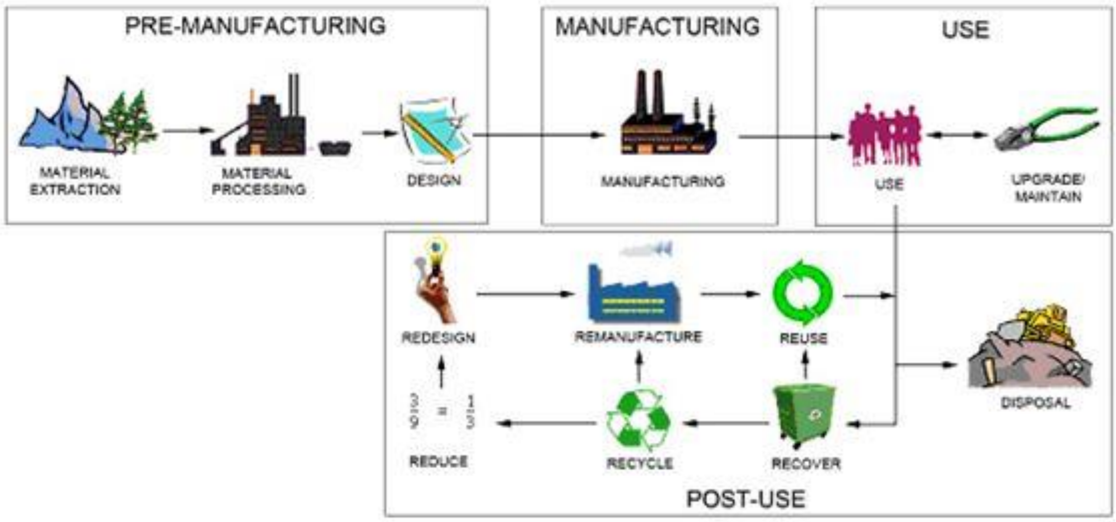


Figure 2-7: The close-loop life cycle of the "6R" sustainable product (Jawahir *et al*., 2006)

According to the 6R concept and methodology, ‘reduce’ refers to the first three stages of the product life cycle and includes the reduced use of resources in the pre-manufacturing phase, reduced use of energy and materials during the manufacturing stage, a reduction in waste at the use phase. ‘Reuse’ refers to reducing the use of new materials to manufacture products and components.

Sustainability issues at the product level rise due to the continuous flow of energy and materials used as inputs and outputs during the product’s life, as shown in Figure 2-8. For that reason it is important to take into consideration the total life cycle of a product, to be able to assess a product's sustainability. After this evaluation, it is easier to select between different designs or process, taking, sustainability into account.

There are various methodologies for the, analysis of product life cycle, for example the matrix approach with the use of target plots for the five life cycle stages of a product: pre-manufacturing, manufacturing, product delivery, use and recycling. Another, more recent approach, includes only four product life cycle stage: pre-manufacturing, manufacturing, use and post-use.

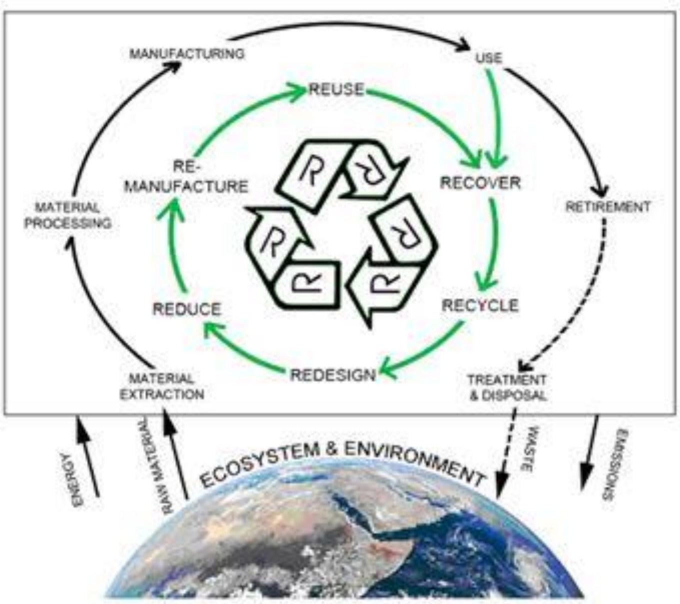


Figure 2-8: Closed loop product life cycle system (Jawahir *et al.*, 2006)

However, the entire issue associated with sustainability within product design and manufacture has not been considered systematically; numerous scholars have developed models and formulated indices and metrics about the method of measuring sustainability. The different types of manufacturing, and how they have developed over time, are described in Figure 2-9. Comparing traditional manufacturing with lean manufacturing, green manufacturing and sustainable manufacturing, green manufacturing and sustainable manufacturing, each one brings a moderate improvement in stakeholder value, as well as ecological progress. Innovation-based sustainability might change the amount of energy required in the production process, and numerous essential elements will be undoubtedly resolved through research, together with efforts to evaluate this particular issue. For this model of manufacturing to be successful, conventional production requires remodeling in order to achieve sustainable manufacturing.

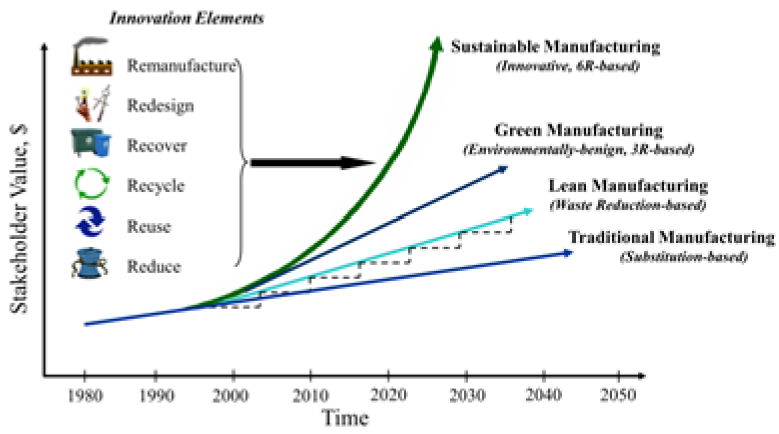


Figure 2-9: Manufacturing evaluation for 6 R

2.3 Manufacturing Furniture

It is clear that great advance have occurred in manufacturing concepts so far in the 21st century, and these have included the idea of transformation, innovation, creativity and product trends, for furniture products. The increase in demand for products has been the driver behind the furniture industries' use new technology and, new materials. The utilisation of creativity in design can greatly increase the complexity of developing a new furniture product (Bei & Yan 2011;Jr et al. 2007 ; Pan & Wang 2011).

Implementing a new manufacturing process in the furniture industry plays a prominent role in the growth and innovate performance of their products. The furniture designers and research development teams must equip themselves with the knowledge to sustain the office furniture by incorporating new technologies into the manufacturing of new products Ng & Thiruchelvam (2012). Ng and Thiruchelvam (2012) used both qualitative and empirical testing factors in their research on the manufacturer of

Malaysian wooden furniture located in the Muar state of Johor. Their findings suggested that the success occurred because of the accumulative efforts of the stakeholders.

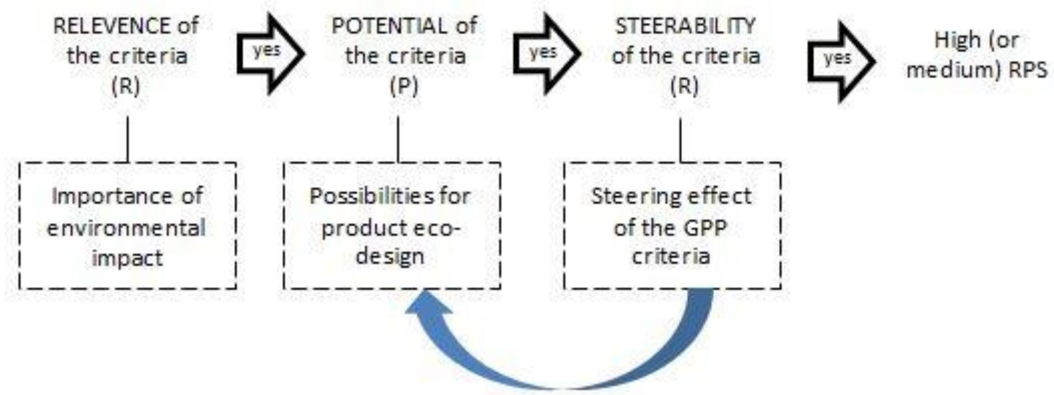


Figure 2-10: RSP selection tool, used notification to assess the relevance, potential and steerability criteria of environmental design (Parikka-Alhola 2008)

The value of the product can be calculated by R x P x S, which is the value present for each criterion (high, medium, or low). The average weight consists of environmental, social and economic issues where the weight is equal to all the criteria as show in Figure 2-10. To determine the environmental contribution, a wheel of environmental criteria was developed as shown in Figure 2-11.

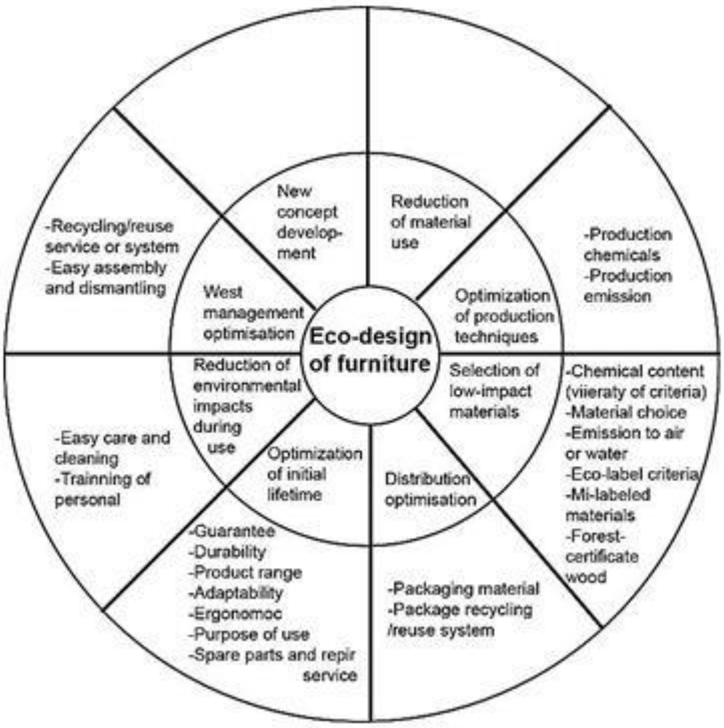


Figure 2-11: Environmental criteria of office furniture supporting eco-design strategies (Parrika-Alhola 2008)

In contradiction, Chaves (2008) asserted that environmental impact is not always correctly measured, with the greatest design decision being the choice of material. As an example, take the comparison between a wooden chair and a cardboard chair, with regard to their lifespan and usability; the, cardboard chair would have to be reconstructed many times, in other words the impact of its life cycle is greater. The best prevention process is a design process rather than at basic change, i.e. end-of-pipe (EOP). A combination of tools and methods can be applied during the design process in the furniture sector in order to make the measure of environmental sustainability more accurate.

2.3.1 Office Furniture

Furniture designers, have been under increasing pressure to work with sustainability, because, in our daily lives and activities are continuously involved with furniture. This is particularly true at work where people in office jobs spend approximately eight hours a day at their desk. Therefore, there is an increased need to create a healthier atmosphere, part of which is dependent on the quality of office furniture (e.g. desk and chairs). On the other hand, it is important to consider the environmental impact of office furniture; this depends not only on the material itself but also on anthropometrics human and ergonomic factors.

The philosophy of “one size fits all”, from a manufacturing point of view focuses on mass production and involves standard production procedures. That is, unless the office furniture required is a customised product, in which case the dimensions will be weather the end user requested. Furthermore, the design process also concerned with time constraints and cost effectiveness (Adu *et al.*, 2014).

Most of the furniture manufacturing companies provide different design ranges with different prices in order to compete with their rivals. Furthermore, with an agenda of sustainable development, they can gain environmental, social and economic benefits, creating new demand and office furniture with less waste and environmental impact. By diversifying their product range, companies increase their market opportunities. This evolution is a positive step towards effective and sustainable work or office furniture products (Boughnim *et al.*, 2004a).

A new method introduced by Besch (2005) is the implementation of product-service systems (PSS). The idea is to reduce the waste of raw materials used to produce office furniture until its disposal. The most significant aspect of PSS is that is offers new opportunities for both sides for the manufacturer as a producer, and to the consumer as an end user. The system tries to reduce the environmental impact of products, making economical, saving and more sustainable end products (in this case, of office furniture). Several authors have suggested strategies suitable for office furniture manufacturer, as mentioned below:

a) Design for durability office furniture has a long life.
b) Maintenance and repair services easy to dismantle and reduce consumption.
c) Reuse of furniture parts modularity; reconfigure parts and components.
d) Remanufacturing of used furniture to reduce the use of raw material.
e) Leasing or renting recycle used furniture.

According to Rosen & Kishawy (2012), many studies investigating environmental impact have been carried out on wood furniture, associated with volatile organic compound (VOC) emissions. Also, according to Luisser *et al.*, (2010) reducing the VOC emissions of office furniture partition, has been evaluated using environmental and biological monitoring to assess its effects on people. The use of formaldehyde in flooring, composite materials, partitions with different surfaces and, furnishing materials, impacts air quality. Improving the sustainability of office panel manufacturing would be beneficial to employees and also reduce the risks of accidents and illnesses among workers.

2.3.2 Open Plan System

Nowadays there is a current trend in the placement of, office furniture known as the open plan system (OPS). It has gained in popularity due to the flexibility and efficiency of the design, and the fact that it results in working spaces more conducive to work. The OPS is easy to re-arrange, according to the needs of each user. It can be reconfigured modular system components.

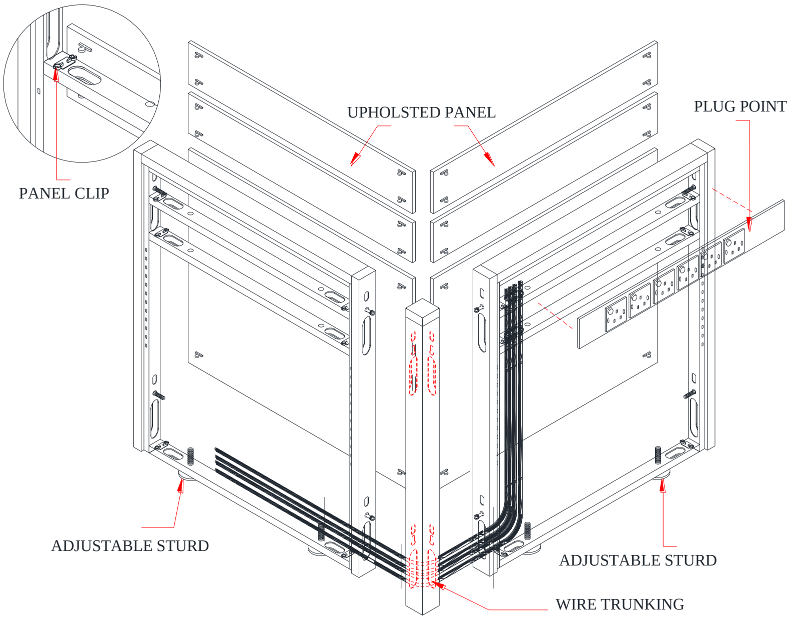


Figure 2-12: The Panel System

According to Dollah *et al.*, (2005) in Malaysia OPS become popular. Since the effectiveness of the system has been proven, demand has increased and designers have had to consider the environmental factors in the system and also the environmental impact on the user. OPS systems provide different possible combinations and configurations for each individual workstation, based on the office layout requested by the customer. The system can be vary in design and it can be reconfigure as required, as shown in Figure 2-12.

Each range of office furniture is normally provided with free standing items such as free standing tables, sets of drawers, filling cabinets, and hanging cabinets which may hooks onto a specific partition slot or attached panel. To provide the visual and auditory privacy in OPS, the work space can be determined using the movable panel system and partitions. For workstations, additional OPS components, and attachable accessories such as hanging cabinets and hanging shelves, can be efficiently too integrated into the design of the panel system, as shown in Figure 2-13. Another advantage of panel or partition systems is that they are able to support work surfaces, connectors and shelving (Sims 1997).

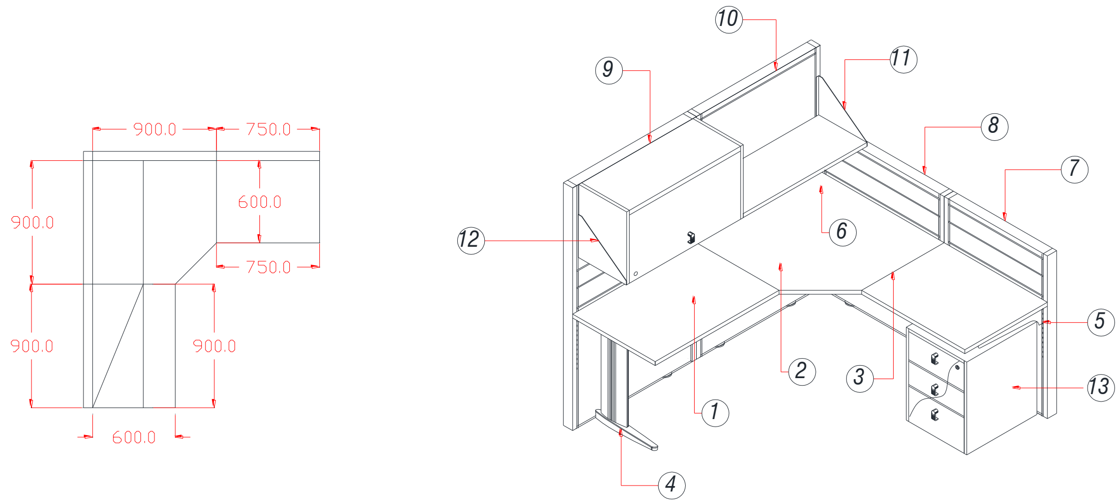


Figure 2-13: The work station full panel 1) work surface 2) work surface connector 3) work surface 4) aluminium leg 5) support bracket 6) hanging shelve 7) panel 8) panel 9) panel 10) panel 11) pole connector 12) overhanging cabinet 13) mobile pedestal

Open plan system; are readily and easily reconfigured in a building to suit any open floor space and to accommodate the specific end user; may different arrangements are possible to meet the divergent demands of various people. A particular set up commonly implemented OPS consists of movable partitions which can partition an open space towards specific workstation in the office (Application *et al.*, 1989). Some of the partitions will be configured according to the status of function of an individual in the organisation, for example hang-on furniture units, overhead cabinets, and shelves, To ensure privacy screen can be mounted on some of the office furniture in order to create individual, workstations (Ikeda *et al.*, 1999) such as that shown in Figure 2.14.

Figure 2-14: The Open Plan System at Open space environment.

This kind of earlier, traditional workstation with a dividing partition is comparatively permanent. Therefore, the multifunction workstation arrangement is needed so that end users can interact among themselves, and also so that groups and teams can be supported in activities such as inter-office conference. This kind of workstation does not support workers who wish to work as a team, or to take part in other interactions, such as those that may take place between designers, engineers, sales and manufacturing personnel. Furthermore, many offices are rented office space, such as managerial workstation, officer workstations, clerical workstations and general workstations as shown in Figure 2-15.

To obtain improvement through the utilisation of expensive office property, the management from the office normally has to discuss designs with the furniture manufacturer. They works together discussed to create the best design, in an attempt to help the workers to have modular OPS in an open office layout, rather than a conventional personal office. Knowledgeable designers/workers are required in order to achieve this. It becomes a major challenge for office furniture manufactures to design a comprehensive open plan system, that can be reconfigured to different work settings in order to meet whatever change are required.

Figure 2-15: The different kind of Workstation

2.4 Modularity & Re-configurability

2.4.1 Modularity definition

The definition of product modularity (Gershenson & Prasad 1997; Gershenson *et al*., 1999; Gershenson *et al*., 2003; Gershenson *et al*., 2004) specify a good brief of the work regarding the modularity mention about the modularity definition, modularity measurement and the application of modularity in product design for manufacturing. Gershenson *et al.*, (1999) however clarify the definition of modularity which incorporating this from customer to production that to cover the whole process produce the product. The manufacturer has made and effort to fulfil the customer's needs by supplying a flexible modular product. The problem is with the configuration of product families the implication is less understandable about the product design features. If the product design need to be redesigned it affects the cost of the whole process of production. Gershenson explains three aspects: a) attribute independence b) process Independence and c) process Similarity.

2.4.2 Benefits of Modularity

Modularity has become a popular key feature for companies if they are considering meeting customer demand with customised products for future development. They should introduce a variety of products with a competitive number of products, and be able to manufacture them in a short period of time a competitive cost and good quality. The complexity of modern products has forced companies to think about modularity, and it has recently gained in importance. The term of 'modular' in product design is commonly used to refer to a standard item that can be modified through multiple configurations and design options. The configuration design is important for furniture development in preliminary design stage, this stage also has a potential implementing the concepts of sustainability, as well as the approach for sustainable design index for office furniture.

Modular products can be classified into many different categories. Modularity has generated interest among many researchers in various fields, and it has also initiated interest in product architecture. Modularity is beneficial as it decreases design work. A common practice in design, product modularity is capable of producing a diverse design options. Its objective is to standardise, and to produce a variety of design options that meet the functional requirements of each design. Modules are based on functions, and each component can be broken down into sub-modules (Pahl & Beitz 2013a ; Ulrich & Eppinger 2004) Modularity in product design influences every phase of the product's life cycle (Ulrich 1995), and It is also play an important role in many activities: product cost, Design for Manufacturing (DFM)/ Design for Assembly (DFA), manufacturing cycle flow time, etc. Design for Manufacturing and Design for Assembly are key factors that for engineers use to assess the product's life cycle and to focus on environmental impact. Perhaps engineers need to maximise and address the activities involved in systematic approach early in the design process stage (Ishii 1998).

The modularity and re-configurability of products enable companies to produce a variety of products at a low cost. Furthermore, using modular products to respond to market demand, and new technology with the application of flexible design, help companies to diversify their product configurations. There are three functions refer that refer to modularity: product, process and resources. All three should be optimised for time, cost, reliability, quality, and manufacturing. One of the examples of modularity in engineering design is the Boeing 777 aircraft. (Kusiak 1999,2002). Furthermore, the most important product decision involved in the design process is product architecture. In order to correlate the functional elements of the product with the physical design attributes, a proper plan is needed, taking both aspects into account. Mapping the functional and physical components takes into account the important characteristics when designing a complex modular product (Ulrich 2003;Ulrich & Eppinger 2004). The verity of product configurations possible for a modular product is depends on the mix and match of the components; if the product is highly modular then several designs and design options are possible, but the opposite is true then only optimisation of the product range is possible (Mikkola & Gassmann 2003). In addition, the modular components can be easily configured according to the users' needs if the company has customised the design range. A high modular, customised product gains high value sharing components with other configurations, and modularity and re-configurability are able to support an assortment of designs of the standard product (Mikkola & Gassmann 2003).

Designers began to produce modular products, especially furniture so that they would fit the design process and meet the customer's requirements. They also need to meet, time constraints, be cost effective and save time from conception to production stage. Modular designs perform an important role as problem solvers in the design process, enabling the manufacturer to meet the design requirements. In furniture products, the whole module is fabricated in a variety of forms and interfaces with different geometric parameters, and then integrated into an acceptable design for a workstation (Su 2010).

Erixon *et al.*, (1996) add that the module driver can be effectively adapted for manufacturing systems in order to continue product renewal and concurrent development. According to Cheng *et al.,* (2012) product modularity can foster the future of product development and an increasing awareness between inventors and scholar's.

As needed, more effective in decision making parallel with modular design, axiomatic design and design structure matrix an appropriate tools are required. The approach enables companies to justify product improvements in the early stages of design. Even if the same products produce are manufactured, they can be put together in different ways so that the end product is different.

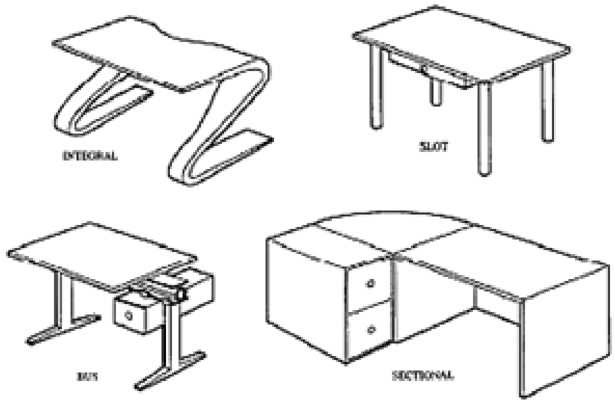


Figure 2-16: The type of product architecture (Ulrich 1995)

According to Ulrich (1995) product architecture is a combination of innovation and decision-making made by an industrial designer and engineer. The ability to achieve performance and product development at an early design stage plays an important role in managerial decision-making. Different customers need to be provided with different modules, and with this modularity and re-configurability the manufacturer is able to mix and match the products' function at a low cost. From Figure 2.17 and 2.18 illustrated by Ulric shows an example of a trailer and desk as a typology to describe the different product architectures. The ideal combination and final assembly show that the different characteristics of product depend on the individual and part assemblies.

Ulrich (1995), as shown in Figure 2-16, divided modular products into three categories:

1) Slot-modular architecture- this has a certain modular fit to certain positions and it cannot exchanged with of other modular products. A radio controller car is an example

2) Bus-modular Architecture- provides a higher flexibility connected to the same interface and is able to mount in various configurations. The most common example is computer compartment and lighting track.

3) Sectional-modular Architecture- provides a free interface with high flexibility and can be configured in various ways. The best example is products such as sofas, panel system, and piping systems. It is important to note that the mapping between the functional elements and components of modular products can be on one-to-one, many-to-one, or one-to-many. The mapping between the functional elements and components of a trailer is an example of this. Figures 2-13 illustrates a one-to-one example, while Figure 2-14 shows a more complex, the integral trailer architecture where the components are attached together.

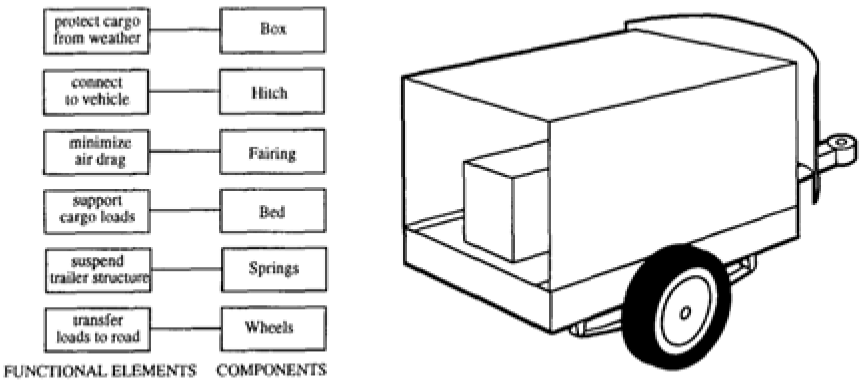


Figure 2-17: A one-to-one mapping of modular trailer

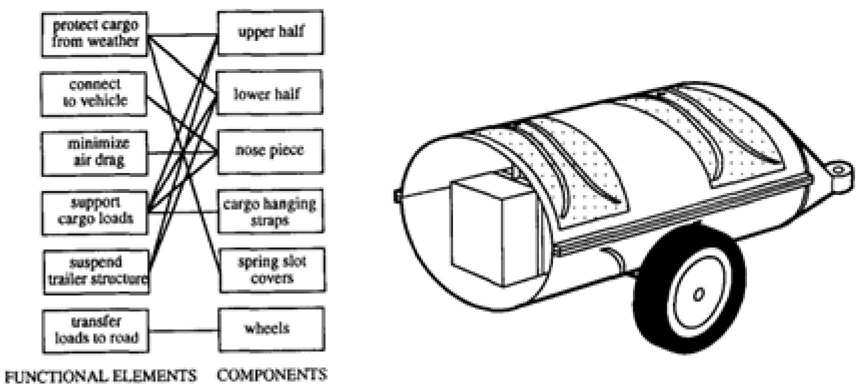


Figure 2-18: The integral trailer Architecture

Ulrich (1995), described the difference between modular architecture and integral architecture. An on-to-one product mapping is a modular architecture in which the components' function can be fulfilled by more than one component. Integral architecture is an example of function sharing it considered more complex as each which component can fulfil more than one function.

In addition, the modular type can be classified according to their function, and they were distinguished by Pahl & Beitz (2013a) based on two modules types- functional and production modules. Functional modules – help to implement technical functions independently or in combination with others. Production modules- are designed independently of their function and are based on production considerations alone. Pahl and Beitz continued to classify the definition of modules according to their functionality and they defined the various types of function (basic, auxiliary, special, and adaptive). Any design or function that is not related to these functions is called 'no-modular' means that it is designed individually (see Figure 2-19).

The designer must make sure the demand of modular product will meet the required product characteristics functions. Pahl & Beitz (2013a) further classified modularity into, closed modular systems and open modular systems. Closed systems correspond to bus modularity and slot modularity, and open system correspond to sectional modularity.

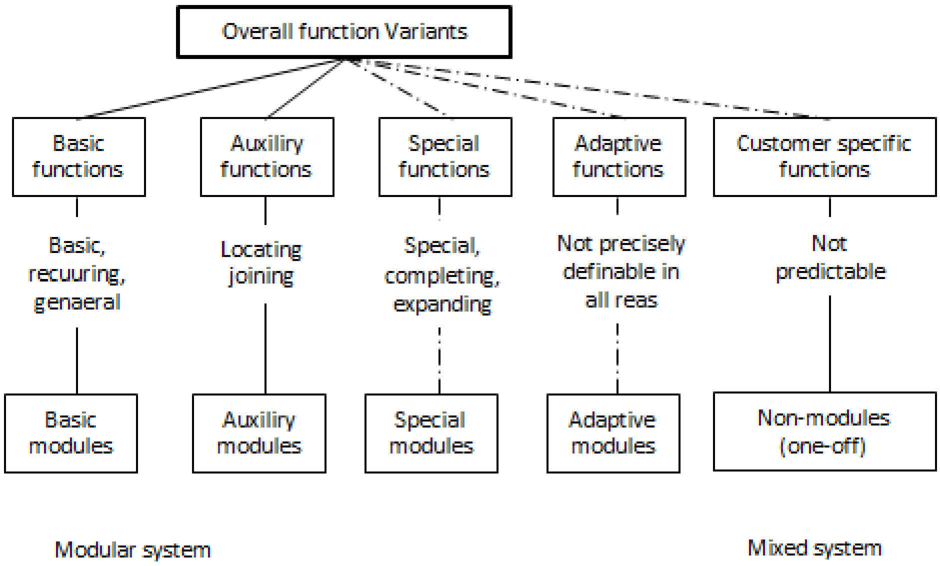


Figure 2-19: Function and modular types in modular and mixed product system (Phal Beitz 2013)

According to Ulrich (2003) most of the product architecture is its modularity. In the other words, in modular architecture there are two elements functional and physical terms. The functional elements of a product are stand-alone but contribute to other parts of the product. Modules are also known as chunks. The product implementing to the chunks is not required to change the overall entire of the product, also easily to fit with other chunks to fit the purpose of the product, because the functional elements of the product are exactly one physical chunk. The opposite of modular architecture is an integral architecture.

2.4.3 Modularity Measure

Previous studies on modularity product design suggest a distinction between integral and modular, in both product and subsystems (Ulrich 1995; Sosa *et al*., 2007; Mikkola & Gassmann 2003). Gershenson *et al*., (1999) state that modularity can be measured during any time of the life cycle of the product. The same approach was taken by Newcomb (1998) who studied the modular level of the product. Sosa *et al.*, (2007) point out that researcher have studied the component level of modularity less than modularity at the system level. Furthermore, modularity can be measured at varying levels such as component level, system level and product level. To measure the modularity, a few points need to be clarified and defined in order to analyse the breakdown of the system and its components. Each of the components is analysed using the relationship and network between the components, either dependent or independent of the modularity product.

However, the particular measurement in modularity remains unclear. As mentioned by Gershenson *et al.*, (2004) there are still few guidelines with which to measure modularity, other than from the perspective of product design. The basic intentions of modularity are to maximise and to minimise the internal similarity, physical architecture and functional components between modules. Due to this designers fail to use an appropriate tool to measure modularity in product design. Without a doubt, according to Zhang & Gershenson (2003) study, the implementation of modularity is mathematical as there is a need to calculate reconfigurations, and to redesign for product architecture components using matrix-based modularity to define the maximum relation of products' modularity. The results of this study show that there is a relationship between modularity and cost. The reality is that normal life cycle modularity measures could not utilise to the design approach that is suitable for classifying the most helpful arrangement. An appropriate tool is needed so that it easy for the designer to identify the benefits that modularity can bring to the life cycle of the product.

An investigation of the literature revealed that a few methods have been applied to measure the degree of modularity. The term is widespread and has received attention from different practitioners, but its definition and the ways to measure it are rather confuse. Kusiak (1999) looked at the problem of modularity in mathematical terms, and the concept of a block-block (component-component) is presented. The problem face by industries when applying modularity is often that most of the standard configurations produce product that cannot reconfigured into other designs. The main reasons for this, according Kuasiak, are poor understanding of a modularity issues; lack of theories and tools for the definition of modules from a broad perspective; and some designer scepticism about the advantages of modular product because no one has been able to demonstrate its benefits to them. The result produces as shown in Figure 2-20 a shows an interaction matrix and Figure 2-20 b shows a transformed modularity matrix.

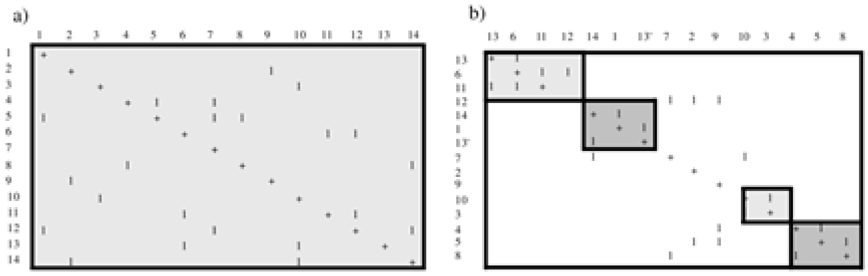


Figure 2-20: Modularity matrix (a) Interaction matrix for 14 components
(b) transformed modularity matrix (Kusiak 2002)

According to Mikkola & Gassmann (2003), modular product architecture is becoming increasingly important to companies. Further development has been facilitated by Mikkola (2007) modularisation function (MF). This model measures the degree of modularisation embedded in a given product architecture by taking into account the number of components, interface, degree of coupling, and substitutability. Mikkola emphasis that, through reverse engineering to customisation, modular products need to satisfy the needs of the customer, and the manager needs to measure this using an appropriate MF tool. She categorises the degree of customisation: standard–noncustomisable; standard- customisable; unique–noncustomisable; and unique–customizable. Mikkola stated that with product customisation the relationship among the components can be either modified or not, as shown in Figure 2-21.

Gershenson *et al.*, (1999) have developed modularity in the context of a product life cycle. The method emphasis on section independence and match throughout the product's life cycle, and contains a step-wise configuration and restructure approach to influence designers toward better modularity of products. The goal of their methodology is to simplify the process and add value to the modular products in terms of life cycle processes; all the components undergo the same process to redesign, rearrange and change the components or modules. Another approach was taken by Umeda *et al.*, (2008) who state that 'modular design' can increase the functioning of the life-cycle.

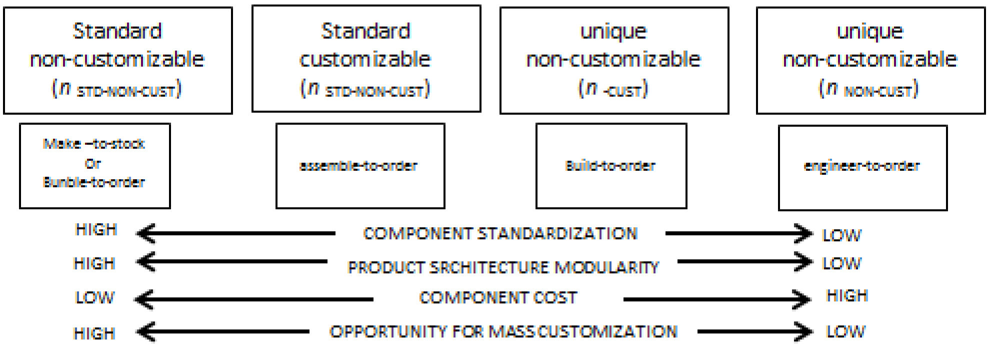


Figure 2-21: A customisation strategy spectrum

The evaluation of modularity is essential for dealing with the product life cycle, reducing the time and cost of disassembly for modular design, with no impact on the environmental assessment. When evaluating the environmental aspect, a new resource is required to introduce a proper tool for an evaluation index. The tool should be able to value the life-cycle to assess the environmental scores. As a result, modular design performance is an essential characteristic in green design. Modular green design supports product modularity, which is more competitive when the cost of the product life cycle is reduced. Newcomb (1998) explored the importance of determining the life cycle product architecture in an early stage of modularity during the design process. There are benefits to modularity seen towards the end of the product's life cycle, such as recycling and disassembly. During the early design process, in order to simplify the disassembly of the product, the designer needs to consider product modularisation, and standardisation of the product components for easy storage and transportation. This can improve project organisation and offer a design choice classified as a modular product.

The method begins with generating the component tree, which is to classified into sub-assemblies. The modular metrics are constructed; one is based on the similarities of the components and the other one is based on the dependency of the components. A set of ratings for the similarity and dependency is, applied in order to evaluate components and modular design, based on their relative modularity. The final stage is to calculate the relative modularity between two components and the life cycle process; these are the similarities and dependencies for the component-component and component-process (Gershenson *et al*., 1999).

Sosa *et al.*, (2007) mentioned that in order to measure modularity, the connectivity of a component within a product need to be quantified. First step to identify the important of nodes in a graph of a network by using empirical studies. To identify the level of product modularity, the dependencies between products need to be broken down into functional or physical components. The design structure matrix is then applied to capture the dependencies between the components with matrix 'X' the design domain and non-zero elements. The components' modularity is then measured using three types of measure: the degree of modularity, distance modularity, and bridge modularity. The degree of modularity is measured by in-degrees and out-degrees to define the maximum degree of modularity that can occur when the components connect to each other. To measure distance modularity, components have a distance where a high value means that the product has more modularity. To calculate using bridge modularity, more product bridge between the components mean that they are less modular. Later Agrawal (2009) developed the products network measure for modularity product to represent the network of interfaces between components. To measure the modularity of products, the Graph Theory was used and two methods (degree modularity and bridge modularity) were applied to calculate the adjacent and criticality related each other between the components. The benefit of the modularity measure is that it assists manager to make better decision in the operational and strategic areas.

2.5 Design Structure Matrix

Steward (1981) introduced the design structure matrix, and it is applied by many researchers using a graphical method. One of the most widely used methods by designers or engineers in the design process is the design structure matrix (DSM). The DSM method is well accepted and applied at many levels of interest to enhance and analyse either products or systems. The Design Structure Matrix (DSM) or Dependency

Structure Matrix (DSM) was developed by Steward for representing and analysing task dependencies (Steward, 1981). Hong & Park (2011) adopted DSM to overcome the problem of not defining modules of a product at the early stages of design. The combination of AD and DSM applied at the phase of modular design to the functional requirements (FRs) and the physical connection between the required designs parameters (DPs) of the components of the product. Hong & Park (2011) DSM is adopted at a sub function level as a solution to solve the problem. For the modelling stage the application of DSM is considered as the components or sub-system are based on DSM only. However the designer knowledge is important in order to specify the concept design at the sub-problem based.

Holtta *et al.*, (2005) state that DSM, as the method to analyse the degree of product modularity, is modular and based on the integral connection between products. To measure and compare the modularity of a system to generate a quantitative metric with a DSM model of a product, they calculate using the Singular value Modularity Index (SMI) for the sake of simplicity. By Using a non-binary DSM unable to present a quantitative method that makes a comparison between two components. Sosa et al., (2007) used the DSM to identify whether the product components using were based on modularity or were integral based.

According to Browning (2001) the DSM has become a well-known method for examining applications meant for program options, in particular, for decomposition and implementation. The DSM shows any associations among the elements of a system in a very compressed, graphic, and also analytically beneficial arrangement. The DSM can be a rectangular matrix using the same row and column labels. For the product DSM shown in Figure 2-22, the components are displayed by the shaded components on the diagonal. An off-diagonal indicates the dependency of one aspect with two others. Looking over a row explains any alternative components that consider which row offers to; checking the column explains any alternative components the factor in which line relies on. Which is, looking at lower the line describes such as suggestions, options, although looking at over a line signifies result comes.

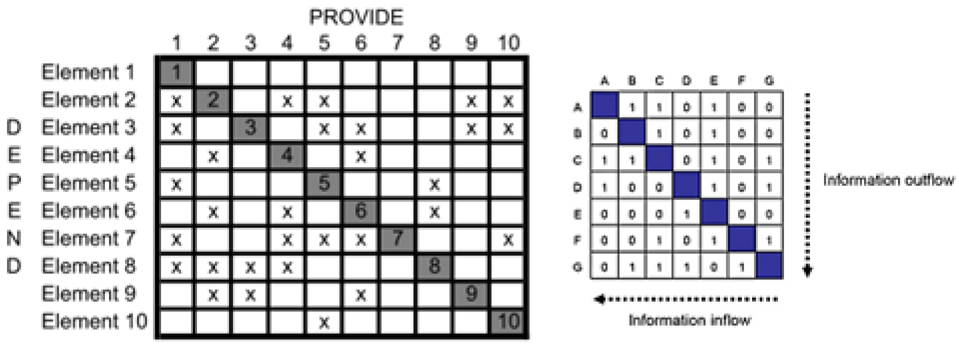


Figure 2-22: Example of DSM (Yassin 2005)

According to Pimmler (1994), it is important to understand the interaction between the components and the need to coordinate depends on the clustering. In terms of functional and physical elements, determining the product concept is based on the appropriate use the cluster of elements. The elements must capture the latest knowledge, including the understanding of both the designer and the manufacturer towards product functionality. The development could begin to identify and describe the interaction by considering the taxonomy systematically. There are four types of interaction to consider: 1) association of physical space and alignment, 2) association of energy exchange, 3) association of information exchange, and 4) association of material exchange. As shown in Figure 2-23 and Figure 2-24 these four are generated as follows:

Spatial	A spatial-type interaction identifies needs for adjacency or orientation between two elements
Energy	An energy-type interaction identifies needs for energy transfer between two elements
Information	An information-type interaction identifies needs for information or signal exchange between elements
Material	A material-type interaction identifies needs for materials exchange between two elements

Figure 2-23: Four generic interaction types (Pimmler 1994),

Spatial	S	E	Energy
Information	I	M	Material

Figure 2-24: Legend for Eppinger Alternate DSM method (Pimmler 1994),

The weight number is given upon the design problem definition and interactions are given. The interaction among elements depends on the important relationship between them all. A five-point scale given is used to quantify the interaction based on the relative type of interactions, as shown in Figure 2-25.

Required	+2	Physical adjacency is necessary for functionality
Desired	+1	Physical adjacency is beneficial, but not necessary for functionality
Indifferent	0	Physical adjacency does not affect functionality
Undesired	-1	Physical adjacency cause negative effect, but does not prevent functionality
Detrimental	-2	Physical adjacency must be prevented to achieve functionality

Figure 2-25: General interaction quantification scheme (Pimmler 1994),

Later Sosa *et al.*, (2007) used the type of design dependency to measure the product modularity among the 54 components of the commercial aircraft engines. They used the five types of design dependencies to define the design interface for the overall functionality of the components. To determine the strength of the connection and the negative energy dependency of the low-pressure turbine blades, the three criticality levels are considered: indifferent (0), Weak (+1,-1), and strong (+2,-2).

2.5.1 Classification of DSM

Design structure matrix (DSM) became popular for project planning, development, product development, system organisation, and system engineers. DSM is a compact that constitute system exchange, activities and corresponding information and company development. The matrix presented required information to feed into the matrix, in order to generate and utilise the output.

To compose the DSM graph two elements need to be considered: the elements "A" and "B". The pictorial method is the best way to present the relationship between the two systems by node or vertex. The connection is linked and captured between each other by arrows, where the result is call directed graph. The normal building block consists of three connections between the process of each elements (Ali Yassine, 2004).

There are three samples shown in Figure 2-26 of the different type of DSM.

- The parallel configuration, in which the design elements (e.g., design parameters or activities) are fully independent of each other
- The sequential "decoupled" configuration, in which the second parameters is dependent upon the output of the first, and
- The couple configuration, in which the parameters are independent upon each other.

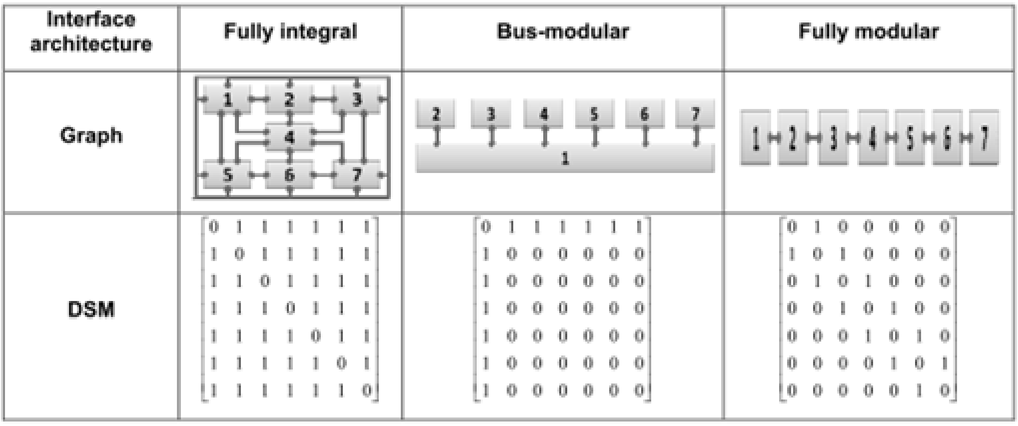


Figure 2-26: The composition of design structure matrix DSM (Yassin 2004)

2.5.2 Integrated Uses of DSM

The matrix is represented by rows and columns and it is filled in with just zeros and ones. The matrix is square if the number of rows and columns is equal. The rows and columns are denoted by m, and n is non-zero elements, where m is nodes and n is edged in the graph. The system layout for the matrix is with the element name placed down the side of the matrix as row headings, and across the top as column headings in the same order. The edge exists from node I to node j, and then the value is ij, and will be marked as "X" and "0". The elements of the matrix can be filled will zeros or otherwise left empty (Ali Yassine, 2004). In system modelling, any absence or presence of the binary matrix is useful to represent the relationship between the elements of the system. The ability to map and easily read the components in the binary matrices is a major advantage.

Holtta *et al.,* (2005) discuss many advantages of modularity thoroughly, but only the degree of modularity the effect of technical performance was analysed. The author also elaborates on the previous literature and developed a new metric that is less sensitive to human choices. The study chose the binary DSM to analyse the matrices as this study continues for Dong & Whitney (2001). Holtta *et al.*, (2005) sought the internal connectivity of the product using the degree of modularity, where the connection between two components using the off-diagonal DSM represented the binary structure matrix of entire zero elements as shown in Figure 2-27.

$$\mathrm{DSM}_{\mathrm{integral}} = \begin{bmatrix} 0 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 1 & 0 \end{bmatrix} \qquad \mathrm{DSM}_{\mathrm{modular}} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

Figure 2-27: Example of the binary matrices of the system (Holtta *et al*., 2005)

Figure 2-4 shows the connection between the five components a) integral system and b) modular system. In the first case, every component connects with every other; this is a fully integrated system. In the second case, the components only connect with the nearest or the most direct component; this is a fully modular system as shown in Figure 2-28. Both systems have five components referred to as N.

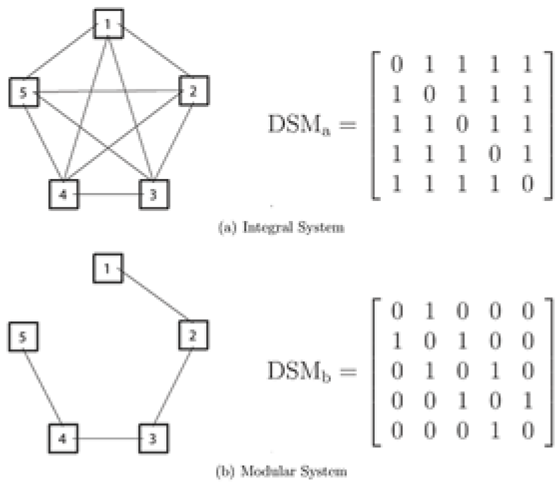


Figure 2-28: Product structure and associate a) Integral system b) modular system

2.6 An Introduction to Axiomatic Design

Axiomatic Design (AD) was introduced by Suh (2001). The idea represents the organised techniques and hierarchical procedures pertaining to an engineering design method. Axiomatic design is an analytical solution to mapping concerning FRs and DPs of some products. Industrial designers, as well as experts, start to search for the functionality associated with the product when they recognize the physical aspects related to the item. Creating a correct selection on a scientific basis is vital for designers or engineers early in the design process. Hong & Park (2011) mentioned that the theory of AD is capable of delivering the guideline to the designer, but at a certain level, designer experience is important to resolve the problem. To examine the concept design difficulties facing the sub-problem, designer knowledge is potentially needed to solve it.

2.6.1 Element of Axiomatic Design

To investigate and to test the validity of the design, a more analytical data structure AD methodology became popular among designers and academics. Axiomatic design is a design methodology that systematically processes information between and within four domains in the design world: the customer domain, the functional domain, the physical domain, and the process domain, as shown in Figure 2-29. An Axiomatic

Design method, introduced by Suh (1990), has become implemented primarily throughout any conceptual product phase. Nevertheless, several challenges appear in utilising this approach, specifically in the development of suitable FRs and DPs.

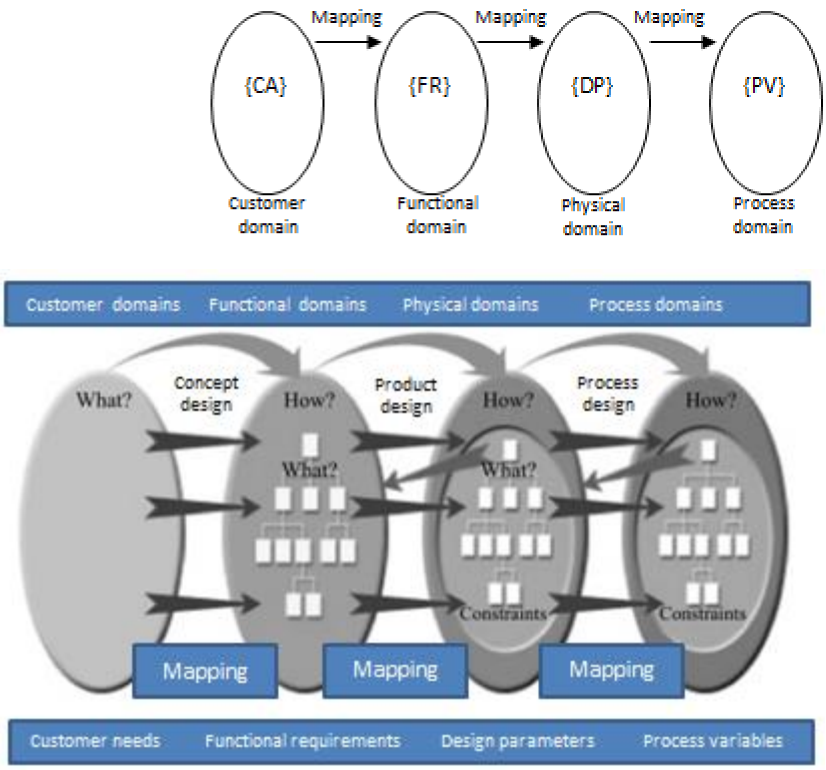


Figure 2-29: The process from an Axiomatic Design perspective

Yu *et al.*, (1998) from their studies, defined an improved Axiomatic Design approach using the House of Quality, decomposition through concept, and also the task on the Quality FRs to Standard FRs. This method seeks to resolve understanding as well as the capability of implementing AD.

Using the AD technique, Suh (90) separated the product development process based on four domains that happen to be coupled through three mappings, as shown in Figure 2-25. The four domains include the customer domain CAs, functional domain FRs, physical domain DPs and process domain PVs. The continuous mappings between a particular domain, “What we want to achieve”, to another domain, “How we want to achieve it”, are controlled by two axioms: the Independence axiom that: maintains the independence of FRs, and the Information axiom which: limits the content information for the design

Axiomatic design begins with the more general requirements, and then these highest-level requirements are decomposed into lower level sub-requirements. The physical and process mapping can be expressed mathematically as:

$$\{FRs\} = [A]\{DPs\} \tag{1}$$

Where $\{\boldsymbol{FRs}\}$ is a vector that describes the functional requirement of the product in terms of its independent component *FRi;* $\{\boldsymbol{DPs}\}$ is a vector that describes the parameters that define the product in terms of its effect on $\{FRs\}$; $[A]$ is a product design matrix. The elements of product matrix, $A_{i\,j}$ are given by

$$A_{i\,j} = \frac{\partial FR_i}{\partial DP_j} \tag{2}$$

In order to satisfy the independent axiom, $[A]$ must be a diagonal or triangular matrix. The design that has a diagonal matrix is called an uncoupled design, which also satisfies the independence axiom, provided that the DPs are changed to a specific sequence. All other designs are coupled designs.

2.6.2 Axiomatic Design Method

All the AD methods use the mapping of a single pair of factors. Most characteristics are typically mapped towards a group of FRs. The principle design in Suh’s development procedure schematic is indicated in Figure 2-26. The particular DPs represent a physical embodiment associated with an achievable designed to fulfil the FRs. As Figure 2-30 indicates, that design process involves mapping the FRs belonging to the functional domain towards the DPs within the physical domain to establish a solution, method, technique, and team which meets these understood societal demands. Notice that a certain mapping procedure is absolutely not unusual. As a result, some designs may possibly be caused by this creation where the DPs match the FRs. The result, however, relies on the designer's versatility. On the other hand, these design axioms offer the guidelines to which the mapping solutions should be matched in order to develop a perfect product, and also provide the foundation for comparison of designs.

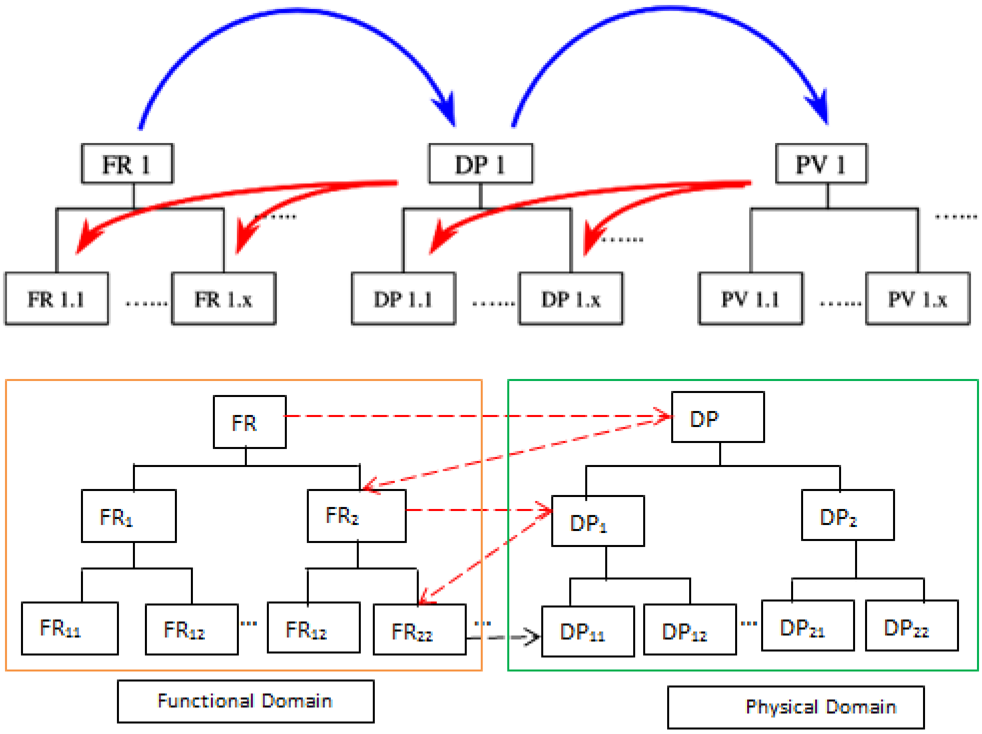


Figure 2-30: the mapping and zig-zag through domain

Throughout the development approach to some furniture initially a hierarchy is obtained towards the FRs. Figure 2-31 presents the functional hierarchy that is needed to obtain an OPS.

According to Gonçalves-Coelho & Mourão (2007), the planning tasks should take into consideration most of the ''input constraints'', and moving from the design domain towards the subsequent domains is one of them. Transferring from the customer domain to the functional domain is known as ''conceptual design''; through functional to the physical domain, one has ''product design''; and ''process design'' signifies shifting from the physical towards the process domain. [A], [B] and [C] consist of design matrices for conceptual design, product design and process design, respectively. A great process, zigzagging, is utilized in order to thoroughly decompose the whole technique towards lower product points. This can be done moving back and forth between a minimum of two continuous product domains. Using mathematical terminology the mapping is denoted by:

$$\{CN\} = [A]\{FR\}, A_{ij} = \frac{\partial CN_i}{\partial FR_j} \tag{3}$$

$$\{FR\} = [A]\{DP\}, A_{ij} = \frac{\partial FR_i}{\partial DP_j} \tag{4}$$

$$\{DP\} = [A]\{PV\}, A_{ij} = \frac{\partial DP_i}{\partial PV_j} \tag{5}$$

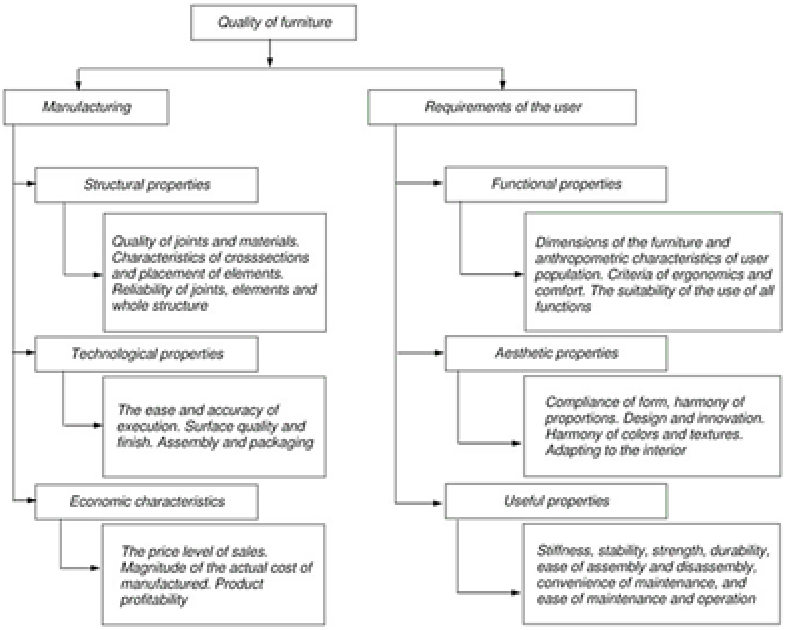


Figure 2-31: The division of furniture in term of quality

Yu et al., (1998) explained an improved AD process using the House of Quality which includes the benefits of both of these techniques. The House of Quality was employed in order to translate consumer demands directly onto engineering requirements; Decomposition is applied to consider the fundamentals; Engineering requirements are generally classified quality functional requirements and potential fundamental functional requirements; Quality functional specifications will be appointed towards various fundamental functional requirements; The Simple Design Matrix, Single Quality Design Matrix and Cross Quality Design Matrix are typically created for examining and analysing product factors from different aspects. Making use of this strategy, relationship can be expressed by a design matrix, it can be achieved, and an enhanced awareness with greater performance could be obtained, as shown in Figure 2-32.

	Design equation	Design process
A) Uncouple Design	$\begin{bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{bmatrix} = \begin{bmatrix} A_{11} & 0 & 0 \\ 0 & A_{12} & 0 \\ 0 & 0 & A_{13} \end{bmatrix} \begin{bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{bmatrix}$	$FR_1 = A_{11}xDP_1$ $FR_2 = A_{12}xDP_2$ $FR_3 = A_{33}xDP_3$
B) Decoupled Design	$\begin{bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{bmatrix} = \begin{bmatrix} A_{11} & 0 & 0 \\ A_{21} & A_{22} & 0 \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \begin{bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{bmatrix}$	$FR_1 = A_{11}xDP_1$ $FR_2 = A_{21}xDP_2 + A_{22}xDP_2$ $FR_3 = A_{31}xDP_3 + A_{32}xDP_2$ $+ A_{33}xDP_3$
C) Coupled design	$\begin{bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \begin{bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{bmatrix}$	$FR_1 = A_{11}xDP_1 + A_{22}xDP_2$ $+ A_{33}xDP_3$ $FR_2 = A_{21}xDP_1 + A_{22}xDP_2$ $+ A_2 3xDP_3$ $FR_3 = A_{31}xDP_1 + A_{32}xDP_2$ $+ A_{33}xDP_3$

Figure 2-32: Uncoupled, Decoupled, and Coupled

2.7 CAD Environment and Conceptual Design

Computer-aided design (CAD) system is essential and universal in the modern industrial design and engineering world to solve problem in the product development process. Commonly, a CAD system is more suitable for detailed design, mainly related to 2D drawing (Gharib & Qin, 2013). CAD software continues to be practical throughout, assisting a designer's work operating in numerous development routines (B. Singh *et al.,* 2007). The particular functions provide approaches that are often enhanced by the designer, involving limitations dependent on the types of procedures. There are several CAD tools available on the market currently, such as AutoCAD, SolidWorks, Solid Edge, I-DEAS, Pro/ENGINEER, CATIA, Inventor Unigraphic, etc. Most of this software enables the designer or engineer to create 2D and 3D drawings. CAD systems are aimed at industrial designers to enable them to obtain a good result in the early design process (van Dijk, 1995).

In modern times, CAD is set to play a part in almost all companies. Manufacturers have to make use of the advantages of CAD to be competitive in the market. CAD offers a decreased time of development as well as manufacturing, and strengthens the drawing quality of product design, enhancing interactions and, minimising mistakes. This helps to develop a data bank of standard products (Tan & Vonderembse, 2006).

Tan & Vonderembse (2006) examined the relationship between CAD usage and product development, and how this has a positive impact on product development and cost performance, by surveying 175 manufacturing companies. CAD usage is not limited to design new products, modifying existing products, or developing technical drawings for production. It also can be used to design and redesign using manufacturing tools, dies, jigs and fixtures. With new features built-in allows industrial designers and engineers to develop a new feature to evaluate the environmental, economic and social factors and thus measure sustainability. As CAD is needed for interaction to communicate between the product and the product process, the involvement of designers and managers will improve product development performance, by increasing information, which results in few errors and enables improved and quicker decision making.

Technology provides results in actual development of CAD system. Malhotra *et al.,* (2001) found that CAD features and complexity tend to be positively associated with product design superiority, flexibility and functionality, and innovative CAD technology will improve CAD's impact on the product development process. Chu *et al*., (2009) aimed to overcome the main concerns regarding environmental issues, and applied a CAD-based 3D product structure to automatically produce a possible product part assembly. For this purpose, it was decided to embed the user interface into a CAD environment.

The User Interface Design (Fall, 2003), states, that the development of User Interface (UI) follows the current best-practices, and the development process use a spiral model as shown in Figure 2-33. Furthermore, to design the UI is difficult, but the spiral model with interaction with the user is the best way and it needs a source of information at the beginning. The two techniques most useful for capturing the important task for analysis are: contextual inquiry – (the collaboration between designer and user through interviews and observation of the actual environment) and participatory design, which involves the user and the designer sharing knowledge, in order to analyse the proposed design idea.

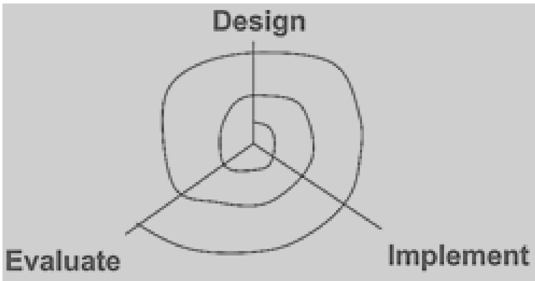


Figure 2-33: Spiral model for interactive design

2.7.1 Product Classification and Life Cycle Assessment of Design Concept

The traditional design process depends on concurrent engineering generally referred to as design is a device, structure, system or process which satisfies the need of the end user. When the design process, where a logical procedure is followed step-by-step, meets a specific need, which is a successful design. The methodology to cover the design process encompasses the following activities: identification of a need, problem definition, search, constraints, criteria, alternative solution, analysis, decision, specification, and communications.

In order to broaden the development of sustainability, a lot of required need to be understands involving the method of life-cycle product process and manufacturing. The process depends on the current curriculum in many universities introducing a topic on social needs. The manufacturing and, concurrent engineering syllabus may cover the basic method of the design process such as the process of design, concept design selection, material and process selection, manufacturing process and other processes (Jawahir & Rouch, 2007). As shown in Figure 2-34, the three steps of the design process are easy to apply, where the design process starts with problem recognition and designer initiates the ideas for product development. LaBat & Sokolowski (1999) further enriched this design process, giving the designer a different role and way of thinking. The end of the model delivers the same, but "creative thinking" is involved in the design process and, the approach to the solution, albeit in diverse ways. This process continues until the implementation of product refinement, but for this study, the research focus for the designer it to make a decision and only define the problem in the design and the conceptual research phase.

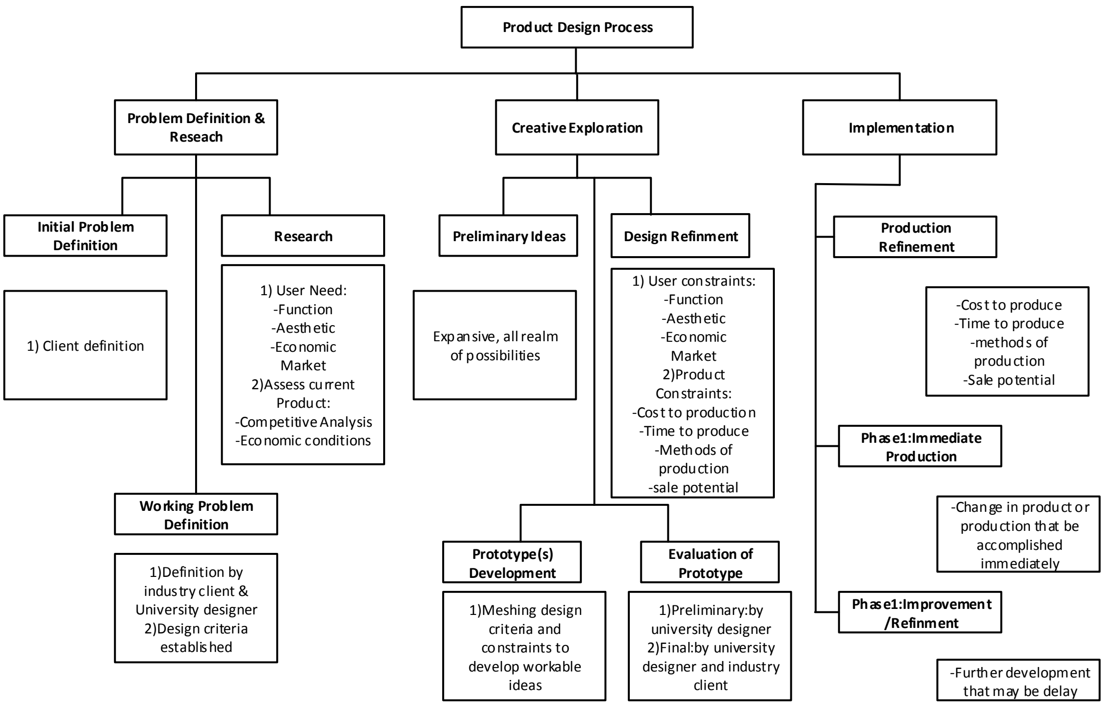


Figure 2-34:Three step design process (Labat & Sokolwski 1999)

As show in Figure 2-35 is that it illustrates how normally designers have to spend a long time, dealing with office furniture namely OPS in the initial stages. The process involves initially research, conceptual design and detailed design, and the arrows show that moving backwards and forwards between different parts of the process represents the alternate condition of the process of decision making. This design process is easy to apply to create a systematic process, where the designer initiates the idea, define the problem, and then explores of problems (Pahl & Beitz, 2013a).

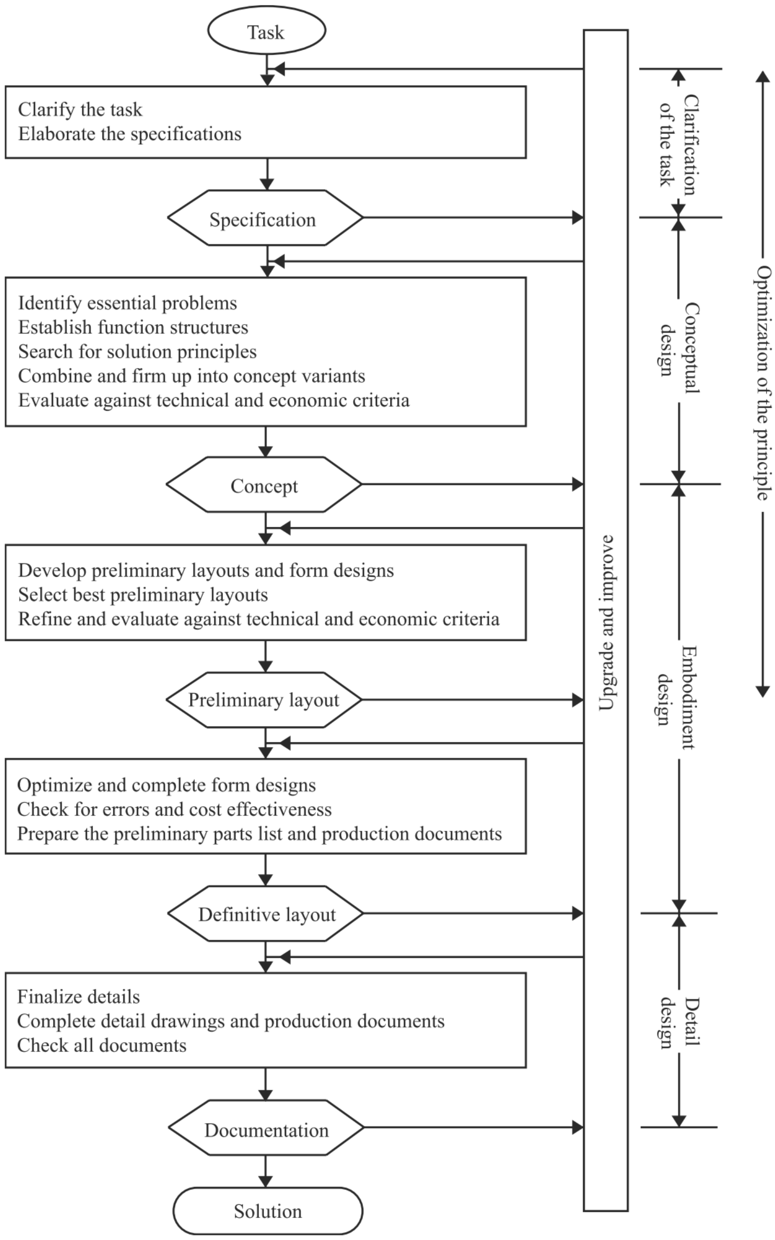


Figure 2-35: The steps in the design process (Pahl & Beitz, 2013)

2.8 Summary of Existing Supporting tool and methods

A comparison of present tools and methods as an approach to sustainability has been made. The consideration is based into Triple Bottom Line (environmental, economic, and social aspects) and the entire method in design stage the (LCA tool, modularity & reconfigurability, axiomatic design, design structure matrix, CAD, decision making and analytical hierarchy process) and decision support tools(furniture study, design for sustainability, sustainability, sustainable design, indicator, design study, weighting, scoring, rating, and GUI). The summary of the existing support tool and methods for this study is presented in Table 2.1.

Since for this research the importance of integrating the method in the design process and decision making for improving the sustainability of office furniture, the method and tools must be the priority to be compared the environmental, economic, and social aspect. In order to achieve sustainable design, the tool and methods have been developed with a focus on triple bottom line. The summary in the Table 2.1 shows that the method that combine an LCA approach and design tools have considered the concept of sustainability and the decision support tools. In order to ensure the sustainability to be a valuable for design process the decision support tools also need to incorporate.

Therefore, the evaluating a product with regard sustainability consideration, there is a growing interest in rating the sustainability of companies. The most prominent effort is to establish the applicable indicator to measure the three sectors on the economic, environmental and social impact for other object as well. The importance of indicators is to indicate progress toward or other then some common goal of sustainability in order to advice the decision maker. Beside that the indicator also is used to identify the opportunities, and to evaluate their effectiveness. From the comparison table 2.1 shows that the assessment effort, the process and the methods with which various measurement effort make choices about indicators, as a primary objective in the decision making.

Table 2-1: Summary of support tools and methods for this study

No	Name of Researcher	Concept of Sustainability				Method In Design Stages						Decision support tool						
		TBS Approach																
		Environmental aspect	Economic aspect	Social aspect	LCA Tool	Modularity & Reconfigurability	Axiomatic Design	Design Structure Matrix	CAD	Decision Making	Analytical Hierarchy Process	Furniture Study Office Furniture	Design for Sustainability/ Sustainability / Sustainable Design	Indicator	Design Study	Index Study	Weighting, scoring, rating	GUI
1	Kartina Parikka Alholala (2008)	x																
2	Chaves 2008	x									X	X	X					
3	Ng & Thiruchelvam, 2012										x		x					
4	Hanger Meyer, 1996	x										x	x					
5	Lele,1991	x										x	x					
6	Rosen & Kishawy, 2012	x	x	x	x							x	x					
7	Handing,2006	x		x	x				x			x	x	x	x			
8	Jenkins,2003											x						
9	Hujungs et. Al.,2010	x		x	x								x					
10	Elkington, 2001	x	x	x														
11	Quin & Baltes, 2009	x	x	x														
12	Liu et. Al.,2010	x	x	x	x													
13	Bheme & Lofthouse,2007	x	x	x														
14	Pope. Et. Al.,2004	x	x	x														
15	Sing, et. al.,2008	x	x	x	x								x		x			
16	Sing,et.al.,2006	x	x	x						x			x	x	x			
17	Ness,et.al.,2007	x			x				x			x						
18	Seevers, et.al.,2013	x	x	x														
19	Jawahir &Rouch,2007	x	x	x								x	x					

Table 2-2: Summary of support tools and methods for this study (Continued)

No	Name of Researcher	Concept of Sustainability				Method In Design Stages						Decision support tool						
		TBS Approach																
		Environmental aspect	Economic aspect	Social aspect	LCA Tool	Modularity & Reconfigurability	Axiomatic Design	Design Structure Matrix	CAD	Decision Making	Analytical Hierarchy Process	Furniture Study Office Furniture	Design for Sustainability/ Sustainability / Sustainable Design	Indicator	Design Study	Index Study	Weighting, scoring, rating	GUI
20	Chang, et.al.,2014	x			x							x		x				
21	Shuib,et.al.,2014	x	x	x	x							x	x		x			
22	Chang, et.al.,2014																	
23	Sharifi & Murayama,2013	x	x	x												x		
24	Inoue,et.al.,2012	x			x				x					x	x			
25	Kates, 2005	x										x	x					
26	Cooper					x						x						
27	Chen, et.al.,2011	x	x	x									x					
28	Chandu & 2012				x								x					
29	Skerlos,et.al.,2006	x	x	x	x					x			x		x			
30	Huang & Zhang,2008												x		x			
31	Chen,et.al.,2011	x											x					
32	Fiksel,2006	x	x	x						x								
33	Adu,et.al.,2014											x			x			
34	Boughnim,2004	x	x	x	x							x						
35	Besch,2005	x								x		x						
36	Ikeda,et.al.,1999											x						
37	Gershenson & Parasad,1997					x				x								
38	Gershenson & Parasad,2004					x		x							x		x	

Table 2-3: Summary of support tools and methods for this study (Continued)

No	Name of Researcher	Concept of Sustainability				Method In Design Stages						Decision support tool						
		TBS Approach																
		Environmental aspect	Economic aspect	Social aspect	LCA Tool	Modularity & Reconfigurability	Axiomatic Design	Design Structure Matrix	CAD	Decision Making	Analytical Hierarchy Process	Furniture Study Office Furniture	Design for Sustainability/ Sustainability / Sustainable Design	Indicator	Design Study	Index Study	Weighting, scoring, rating	GUI
39	Kusiak, 1999,2002					x		x										
40	Mikkola &Gassmann,2003					x							x		x			
41	Su,et.al., 2010					x						x			x			
42	Erixon,et,al.,1996					x		x							x			
43	Cheng,etal.,2012					x	x	x			x				x			
44	Pahl & Beitz,2013					x		x							x		x	
45	Mikkola,2007					x							x		x			
46	Umed,et,al.2008	x			x	x									x			
47	Sosa,et,al.,2007					x												
48	Agrawal,2009					x		x									x	
49	Steward,1981							x									x	
50	Hong & Park, 2011					x	x	x		x					x			
51	Browning,2001							x		x					x			
52	Pimmler,1994							x									x	
53	Ali Yassine,2004							x		x								
54	Holtta,et,al. 2003,2005,2007					x		x		x							x	
55	Dong & Whitney,2001						x	x		x					x			
56	Suh,1990,2001						x			x				x	x	x	x	
57	Yu,et,at.,1998						x	x		x								
58	Goncalves-Coelho & Mourau 2007						x			x					x			

Table 2-4: Summary of support tools and methods for this study (Continued)

No	Name of Researcher	Concept of Sustainability				Method In Design Stages						Decision support tool							
		TBS Approach																	
		Environmental aspect	Economic aspect	Social aspect	LCA Tool	Modularity & Reconfigurability	Axiomatic Design	Design Structure Matrix	CAD	Decision Making	Analytical Hierarchy Process	Furniture Study Office Furniture	Design for Sustainability/ Sustainability / Sustainable Design	Indicator	Design Study	Index Study	Weighting, scoring, rating	GUI
59	Gharib & Qin, 2013								x	x								
60	B.Sing,et,al.,2007								x	x								
61	Van Dijik,1995								x						x			
62	Tan & Vonderembse,2006								x						x			
63	Waage,2007									x			x		x			
64	Clark,G. et. al., 2009	x	x	x	x								x		x			
65	Boulanger & Brechet,2005	x		x						x	x		x				x	
66	Azapagic & Perdan, 2000	x	x	x						x			x	x				
67	Zhou & Kuhl,2010	x	x	x									x					
68	Adam,W.M.,2006	x	x	x						x			x					
69	Pugh, 1991							x		x				x	x		x	
70	Malmqvist,J.,2002							x						x	x			
71	Bohringer,C. & Jochem,2007	x	x	x										x		x	x	
72	Schmidt & Taylor,2006				x									x		x		
73	Khan, et.al.,2004	x			x									x		x	x	
74	Sagar & Najam,1998													x		x		
75	Vilalba,2004													x		x	x	
76	Salvati & Zitti,2009	x								x				x			x	
77	Sing,et.al.,2007									x	x		x	x		x	x	

Apart from specific theories of thinking, creativity, and implementation of this research is Langley influence by a few famous method such as modularity & reconfigurability, axiomatic design, and design structure matrix. In line with the sustainability requirement my action of the subject of sustainable design index is relaised on designer expert interpretation. For the empirical study is used to justify the results, and the cognitive process are also identified. As a creative engineering solution the development in the first part of study, and the SDI method develop in the second part which is become a part in chapter 4, 5 and 6.

Sustainability concern especially in furniture industries rapidly change in material, customer needs and the technologies will influence the environmental, economic, and social impact in daily activities. These changes need the creativity to identify the solution and opportunity to optimisation and concept selection, to support a tool at the early design phase as a decision making. In order to take all the potential environmental criteria and problem into consideration at the design stage, which the environmental sustainability criteria need to be establish the sustainable design index (SDI) analysis, for beginning of life (BOL), middle of life (MOL), and end of life (EOL). Indeed some of the triple bottom line criteria are fuzzy criteria, in order to quantitatively apply to all the sustainability criteria the weight, score and AHP is used to rank it. The modularity & reconfigurability, and design structure matrix is used to represent the structure of a product, the relationship between the components are measure according to the sustainability criteria.

This research fills a gap in knowledge by comparing the method and evaluating their ability to support the design decision in office furniture, particularly when decisions consider sustainability issues. Usually lack of clear and share rationale requires decisions to be changed late in the design process, which have a different perspective and often conflicting interest.

2.9 Summary

This chapter pointed out the importance of sustainability within the office furniture (industry) and its suitable application in the design process. Product innovation becomes more competitive and challenging for firms. The demand for higher quality products means that, the company will not survive without new product innovation and competitiveness. To compete, the manufacturing companies must have an expert to look after product innovation. The focus of product development becomes important in the long-run for small and medium sized industries. To fulfil the uses' needs, the sustainability criteria become important and are applied the Design Sustainable Index (SDI) for office furniture especially for OPS.

At this moment, many authors have focused on minimising the environmental impact; to do that, a new tool and approaches were introduced, to help the companies. The Design Sustainability Index (SDI) is used for improving environmental issues; the three elements, (environmental, economic and social) need to be developed, alongside new ways for improvement. Product innovation and sustainability are concerns for human beings and product improvement for future generations. To counter the problems face by designers when applying the modularity design, Hong & Park (2011) proposed a new approach, to combine the AD and DSM at the design stage. The FR and DP domains were used to integrate the design process for this study.

Finally, one major finding of the comparative evaluation is that is a gap in SA where the use of sustainability to measure products needs to be developed for further action. The research gap in implementing a new tool for the sustainable design index (SDI) embedded in the CAD environment was further studied in this chapter.

3 Formulation of the Integrated Sustainable Design Approach

3.1 Introduction

This chapter describes the approach and methods used in this research. The chapter starts by presenting the approach of the framework to achieve the objective outlined in this research, and continues by presenting the tool that used in the research work are presented. Furthermore, the concept integrating a modularity & re-configurability, design structure matrix and axiomatic design, CAD environment and analytical hierarchy process approach used as an element for the evaluation sustainable design index as describe in this chapter. In the design stages and manufacturing process the decision making needs to be clear, and of both qualitative and quantitative information are necessary to formulate a sustainable design.

3.2 Methodology, Tools and Framework

This section describes the specification of a conceptual framework that enables the effective developing of sustainable design. The general methodologies framework proposed in this study is an attempted to contribute towards sustainable design index (SDI) for Furniture Company; nevertheless, additional specifications for industries are needed, meaning frameworks can be designed using case-by case study. Different kind of sustainability framework, the emphasis is entirely on different expressions involved with sustainability. Because companies have different type of interest, it must be able to handle at variety kind of problems. Furthermore the designer needs to formulate the problem, discover innovative solutions, and test existing thoughts and behaviors.

Figure 3-1: Sustainability driven design process flow

Support tools required in the product development process are intended to highlight the potential and importance of the environmental aspect. As shown in Figure 3.1, the sustainability driven design process aims to resolve the problem facing by the designer and manufacturer when handling sustainability issues. The choice of tools is based on several factors connected with regarding the different environmental aspects.

3.2.1 The Derivation of Project Appraisal Criteria

The systematic modelling approach presented here may be the best practical approach for analysing the sustainable design approach of a furniture company, why is the subject of this study, i.e. an open plan system (OPS). Commonly, there are four steps in real practice for reducing the environmental impact of a furniture company. First, the company needs to meet the design requested by the customer through modularity and re-configurability; there may be various proposed designs at this stage. Second the design modularity should be measure by the Design Structure Matrix (DSM), and third the company needs to understand the criteria and the relationship between the different parts and components of the OPS. Finally, consideration needs to be given to the sustainable design index (SDI) in order to decrease the environmental impact and to assess the efficiency of the product and the productions process. These are shown in Figures 3.2 and 3.3.

In the following paragraph, the four main steps of the SDI project will be described: (i) establishment of design modularity and re-configurability (ii) use of Axiomatic Design; (iii) use of Design Structure Matrix (DSM); and (iv) generating the Sustainable Design Index (SDI) with a CAD-based system as an implementation of this study.

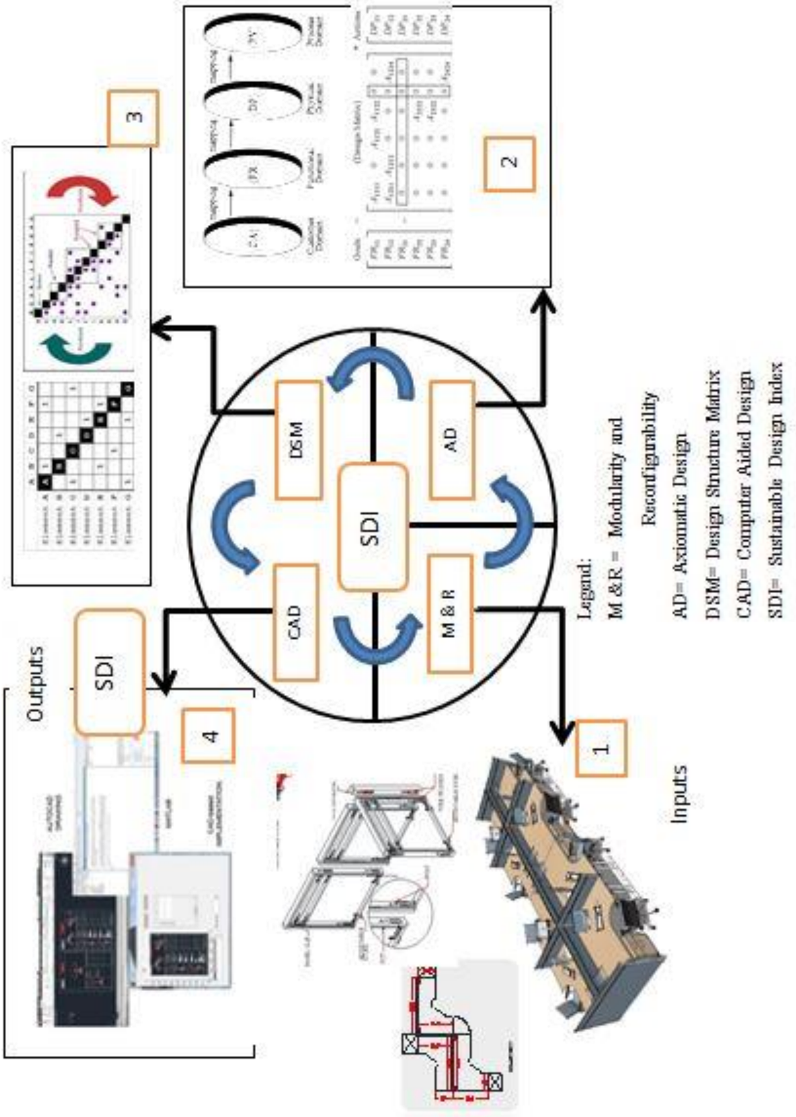


Figure 3-2: The framework for this research

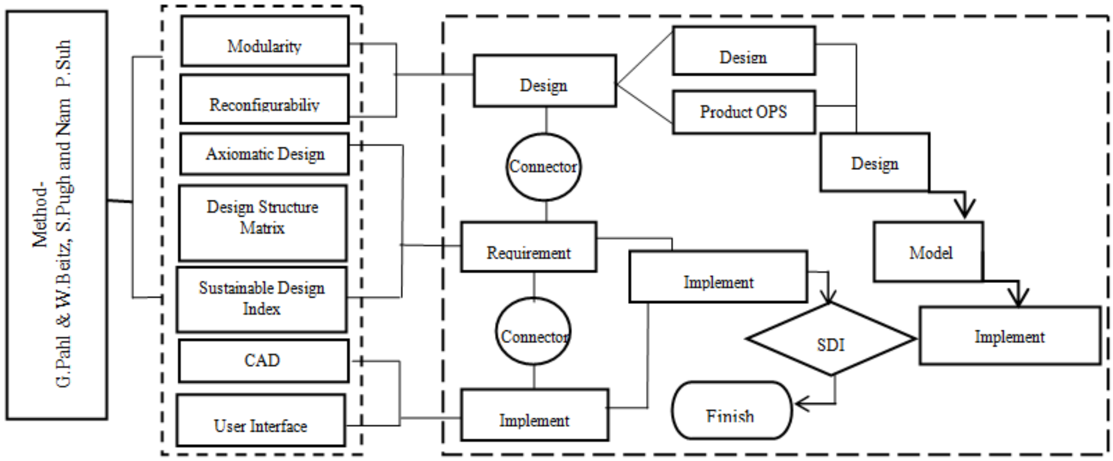


Figure 3-3: The study method is the integration between Pahl & Beitz, Pugh and Suh.

3.3 Integrated Sustainable Design

In today's demanding market, style, trends, and fast response are essential for furniture companies to compete and survive. A furniture company must try to develop new products in order to satisfy the changing needs and sustainability trends. The demand and development of sustainable furniture have recently emerged as a new market. Therefore, sustainable furniture could be regarded as having a lot of potential for furniture companies. The motivations for the implementation of the SDI with the adaptive office furniture OPS illustrated in Figure 3-4, to preserve the sustainable furniture and sustainable design. The needs of the designer in the early decision making process are the drivers towards sustainability with smart CAD tools SDI. The performance of this approach is can based on sustainable design, sustainable furniture and also the designers themselves.

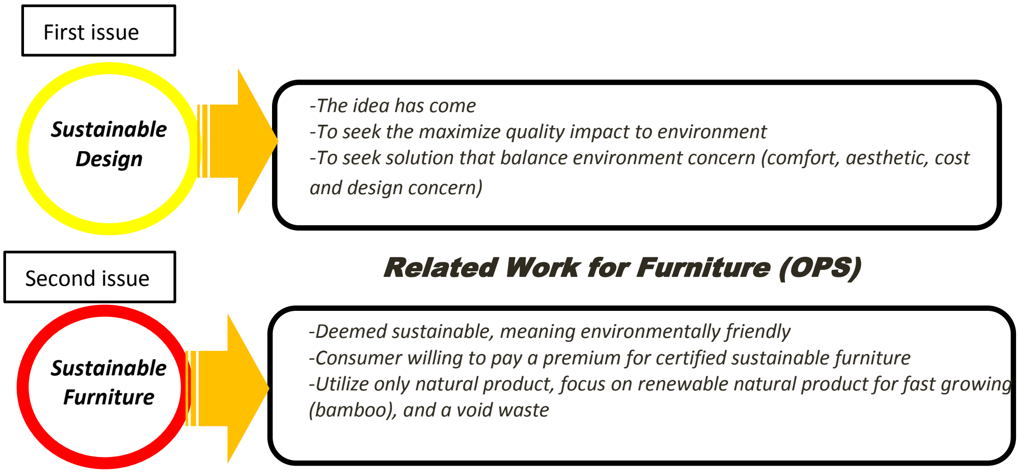


Figure 3-4: The adaptive and related work for furniture (OPS)

3.4 A Framework for Developing a Sustainable Design Index (SDI)

The roadmap for a sustainable design index (SDI) is - illustrated in Figure 3-5, and it provides the methodological aspects that need to be looked at in this work. The organisation consists of four processes, as shown in Figure 3-5. The objective of this study is to provide a framework to help decision-makers choose the most appropriate (or most appropriate mix) of models by assessing their relative strengths and weaknesses (Boulanger & Bréchet, 2005). The paradigm shift was accompanied by considerable efforts by industry to convey their part in defining sustainable strategies for commercial enterprises. The increasing involvement of industry in sustainability has resulted in a number of approaches being developed by various societies and business associations (Azapagic & Perdan, 2000). The significant challenge for office furniture OPSs is the improvement of environmental performance and the limited knowledge of sustainability by the designer and customer especially. The overall goal of this work is to provide a comprehensive view SDI to the office furniture business, namely OPS, such as for the managerial cubical, executive cubical and general staff cubical. The specific objectives of the project were to:

-Highlight product environmental attributes and opportunities for design improvement.

-Establish a streamlined approach for SDI for furniture products.

-Complete a streamline SDI assessment for three different categories of OPS, modularity and re-configurability, design structure matrix and axiomatic design.

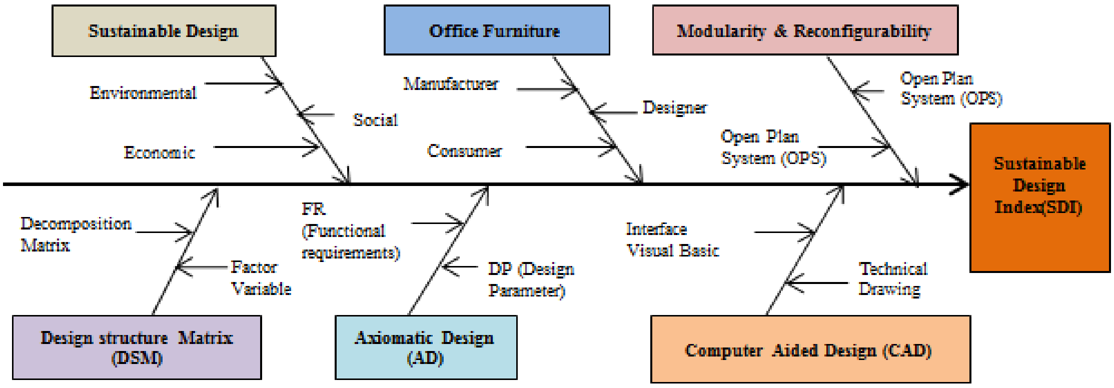


Figure 3-5: Sustainability driven design process flow

Adaptive sustainability has ability for designer to predict the OPS, in the early design stage and the useful tool of CAD environments and is also capable of taking appropriate decisions on (SDI) when needed. A more efficient way to reach sustainability in a project is to consider and to incorporate environmental issues at the stage before a design is even conceived. If they not considered before and during the appraisal phase of a project, a later alteration to the brief will cost money and effort and increase costs. Thus the implementation of sustainable product design by incorporating existing methodologies and new technologies in a creative manner is a more complex task than traditional approaches (Yan *et al.*, 2009). Once a sustainable design is incorporated into the design process of furniture, it should be used from the early stage of product design in order to offer the strongest positive effect on the environmental aspect.

The methodology for integrating sustainability, as shown in Figure 3-6, takes into consideration aspects of the traditional design process such as project initiation, preliminary design, detail design and final design. At present there is no standardised methodology and almost no practical experience of integrating sustainable criteria into the design process (Azapagic *et al.*, 2006).

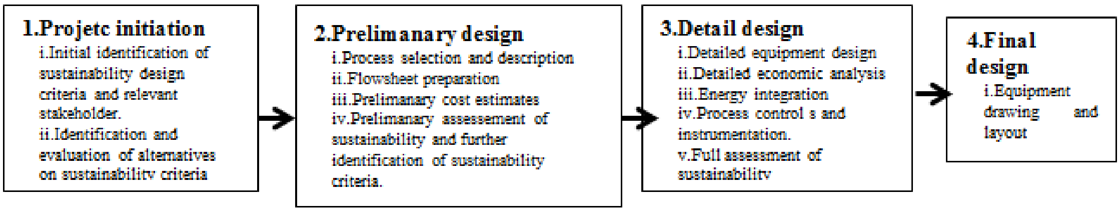


Figure 3-6: The stages of sustainability (Azapigic *et al.*,2006)

3.4.1 The Conceptual Framework of the Sustainability Index

To achieve this goal, in this research a new method is proposed to link these approaches in order to define practical and rational modularity and re-configurability from the viewpoint of a designer and manufacture. The proposed method to link between them is too simultaneously to define SDI as a main focus for this research. The research will also consider the relationship between function and components with the proposed method.

Figure 3-7, shows the spiral of the design activity for, the process of SDI. It will carry out by a designer, namely an industrial designer, product designer and design engineer. To generate SDI for sustainable concept design, the designer needs support from tools that can help with the design activities, especially in the early design stages. In this framework, a suitable design method and tools are proposed to guide the SDI in a more sustainable design direction, from the early design phase until the end. The tools attempt to decrease the negative effect of the environment which is a vital part affecting the sustainable design.

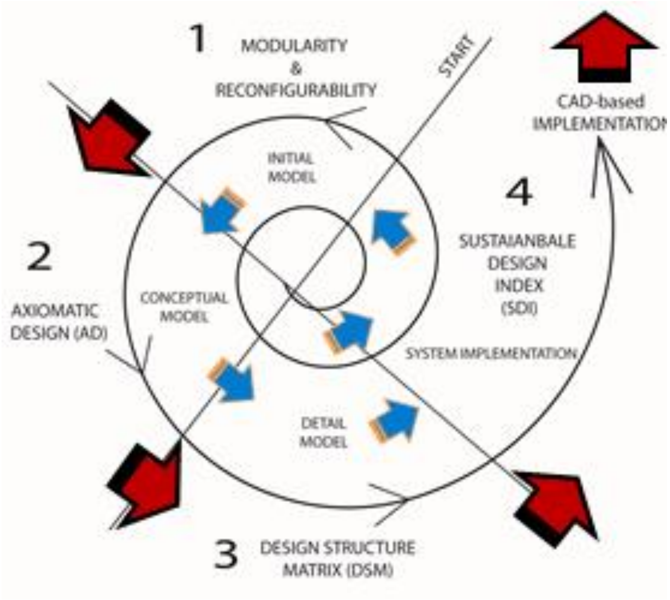


Figure 3-7: Research implementation scope

3.5 Sustainable Design Index (SDI) and Design Assessment

The main purpose of the indicators of sustainable design is to provide information to decision makers on the overall usefulness of the SDI system. The designer needs to consider the information and number given that can potentially be involved in the decision-making process. The decision maker knows, as an expert in this particular project, how to determine the best option for improvements. The compromise solution is to be identified and agreed upon by all interested parties and a CAD-based environment tool with new features has been developed to facilitate the early design decision-making process. The indicator concerned with the SDI is shown in Figure 3-8.

The process for the fabrication of an integrated appraisal of sustainability can be conceived as a three dimensional approach: (i) the identification of the various dimensions underlying the concept of sustainable development, (ii) the process of aggregating lower dimension indicators in higher level composite indices and the (iii) attribution of weightings at various layers of the indicators hierarchy(Boulanger 2008).

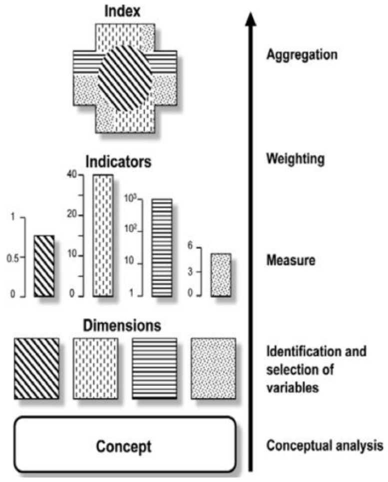


Figure 3-8: From a concept of sustainability of indicators and indices (Boulanger, 2008)

Nevertheless, it is certain that identification of sustainable possibilities and decision-making in this context are not easy problems to solve, and the authors cannot pretend to have a ready-made solution for them. However, it is all important that today's decision makers state and discuss the topics of sustainability, however imperfectly, as it would be difficult to think that future generations would use 'the difficulty of the problem' as an excuse for ignoring it (Azapagic *et al.,* 2006).

Figure 3-9: Three-dimensional view of sustainable development, overlapping circle model
Source: IUCN (2006)

The established method of viewing sustainable development offerings is as a three-dimensional idea composed of the environmental, societal, and economic models (Zhou & Kuhl, 2010). It is easy to see that the modular systems are not only interconnected but that they also closely and mutually support each other. A usual way to refer to these three elements or pillars (especially in the corporate arena) is as Planet, People, Profit or the ‘triple bottom line’. Equally (as was previously discussed in Section 2), understanding sustainable development as a three-dimensional concept (environment, society and economic dimensions or pillars) has become widely accepted as shown in Figure 3-9 (Adams, 2006;Resolution, 2005).

3.5.1 Design Methodology and Sustainable Design Needs

The design of furniture for OPS has been prepared mainly for CAD software. However, during the design process, the design of the SDI has partially taken the rules of Nam (2001), Pahl & Beitz (2013b) and Pugh (1991b). This is illustrated in Table 3-1, which starts with the identification of the demand and requirements of the end user, particularly the needs for sustainable furniture with respect to the environmental impact. The correlation between axiomatic design, engineering design, and total design process is actually an interactive process where the outcome of each stage continues to create innovation in sustainable furniture. There are some common principles of sustainable design such as renewability, low impact materials, energy efficiency, re-using and recycling (Anastas & Zimmerman, 2007). The sustainable design reflects the new ideas of human beings and new aesthetic and ecological values, which are be kind to nature, and to cooperate with nature rather than to exploit it.

Table 3-1: The correlation between Axiomatic, Engineering design and Total design process

Correlation between Axiomatic Engineering and Total Design Methodology					
Nam(2001)	Customer Attribute (CA)	Functional requirements (FR)	Design Parameter (DP)		Process Variable (PV)
Phal et al., (2007)	Clarification of the task	Conceptual design	Embodiment design	Detail design	Production instruction
Stuart (1991)	Market needs or ideas	Design Specification	Concept model	Detail design	Manufacturing /Production

Sustainable design addresses not only the functional and aesthetic requirements of products, but more importantly aims to meet the needs of the present without compromising the ability of future generations to meet their needs (Subic *et al*., 2010).

Technical aspects have been formulated and evaluated in a universal way at the development stage. The synthesis between sustainable furniture and designer systems required the development of an SDI based on the principle of interactive development procedures for a more evolutionary approach to the improvement. Analytical models for modularity and re-configurability, the design structure matrix and axiomatic design have been developed in order to provide better understanding of the influence of the main process parameters.

3.5.2 The Procedure of SDI Calculation

The basic hierarchy of developing the algorithm into the SDI is as shown in Figure 3-25. The procedure of calculating the SDI is divided into several sections. The author developed the SDI algorithm for taking account of all the functionalities simultaneously. These are in the form of a Design Structure Matrix (DSM) and Axiomatic Design (AD). The calculation consists of three stages: modularity and re-configurability, DSM, and AD. These calculations will be incorporated into the sustainable design optimisation as a modular structure. SDI tools are oriented towards the planning process at the beginning of life (BOL), middle of life (MOL), and end of life (EOL).

In order to fulfil the customer requirements and needs for this research a new approach has been proposed as shown in Figure 3-1 for furniture design, in this case OPS. As shown in Figure 3-2, the design activity is the process of SDI will be carried out by a designer, namely an industrial designer, product designer and design engineer. This is known as a sustainability driven design process flow. In order to generate SDI, the designer needs support tools that can help the design activities, especially in the early design stages.

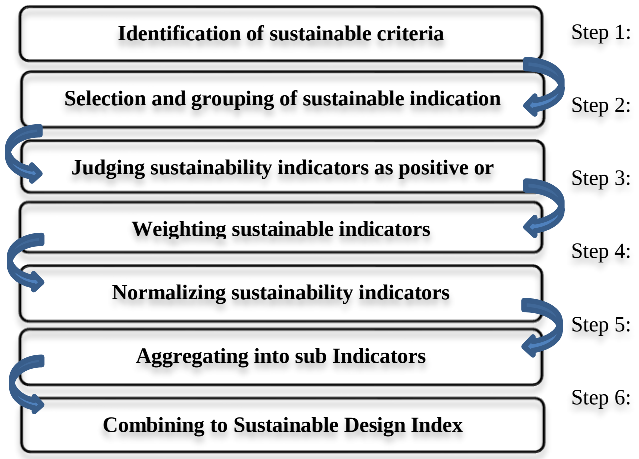


Figure 3-10: The procedure of sustainable design index calculation

In this framework, as shown in Figure 3-10, the suitable design method and tools are proposed to guide the SDI in a more sustainable design direction form the early design stage until the end. The tools attempt to decrease the negative effect of the environment which is a vital part of sustainable design, and also the indicator must be quantitative whenever possible. However, for some aspects of sustainability, qualitative descriptions may be more appropriate (e.g. societal aspects).The important concept; methodology is the element of SDI that is a summation of modularity, re-configurability, Axiomatic Design and the Design Structure Matrix as below: The integration of the equation can be expressed as:

$$\boldsymbol{SDI} \, \epsilon \sum(\boldsymbol{M_i} + \boldsymbol{R_i} + \boldsymbol{Erg_i}\,(\boldsymbol{DSM}) + \boldsymbol{Material_i}\,(\boldsymbol{AD}) + \boldsymbol{Manuf_i}\,(\boldsymbol{AD}) + \cdots)$$

Where SDI is the Sustainable Design Index, M_i is the Modularity, R_i is the re-configurability, Erg_i is ergonomic, DSM is a Design Structure Matrix, Materiali is a material selection, AD Axiomatic Design, $Manuf_i$ is a design for manufacturing the AD.

3.6 Modularity Integration

Being able to provide a variety of design options is a major part of a company's ability to meet niche markets. Modular design is known as an the essential approach to the product design process as it permits companies to satisfy consumers' needs quickly, Currently, companies are focusing on improving their 3R capabilities (reuse, recycle, and reduce) via eco-friendly products. Nevertheless, due to the growing awareness of sustainable development, a wider aim for product modularity is required in order to obtain useful and, sustainable design and manufacturing. These can be obtained, through the 6R principles, adding 'recover', 'redesign', and 're-manufacture' to the traditional 3Rs.

Current products are becoming increasingly complex. In the development of complex product considerations of the product structure and relations within the product are crucial. Johan Malmqvist has presented a summary of the presentation and analysis methods of the metrics (Malmqvist 2002). The Figure 3-11 illustrates the presentation types of the matrix methods: what is being compared and to what. The relations may be non-directional. In which case the matrix is symmetrical or directional and in which case causality is related to the dependency. Malmqvist classifies the methods in which several matrix presentations are linked together as belonging to the matrix methodology class, as for example the Quality Function Deployment method. Malmquist recognise seven methods of analysis:

-Clustering, in which the elements are grouped as a cluster are grouped as cluster with strong internal relations and weak cluster-external relations.

-Partitioning, in which the interactions in the process are minimised (design)

-Coverage, in which the completeness and the coverage of the entity is examined

-Index computation, in which indices are computed to produce deductions

-Interaction focuses on the contents of the relations and guides the redesign

-Change propagation, in which the effect of the changes can be estimated by examining the relations

-Alignment, between the relations of the product and the organisation structure are compared (Malmqvist 2002).

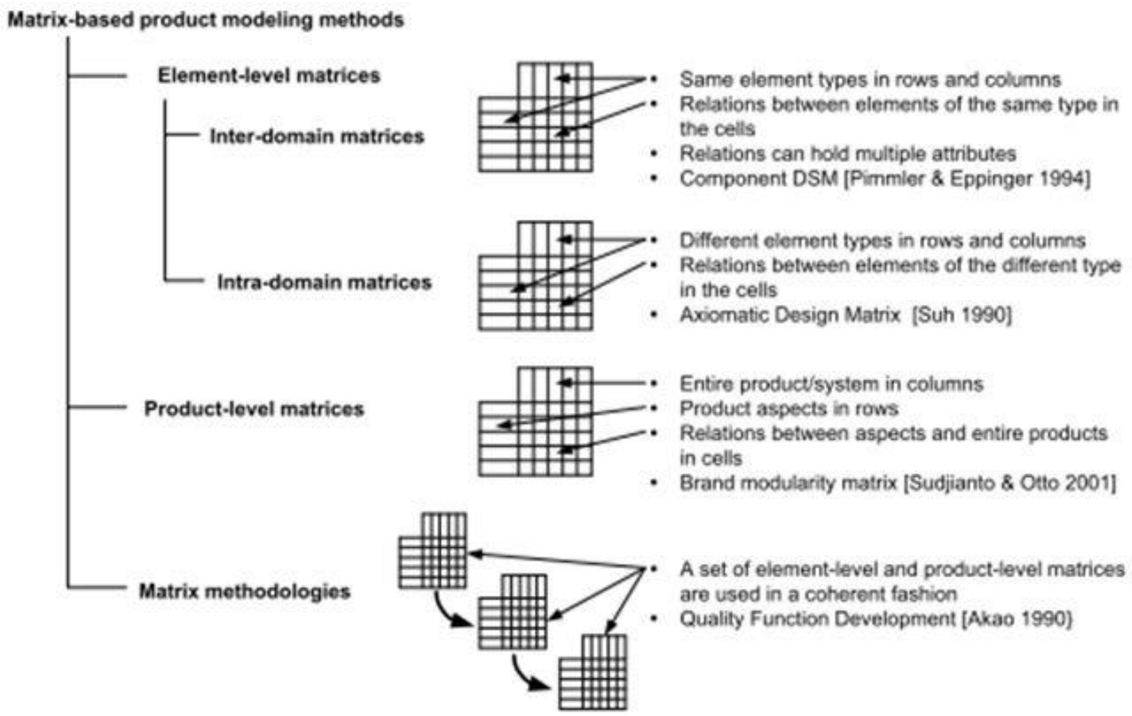


Figure 3-11: A classification of matrix-based product modelling method types (Malmqvist 2002)

3.6.1 Benefits of Modularity and Re-configurability

Luh et al., (2010) approached the modularity design concept by promoting standardisation and also reusing existing modules in new products. The concept of modularisation already established in product development in areas such as the software industry, automotive components, machine tools, aerospace, and IT industries. Modularity benefits are:

- Reducing the cost: the number of product components can be reduced by using a modular design. At the same time this reduces component incompatibility and lowers the defective rate of the product.
- Increasing product variants: a variety of product can be produced in many combinations within a set period of time.

- Shortening new product development time: by using standardized components and interfaces, a whole family of products can be produced by applying modular architecture.
- Leveraging the design efficiency: with modular design, it is easy to separate any complex component into smaller individual parts.
-

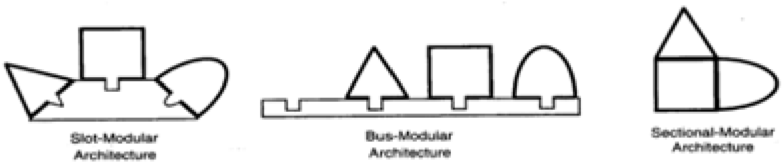


Figure 3-12: Three types of interface modular architecture (Ulrich & Eppinger 2005)

Type of modularisation

Modularisation can be of different types. Ulrich *et al*., (2005) classified modularisation into a three type, depending on the mapping between the functional and physical elements of the products as shown in Figure 3-12.

1. Slot modularity
2. Bus modularity
3. Sectional modularity

Slot modularity: it is impossible to interchange components because each interface is individual and not the same as the others. Only the specific interface can change.

Bus modularity: all the interfaces have same characteristics and the physical components are connected via the same interface.

Sectional modularity: not the single module has the same interface and all the components can connect to each other via identical interfaces (Ulrich *et al.,* 2000).

3.6.2 Modularity Methods

In recent years, evaluating modularity has become more popular in the design of a life cycle (Umeda *et al*., 2008). The idea is to find the solution that optimises the whole process, where the designer has to point out the important and the situation of the life cycle with an accurately chosen lifecycle option (LCOP). The idea behind this index is to group together all the components such as upgrading, recycling, reusing and maintenance. Researchers have used self-organising maps (SOMs) to cluster components together in order to evaluate the same components in modularisations. By using SOMs with a cluster of similar components and tracing method makes it easy for the group in one entire classification of the life cycle. To determine the similarity of the modules the weighting attributes technique is applied using LCOP, to assign the clustering number to each of the components by SOM. Next, by using the SOM again, the components of the clustering are finally determined to classify.

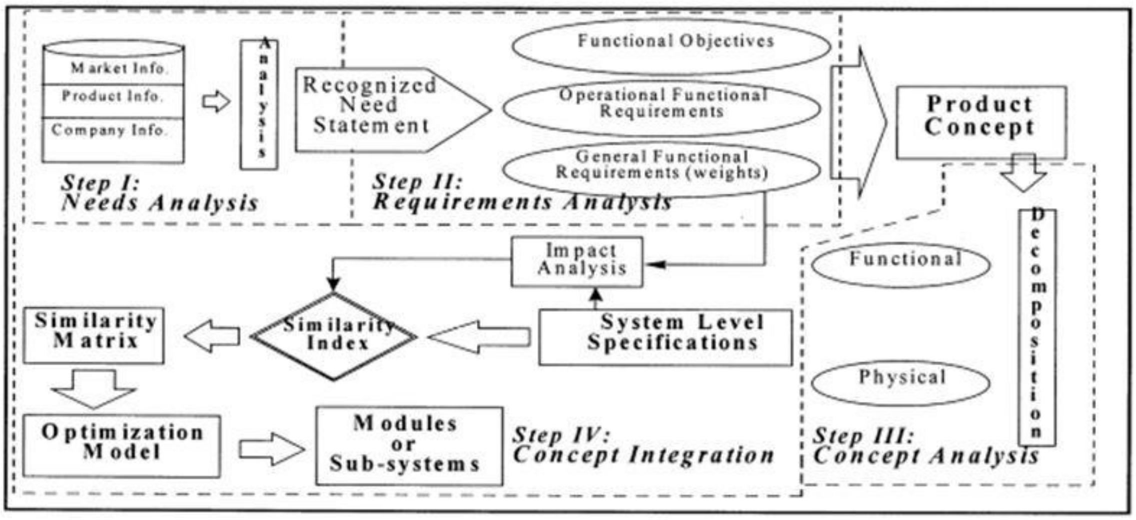


Figure 3-13: Design for modularity (Salhieh and Kamrani, 1999)

According to Salhieh & Kamrani (1999), modularity can be used in complex products in engineering; the process is separate in to sub-systems and individual components and each of components to form a product. The goal for modularity is to create a variety of designs, with a configuration based on independent and standard components. As shown in Figure 3-13, it is important to establish the FRs. The product decomposition is based on functional and physical characteristics.

As such, product modularity has gained increasing prominence as a potential means of facilitating improvement product architecture/platform design and reuse support. Modular design involves the creation of product variants based on the configuration of a defined set of modules. The principle is to create variety, reduce complexity and maximize kinship in designs and cross product families. The advantages of modularity, such as efficient upgrade, reduced complexity, reduced cost, rapid product development, and improved design knowledge structuring are shown in Figure 3-14 (Salhieh & Kamrani, 1999).

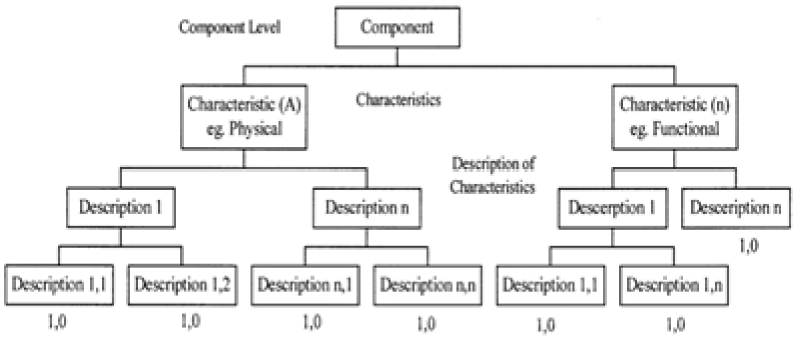


Figure 3-14: System level specification decomposition hierarchy (Salhieh and Kamrani 1999)

3.7 Design Structure Matrix

The Design Structure Matrix (DSM) introduced by Steward (1981), is widely used for managing complex systems based on decomposing a product into components/systems and also the information flow, determining the actual dependencies among activities in the process (Kusiak, 2008).

DSM is an interaction between elements and makes a comparison of the system using network modelling. DSM is mainly applied in the development of complex, integrated designs of system architecture. The DSM is represent by a square N x N matrix which identifies the effect of the combination on the functionality of the system (Eppinger & Browning 2012). As shown in Figure 3-15 the interaction of an element in the column and the row such as 'A' attained the interaction provided by 'E' as well as providing to 'D'.

Similarly every single one of the elements complies with these particular methods (Eppinger & Browning 2012).

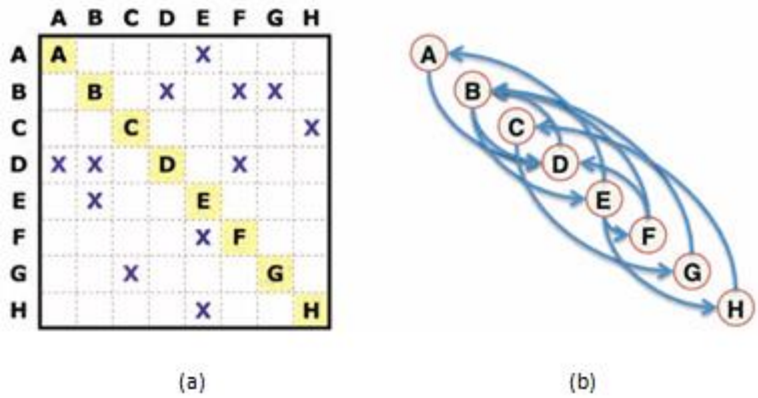


Figure 3-15:The binary DSM (a) with inputs in rows (IR) and its equivalent in diagraph from (b) (Eppinger & Browning 2012)

According to Eppinger & Browning (2012), each of the DSM applications presented in this process essentially follows a five step approach of architectural modelling and analysis. These steps, as shown in Figure 3-16 are:

A) Decompose: Break the system down into it does constitute elements, perhaps through several hierarchal levels.

B) Identify: Document the relationship among the system's elements

C) Analyse: Rearrange the elements and relationships, to understand the structural pattern and their implication for system behaviour.

D) Display: create a useful representation of the DSM model, highlight feature's importance special interest.

E) Improve: Most DSM application results in not only a better understanding of the system, but also improvement of the system through actions as a result of the DSM analysis and interpretation of its display.

Figure 3-16: The DSM approach to system modelling, analysis, and improvement (Eppinger & Browning 2012)

The implementation of the priorities of the components of furniture product goes through the DSM approach in order to effectively meet the customer's requirements. There are three steps to implementing the sequence of task in the DSM.

1) Choose the actual arrangement regarding the empty rows from the top of the lower part of the DSM matrix: blank rows are the initial sequence since they do not have any predecessors.
2) Determine and group those tasks that could be applied at the same time. Mostly, the activity sequence is provided by the top to the lower part of the DSM matrix. It is important to repeat it until eventually there are not any rows remaining.
3) Focus on the particular steps within similar groups: we are able to obtain a particular task group after step 2 and the steps that are part of exactly the same group, can easily be applied at the same time (Eppinger & Browning, 2012).

3.7.1 Matrix Analysis Using Weight Factor

The interaction between components in the Design Structure Matrix (DSM) as functions as a tool that captures the components so that the complex system can be analysed in a compact and easy to understand way. As an example, if given the components of A and B, they interact in either a parallel, serial or couple trend. The interaction among them may be material, energy, structure, or spatial or may be an information interface. Figure 3-17 represents the association and interaction between the components in the design structure matrices. The off-diagonal “X” instance represents the interaction between two components. However to determine the interaction, some authors replace the “X” with s number to justify the weight and the strength of the interaction between components such as A and B. The attribute which signifies the difference between components also can convey the DSM by using the binary DSM notation (where the matrix is populated with “ones” & “zeros” or “X” marks empty cells) (Yassine, 2004).

It is recommended by Yassine (2004) to start in built the form of DSM with simple documentation, then to obtain the information from an expert interview. Later all the information is collected from a different group of experts or managers to the sub-systems and the whole system. As shown in Figure 3-17 appropriate information must be obtain from the manager or expert with a minimum set of parameters, and then the relationships between the elements are marked with “X” or “0”.

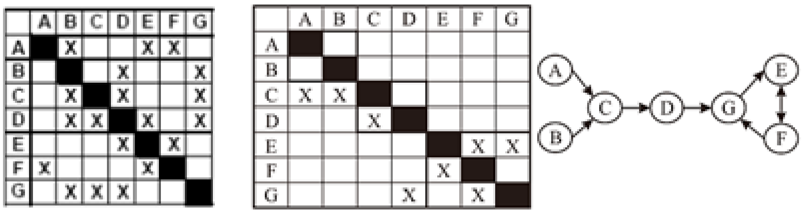
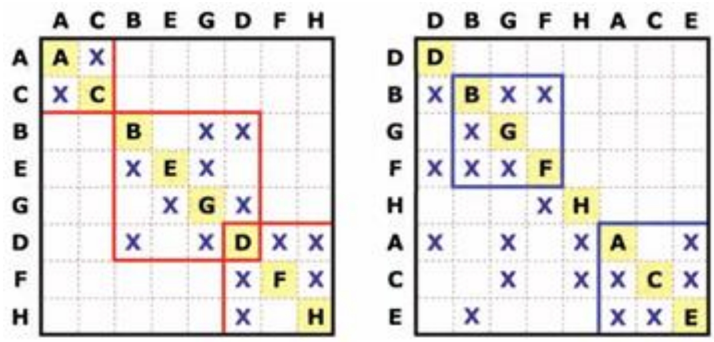


Figure 3-17: The sample of DSM and the interaction between components (Yassine 2004)

3.7.2 Partitioning the DSM and Configuration

According to Eppinger and Browning (Eppinger & Browning 2012) the particular straightforward DSM as highlighted in Figure 3-18 (a)&(b) is known as a binary DSM, due to the fact that the off-diagonal indicate basically the existence or lack of a conversation.

The DSM can be partitioned or rearranged using a variety of analytical methods, the most common of which are clustering and sequencing, as shown in Figure 3- a and b, respectively.



(a) (b)

Figure 3-18: Partitioning analysis commonly entails clustering (a) or sequencing (b) based on the interaction contained in the matrix (Eppinger & Browning, 2012)

3.8 Axiomatic Design

According to Dr. Nam Suh, the ultimate goal of axiomatic design is to establish a scientific basis for design and to improve design activities by providing the designer with the theoretical foundation based on logical and rational thought processes and tools. When developing a real product, there are two axioms: the independent axiom and information axioms. The ‘independent axiom’ is that the functional requirement (FRs), and must be maintained, the minimum FRs of the absolute requirements are defined as a design goal. The ‘information axiom’ states that the minimum information is the best design. To make sure that a particular design is applicable and accepted the information must come from the end users of the design output. The term ‘good design’ means that the design is easy to manufacture or that it fulfils its FRs.

3.8.1 Axiomatic Design Framework

In the case of furniture industries, product development is much more mature in terms of product development, therefore the construction of Design Matrix’s (DMs) encourage designers to reduce the interaction by successful transformation of the DM ad DSM as show in Figure 3-19.

There are three steps to transferring DM to a DSM (Dsmweb.org):

Step 1 DM construction (Axiomatic Design Matrix)

From the DM, in the coupled systems as represented below, there are three function requirements (FRs) and three design parameter (DPs) as shown, The “X” represents a relation affecting FR, and the “O” represents no relation.

	DP_1	DP_2	DP_3
FR_1	X	O	X
FR_2	X	X	O
FR_3	O	X	X
Couple System			

Each row of DM can translate into:

FR_1=a_{11} *DP_1 + a_{13}* DP_3

FR_2=a_{21} *DP_2 + a_{22}* DP_2

FR_3=a_{32} *DP_3 + a_{33} *DP_3

Step 2: Choose the output variables

Where the a_{ij} are coefficients of the design matrix for DP1, DP2 and DP3

DP_3=f (FR_1, DP_1) from (1,3)

DP_1=f (FR_2, DP_2) from (1,4)

DP_2=f (FR_3, DP_3) from (1,5)

Step 3: DSM Construction.

Now the relation between DP can be represented in the DSM; the dashed circle indicates the diagonal of the matrix.

	DP_1	DP_2	DP_3
FR_1	X	O	X
FR_2	X	X	O
FR_3	O	X	X

Couple System

The choice of the output variable.

As shown in step 2, it is not a unique choice because of the coupling. Therefore, the choice of output is unique when the systems do not involve coupling, but are rather sequential or uncoupled as shown below.

	DP_1	DP_2	DP_3	DP_4
FR_1	X	O	O	O
FR_2	X	X	O	O
FR_3	X	X	X	O
FR_4	X	X	X	X

Decouple System

	DP_1	DP_2	DP_3	DP_4
DP_1	X	O	O	O
DP_2	X	X	O	O
DP_3	X	X	X	O
DP_4	X	X	X	X

Decouple System

Clustering is used for grouping all the elements that perform a simultaneous action that can be grouped.

Define the customer requirements:

In any particular design it is a vital to derive the requirement from the customer's perspective with an appropriate design need, such as high quality, easy to set up, easy to maintain, adaptable to satisfy the customer's requirements, transportable, long service life, low price, ergonomic, or sustainable.

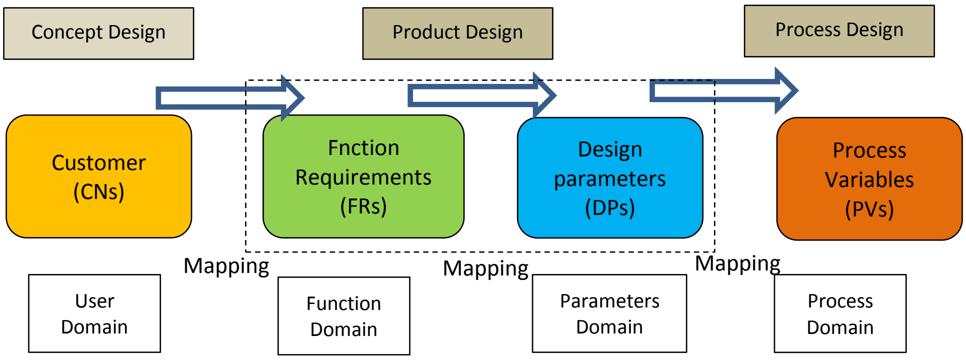


Figure 3-19: Axiomatic design application in framework design

In order to correspond to the customer's requirements, the product's attributes can be derived such as, size, material, weight, connector requirements (interface), maintenance interval, comfortable, and flexibility as shown in Table 3-2. From the customer's needs the product properties are analysed as follows. The relation is weighted based on the three point relations. The relation is indicated by a strong equal to 9 points, medium being equal to 3 points, and a weak relation being 1 point. The analysis values are influenced by the customer segment because different designers and firms have diverse business goals so the result will yield different design requirements.

Table 3-2: The modularity matrix block

Product attributes / Customer requirements	Weight	Modularization	Size	weight	Material	Connector req.	Comfort level	Flexibility	Sum
High quality	5				3		1	3	7
Easy to setup	4		1	1				3	5
Flexible	4		3			9		9	21
Easy maintenance	3							1	1
Adaptable	5	9				4		1	5
Transportable	3	9	9	3				1	22
Long service life	2	3			1		3		4
Sum	x								

3.9 Measurements of Indicator

An indicator can translate information about levels of sustainability; it is essential to provide a guide for decision making in the early stages of product design. An indicator is an important tool able to communicate ideas, thoughts and values, because as an authority said, “We measure what we value, and value what we measure” (DiSano 2002;Economic 2001).

Sustainability is without doubt important in our approach to nature. In order to make decision based on proper indicators that enable producers to measure sustainability capabilities, would be beneficial to position the indicator inside the bigger sustainability platform (Kellett *et al*., 2009). According to Joseph *et al.,* (1998), effective sustainability measurement should consider the complete triple bottom line as it relates to the product in question. Both consumption and value creation should be considered in terms of economic, environmental, and social aspects. Measuring product sustainability requires correct information; a company must learn to integrate the sustainability concept into its product development processes.

3.9.1 Applications of Sustainability Metrics

Once the metric is established the company can use it to construct and measure the improvement of operations with various methods. The purpose of a metric is to help the user to make improvements in their current operation or for future improvement. The use of a metric as an indicator of sustainability follows the simple rule that the lower the metric, the more efficient the process. The lower metrics have lower impact with fewer processes or the process is larger. The development of the metric depends on the needs of the particular area and desired future improvements (Schwarz *et al*., 2002). In order to be useful, the method for making comparisons across products must be simple, versatile and able to meet the specific needs of industries. Having a standard metric for sustainability will meet the objectives of companies in various ways, such as serving to highlight their energy usage or toxic emission, and it will also make it possible for them to evaluate the environmental impact of their products their products in terms of future or present improvements (Schwarz *et al.*, 2002). The basic metric construction will contain five indicators of sustainability: a) material intensity, b)energy intensity, c)water consumption, d)toxic emissions and e)pollutant emissions (Schwarz *et al.,* 2002).

To properly address environmental, economic, and social impacts, a metric needs to be developed that will monitor sustainability (Hussey *et al*., 2001). From their study consumer (people purchase frequently) and durable consumer goods (buy infrequently) decide on towards assessment to see the satisfies along with differences took place his or her sustainability concepts together with metrics. To fulfil the different kind of product related to end user could be measurable, depending on the consumer's needs or knowledge (Hussey et al. 2001)**.**

After the indicator has been determined, the next step is too normalised to a different sectors. Because different product functions have a different value associated with them in relation to measuring the performance of the product. Azapagic and Perdan (2000) argue that is not possible to fix a single measure of normalisation to apply equally in all cases and for all industry sectors.

3.9.2 Classification of Index

According to Elrefaei, (2012), the word 'index' has several uses from the various sciences, as well as in regular living. Hence, one meaning related to the term 'Index' can be: It is a normalised and dimension less scale that gives a quantitative measure of a defined aspect of a country. To find the maximum and the minimum value of an 'Index', a "normalised scale" has to be applied. There are two kinds of values the minimum value is "0" and the maximum value is either "1" or "100." There are a large number of existing indices that have been created by various international associations, organisations, educational institutions, Non-Government Associations (NGO), as well as manufacturers.

Although the utilisation of the term ‘Index’ is the most common – it is also occasionally known as ‘Coefficient’ (e.g. Gini coefficient). Provided that the word utilised has been previously defined, either term can be used (Elrefaei, 2012).

An index represents the magnitude of numerical values of the same kind in the form of a ratio. The index becomes a criterion, and the index indicators in a ratio are assumed to be 100. Therefore, with an index it is easy to compare temporal variation and locational variation. An ‘index’ ‘according to ‘Bosello *et al.*, (2011), are the character and aspect of the indicator summarising complex phenomena.

Aggregate indices may function as an “early warning” and they have several positive aspects for decision makers (Network 1998). The first steps towards achieving sustainable development were carried out by an international organisation, the United Nations World Commission upon Environment and Development (WCED), they are responsible for, nearly all the indicators measuring sustainability, weather global, regional or national Ebert & Welsch (2004) mention there are not any unambiguous guidelines for choosing variables, normalisation, and weighting, which can make the choice of indicators difficult or research and policy makers.

Böhringer & Patrick E.P. Jochem (2007) mention in their studies the found that although SD indices are imputed with being concise and transparent they fail to meet fundamental scientific requirements. There are three significant fundamental scientific requirements. Firstly, when deciding on input, it is important to be aware of the thematic aggregation method to determine the themes of the technical aggregation methods. Secondly, there are no basic guidelines to achieve normalisation of these factors as well as their weighting. Finally, the commensurability involving information variables should be assured (Böhringer & Jochem, 2007).

The following are the indicators that have been developed to analyses and score sustainability:

-Dow Jones Sustainability Indexes (DJSI): The DJSI assesses the financial and sustainability performance of the top 10% of the companies in the Dow Jones Global Total Stock Market Index. The result of the index is used as criteria for investors and investment firms. Analysis of media and stakeholders along with a questionnaire for the organisation form the basis of the index. The index evaluates the performance of a company using 12 criteria, covering mainly the economic dimension, but also including some aspects of the environmental and social dimensions(Josefstrasse 2013;).

Environmental Sustainability Indicators (ESI): The 2005 ESI was developed by the Yale Centre for Environmental Law & Policy for measuring and evaluating environmental stewardship for regions and countries. The ESI is a single value index that is an aggregate of six policy categories and 21 core factors consisting of 68 indicators. AN ESI value for one country is the average of 68 indicators within the 21 factors.

- Ford Product Sustainability Index (Ford PSI): The Ford PSI considers sustainable indicators with the environmental, economic, and societal dimensions that are specifically relevant to automobile manufacturing and service. Because of the specialization, Ford's PSI has eight indicators: mobility capability, life cycle cost, Impact on life style global warming. life cycle air quality, sustainable materials, restricted substances, safety, and drive by exterior noise (Schmidt & Taylor 2006).

- Life cycle iNdex (LInX): this is an index incorporating life cycle assessment in decision making in product design development. Its purpose is to aid the selection of product design, and the activities are assessed the based on four important sub-indices-environment, health, safety and cost, and technical feasibility. The overall index is biased to the environmental parameters, and furthermore the index system is flexible and can be altered according to the requirements and scope of the study. In practice the system is able to perform uncertainty analysis, and with LInX such a model can make predictions more realistic (Khan *et al*., 2004).

- Composite sustainability performance index (CSPI)-: The CSPI is a special indicator developed specifically for the steel companies in India. The integration of a sustainability indicator is a key to decision making, but due to the large number of sustainability indicators it is difficult for companies to apply. The CSPI addresses the three pillars of sustainability- economic, environmental, and societal. To assist the conceptual decision model of CSPI in order to evaluate the impact of the organisation the analytical hierarchy process (AHP) has been used (Singh *et al.*, 2007).

- The Human Development Index (HDI): this – was first reported annually as part of the United Nation's Human Development Report in 1990. It consists of three equally weighted sub-indices which are then aggregated by an arithmetic mean: the Health Index, Education Index, and Standard of Living Index. To represent the dimension with a balance of the three HDI the selection of suitable indicators is important. The value of the index is captured on a scale of 0-1, where 0 corresponds to the minimum, and 1 is the maximum. The formula can be computed as HDI(*i*)=(Actual x value - minimum x_i value)/(Maximum x_i value – minimum x_i value) (Sagar & Najam 1998).

- The recyclability index of material (R) (Villalba *et al*., 2004): this is used to determine the feasibility of disassembling a product. The calculation of (R) implemented to the highest of the product contains the important of the material. The purpose is to estimate how much of the waste materials can be recovered. The R index can be calculated more simply based on the different material gains through the recyclability index methods. Furthermore, a product may be made up of a variety of materials such as ceramic, plastic, glass, fiberglass and other reinforced material. Due to that, not all material can be recycle of disassemble, therefore with the recyclability index it is possible to see whether the material can be recycled or not. The R calculation is determined by the percentage of the product that can be recycled. It is useful for any industry sector to apply as they can compare any products with the same scale.

3.9.3 Weighting Factor

The application of multi-criteria, methodologies involves normalisation and weighting procedures. To integrate the choice of indicator in a sustainable furniture design, the relative weight in the early decision making will be considered. The aggregations of weighting factors derive from the expert experience and knowledge used to determine the environmental impact of the furniture product. At the design stage the weight assigned to each factor depends on the designer or individual impact and assumes that society agrees with the selection.

To provide a sense of the importance of each element in a design, a weight factor is assigned, and each of the scores is normalised. Each impact of the factors influences the decision made, depending on how the weights are assigned. According to Zhang et al., (2012) there are three kinds of weighting: subjective weighting, equal weighting, and weighting followed by analytical approaches. The subjective weights can be drawn from judgements of the importance value of the elements, and these are derived from questionnaires, statistics and surveys. The importance of each element is equal when the metrics not sensitive or the metric is not emphasised. Most of the time, the suggestions of idea may come from consumers, commercial colleagues, specialists, original equipment manufacturers, authorities, administrators, and other relevant parties.

Hizsnyik and Toth (2011) mention weights from other studies, such as the Dashboard of Sustainability. All of the 46 indicators are taken from over one hundred countries by three clusters given equal weight during the aggregation. Another interesting contribution to the evaluations of the methods for quantitatively, where the aspect evaluating for the different product system is useful in decision making, the most important is to indicate the weighting together with environmental and economic aspect. The significant to obtain the weight to assign the value the best is from an expert for the various criteria. Hizsnyik (2011) form his studies the combination of the weighting methods to calculate the sustainability index of the environmental, social, and economic using the equal weighting in order to exam four dimension in their framework.

Salvati & Zitti (2009) estimated the importance of weighting through their study on developing the regional factor weight model (FWM). They apply the FWM to different environmental variables with a composite index, using case studies to assess sensitivity to land degradation in Italy. The goal is to use a single variable and them to develop an assessment of indicators. To achieve the goal, the authors developed the following procedure: (i) deciding on alternatives variables as well as including the data linked to the different dimensions; (ii) converting factors directly into sufficient environmental indicators; (iii) determining a weight for every single indicator by using a multivariate time-series strategy; and (iv) identifying and analysing potential modifications in indicator weights as time passes.

Singh et al., (2007) introduced the conceptual decision model linked to the notion of sustainability. To assist an organisation's sustainability performance, the AHP model is applied in order to evaluate the impact of the CSPI. The weight of AHP is determined at various levels. The evaluation focused on a steel company in India as a case study, and to perform the CSPI sub-indices have been aggregated and evaluated accordingly.

3.9.4 Concept Selection Problem

Most well-known is the concept design selection of Pugh (1991a). The concept generates a solution to meet the stated need. In other words, during this phase the concern with the proposal of new ideas and the generation of solutions, to meet the product design specification. Furthermore, the selection of the best concept product can be done in many ways. The improvement of the concept and selection is normally based on narrowing down the number of concepts. The concept selection by Stone *et al*., (2000) given an overview of the product architecture design methodology as shown in Figure 3-19. This has five steps: 1) gather the customer's needs, 2) derive a functional model, 3) identifies the product architecture and 4) generate modular concept and 5) embody design.

According to Ulrich (1995), the product architecture is particularly relevant to the research and development (R & D) department of a company. Furthermore the early decision often plays a leading part in the R&D team's ability to achieve a certain product performance in the innovation process.

"The paper builds on knowledge from several somewhat disparate research communities" Ulrich (1995). The approach is to synthesise the product and it relates to manufacturing firm's performance, putting the existing theory and knowledge into a framework as shown in Figure 3-20. The basic level of the product development process consists of four stages: concept development, system-level design, detail design, and product test and refine. The activities of designer in the early decision-making, at the design stage are the main subject concern of this study.

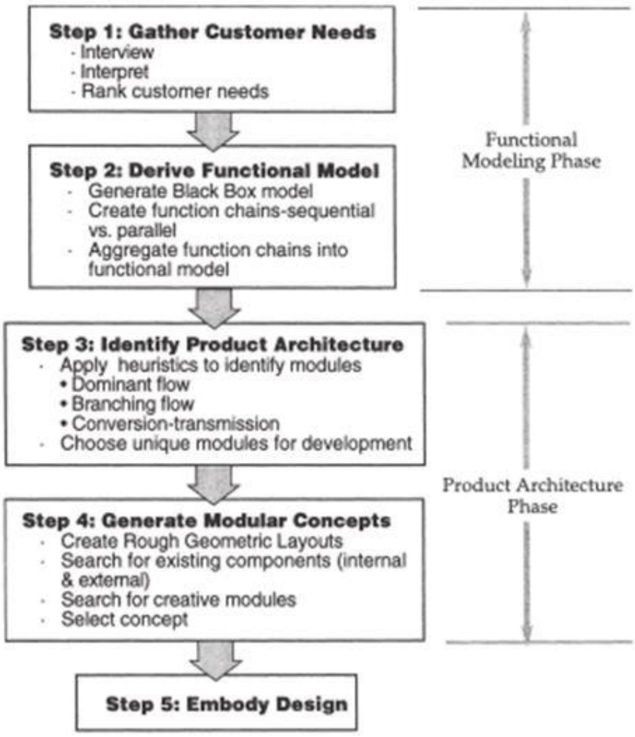


Figure 3-20: An overview of the Product Architecture Design Methodology (Stone *et al*., 2000)

3.10 Analytical Hierarchy Process (AHP)

The AHP refers to the researcher, scientists, educationalists and industrialists as supporting tools that, which can be used to solve a complex decision problem. There are numerous techniques offered when measuring different weights for recording problems. Saaty produced the AHP during the early 1970's, and it was determined equally by mathematics and psychology (Saaty, 1980).

The AHP allows for end users to make use of the practical platform to produce a sophisticated selection of different answers. This process is by government, enterprises, and also in medical and academic fields. The AHP could be utilised by a single individual attempting to produce any uncomplicated selection, or it could be used by someone wanting to examine another complicated issue. Generally, there are three basic principles of AHP, namely decomposition, comparative judgement and the synthesis of priority (Saaty 1999; Cheng *et al.,* 2007; Adhikaril *et al.*, 2006). These steps can be broken down into a nine step process as shown in Figure 3-21.

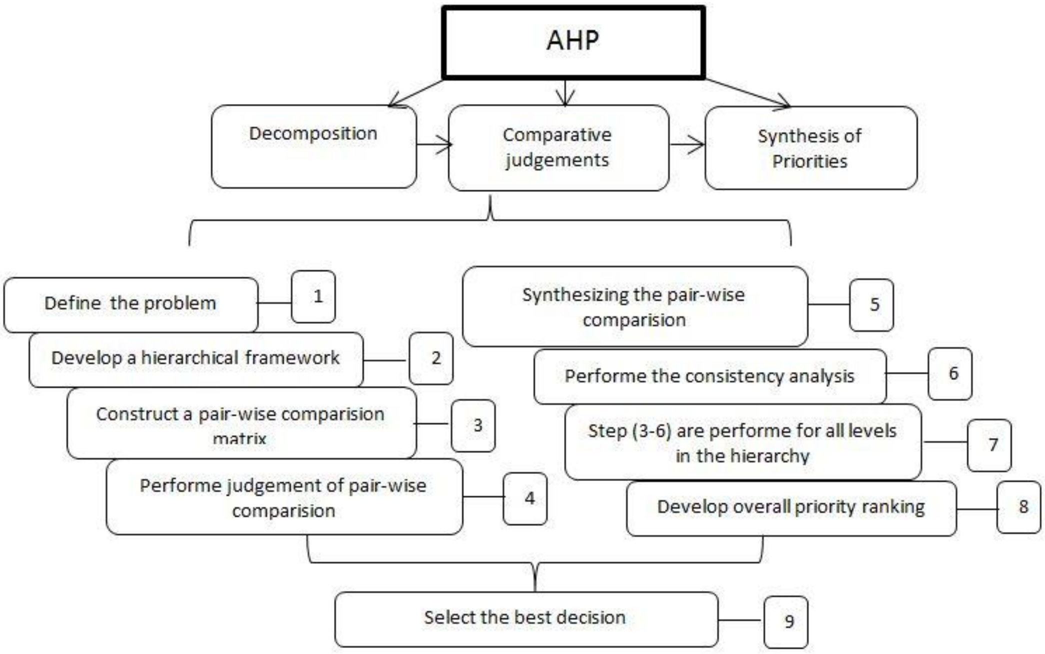


Figure 3-21: The level for design selection

Step 1: Define the problem

The AHP provides any operator with the capability of obtaining proportion weighting scales via paired comparisons. The idea of paired comparisons is the foundation for all analysis of any decision-making matter by way of the application with AHP. A paired comparison can be made once the decision maker compares factors two by two. The AHP was selected for this particular development. The AHP is known as the assessment, creating an application that is extensively used by individuals in administration (Saaty, 1980).

Step 2: Develop a hierarchical structure.

Applying the AHP to this particular method is often a new idea. Hence, a portion of the value of the study provided by this research is to try to assess the effectiveness of AHP in focused investigation. From these studies, use the AHP to solve a problem based on the pairwise comparison method. Multi-criteria decision making (MCDM) based on an AHP approach was applied to demonstrate the best design selection for a laminated bamboo chair, as shown in Figure 3-22. The pairwise comparison judgement gave the attributes from the most important factors to the least important factors. The top level is considered a goal and it is followed by the next higher level of the sub-criteria. An AHP is also capable of obtaining and handling subjective expert judgement via the consistency test.

To be able to achieve a comprehensive way of measuring sustainability, it is crucial to find the relative significance of different criteria as well as their sub-criteria. The AHP is a famous multi-criteria assessment model. It truly depends on a pairwise comparison connected to a selection of criteria, to find a new rating for every single criterion. The AHP involves measuring using pairwise comparisons and then typically depends on the judgement made from knowledge to obtain top priority weighing machines. The actual evaluations are created utilising a scale involving complete decision making that is representative of which amount is greater; one particular aspect dominates others (Saaty, 2008).

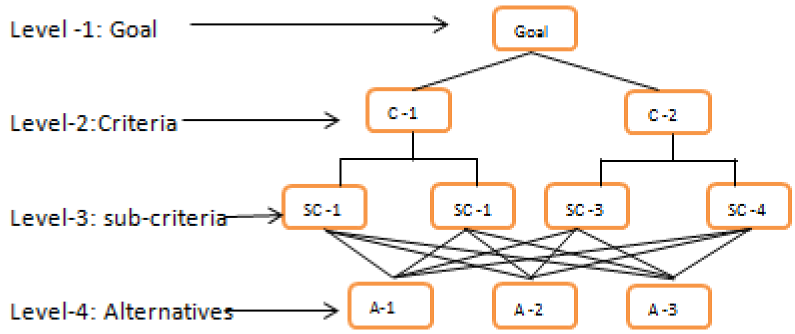


Figure 3-22: A level of hierarchy model

Step 3: Construct a pairwise comparison matrix.

To figure out the criteria weight for all of the indications a total of pairwise comparison matrices are required: one particular to the primary hierarchy point (environment, economic, and social) All the pairwise comparison are created on a nine-point scale highlighting the comparable need for every couple. A pairwise comparison matrix (size n x n) is constructed for the lower levels with one matrix in each level. Immediately the pairwise comparisons generate a matrix of relative rankings for each level of the hierarchy. The number of matrices depends on the number of elements at each level (Coyle, 2004).

Table 3-3: Pairwise comparison matrix

Goal	C_1	C_2	....	C_n
C_1	1	Wn/Wh	Wn/Wh	Wn/Ws
C_2	Wn/Wh	1	Wn/Wh	Wn/Ws
C_3	Wn/Wh	Wh/Wn	1	Wn/Ws
C_n	Ws/Wn	Ws/Wn	Ws/Wn	1

Where

N= Criteria/alternative number to be evaluated

C=Criteria/alternative

Step 4: Perform judgements of pairwise comparison.

Pairwise comparison starts by comparing the relative importance of two selected criteria, the *i*th criterion the *j*th criterion, for evaluation. There are n x n (n-1) judgements required to develop the set of matrices in step 3. To obtain a new unidimensional scaling attribute involving accurate comparisons, Saaty produced the well-known Saaty absolute 9-point scale as shown in Table 3-4.

The decision hierarchies depict the attribute for design selection where the selection criteria and sub-criteria are used to identify the comparison matrices. The selected criteria are chosen for sub-criteria such as function, material, construction, process, economy, aesthetics, and ergonomics. The relatively most important criteria and sub-criteria were rated based on a scale rating as shown in Figure 3-23 which indicates the level, of importance, from equal, moderate, strong, and very strong, to extreme (Laemlaksakul & Bangsarantrip, 2008).

Table 3-4: Saaty fundamental scale (Saaty, 2008)

Give values (1-9)	Explanation
1 Equal	Both alternatives have equal importance.
3 Moderate	One of the alternatives is slightly more important than the other.
5 Strong	One of the alternatives is judged as strongly more important than the other by experts.
7 Very Strong	One of the alternatives is judged as very strongly important compared to the other.
9 Extreme Importance	One alternative is strictly superior to the other one.
2, 4, 6, 8 intermediate values	Used for compromised judgements when necessary

Step 5: Synthesising the pairwise comparison.

The consistency is determined using the eigenvalue after the pairwise comparison has been done and the data has been entered. (Aw= $\lambda \max$ w is determined. The value of the random average of entire the consistency ratio (CR) will be compared with the departure of $\lambda \max$ from the *n* value of the consistency index. The normalised column divides the elements or scale points of each column by the sum of the columns, then adds the element in each resulting row and divides this sum by the number of elements in the row (n). This is a process of averaging over the normalised columns. In mathematical form, the eigenvector or vectors of priorities can be calculated (Saaty, 1983)

$$W_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}, i, j = 1,2,...n \qquad (1)$$

Where W is an eigenvector (priority vector)

A_{ij} is the element/scale point i.. 1,3,5,etc

n is a number of criteria.

Step 6: Perform the consistency.

Some degree of the comparison is not consistent because the judgement is based on a personal and subjective decision. Due to that, to guarantee that decisions are consistent, the final consistency verification is needed. The consistency is determined by the consistency ratio (CR). Consistency ratio is the ratio of consistency index (CI) to the random index (RI) for the same order matrices. The CR can be calculated as follows:

Firstly, to calculate the eigenvalue $\lambda \max$.

$$\lambda_{\max} = \sum_{i=1}^{n}\left\{\frac{\sum_{j=1}^{n} a_{ij} \times \omega_j}{\omega_i}\right\} \qquad (2)$$

Secondly, calculate the consistency index (CI)

$$CI = (\lambda \max - n)/(n-1) \qquad (3)$$

Finally, calculate the consistency ratio (CR),

$$CR = CI / RI \qquad (4)$$

Where the RI is a random index of the same order matrix as shown in Table 3-5.

Table 3-5: Random Index (RI)

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.58

The CR is accepted if it does not exceed 0.1. If the value exceeds 0.1, the judgement matrix is inconsistent. To obtain a consistent matrix, the judgements should be reviewed and improved by repeating steps 4 to 6.

Step 7: Repeat steps 3-6.

Steps 3-6 are performed for all levels in the hierarchy.

Step 8: Develop overall priority ranking.

Development of the overall priority ranking is carried out in order to determine the best alternative arrangement. After the consistency calculation for all levels is completed, further calculations of the overall priority vector must be performed to select the best concept.

Step 9: Select the best decision.

The end result is achieved from step 8 to work out the optimum choice selection.

3.11 CAD and Graphical User Interface

Graphical User Interface (GUI), also commonly known as a dialogue box, facilitates communication between the Expert system (ES) and the end-user. The input dialogue box is used for the end-user to input enquires into the system and the output dialogue box displays the ES outputs. GUI represents knowledge in a pictorial format and works interactively with the end-user, as shown in Figure 3-23. This will be discussed in further detail in Chapter 6.

Figure 3-23: Graphical User Interface (GUI)

3.12 Summary

Part of the challenge of realising the value of the modularity is that it needs several kinds of knowledge. The detail part makes the components work and function together. The important part is how to standardise the performance at both the component and system level. The axiomatic design theory provides a fundamental understanding of which information should be used in the design. According to this particular theory knowing, it is easy to apply the data taken throughout the design method, for example, design modifications as well as field service. The purpose of this study is to utilise the information of modularity & re-configurability, DSM, and AD, into the SDI intervention to find the best design in term of sustainability. In order to implement these capabilities on a CAD computer a new tool call SDI is programming using Visual basic which is suitable for version CAD 2014 will discussed in chapter six.

4 Characteristics of Sustainable Furniture Design

4.1 Introduction

This chapter discusses the characteristics of sustainable furniture design, which is to addresses the second objective of this study to analyse the criteria of sustainable design, in order to develop the sustainable design index (SDI) applicable to furniture design (OPS). An application of the proposed approach is presented in the context of modularity and re-configurability of open plan system. This research work focuses on developing a tool to enable the designer to measure the sustainability of furniture design and development of an open plan system (OPS). As an important element of human life and a significant consumer item, furniture “reflects the various elements of social phenomena, such as political and economic ideas, art, skill and life. This tool development will allow the designer and Furniture Company to achieve a more sustainable performance.

4.2 The Concept Sustainability Model for Furniture

Sustainability has the tremendous influence on product design, especially in quick decision-making. To define a good design procedure and a proper solution, the designer should not only be knowledgeable about the technical and commercial properties of the product but also capable of being planned, optimized and verified the furniture design process. The design methodology should, therefore, foster and guide creativity. The systematic design process provides an efficient way to rationalise the design and production process (Pahl & Beitz, 2013a).

The evaluation of the design concept implies and involves both comparison and decision making. An assessment technique requires comparisons between the concept development and specifications; together they have to effectively satisfy individual specifications. The hardest concepts to evaluate are those where it is not immediately evident whether the idea is goods or not, but the concepts are worth considering. The approach of this study will evaluate decision making in areas, such as modularity, re-configurability, axiomatic design and the design structure matrix.

The approach is a relatively easy procedure to implement. The first step is to understand the product modularity; that is the most important element for the customer and also for the manufacturing companies. Then it returns to the set of customer requirements that were developed during the early stage of design development. Our final evaluation is carried out by the decision matrix, before proceeding to the sustainable design index to determine the best design produces the most sustainable product.

Through the decision matrix, the concepts are not compared to one another, but only to the criteria of evaluation using pairwise comparisons. Next is the selection criteria for the decision matrix based on the functional requirements and or the objective of the problem. Creating certain criteria weighting aspects is an essential section of the decision matrix. The weight for each criterion quantitatively describes how important each criterion is compared to the other criteria. There are many types of weighting scale use by companies; some industries prefer using nonlinear and asymmetrical scales (Saaty, 1990; Abba *et al*., 2013).

This study will analyse the sustainability issues related to the furniture industry and it aims to provide new guidelines for local designers and furniture manufacturers. The Malaysian furniture industry still needs a lot of development to catch up with the developed countries for producing high-quality and creative designs. The process of furniture design means the right technology preparation for the product design, i.e. from planning to mass production. The exact product design and development process includes material selection, functionality, design and analysis, economic costing and aesthetics, plus the right management, which all together can ensure design quality through the appropriate design cycle arrangement. Therefore a furniture designer focuses on the technology, art and economy of furniture, but lacks the comprehension and cognition of environmental protection and ecological engineering technology. Due to that, the implementation of the modern furniture design, the “three dimensions of rational analysis and system design” as shown in Figure 4-1 should be studied and analysed by the team (Zhang & Xu, 2010). The designer should evaluate the life cycle, that is to say, the model makes the complete identification of the environment, energy and resource factors in the whole potential environmental impact in furniture production. The full intent of these studies would have been to find out the mind set related to sustainable furniture design, its principle in design, and the challenges for the designer (Pahl & Beitz, 2013b; Ulrich 2003). The mediation between sustainability, designer, and furniture design is sustainable design as shown in Figure 4-1.

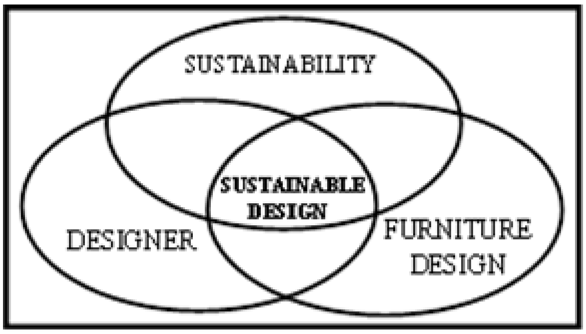


Figure 4-1: Three major areas the connection between sustainable design

4.3 The Strategy of Modern Furniture

Furniture is part of what peoples would regard as an essential requirement for living, as well an important customer item. Furniture considers the numerous factors related sociable trend, for example, politics, financial, craft, ability and also lifestyle. Throughout the whole process of economic improvement, together with global economic expansion, most people need to give consideration to further serious environmental problems. These are due to the interior air pollution and then energy dissipation generated during the whole process of the furniture life-cycle. These are important aspects that influence people's quality of life, as well as limiting the economy and industrial trade.

Like an organised design concept and method, the eco-friendly style takes a comprehensive look at, and maximises the connection between all the practical benefits and environmental benefits involving manufacturing "from cradle to grave co-ordinately". The idea includes environmental factors for successful product design restrictions and assessment methods.

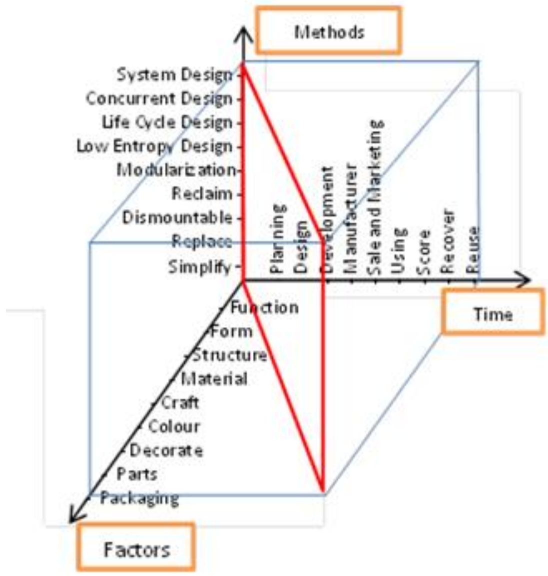


Figure 4-2: The analysis system for furniture (Zhang & Xu 2010)

Academics have discussed and studied in depth the concept of sustainable furniture, but some furniture design still applies traditional methods. Conventional furniture design is mainly carried out by architectural designers and innovative artists, and most of the expert experience is undoubtedly in timber processing, style design and constructional design. Consequently, furniture design concerns further concentrate on technologies, art and the financial aspects of furniture. However, there are inadequate understanding and knowledge related to environmental protection and also ecological engineering technologies. The actual execution of the modem furniture design approach needs ecologists and environmentally good researchers to take part in the design process and to create, a development group along with furniture designer, structural engineers, production people, and salesmen. All the team then examines the furniture design and manufacturing procedure carefully, and constructs the "three dimensions related fair evaluation as well as techniques, design" model of green furniture design (see Figure 4-2) (Zhang & Xu, 2010).

4.4 Priorities in Furniture Design

The environmental impact of furniture is significantly influenced by manufacturing, material choice and fashions or trends. That is the reason why sustainable design strategies have, mostly been developed by focusing on this area. Common raw materials used in manufacturing are wood, metal and plastic. For wooden furniture, the use of certified wood from sustainable forests play a key role, where as in the case of plastic parts and metal, the recyclability, and additives cause more concerns.

The Office Furniture Standard (2013) prepared by McGill University, focus on the environmental impact of office furniture standardisation. The main sustainability issues related to furniture and the furniture life cycle are shown in Figure 4-3.

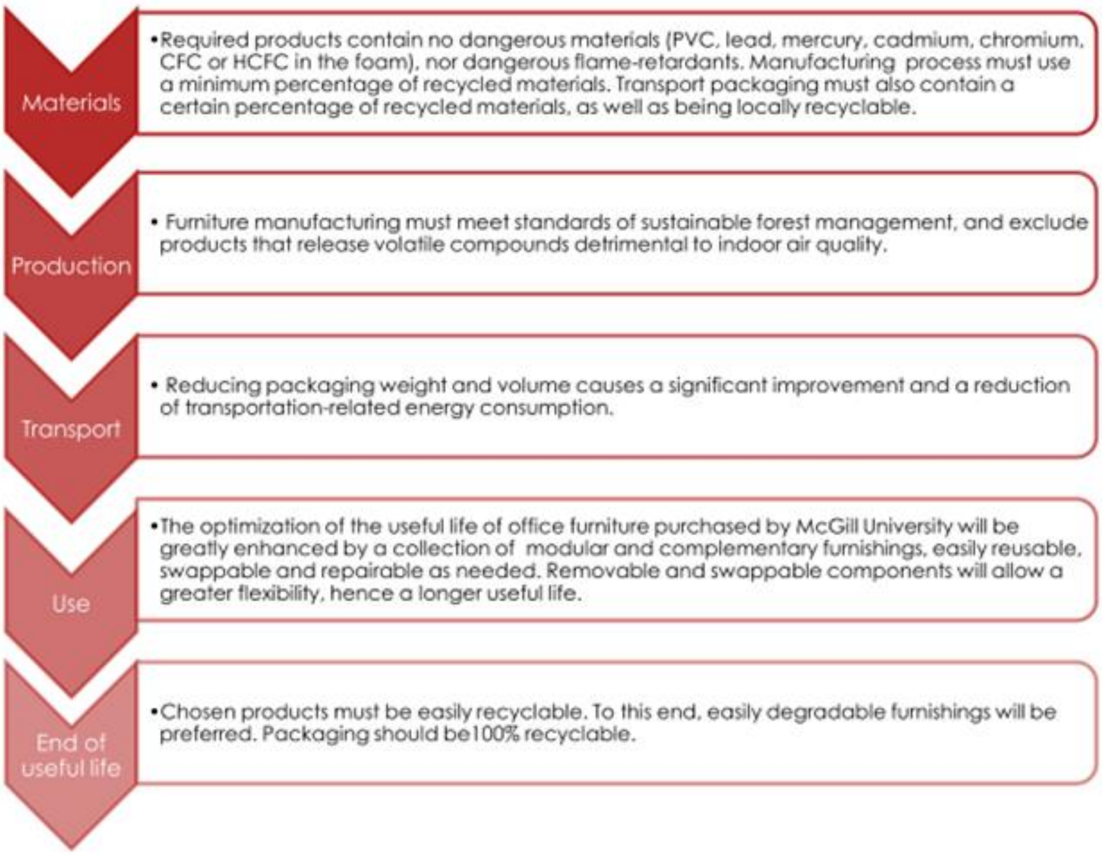


Figure 4-3: Main sustainability issues related to furniture life-cycle (Office Furniture Standard, 2013)

4.5 The Decision-Making Process

In the field of sustainable product development, there exists a strong indication that future research will focus on the challenges regarding establishing valuable information by following life cycle development directly into the early design stage. Consequently, studies in the profession fields of knowledge modeling, uncertainness quantification, and making decisions as utilised on sustainability are going to be of significant value (Ramani *et al*., 2010) . The decision-making skill becomes complex if too much environmental information leads to anxiety and confusion. Furthermore, most of the users have limited understanding of the environmental problems and risks. However, simplifying environment related decisions and equipping people with the tools required to address them, is a good example (MacDonald & She, 2015).

According to Wallace & Burgess (1995), design is the best solution in decision-making as it includes synthesis and modeling. The design process without decisions will bring no improvements for new products. It depends on predictions and appraisal conditions and it is made for better manufacture, safely, and reliability, being easy to maintain and recycle at the end of life (EOL).

Decisions made during the conceptual stage have significant influence on the cost, performance, reliability, safety and environmental impact of the product. It has been estimated that about 75% of final product cost is due to the design decisions. Therefore, the right tools are needed for a designer to access and to support such approaches (Hsu & Liu, 2000). The product developer and the purchaser need to consider different criteria for each product or product concept, for example, price, quality, product lifespan, materials maintenance and the environmental performance characteristics, to take a decision. It is important to have an overview of the situation when making a decision in complex systems and this demands an understanding of how different things are connected (Byggeth & Hochschorner, 2006).

There have three basic elements to achieving sustainable development: identifying environmental quality, economic prosperity, and social justice. To consider the triple bottom line means a concerted effort for the company to evaluate and make use of the decision-making process by incorporating the environmental, economic and social aspects (Wang & Lin, 2007). For the decision-making purpose, the most straightforward and attractive tool enables the system performance, and evaluates and presents the information by applying the performance indicators. In industrial performance there is pressure from the stakeholders which is often perceived as a driving force towards sustainability. The development of decision making applicable to the core sustainability of environmental, economic, and social factor is a valuable tool for senior management at the operational level for preparing report on the environmental, economic, and social impacts of the company's activities (Staniškis & Arbačiauskas, 2009). Consequently, sufficient measures are undoubtedly required to make sure that the idea behind certain changes has a positive environmental impact on the enterprise's operations. In general, the most significant disadvantage involving present sustainability performance evaluation systems is the focus on outside reports and an underestimation of the internal information required to achieve decision-making, improved operational performance and specific effectiveness enhancement. Due to this fact, to assist with the operational decision-making in the enterprise, there is a fundamental challenge which is choosing an appropriate indicator. In order to ensure the effectiveness of the indicator, all the specific levels should be applied (environmental, economic, and social) (Staniškis & Arbačiauskas, 2009).

Hence, the design priority is important in the decision-making process. Regardless of this, this kind of participation demands decision making and an accompanying consideration. When the user plays a part in the decision making and also in actively taking a part, the end result is more satisfying for all parties. Engaging with the stakeholders is also an effective way of determining environmental decision-making (Vezzoli *et al.*, 2014).

4.6 Estimation Weights

To determine the weight regarding the final result, the information must be sufficient, so that the weight does not just depend on ad hoc restrictions. The different choices of indicators also influence the different concepts of sustainability, which influences the weight of the decision-making process. According to Grießhammer *et al.*, (2007) from their Product Sustainability Assessment (PROSA) guidelines, it is important to consider the variety of products and aggregated environmental indicators when involved with economic, environmental, and social factors. The weight target for all environmental factors is assumed to be agreed by societal consensus or legislative status with an equal weight. The weight percentage has been formulating with the impact categories without any quantitative environmental target. Griebhammer *et al.*, (2007) interpret the framework which is operationalised in an Excel spreadsheet model. The evaluation indicators are placed on a scale of 1 to 10, where 1 is considered to be –'high', meaning the social indicator is good, and 10 is considered to be 'low', meaning that the social situation is very poor. The Excel weight factor is set at 1:1, but later the end user can modify the weight factor. As shown in Figure 4.4, the spider diagram interpretation of the framework is based on the three dimensions (ecology, society and economy) each one varying between 1= very good, and 10 = very poor.

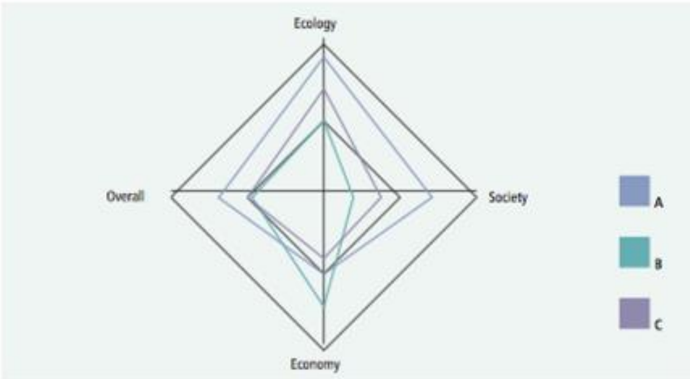


Figure 4-4: Spider graph of the integral of the product alternative under PROSA (GrieBhammer *et al*.,2007)

According to Rockstrom *et al*., (2009) any functional unit provided for environmental impact can be translated, structured, and evaluated according to the similar effects of each boundary. There are no basics with which to determine the key prioritisation, however the weighting factor can also be determined using a so-called 'distance-to-target' (DTT) approach, where the highest priority weight is given to the indicators that are closer to the environment boundaries.

All of the development methods utilising an integrated assessment of sustainability can be defined as a three step methodology: A) the particular recognition of the several dimensions underlying the idea of sustainable development; B) the procedure of aggregating reduced aspect indications in advanced level composite indices; and C) also the attribution regarding weights at various levels of the indicators hierarchy (Böhringer & Jochem, 2007).

The differences in the sustainability aspect reflect the relevance and importance of each number weighting factor given. Furthermore, determining the weight factor is normally based on decision maker's knowledge and understanding. Hence, this assessment framework, conducted as part of this research provides opportunities for the designer or expert to assign the preferred values to determine the weighting factor in their application. For furniture OPS, part and components the designer can also assign different values of those weighting factors and then compare the results.

4.7 Formulation and Concepts

By providing the formulation and conceptual of SDI in this study, the researcher is able to focus attention on the need to use the sustainable design index for furniture companies in the development of sustainable furniture. In addition, the relatively in depth interpretation of sustainable design index formulation, will be the focus of the next chapter. The implication of sustainability is manifold and developed from many scholars who have proposed different ideas, interpretations and level of constructs. Due to that, the broad of studied of sustainability make the concept attract too many, and some difficult to implement according to the specific end user.

4.8 Industrial Design

The relationship between design and sustainable design has been studied in the context of office furniture in OPS. The decisions made during the design process such as the type of goods, their manufacturer, appearance, and an assessment of their suitability for the market and whether they will fulfil the consumer's needs, are all undertaken by designers.

The product designer or industrial designer has to concentrate on achieving the technical performance and cost demanded by the client and they also have to be a universal judge of other aspects, such as aesthetic and ergonomic, but this does not include all aspects, such as waste, ethics, etc. There is often little awareness and understanding of the wide environmental, social, and economic impacts of the design.

The use of disposal finished products and legislation, related to disposal, increase the reuse and recycling of products, which can make the product more sustainable (Howarth & Hadfield, 2006).

Howard et al, (2008) state that there should be variance concerning creativity as well as the design process, even if the design process seems like a mechanical process, but at the same time is in harmony with the creative process. The designer is actively involved with creativity, like the conductor of an orchestra he puts into action the necessary skill at an appropriate moment in time.

Much of the office furniture industry makes decision about materials, and their consideration of the environmental impact depends on their own intuition and decisions made by the expert or designer. Gemser and Leenders (2001) believe that for improve company performance, investing in industrial design is beneficial. They state that the industrial design activity is normally related to the product requirements and is also involved with the product requirement into a configuration of materials, product features and components. The impact of industrial design is dependent on company performance and design strategy. The industrial design process can have an influence on the product's aesthetics, functionality, material usage, how easy it is to manufacture, product functional performance, if it is safe to use and so on. Gemser and Leenders (2001) from their empirical study collected data from two Dutch manufacturing industries, namely home furniture and precision instruments. They found that when the company integrates industrial design it has a significant influence on new product development and product performance. Also, they found that design innovation has a significant influence on the furniture industries. By employing the industrial design, a company can differentiate on product appearances and benefit from market trends. The strategy of involvement of industrial design in the performance of products in the furniture company can be done by integrating industrial design into new product development (NPD) projects.

4.9 Design and Sustainability

The designer first needs an awareness and understanding of complex and wide-ranging issues when applying complex and wide-ranging issues to a new product. The designer must have the appropriate tools to make the sustainable issues more manageable (Howarth & Hadfield, 2006). Due to these characteristics, sustainable design requires consistent and well-coordinated implementation to achieve it in a meaningful way (Skerlos *et al*., 2006). At present, there is a clear need for a comprehensive body of knowledge and qualitative approaches that integrate engineering, economic, societal, and environmental science models towards a holistic definition of sustainable design. As designers, we must integrate a new design philosophy and innovative inspirations into the design ideas of products concepts and explore our designs with the idea of sustainable design so as to make the conceptual design more innovative (Huang & Zhang, 2008).

The most encouraging characteristic of sustainable from an organisational perspective is its profitability. By adopting sustainable design criteria, considering environmental and social aspects will lead to more profit. A simple example is using local resources; that is one of the major sustainability guidelines and it will result in less transportation, less energy consumption, less air pollution and finally saving production expenses and making more profit for manufacturing companies. In fact, the most significant expectation of involving the triple bottom line of sustainability is making more money. Manufacturing companies who are following sustainability policies are definitely aware of its benefits.

Although conventional furniture design demands a comprehensive understanding of materials and exactly how they could be utilised, sustainable furniture design needs to include a new wider perspective involving style and design. This is important not just for the characteristics and performance of the raw material, but to consider how to make the raw material also the priority. From the early stage design process until the end, the benefit of the items with regard to the environmental and social impact needs to be determined.

Sustainability is one of the biggest trends in recent years. Many designers and manufactures are making the best use of the resources in a responsible way. One of the greatest things about modern, sustainable furniture is that it is not boring or ugly. It shows a lot of creativity and a tremendous sense of design. Sustainable furniture is made from materials that have certain characteristics. These materials may be re-purposed or recycled. Furniture that is made from renewable material is considered to be sustainable furniture. One of the renewable resources that can quickly be produced and replaced is bamboo found readily growing.

Furniture that is considered to be a sustainable product is, produced from the materials as mentioned below. The product's level of sustainability can be influenced by how many of these characteristics it has.

a) It is recycled or recyclable - The furniture should be made from recycle or re-purposed materials, or be recycled by itself.
b) It is made from renewable materials - It is a good sign that the furniture is made from organic material that is easily grown and replaced.
c) Safer material used in construction - The furniture is a safer material instead of using highly toxic, gas-emitting finishes. High toxicity is found in products such as sofas that are treated with flame retardants, or chemicals that could be absorbed into the user's bodies.
d) Look for stewardship sourcing - The materials used should come from fairly-traded sources or be certified low impact sources such Forest Steward Council (FSC)-approved forest.

Source Abe Abbas Furniture Expert [online]. Available at: http/www.furniture.about.com/od/furnitureterms.

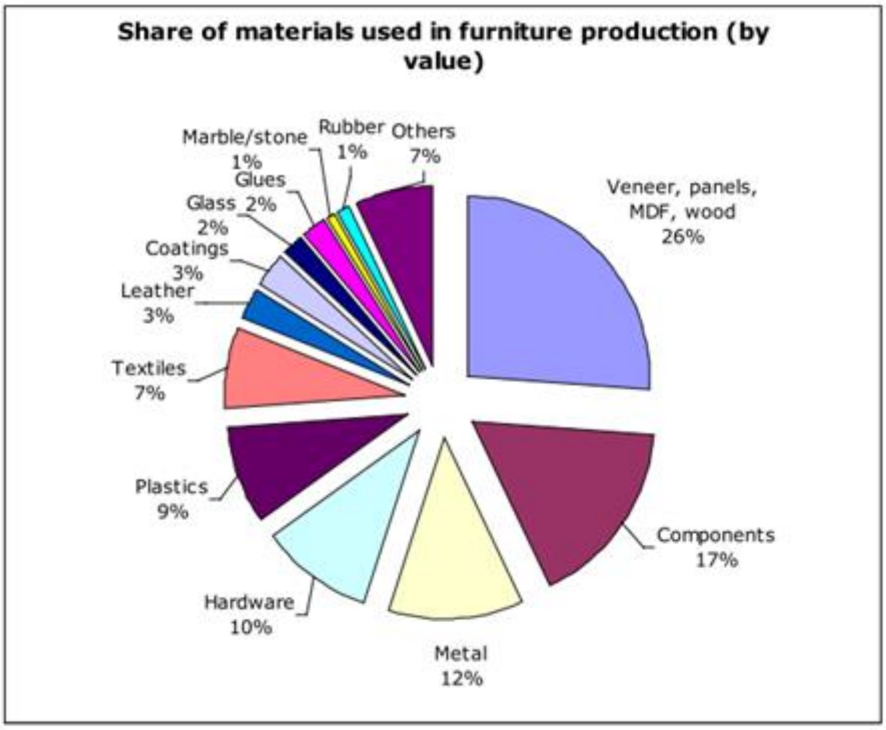


Figure 4-5: Share of materials used in furniture production

There are two factors that need to be considered and which are key indicators for any particular furniture items to reflect the environmental impact. A) The designer needs to consider the life cycle impacts of the material selection to make the furniture. B) The impact of the final product during the life span and after the end of life i.e. the product disposal.

Figure 4-5 shows the distribution of the material used for furniture production in Europe, according to the European Furniture Manufacturers Federation. As the chart indicates, there is a wide choice of material available to the manufacturer (Program, 2008). At the same time it is impossible for a manufacturer to produce a piece of furniture using all the materials at one time. Consequently, many experts have suggested with regard to this particular product segment guideline that the first priority should be determine and an appropriate material use for certain designs in the final furniture product. As shown in the chart, most of the furniture consists of wood (70%) as a main material, 15% is padding such as polyurethane and polyester foam, 10% is based on metal and 5% are others such as leather, glass, textiles, etc. The main focus is on sustainability and environmental issues, and the main material that is utilised in furniture needs to be treated to protect it from weather, human activities and also to protect from the nature of the material itself. This includes the surface treatment and the adhesive used to join the material, main materials used is like in furniture for OPSs are wood, metals, plastic, textiles and foam material. The important factor is the life of the material for the particular furniture product, furthermore the manufacture is also a major consumer of raw material, which reflects the whole process and contributes to the environmental impact UNEP McCabe (Program 2008).

4.9.1 Sustainable Design and Innovation

Skerlos *et al*., (2006) state that design is a creative decision-making process that aims to find an optimal balance of trade-offs in the production of a product or service that best satisfies a customer's and other stakeholder's preferences. From their point of view, sustainable design only adds specific focus to design: design, with particular attention paid to life-cycle trade-offs between functional performance, economic success, and the establishment of healthy social and environmental systems.

Many of us are aware of the impact of products that many have a side effect on our health and also the environment. Due to this sustainable material is useful and there are many reasons why users want this kind of furniture. Environmentally friendly material is not the only thing to consider as sustainable furniture is related to manufacturing issues. Another thing needs to focus on how the furniture design, transportation, and disposal are carried out.

4.10 Multi-Criteria Decision Making

Multi-criteria decision analysis (MCDA) is a useful method in the field of environmental policy, such as related to environmental, economic, and social decision-making issues. Industrial designers and engineering designers in the furniture industries, often engaged with various suggestions, but only one will be the best option. The decision could be unequivocal, if there are many different disciplines participating, they can give support either with their knowledge or skill. The decision makers have to consider the correct solution that is relevant to sustainable design for furniture design.

A tool widely used and suggested to be helpful for assessing environmental impact is the MCDA. The multi-criteria decision making (MCDM) method is most widely apply in corporate management due to that an appropriate decision making method is needed to develop sustainable strategies (Wang & Lin, 2007).

4.11 Office Furniture Design

Office furniture comprises chairs and other categories of seating, workstations, tables, filing and storage cabinets and also their specific connected components and accessories. These are usually created from a broad range of materials including steel, timber and wood-based products, plastic and textiles. Office furniture consumers' understanding of present ecological concerns has expanded demands for office furniture manufacturers to reduce their particular environmental impact. Typically the potential buyers of this type of office furniture include the public as major consumers; institutions, universities or even medical centres require improvements this particular market, in order to achieve a significantly more sustainable solution.

The process of furniture design encompasses the whole technology for the product design, i.e. from planning to mass production. The scientific product design and development process includes material selection, functionality, design and analysis, economic costing and aesthetics, plus reasonable management; all of these together can ensure design quality through the appropriate design cycle arrangement. The development of furniture design is a complicated process of knowledge movement that, involves marketing analysis, suppliers, production, and design techniques, etc. The designer should be equipped with multidisciplinary knowledge. The product design and development will proceed as shown in Figure 4-6, including four main stages: ideaformation, research and development (R&D), manufacturing and marketing (Zhang & Zhang, 2010). Design Furniture is mainly dependent on trends and timeliness; to fulfil the changing customer demands it is necessary to develop a new type of furniture with improved functionality.

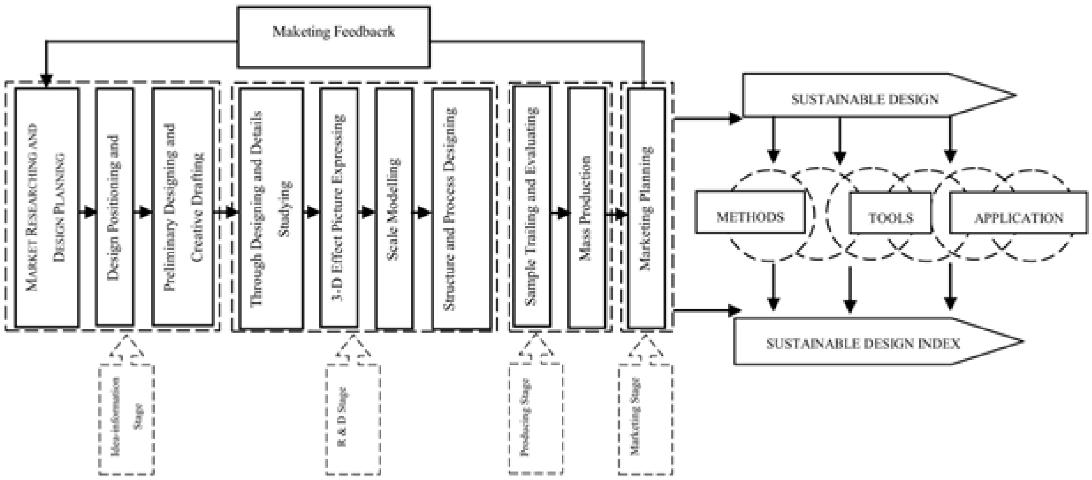


Figure 4-6: The development of furniture design (Zhang & Zhang ,2010)

Figure 4-7 illustrates the number of usages for office furniture as reported by FIRA 2011. The responses were gathered from a questionnaire via the internet and also from “FIRA e-news” and media. The graph shows from the 12 responses the type of office furniture used, including chairs, workstation, cabinets, screens and others. From the graph it was concluded that the use of furniture in offices is vital for everybody (FIRA International Ltd, 2010).

All the designers from the majority of manufacturers interested in these studies state that in some years’ there will not be any choice, however, to provide the situation regarding sustainability the same concern with the additional factors, for example, economics and also how the designer and also manufacturer wants to perceive by consumers. Sustainable design is a concern for all designers, but in this study the focus on office furniture industry.

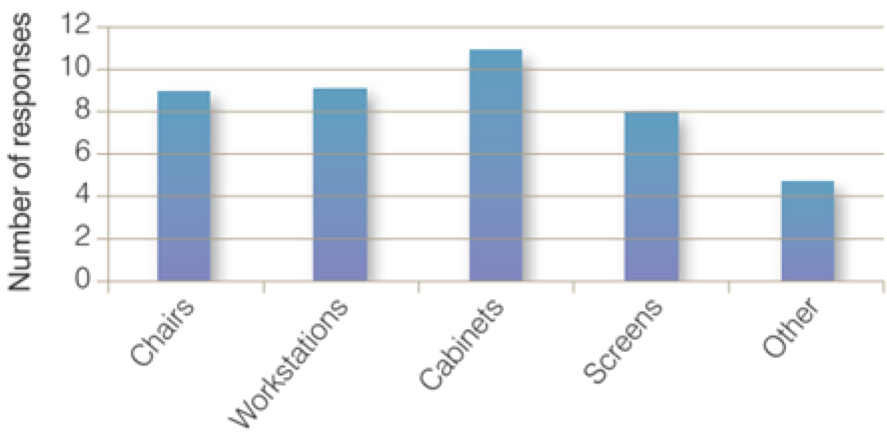


Figure 4-7: The number of responses for usage for office furniture (FIRA International Ltd, 2010)

4.11.1 Open Plan System

Open Plan System were popular in the mid-1980s and they were pioneered by Herman Miller and generally based on re-manufacture they have a thousand of customers. Open Plan Systems consider high quality new trends for furniture producers and offer a sustainable system choice at a good price. Some of the furniture manufacturers produce a standard product with a particular design and add new features such as automation or they follow the specific size determined by customers. Most of the suppliers provide a variety of modules with different configurations of design styles. The configuration of each workstation has a modern look with lower panels, open or free standing layouts, system desking, and panel tiles with modular walls. On top of that a variety of design choices is offered by the manufacture with the additional benefit of flexibility and selection. The configuration of design comes together with a reasonable cost saving for each design provides.

The company is willing to offer a better price due to the competition, it faces and also it is looking for the right customer who is sustainability minded, and who demands a standard of high quality and durable OPS. All of these can be provided with three core components: the panel core, connector core and overhead core. On top of that, some manufacturers are willing to provide the LEED certificate. This is given to those who use environmentally friendly or low impact materials. Most of the furniture companies provide with warranty is covered by a limited come together with the original purchaser. A warranty such as a ten-year warranty can be offered for components and also case goods. All of these cover for any defects in material and workmanship. (www.openplan.com/about/).

4.11.2 Modular Components of the Open Plan System

Since OPS development moved rapidly to fulfil the demand and the needs of end users, this forced the manufacturers to compete and produce systems with a better look and functionality. In Malaysia for example, Artwright Holding and Bristol Technologies Sdn. Bhd developed the system according to the needs and demands of consumers since back in 1994. The designs and development under R&D departments produces such a design range based on the reverse engineering process; as shown in Figure 4-8.

To construct the full frame of OPS depends on what kind of range is produced for that particular design, as shown in Figure 4-9. The structure constructed of steel or aluminium is considered as the main material of an OPS. The OPS system is flexible and can be configured according to its suitability to fulfil the requests from the customer, who may be a consultant, interior designer or architect. Different designs and compositions of the module can follow the specification of the floor plan or layout of each building, and most importantly, the design configuration must meet the budget and cost restriction.

No	Description of Components and part of Open Plan System
1	Panels of various widths are stacked to achieve the desired overall panel height. The fabric and paint colours can be customized.
2	Surfaces are available in a variety of lengths & colours. Made of durable wood or laminate.
3	2-Way Connector pictured above. 3 and 4 way connectors are used to create common-wall configurations.
4	Flipper Door Unit: Locking overhead storage for binders and other material
5	Full Height Shelf: Open, easy access storage
6	Half Height Shelf: Open, easy access storage
6- 7	Keyboard Tray: Fully adjustable
8	Powered Panel (Kick Plate): Provides power to the workstation
9	Lateral File: High-capacity file storage for letter and legal size documents
9-10	Rolling pedestal: Filing on wheels. Create more knee space or counter space as needed.
11	Standard Pedestal: Comes as a File/File Pedestal with two 12" filing drawers or a Box/Box/File Pedestal with two 6" utility drawers and one 12" filing drawer
12	Interchangeable Panels: Panels come in styles and colours and are easily changed to meet your design needs. Can be glass, metal or covered in fabric. Tack-able, non-tack-able, and sound absorbing panels are also available.

Figure 4-8: The components and parts of the OPS.

Open Plan Systems also have a variety of components to support each of the configurations. The OPS module can be, reconfigured with a variety of clusters such as cluster of two, a cluster of three, a cluster of four, a cluster of five and different kinds of arrangements according to the job function of any particular office. OPS parts have also become part of a manufacture's furniture package, which means that each of the components to support other parts and components such as a work surface, and the accessories such as storage, pedestal and side cabinets. The panel can be produced with various kinds of materials and the finish can be an epoxy coated metal panel, an MDF panel finished with lacquer spray, an MDF panel covered with selected textiles and many others.

Figure 4-9: The different height of panel system(Workstation Components, panel Height & Lamp, Configuration, http://officefurniture.com/workstation-components/(accessed December 18,2015)

When practising any kind of construction of the OPS, if the designer takes precautions and pay attention to detail in the design process then the result will require less labour cost for installation and less productivity loss due to downtime. Hence, the advantages during disassembly and reassembly can be minimised if there are any interruptions or technical errors. The OPS can be produced in several sizes depending to the needs of the customers. Table 4.1 shows the standard OPS frame sizes for any type of OPS system. The package of an OPS system comes with different sizes, such as low screens and table screens, medium frames, high frames, and full height frames. The arrangement of the height of frame is based on the type of workstation such as clerical workstation, executive workstation, manager workstation, and free standing workstation.

Table 4-1: OPS frame dimensions

	Low & table screen	Medium frame	High frame	Full height frame
1	-950H x 450W	-1350H x 450W	-1750H x 450W	-1250h x 450W
2	-950H x 600W	-1350H x 600W	-1750H x 600W	-1250h x 600W
3	-950H x 750W	-1350H x 750W	-1750H x 750W	-1250h x 750W
4	-950H x 900W	-1350H x 900W	-1750H x 900W	-1250h x 900W
5	-950H x 1200W	-1350H x 1200W	-1750H x 1200W	-1250h x 1200W
6	-950H x 1500W	-1350H x 1500W	-1750H x 1500W	-1250h x 1500W

There are different styles of OPS models and the configurations of each module can be customised according to the type of office environment and it can also depend on the organisational position of the person and their job designation Table 4-2 shows some of the different possible configurations.

A) Panel

Greater flexibility – The designer of the end user will enjoy the flexibility and variety of the panel systems, which have a larger selection of fabrics and a good finish. The number of configurations with different types of module means that many options are available and it can be modified to suit any project request by the customer and end user.

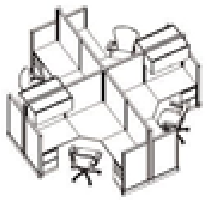
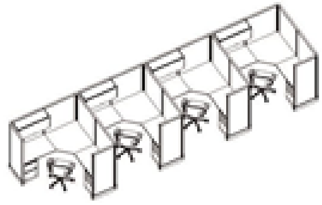
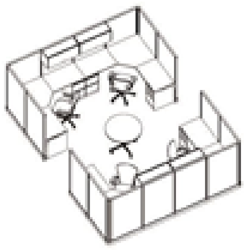
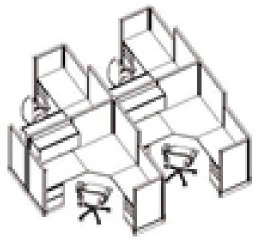
B) Modular Walls.

Refine the Space - With the panel system, to collaborate with the working environment, modular walls allow for the open plan concept paired with the management of noise and distractions.

C) Tile.

Evaluation of Work Space - The tile system with OPS gives the end user the flexibility and adaptability to create their desired business setting of today and also an affordable way to evolve it in the future. The benefit for designers who are looking at budget price is the availability of modular systems with fully compatible workstations and accessories.

Table 4-2: Different types of configurations

Cluster of four Facing Configuration	Cluster of Four L shape Configuration
a 	b 
A 6 x 6 unit with end panels equals 16 panels total	A 6 x 6 unit with end panels equals 19 panels total
Cluster of Four Uniform Configuration	Cluster of Four Bullpen Configuration
c 	d 
A 6 x 6 unit with end panels equals 18 panels total	A 6 x 6 unit with end panels equals 18 panels total

CUBICLE

This is an example of a reconfiguration for a work station as shown in plan view in Figure 4-10 based on the customer’s requirements.

1 - One freestanding L-shape workstation with integrated storage.

-Work surface and side unit.

-Integrated storage units consisting of a drawer pedestal and storage tower with a door.

2 - One file cabinet as required.

-Lateral metal storage.

3 - One multipurpose chair.

-Ergonomic.

-Fully adjustable (bracket, armrest, seat, height).

-Choice of finish (Grade 1 or 2 fabrics).

-Steel structure.

4 - Two visitors’ chairs.

-On coasters

-With armrest

5 - The Panel system as required

-Open storage unit with shelves

-Divider panels: 54” maximum height

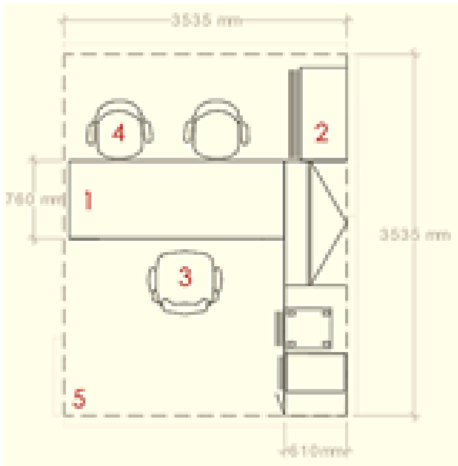


Figure 4-10: Plan view of Open Plan System (OPS).

Figures 4-11 and 4-12 show an example of the configuration of OPS. The system of OPS can be decorated accordingly depending on the office space. The tile system of the OPS is able to be decorated and organised to fit the office layout. The OPS offers the highest level of practicality and aesthetic value because it was designed to coordinate with the furniture elements.

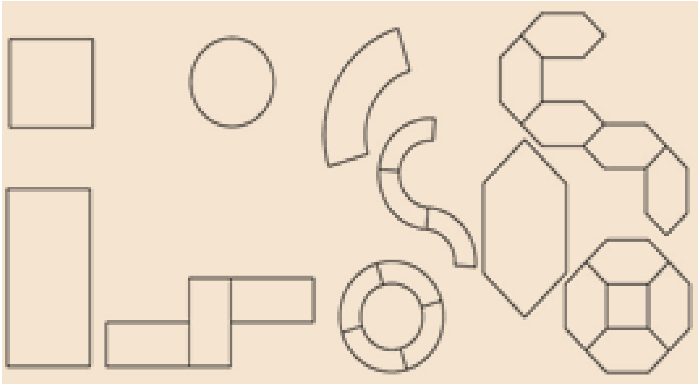


Figure 4-11: The shape of the configuration choices of work surface on their connection (Smardzewski 2015)

In furniture the modularity is distinguished as two situations: furniture with volume spatial structure and with an added feature. The advantages of these features increase the functionality of the furniture with the variety of the range and in addition they provide high quality design with good finishes. Modular furniture has a foundation of shape with a standard construction regarding the features and closed dimensions in standard layouts, with the possibility to complete the configuration of the systems according to the needs and the consumer desire. The completeness of the modular system is shown in Table 4-2. The arrangement of the shapes can be done vertically, horizontally and in a matrix to form a configuration using a simple connection between the components with high quality furniture. With respect to the design, modularity is usually separated into four categories as shown in Figure 4-12 a) single-bodies b) multi-bodies c) universal for completion d) on a frame and e) for hanging (Smardzewski, 2015).

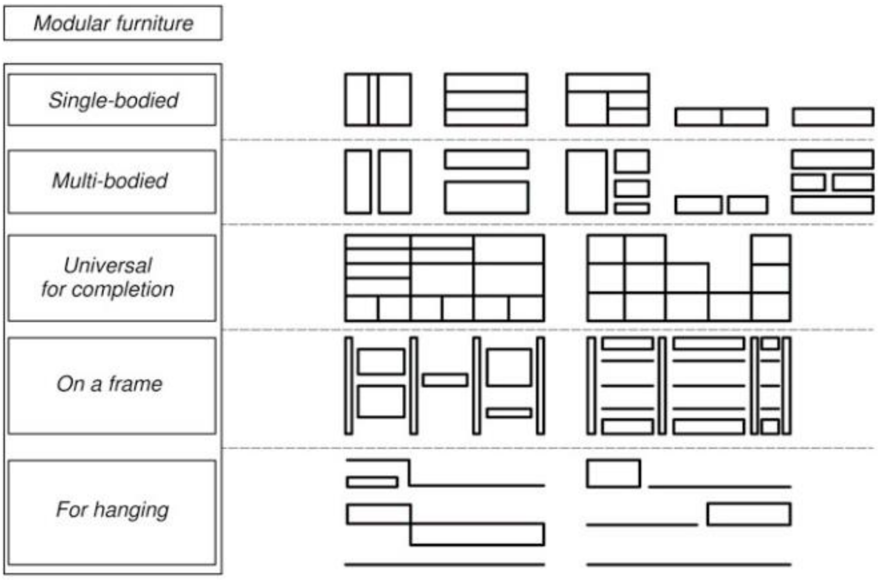


Figure 4-12: The modular furniture (Smardzewski 2015)

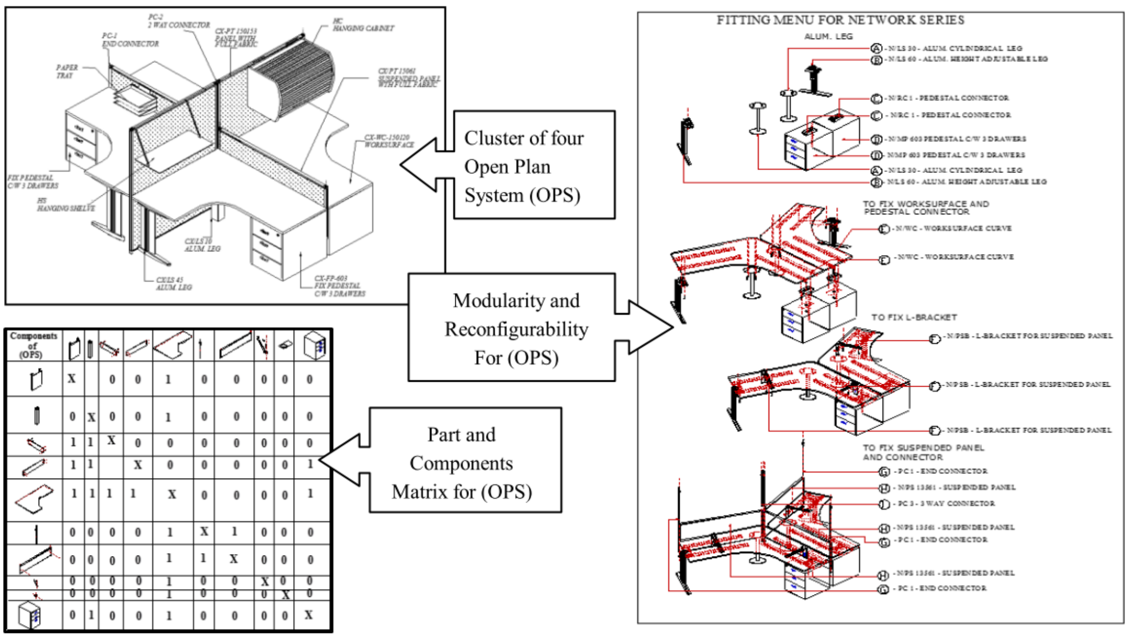


Figure 4-13: The decomposition of product OPS structure

An OPS is considered to be a complex product because of its modularity; components can be developed using similar elements. The modular product is built with several of the overall functions of components which enable a variety of versions to fit with the differentiator of parts. The implementation of concept modularity in OPS systems in product design focuses on the decomposition of the functionality so that the interaction and interdependence is minimised. The idea of interaction between design components or modules using decomposition can reduce the design development time and also lower the complexity of the design range as show in Figure 4-13. Modularity design focuses on the minimum interaction between the components and enables the designer to connect the components with different interfaces to form a unique independent product. With the application of modularity, it is easy to determine the product function of the OPS and at the same time the process involves design problems, product design, and production systems. The decomposition of an OPS product is a result of independently making up the product. There is a research interest in office furniture in the OPS and the decomposition into systems. The OPS system is then decomposed into systems/sub-systems and this is shown in Figures 4-13.

4.11.3 Modularity and Re-configurability Principle Incorporated in the Design of Pedestal

Product modularity and re-configurability play a very important role in modern furniture flat pack design as shown in Figure 4.14. Flat pack design is the term associated with modern furniture design using product modularity principles. These types of product are normally delivered in pieces inside a pack.

Modular designed flat pack furniture offers the following advantages:

-Customers can easily take the modular flat pack product home themselves, hence reducing the inconvenience involved in transporting a fully assembled and possible heavy product.

-Customers can carry large pieces of furniture’s through narrow doors whilst in a flat pack state

-Very easy to assemble for most customers.

-For customers moving home they can easily be disassembled and transported.

-Customers can easily choose to mix and match furniture textures, colour etc.

-For retailers modular designed furniture take up less space because they are stacked on shelves and are less expensive to store as they take up less floor space.

- For retailers more products are stacked on the shelves because of the regular shape of the packaging.

- For furniture manufacturing it is cheaper, more profitable and less expensive than permanently jointed furniture's.

-Furniture manufacturers may specialise in manufacturing individual, made to measure, flat pack furniture products. Assembly cost is very low for the manufacturers because assembly is done by the customers.

-For both manufacturers and retailers the cost of transportation is low when compared to assembled products because of the large quantity that can be transported.

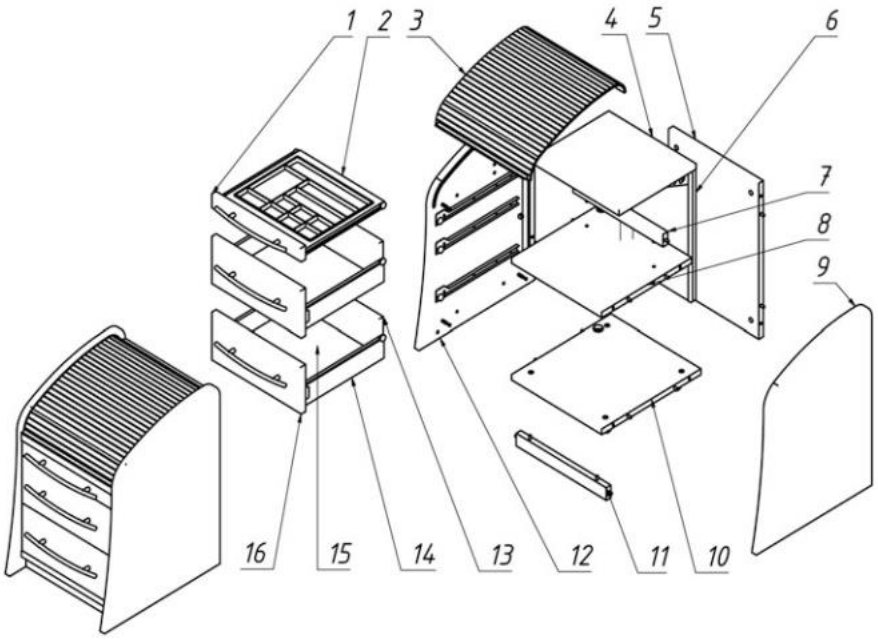


Figure 4-14: Name of elements of pedestal 1-front of the case 2- case 3- blinds 4- top 5- rear wall 6- partition wall 7- skirt 8- horizontal partition 9-right side wall 10-bottom 11-lower skirt 12- left side wall 13- rear wall of the drawer 14- side wall of the drawer 15- bottom of the drawer 16- front of the drawer

4.11.4 Modular Components of the Designed Drawer

The pedestal constitute of different modules of components parts assembled together. Each modular component is made of different plywood layers, which are constructed by manufactured by, handcraft method using hand and power tools. For mass production, the process involved with CNC machine tool is used. The reason for using plywood because is easy to screw or even too nailed. The thickness layer of veneers will affect the physical look and that plywood become stronger, strength and stability. The modular architecture of the pedestal consists of the following as shown in the hierarchy decomposition tree in Figure 4-15:

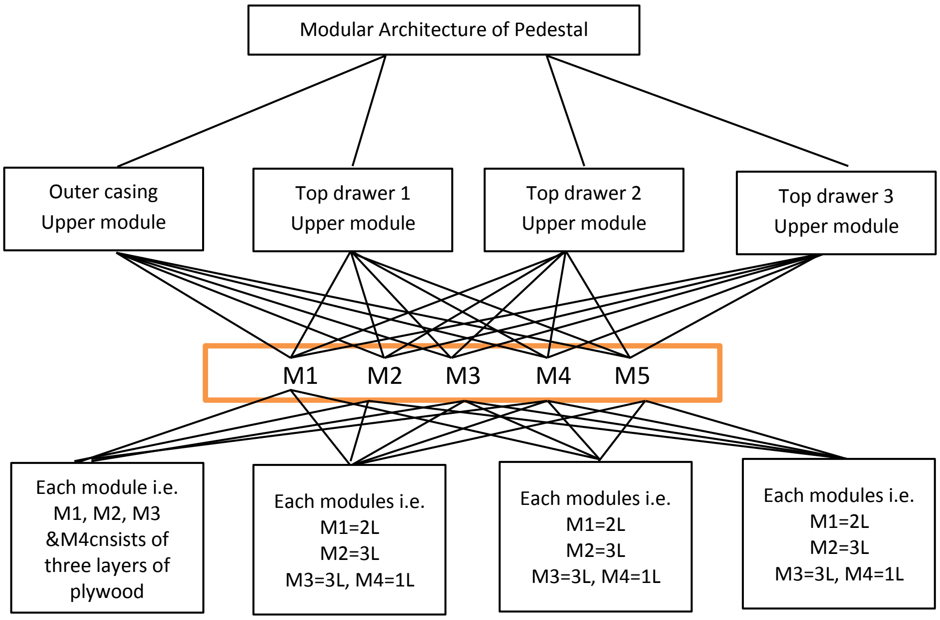


Figure 4-15: The decomposition process of the modular architecture of the pedestal

Where M1 to M5=Module 1to 5 and 1L to 3L= Number of layers from 1to 3

The modular design allows the designer to concentrate on the demand of the sustainability of the office furniture in term of the resources, disassembly, recyclability, and reductions use at the conceptual design stage.

4.12 Summary

This chapter presents the characteristics of sustainable furniture where sustainability is essential for human activity; making sustainable design is a crucial objective for human development. There is no doubt of the seriousness environmental problems, but the most important issues are to find the way that these problems can be solved. Design for sustainability involves the incorporation of sustainability objectives in design activities.

Sustainable design is one of the most useful instruments available for the designer to tackle environmental problems. Sustainable design has the potential to improve efficiencies, product quality and market opportunities and at the same time enhance environmental performance. Probably the most significant problems that production companies should think about and turn into aggressive strategies on the market are sustaining good quality. The goal for any sustainable manufacturing is to meet the customer’s requirement, achieve low costs and influence the environment types. Sustainable design is about making ethical design decisions throughout the life cycle of a product that must be economical and beautiful. The principle of sustainable design also gives insight, inspiration and guidance for a redesign of our way of life.

5 Development of a Sustainable Design Index (SDI)

5.1 Introduction

This chapter address the third research objective by developing the tool for supporting sustainable design and decision making for design stage. The idea of the Sustainable Design Index (SDI) is to consider the aspects related to sustainability, namely the environment, economy, and social issues, in this case of office furniture for an open plan system (OPS). The SDI developed in this study aim to offer new tools that are embedded in a CAD-based environment, and a method for improving the way to predict the sustainable design of the furniture product, this will, help designers or an expert to take a decision in the early design stages to fulfil the customer's requirements.

5.2 Sustainable Design Index (SDI) Development Process

The purpose of developing a new SDI is to highlight the importance of the concept stage to sustainability for office furniture, namely that in an open plan system (OPS). The proposed SDI model incorporates elements from three design processes; the design proposed by Suh (1990) that proposed by Pahl & Beitz (2013b), and total design integrated methods for successful product engineering (Pugh 1991a). To integrate the environmental aspects into the product development process, a support tool is needed.

The ability of design products to meet customers' requirements has become critical to success. Due to consumers' demands to have their needs fulfilled by a total product concept, companies are forced to offer a broader variety of products, whereas the differentiation of a product goes beyond technical performance or superficial design features. Sustainable design addresses not only the functional and aesthetic requirements of products, but more importantly, aims to meet the needs of the present, without compromising the ability of future generations to meet their needs (Subic *et al.*, 2010). The industrial designer is the creator of elegance, style and functionality, but there is also, an urgent need to make industrial products, more sustainable, as this benefits both, people and the planet. The goal of sustainable design is to make all products, one hundred percent cyclic, safe and renewable. Some of the important decisions with respect to the environmental properties of a new product are taken during the product development stage, as shown in Figure 5-1.

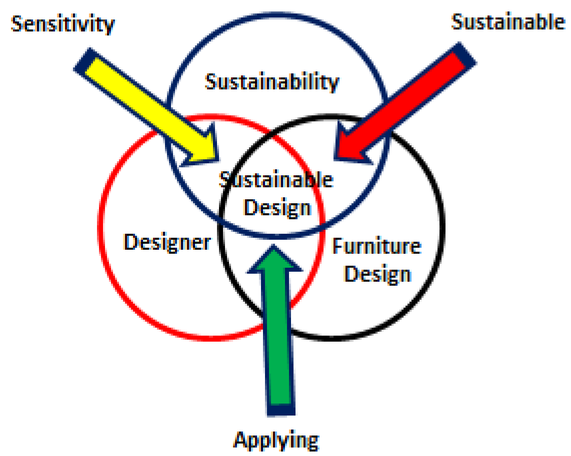


Figure 5-1: Three major areas connecting to sustainable design

The aim of this study is to identify the attitude of furniture designers towards sustainability, its principle in design, and the challenge for the designer. The combination of sustainability, the designer, and furniture design leads to sustainable design, as shown in Figure 5-1. Sustainable design is one that exploits, the triple bottoms –line; it is good for the environment, profitable for the company, and help to improve society. There is a link between the designer, sustainability, and furniture design, which is the center of the figure 5-1 where all three circles overlap.

5.3 Sustainable Design and Furniture

A sustainable product design aims, to develop a more environmentally conscious product and process. Sustainable design approaches consider the environmental impact of products during their whole lifecycle (Chen *et al.*, 2011). The challenge of sustainable design is to consider environmental factors in the early design stage. Consequently, sustainable design seeks to interpret socio-environmental concerns into products, and this is becoming one of the most important requirements for companies' alongside the aim to reduce the environmental impacts (Fargnoli, 2003).

One of the essential parts of assessment for sustainability is the use of proper tools. For this study the discussion an importance of the involvement of designers and engineers, and their role in shaping the future to increase sustainability. Indeed, a designer is able to educate the society about the unsustainable process around them. This thinking is not new in this particular area. When developing a concept and a framework for sustainable design, designers are responding to current trends concerned with social and environmental issues. A designer may to propose a new product development integrated with the mass-produced items. Properly planned, the benefits to both parties include reducing the impact on the environment, increasing profitability for the company, and improving society. It is difficult to measure social sustainability and environmental sustainability because they are intangible, compare with economic benefits which are easy to measure. To resolve this, many methodologies and tools such as cradle-to-cradle, cradle-to-grave, and life cycle analysis have attempted to maximise the benefit and minimise the environmental impact of products. For this study the value added that an effective way of fulfilling the end users' needs is integration between the product design process and computer-aided design (CAD).

Therefore indicators are used for comparison and assessment to evaluate the development activities on a scale in order to identify if they are environmentally sound and sustainable (Harger & Meyer 1996). An indicator of sustainability is to be used as a "checklist" for the identification of progress in environmental activities. According to (Rosen & Kishawy 2012) it is important to use sustainability indicators for measuring and assessing the sustainability. Furthermore, the three aspects environmental, economic and social, link together between design and manufacturing to become an important aspect of decision making. They have four common characteristics which are a) relevant information b) understandability by experts and non-experts c) reliable trusted information and d) easily accessible data.

The definition and, characteristics of the indicator of the sustainability depend on the expectations and needs of each country, and different types of indicators are therefore needed. The number of certain indicators is assigned based on the degree of importance of the social need of the country, how economically developed it is, and its ecological resources. On the other hand, the influence of each given indicator is described from observation, and it is necessary to narrow them down to obtain the final value in a simple way. Each of the indicators is a variable relative value; to have a better value the weight coefficient is calculated using the special unique mathematical formulae (Golusin & Ivanovic, 2009).

5.3.1 Proposed Sustainability Evaluation

Sustainable design is a universal concern and because of that, it becomes a significant reference in numerous industries, especially furniture products. In order to overcome the difficulties in the furniture industry with determining the sustainable design of their products, the concept of the SDI was proposed in this study. The SDI construction is combined with the designer’s daily activities and the design process; in this research the OPS is used for the subject matter. This research presents several design tools and strategies which are integrated to support the development of SDI as a solution. It is important to develop a model or method for formulating the SDI for industry to work with particularly the product’s sustainability performance which is strongly linked to the consumer’s satisfaction. In order to develop a robust SDI representation, an innovative approach needs to be structured and systematic. Sustainable furniture design is proposed, based mainly on modular product architecture, re-configurability, using a design structure matrix (DSM) and axiomatic design (AD). SDI implementation enhances the designer’s work by seamlessly integrating SDI algorithms within the CAD design environment and the designers design operations.

5.3.2 The Conceptual Framework of the Sustainable Design Index

The process of furniture design means the whole technology process, from planning to mass production. Furniture design, particularly, depends on trends and timelines, to fulfil the changing customer demand; it is therefore necessary to develop a new type of furniture with improved functionality (Petutschnigg & Ebner 2007). For this reason, design must incorporate multidisciplinary of knowledge. To meet consumer demands and the requirements for this research, an entirely new solution has been projected in Figure 5-2 for OPS.

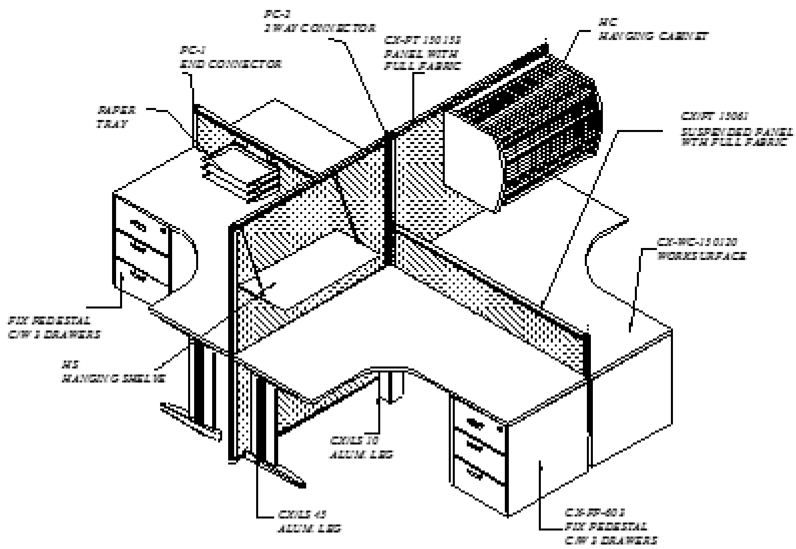


Figure 5-2: The cluster of four Open Plan Systems (OPS)

To run-through this concept, an appropriate furniture design OPS have been selected and the candidate product has been chosen as the cluster of four, designed by the author as shown in Figure 5-3. In Figure 5-4, an example is given of the components of OPS; 23% of the material is steel, fabric is 1%, particleboard is 68%, and aluminium is 8%. All die-cast aluminium components are made from 100 percent recycled material and is 100 percent recyclable. Steel material is 100 percent recovered. Steel does not lose any of its inherent physical properties during the recycling process and has drastically reduced energy and material requirements. Most metals have a powder-coated paint finish that emits negligible volatile organic compounds (VOCs). Since wood is a renewable, it is a natural raw material.

Wood products cannot be melted down, but can be used thermally to generate energy. The emission of formaldehyde has always been a concern to chipboard users. The supplier's chipboard has been produced to E1 standards by the highest British Standard stipulations. The packaging materials consist of corrugated cardboard and polyethylene stretch wrap. These materials are part of a closed-loop recycling system, meaning they are repeatedly recycled. Requirements for, packaging material are reduced due to palletising.

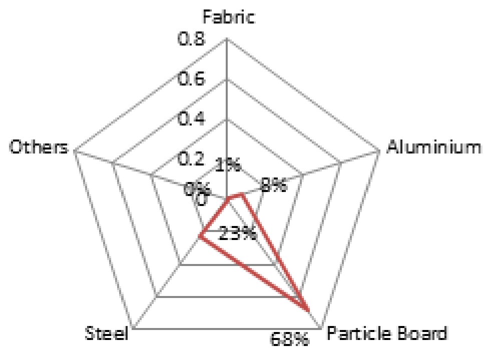


Figure 5-3: Material use for OPS

Although there are furniture companies that produce green products, and there are even a few companies that have started to build sustainability into the creative process of producing a new product, innovative sustainability is unusual and it is still an ongoing process. The value added to product through sustainability has already been recognised, but to change these designer paradigms to sustainable design is still not their priority in the design process (Chaves, 2008). Data has been obtained from the interviewing an expert designer in a furniture design company with more than 10-years' experience. Also data from the author's own working experience, as a designer in the furniture industry for over 10 years are considered.

5.4 Developing a Sustainability Index for Project Appraisal

5.5

Developing the sustainability index for this particular study consists of 4 steps, as described in detail below:

5.5.1 STEP 1. Potentials of Product Modularity and Re-configurability

Modularity is considered to be an effective enlargement strategy for handling product variety and complexity. The first step in designing sustainable modules is product modularisation. The development of modular re-configurability tools has the potential to reduce development time and cost by multi-criteria modularisation and also prove to change the productivity of resources (Seliger & Zettl 2008; Wang *et al*., 2009). Even the same companies manufacturing the same type of product could have a different modularisation product structure, depending on their product strategies. The approaches of modular analysis at the early stage not only assist the product development process, but also provide the reference for improvement redesign and product involvement. Evaluation of product modularisation needs to be established because it significantly influences the benefits to a company (Cheng *et al.*, 2012).

In innovation of modular design and re-configurability, the designer needs more time to focus on design alterations rather than to make a new invention. Modular design is the best way to reshape and create change. It can contribute to using manufacturing or assembly resources efficiently, and it can also help to reach the goal of rapid production with low costs (Huang & Kusiak 1998).

When comparing reconfiguration with configuration, the main difference lies in an existing product that mainly influences the process of reconfiguration. Besides minimising the number of changes needed, request by customer re-configurability can be guided by other optimisation functions i.e. changing the parameter may be cheaper than changing an integral component (Felfernig *et a*l., 2001). Product configuration mostly depends on customer requirements for the modular product model (Yuan & Wang 2013). As firms strive to rationalise their product lines and to provide an increasing diversity of products at a lower cost, the concept of modularity has gained attention (Gershenson *et al.,* 2003). When the decision has been made the modularity needs to be measured (Gershenson *et al*., 2004).

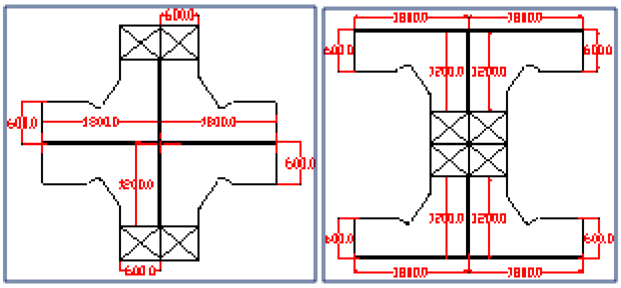


Figure 5-4: The configuration of an OPS system

Most of the design for OPS is simple, modular, and sleek, being efficient in terms of space and cost. By using the connection pole or insert nut to connect frame-to-frame or other connections, the installation process becomes easier and faster. The OPS can be reconfigured in various ways based on the office layout required by the customer. For the most important parts, the designer needs to consider the different levels of management and staff working on at every particular floor plan. The OPS can be configured as a cluster of two, a cluster of four as shown in Figure 5-7. During the installation work on the site, the frames are attached in many ways, such as frame-to-frame, two-way, three-way, or four-way connection, according to the configuration of the office layout. In these designs the configurations are different, but they use the same type of connection (suspended panel stand), and also the same fixed pedestal as a stand. The configuration is dependent on the customer's budget and also the space to be occupied by the workstation in proportion to the working area, and the suitability with the nature of the work being carried out in the space.

However, as a design process proceeds, it is necessary to find out various parts through re-configurability (Ullman 2009). In order to analyses the sustainability of furniture products for OPS, a method or tool will be required. To find the solution, various parameters and criteria needed to be applied and measured. For this reason, the designer and engineering system or process should start with information being delivered to the customer about the needs, requirements and constraints of the technical process or product being designed. The AD method will therefore apply to the process of obtaining the appropriate information from the customer request.

The following equations (1, 2 and 3) represent the mathematical description of the factory set. MR represents a total factor set for modularity and re-configurability, which can be defined as follows:

$$MR = \left(MR_{ij}\right)m \otimes n \begin{bmatrix} MR_{11} & MR_{12} & \cdots & MR_{n} \\ MR_{21} & MR_{22} & \cdots & MR_{n} \\ \vdots & \vdots & \ddots & \vdots \\ MR_{m1} & MR_{m2} & \cdots & MR_{mn} \end{bmatrix} \tag{1}$$

In Equation 1, MRij (ij= 1,2,…n) denotes any one of the factors evaluate in Figure 7-4.

$$w = \left(w_{j}\right) \text{ 1xn} = \begin{bmatrix} w_{1} & w_{2} & w_{3} & \dots & w_{n} \end{bmatrix} \text{then } w^{T} \begin{bmatrix} w_{1} \\ w_{2} \\ w_{3} \\ \vdots \\ w_{n} \end{bmatrix} \tag{2}$$

In Equation (2) wj (j= 1,2,…n) denotes the weight of the factors and thus the relative importance score, and 1,2,3,…n. Score, which respectively means equal importance, weak importance, more importance and distinct importance. The requirement weighting matrix is marked as M & R as follows:

$$M \ \& \ R = R \otimes W^{T} = \begin{bmatrix} R_{11} & R_{12} & R_{13} & \cdots & R_{n} \\ R_{21} & R_{22} & R_{23} & \cdots & R_{n} \\ R_{31} & R_{32} & R_{33} & \cdots & R_{n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ R_{m} & R_{m} & R_{m} & \cdots & R_{mn} \end{bmatrix} \otimes \begin{bmatrix} w_{1} \\ w_{2} \\ w_{3} \\ \vdots \\ w_{n} \end{bmatrix} =$$

$$= \begin{bmatrix} R_{11} \otimes W_{11} \oplus & R_{12} \otimes W_{12} \oplus & R_{13} \otimes W_{13} \oplus & \cdots & R_{n} \otimes W_{n} \\ R_{21} \otimes W_{21} \oplus & R_{22} \otimes W_{22} \oplus & R_{23} \otimes W_{23} \oplus & \cdots & R_{n} \otimes W_{n} \\ R_{31} \otimes W_{31} \oplus & R_{32} \otimes W_{32} \oplus & R_{33} \otimes W_{33} & \vdots & R_{n} \otimes W_{n} \\ \vdots & \vdots & \vdots & \ddots & \\ R_{m} \otimes W_{m} \oplus & R_{m} \otimes W_{m} \oplus & R_{m} \otimes W_{m} \oplus & \cdots & R_{mn} \otimes W_{mn} \end{bmatrix} = \begin{bmatrix} MR_{1} \\ MR_{2} \\ MR_{3} \\ \vdots \\ MR_{mn} \end{bmatrix} \tag{3}$$

In order to express the relative importance of the required elements and to easily calculated, this is simplified as Equation (3).

5.5.2 STEP 2. Axiomatic Design Approach

To provide a more efficient product design process and appropriate tools based on an AD principle, this was developed for the design of OPS. The AD method was explained in detail in Suh (1990). It addresses the above mentioned engineering design issues, and it is known as one of the most important approaches to decision-making; at the same time, it is also one of the hardest tools to master. The AD provides a framework for describing design objectives at all levels of detail. The AD helps design creativity by demanding a clear formulation of the design purpose through the establishment of functional requirements (FRs) and design parameters (DPs). The AD methods originate from the understanding that design is the interplay between "what we want to achieve" and "how we want to achieve it" (Guenov & Barker 2005)

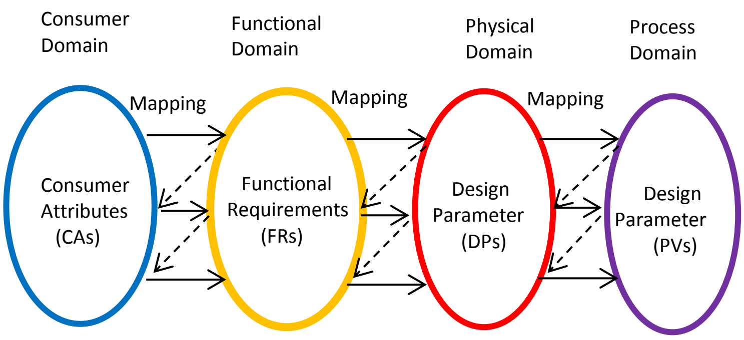


Figure 5-5: Fundamental principle of AD

The AD framework consists of four separate domains: the customer domain, the functional domains, the physical domain, and the process domain. The customer domain is a set of customer attributes (CAs). The functional domain is a set of functional requirement (FRs), defined as the minimum set of independent requirements that the design must satisfy. The physical domain and the process domain are respectively a set of

DPs and a set of process variables (PVs). The domain structure is presented schematically in Figures 5-8 (Suh, 1990).

The best method to show clearly the relationship between the FR and the DP variables is the design matrix (DM) which is a design structure matrix (DSM). Functional requirements have a hierarchical structure and the design variables that satisfy it also construct a similar hierarchical structure, therefore FR has only 1 DP. This means that if one design variable is altered by a FR change, it will cause changes to other FR. At each level of design hierarchy the relations between FRs and DPs can be represented in an equation of the form:

$$FR = [A]DP \tag{1}$$

Where each element of the design matrix [A] can be express as $A_{ij} = \partial FR_i / \partial DP_j (i = 1, \ldots, m \; and \; j = 1, \ldots, n)$. The value of an element A_{ij} can be expressed as 0 (i.e. the functional requirement does not depend on the particular design parameter), or otherwise X. Depending on the type of resulting design matrix [A], three types of design exist: uncoupled, decoupled, and a couple.

The ability to create products that meet customer's requirements has become critical to success. The key element to developing such a product is identifying the FRs and using a knowledge based scientific approach to provide designers of both new products and redesigns of existing product with an appropriate alternative that will fit customers' demands (Janthong *et al*., 2010). While the Design Structure Matrix (DSM) provides a powerful technique for the analysis of design interactions within a complex development program, it seems to be more efficient with AD (Dong & Whitney, 2001). The best method to clearly show the relation between the FRs and DPs can be expressed using the design matrix (Kang, 2004).

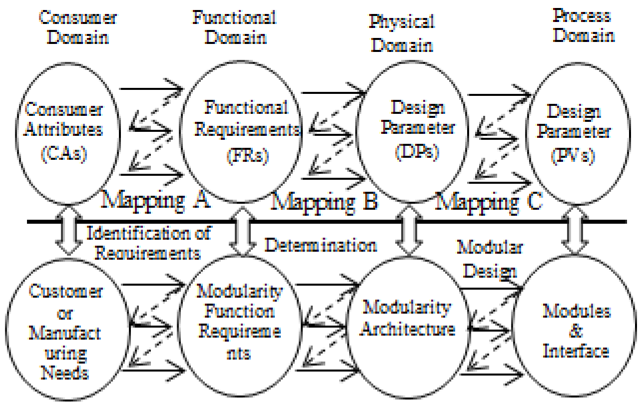


Figure 5-6: Design mapping and domains

Therefore the mapping from the purpose requirement of the design parameter for the Axiomatic Design is expressed equally:

$$\begin{aligned}&[FR_S] = B[DP_S] = [b_{ji}][DP_S] \\ &\text{const } [DP_S] = [C][PV_S]\end{aligned} \tag{4}$$

Where

$$\begin{aligned}&[FRs] \ \text{Functional requirements} \\ &[DPs] \ \text{Design Parameters} \\ &[PVs] \ \text{Process Variable determi by modular} \\ &[B] \quad \text{Mapping for FRs to DPs} \\ &[C] \quad \text{Transformation from DPs to PVs}\end{aligned}$$

Thus, the following matrix [A] of pair-wise comparison is created:

$$A = \begin{bmatrix} a_{ij} & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \tag{5}$$

And a_{ij} values are based on:

If i=j the decision parameter is compared to itself, and thus aij=1

If i≠j, and the decision parameter requires more knowledge, then

a_{ij} =1,2,3,…,9. The

Reciprocal (1-1,2-1,3-1,4-1,…9-1) is placed on the inverse comparison.

5.5.3 STEP 3. Design Structure Matrix (DSM)

The DSM has become increasingly popular as a means of planning, product development, project planning and management, system engineering, and organisational development (Browning, 2001). Combining the DSM with other tools and several design methods was identified as a potential technology deployment approach. The impact of the product architecture on a sustainable solution, during the early conceptual phase, can be evaluated using the DSM. The DSM precedence matrix represents a structure of the system, i.e., what affects what. Semantics are the “why” and “how” of these effects. The variable will be determined and marked with circle or x’s. A mark in row *i*, column j means *i* has a predecessor *j*. For example to determine variable 4, variables 1,2,3,4,3,7, and 12 are required, and they must be known or estimated (Steward, 1981).

Design becomes the instrument linking FR (which is part of the functional domain) to the physical solution (characterised by DP and belonging to the physical domain). The process of product design begins, therefore, with defining the FR that satisfy a given set of needs and translating them into DP (Cheng *et al.*, 2012). Another researcher also studied the relationship between DSM and AD, which is the output of variable concept use, using a solving system of linear equations (Dong & Whitney 2001).

5.5.4 STEP 4. Product Sustainable Design Formulation

In this study, criteria for generating modular furniture have been proposed. The objective is to improve the environmental behaviour of the product with emphasis on the product function. The following criteria are taken into consideration for our modular design approach and are briefly stated below. Modularity is considered to be an effective enlargement strategy for handling product variety (Pahl & Beitz 2013b). Open plan systems consider product reconfiguration through decomposition of product components into a new module, which should not destroy the original product function. Product function is related to the customers’ needs. Therefore, a proper modular design and exact configuration are able to reduce the production cost and assemble components effectively, with a tremendous change in design, in order to meet the customers' needs (Tseng *et al.*, 2008).

It involves the geometric positioning and connection of components. The selections of joints depends on the products behind joined, and the importance of the joint to a better assembly (Ashby & Johnson, 2013).

5.5.5 The Derivation of Project Appraisal Criteria

There are various types of OPS models and systems; they are in different types of furniture, heights, functions and ranges. Most products can be customised according to the needs of the office environment and the needs of the user. Modular furniture is standardised for all office space. Designers need to specify standard product lines and components for a better presentation, and there needs to be good quality throughout the organisation. As the workstation is a cluster of four, taking account of a medium class office range, it is important to point out that not every component is necessarily included in the modular design, because the common parts, such as screws or nuts, have a small role in design results, as shown in Table 5-1. For the modular and re-configurability function of the design aspect, some requirements and components play an important role in delivering, real satisfactions to the customer.

Table 5-1: Component of OPS

No	Component
1	Work surface
2	Fix pedestal w/drawer
3	Aluminium leg 1
4	Aluminium leg 2
5	Suspended panel w/fabric
6	Full high panel w/fabric
7	2 way connector
8	End connector
9	Hanging shelf
10	Hanging cabinet
11	Paper tray
12	Cantilever Bracket
13	Closet

Based on AD (Suh, 2001), each DP is the main solution to the FR with the same ID; an example is shown in Table 5-2. Once the part and components, especially for modular and re-configurability, has been satisfied, generating the axiomatic design based on the information required by the customer can be occur example as Table 5-3 which is the corresponding correlation matrix produced.

Table 5-2: Components considered for modular OPS

LEVEL 3	Comfort		DP1.2.1	DP1.2.2	DP1.2.3
			High energy efficiency	High energy efficiency	High energy efficiency
	FR1.2.1	To guarantee comfort	x	0	0
	FR1.2.2	To guarantee durability of the product	0	x	0
	FR1.2.3	To guarantee structure stability	0	0	x

Table 5-3: Corresponding correlation matrix example

		Description							
		Task1	Task 2	Task 3	Task 4	Task 5	Task 6	Task7	Task8
Description	Task1		0	X	0	0	0	0	0
	Task 2	0		0	0	X	0	0	0
	Task 3	0	0		0	0	X	0	0
	Task 4	X	0	0		0	0	0	0
	Task 5	0	0	0	0		0	0	X
	Task 6	0	0	X	0	0		0	0
	Task 7	0	0	0	0	0	0		0
	Task 8	X	0	0	0	0	X	0	

However, when developing the initial concepts, the teams need a basic set of criteria against which to assess OPS and decide that the requirements at the level of the tree were sufficient for this purpose. At the level of modular drivers, the two levels of requirements of a functional factor and sustainable design factor are subdivided as shown in Figure 5-7, in order to determine the weight of each component derived from the weight given. The design team is working on office furniture, and studying the use of the product helps them to develop a weighted requirement tree. Requirement trees can be a useful tool at all stages of the design process. The method makes people think about what it is that they are trying to achieve, and to develop these requirements to a point where they can be formularised.

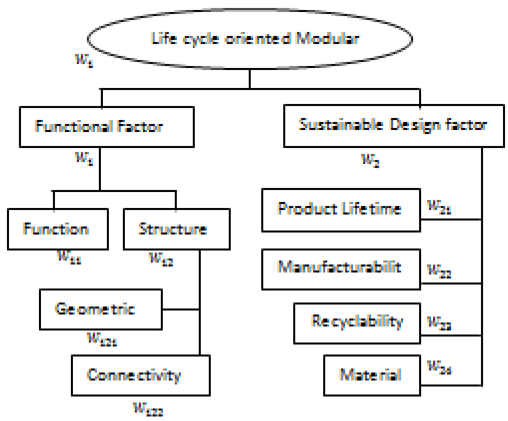


Figure 5-7: Weight hierarchy of modular drivers example

5.5.6 Determination Weight Factor

Based on the DSM technique, a correlation matrix of all the components-function-based DSM can be expressed as:

$$CM_{func} = \begin{bmatrix} 1 & R_{21} & R_{1(n-1)} & \cdots & R_{1n} & \cdots \\ R_{21} & 1 & R_{2(n-1)} & \cdots & R_{2n} & \cdots \\ \vdots & \vdots & \vdots & R_{(n-1)(n-1)} & \vdots & \vdots \\ R_{n1} & R_{n2} & R_{n3} & \cdots & 1 & \cdots \end{bmatrix} \quad (2)$$

To integrate the seven matrices into one matrix, the weight of the modular driver should be identified based on the requirements of the product and the customers. The weight hierarchy is determined according to designer preferences. Figure 5-9 illustrates the relations of the weight of the modular drivers based on the hierarchy of the life-cycle oriented modular. The weight value of the modular driver is constrained by (3):

$$W = \begin{cases} 1 = w_1 + w_2 \\ w_1 = w_1 + w_{12} \\ w_{12} = w_{121} + w_{122} \\ w_2 = w_{21} + w_{22} + w_{23} = w_{24} \\ w_{12} = w_{121} + w_{122} \end{cases} \quad (3)$$

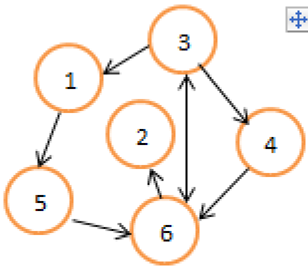
Where ω_1 is the weight of functional factors, and ω_2 is a sustainable weight factor. This is particularly important as the weight criteria will reflect the level of impact of a development on individuals. Therefore, the exercise may be regarded as approximations of weight, which provide a set of weight criteria and are a representation of the relative importance of the criteria. Weight (w) can be expressed as:

$$\omega = [\omega_1, \quad \omega_2. \quad \omega_3, \quad \omega_n], \omega_i > 0, \sum_{i=1}^{n} \omega_i = 1 \quad (4)$$

Where *n* denotes the number of required items for product design and the weight coefficient ω_i depends on the importance of the item in product design, and the weight assigned to the criteria *i*. From a decision theory point of view, criterion weight must reflect the trade-offs among marginal shifts in the criterion scores. It is just the same role as price in the economic evaluation methods. It serves to maximise wealth and utility while minimising resource use and impact. Following the same procedure outline, the bigger C_{ij} is, the stronger the interactive impact of the two components is, and vice versa. This matrix will be applied to modular optimisation. In order to consider the importance of different evaluation factors, a weight vector of evaluation factor is used as shown below:

$$\begin{aligned} C_{ij} &= \omega_{11} x[DSM]_{fun,ij} + \omega_{12} x[DSM]_{geom,ij} \\ &+ \omega_{122} x[DSM]_{conn.ij} + (\omega_{21} x[DSM]_{p.life,ij} \\ &+ \omega_{22} x[DSM]_{manu,i_j} + \omega_{23} x[DSM]_{rec,ij} \\ &+ \omega_{24} x[DSM]_{mate_{ij}} \end{aligned} \tag{5}$$

A sample correlation matrix between components of each modular DSM is shown in Figure 5-8. A spaghetti graph of the components is shown in Figure 5-10 (a). For example the product has six components, and the interrelationships between the components, as a basic DSM, are shown in Figure 5-10 (b). Each metric indicates the correlations between the components (Kusiak 2002).



	C_1	C_2	C_3	C_4	C_5	C_6
C_1		0	0.4	0	0	0
C_2	0		0	0	0	0.8
C_3	0	0		0	0	0.4
C_4	0	0	0.4		0	0
C_5	0	0.2	0	0		0
C_6	0	0	0.2	0.6	0.8	

(a) (b)

Figure 5-8: A simple DSM (a) Spaghetti (b) Basic DSM

Where R(n-1)(n-1) denotes the relation intensity of the component i and j to the realisation of the product function and its value is determined from the grade number 0,2,4,6, and 8 according to Table 5-4.

Table 5-4: Standard relationship for two components

Type of	Interaction relationship	Description
No	0	No relation at all
Weak	2	Loose connection and medium relation
Medium strong	4	Medium connection and medium relation
Strong	6	Medium connection and high relation
Very strong	8	Firm connection and high relation

The example results are given in Table 5-5. Next, the inputs (concepts and criteria) are entered into the matrix. Although possibly generated by different individuals, concepts should be presented at the same level of detail for meaningful comparison and unbiased selection. Based on the selection matrix, the team may decide to select the top or more concepts. These concepts may be further developed, prototyped, and tested to elicit SDI product concepts.

Table 5-5: Sustainability Matrix based on End-of life Options

	Reuse	**Recycle**	**Disposal**
Reuse	Strongly desired	Desired	Strongly undesired
Recycle	Desired	Strongly desired	Undesired
Disposal	Strongly Undesired	Undesired	Strongly desired

5.6 Sustainable Design Index (SDI)

The decision is made by the customer to purchase products based on prices, quality, and functionality. Sometimes the decision is made based on the value of the product, and to ensure this, the designer and end user must systematically understand a common language, namely an index (Chen & Chu 2012). In this study the author used semi-structured interviews with designers and experts in furniture products. To overcome this problem, this study will call an expert and carry out a face-to-face interview. This expert has been working for more than 10 years with an office furniture company on OPS. The investigation of the criteria will be done by the expert through an open-ended questionnaire; this will then be applied to the SDI as shown in Table 5-6. There are three important issues regarding product design, namely: environmental, social and economic aspects (Hervani *et al*., 2005; Reay *et al.,* 2011;Gehin *et al.*, 2008).

The total SDI is achieved by computing a weighted average of overall marks from the environmental, social, and economic elements. The influencing element scores are recorded by the designer in each entity of the matrix and the SDI is evaluated in each matrix. For sustainable criteria (SC) as in Table 5-6, the model can be expressed as follows:

$$SCenv = \frac{\sum_{i=1}^{n}(\omega iSi)}{\sum_{i=1}^{n}\omega i} \tag{6}$$

$$SCenv = \frac{\sum_{i=1}^{n}(\omega iSi)}{\sum_{i=1}^{n}\omega i} \tag{7}$$

$$SCsoc = \frac{\sum_{i=1}^{n}(\omega_i S_i)}{\sum_{i=1}^{n}\omega_i} \tag{8}$$

Where the symbol SCenv denotes the sustainability criteria, S_i is the impact factor based on a ranking 0-10 for the environmental elements of material, and ω_i is the weight of every factor of the material stage. The value of the social (SCsoc) and economic (SCeco) elements of the materials can be calculated in a similar procedure. The use of weight and ranking methods is also showing how well a design achieved each customer attribute in the competitive analysis. The rule is the higher number assigned the stronger relationship between attribute. The parameter in each sustainable criterion can be elaborate as; for sustainable criteria environment factor (SCenv) the number of parameter n=10 for sustainable criteria economic factor (SCeco) the number of parameter m=11 and the number of parameter for sustainable criteria social factor (SCsoc) the number of parameter k=10

The methods for SDI are developed in this study, which looks at the areas relevant to the designer's work, and the effectiveness of sustainable design for an office furniture OPS through a data analysis within the process of final calculation. The data collection enquiry is aimed at designers whose expertise is in furniture OPSs.

5.6.1 Computing the Sustainable Design Index and its Implementation

The three criteria (environmental, social and economic) have been collected and result has been calculated (see Table 5-6). The three criteria were combined with the SDI. The weights of the three criteria were derived from the pairwise evaluation matrix as assessed by the design team member. It is calculated for each option by multiplying each value by the weight, followed by summing the weight scores for all the criteria using the weight summation method. The best design option has the highest score in the sustainability design index. The higher the sustainability index, the better the option. Once the criteria are standardised, they can be incorporated into a decision-making model. The SDI model can be expressed as follows:

$$SDI = \frac{1}{3}\sum_{q=1}^{3} F_q W_q \tag{9}$$

Then

$$SDI = \sum_{i=1}^{n} \frac{F_{eco} * W_i + F_{env} * W_i + F_{soc} * W_i}{3} \tag{10}$$

Where the symbol SDI denotes Sustainable design index and F*env* is an environmental factor, Fsoc is social factor, and F*eco* is an economic factor. Each of these factors will be multiplied by the weight. The total of the score from Table 5-7, show that design b has the higher score for means design, therefore design b is the better option for the sustainable design index. The values of the SDI for each design option vary between 0 (most unsustainable) and 10 (most sustainable).

The umbrella of sustainability assessment tools consists of indicators and indices. Indicators must be simple to measure, and are most often quantitative, representatives of environmental, social and economic factors. Indicators should be simple, quantifiable, and they should allow the trend to be determined. The tool is continuously measured and calculated (Siche *et al*., 2008; Ness *et al*., 2007).

Table 5-6: Components of Sustainability criteria

	Life cycle oriented sustainable design				
Sustainability Criteria	Environment	Beginning of life (BOL)	Middle of life (MOL)	End-of life (EOL)	
		Renewable resources	Technology	Reuse	
		Non-renewable (durable)	Process	Recycle	
		Non-renewable (non-durable)	Energy Used	Re-manufacturing	
				Redesign	
				Disposal	
	Economic	Raw material cost	Production Cost	Reuse Cost	
		Procurement	Energy Cost	Recycle Cost	
			Packaging Cost	Re-manufacturing Cost	
			Transportation Cost	Redesign Cost	
	Society	Detail design	Worker Health	Recycle	
		Safety	Safety	Re-manufacturing	
		Conceptual design		Redesign	
		Part manufacturing		Replacement	

The purpose of this SDI is to provide the indicator for an object selection of the best modular architecture solution in the design stage toward sustainability. In many company the modularity and reconfigurability is considered a fundamental design issues in many product epically in furniture system. The consideration to face the unexpected changes in furniture reconfiguration the concept involve the “Life cycle oriented sustainable design” analysis in which it possible to add or consider modular architecture principle. The concept is an evolution of the beginning of life (BOL) middle of life (MOL) and end of life (EOL) are the involvement of a product life cycle analysis to determine the best sustainable design for office furniture.

As show in Table 5-6, the used term of (BOL), (MOL), and (EOL) because the successful product is a collective stage the product goes through this three step for product lifecycle in manufacturing. The lifecycle for office furniture goes through from its conception and design through to its final disposal. The beginning of life (BOL) stage covers everything in the development: the initial design, creation, mock-up, testing and early define the product by promoting of a new product. If the office furniture product is successful, the middle of life (MOL) stage is a longer duration than the other stage. The concentrated and action taken by sale or marketing for office furniture industries majority in MOL. The promotion and the active of activity in product lifecycle are mainly in MOL until decided to finish with the decline in sale. Where, end of life (EOL), in the context of manufacturing and product lifecycle, is the final stage of product for office furniture life. The EOL concerns from the end of product until the continuing to address the market needs that the product might lead to develop a new series. The important using this EOL in this sustainability criteria concerns include recycle, reused, recycle, redesign, remanufacturing up to stage disposal the office furniture product and ensuring that the environmental impact will be minimal. For the final stage concerns, to ensuring the best selection toward sustainability the sustainable design index (SDI) a systematic approach can be used automate to integrate data as show in Table 5-7 and will explain more detail in chapter 6.

Table 5-7: The evaluation matrix for the purpose of development

Sustainable Criteria	**Office Furniture (Open Plan System)**					
	Design A		Design B		Design C	
	Score	Weight	Score	Weight	Score	Weight
Environment						
Economic						
Social						
Sustainable design index (SDI)						

5.6.2 CAD- based Implementation

The CAD-based implementation will be elaborate more detail in chapter 6. In order to offer a tool for designers with high quality visualisation integrated with high end technology, SDI using a CAD-based environment was proposed. From these data structures, the SDI can be generated automatically as in Figure 5-9. The novelty of this study using the CAD-based implementation is that it will consider the three sustainability dimensions: environmental, social and economic. SDI uses this interface with CAD-based technology for a number of tasks. Firstly, the user may preview the drawing file associated with the file component document, Secondly, the user is expected to select a part in drawing. A feature is defined as a component surface that has a relationship to other components. This is done by taking a pair of related parts in their assembled configuration. Furthermore, the use of software such as CAD and other software is widely used in the preliminary design phases.

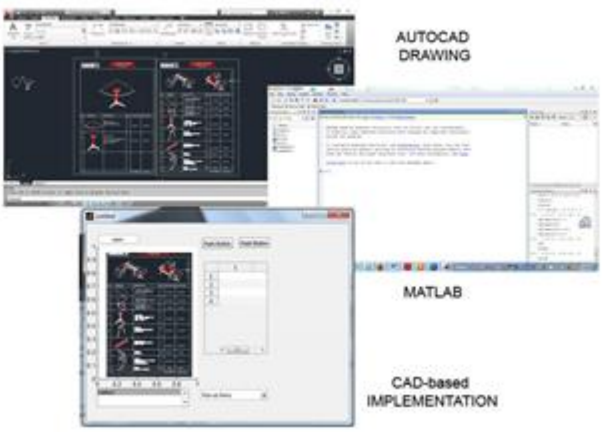


Figure 5-9: CAD-based implementation of SDI-(GUI) in this study

5.7 Summary

This chapter presents the research output to establish useful tools for the designer in the process of sustainable design. The research has developed a method and the type of criteria required for a sustainable design tool to make it more appropriate and useful for the designer. The combination of sustainable design information and sustainable design tools help to educate designers to ensure that the environmental issues are addressed at the early stages of product development, resulting in a more innovative solution. The sustainability design index is observed to help the designer to identify and integrate sustainability into their purpose and processes. Also, it indicates that cost and functionality are important constraints for environmental innovations. To avoid restriction it has been proposed that the innovations should be conducted as early as possible during the design process.

This tool is expected to be used in the early design stage, guiding designers and driving towards a more sustainable design value. The SDI will be used as a solution to identify an area of improvement or refinement during the early design stage in order to fulfil consumer demands for sustainable products.

According to the analysis on sustainable design for office furniture over the whole life-cycle, the factor to achieve the successes on the sustainable design index was identified. This entire factor (environmental, economic and social) is an important aspect relevant to the sustainability of furniture for OPSs. The sustainable design was accepted with the support of the method which can provide useful information about this issue.

6 Development of a CAD-based Sustainable Design Tool and Its Implementation Perspective

6.1 Introduction

In this chapter, addresses the third research objective a new CAD-based sustainable design index tool methodology is presented. This chapter is structured as follows: A) Related work; CAD is the incorporation of computer technology into the design (process). Designers are increasingly learning to adopt CAD at the earliest stage in a design. B) The concept modelling for a CAD Graphic User Interface. C) Designing the GUI in CAD- based systems. D) A case study to test the application of (SDI) office furniture namely open plan systems (OPS). At the end of this section, the summary of this chapter is represented.

6.2 Related Work

In recent years, the natural environment has become a key strategic issue in both business and academic communities. Sustainability has become a major challenge in many countries. As a consequence, engineering systems are becoming increasingly complex, which is well reflected in their design, particularly because of their multi-disciplinary nature, and the complexity and sustainability involved. Therefore, a feasible, sustainable industrial, design approach is essential. There are a number of initiatives working on indicators and frameworks for sustainable development (SD) (Singh *et al.*, 2012). These researchers have developed a new sustainable design index feature which is embedded in the computer aided design (CAD) environment and is applied for early decision making toward sustainability.

Sustainability has been a major issue in product development and product developers take this issue very seriously. The importance of sustainability-oriented design and manufacturing within the engineering community is beginning to be realised. Furthermore, the modern customer is more environmentally conscious, so designers should consider environmental issues in their product development. To do so, an effective computer support tool the CAD environment will help the designer to make a better decision early in the design process (Chandrasegaran *et al*., 2013).

According to Wallace (Wallace & Burgess 1995) if new knowledge is required through engineering design research to help industries become more competitive and generate wealth, then this knowledge must be readily accessible in the form of methods and tools that can be easily understood and applied by practicing engineering designers. Ideally, the idea should be embedded in an interactive computer-based support environment that will enhance both individual and group working. This research aims to identify and understanding the nature of sustainable engineering design and analysis, through development of sustainable design index and the associated analysis and feasible industrial implementation within a computer aided engineering design (CAD) environment. With the widespread identification and publication of environmental problems, there has been increasing pressure on the furniture industry to take a more responsible attitude towards sustainability. To achieve the goal of sustainable design for the furniture industry, three significant dimensions of sustainability economic, social, and environmental must be incorporated in the decision making at the early design stage.

6.3 Integrated Design Process and Sustainability Design Index (SDI)

The designer has the ability to implement sustainability in all stages of redesigning and creating a new design especially in the furniture industry. Designers have not been cut off from these issues, because an increasing number of industrial companies are developing new market orientations towards more sustainable practices (Boughnim *et* *al*., 2004b). However, to be successful in the process of sustainable design, designers are being prioritised and commissioned on the basis of who can consider the environmental, social and economic aspects in the early design process. Sustainable design intervention can be categorized into four groups: redesign, design, product consumption and creating new scenarios for sustainable lifestyle (Manzini & Vezzoli, 2003). As such, this research work focuses on developing a tool to enable designers to measure the sustainability in furniture design and development of OPS.

As one of the most important human necessities of life and consumer goods, furniture reflects various elements of social phenomena, such as politics, economics, art, skill and life (Wallace & Burgess, 1995). Deeper knowledge of the environmental impacts of the materials and processes used in the furniture industry, as well as awareness of the consumer criteria for ecological furniture enables companies to make their products 'green' (Parikka-Alhola 2008). Furniture is defined as one of the major causes of environmental problems. The main distinct objectives of the research are to develop the SDI algorithm and its implementation protocol within a CAD environment, for supporting sustainable design and decision makings through the design process. Many furniture companies have implemented CAD at some level. What is often lacking is a source of information on how their current tools might be improved or what other tools are available to enhance their environmental impact in early decision making in the design process.

The environmental challenge of sustainable design is to design products that minimise environmental impacts during the entire product life cycle. Many organisations have developed tools and approaches to help companies rethink how to design and produce products to improve profits and competitiveness and to reduce environmental impacts at the same time (Clark *et al*., 2009).

The more quickly and accurately these predictions can be made, the shorter will be the product development time and the greater the chances of securing a competitive advantage. Design methods aim to help designers improve their decision making. The design has been described as an interactive decision making process. All decisions depend on forecast and evaluating criteria, and the aim is to make the best possible decision through the process. The design process is very dynamic there is continuous interaction between problem definition and solution generation. For this study the movement from sustainable design is towards a sustainable design index (SDI), the general accepted main phase of the design process as shown in Figure 6-1. To deal with the problem of sustainability issues there are motivations and sustainable criteria according to necessities such as the human development index, the city development index (CDI), the environmental performance index, the environmental vulnerability index, the environmental sustainability index (Bosello *et al*., 2011), For software there is a guide called Sustainability Design-Solid work (Ruggles & Linder 2012), which has been studied through different approaches in order to incorporate sustainability practices (economic, environmental and social), for better understanding of the need and expectations of the stakeholder and also relevance to the company's activities.

The uses of the adequate CAD tool reduce the development cycle of new products and make them more competitive in market terms. For this study the CAD tool offers facilities for the whole development cycle of SDI in the CAD environment. The designer is a main actor in the process in all phases from problem identification to the implantation phases. The role of CAD is in aiding him/her by providing, accurately generated and early modifiable ideas on screen without any prototype, especially during the early stage of the design process, and to perform a complex design analysis in a short time (Pahl & Beitz, 2013b).

The selection of the most suitable CAD system for every IT application must be taken into consideration in drawing the specification. Also the current trends in CAD development must be considered. The system should cover the user's needs (Pugh 1991a).

As a designer, to produce a technical drawing is the major design method by which ideas about the form, shape, dimensions, material, machining methods and finishes are presented. There are many current CAD software packages available for use on a computer. The software is capable of producing any technical drawing; no matter how complicated the drawing is to produce. In this manner, an industrial designer or an engineering designer can potentially generate a greater number of detailed concepts more quickly, which may lead to more innovative design solutions (Ulrich & Eppinger, 2004.).

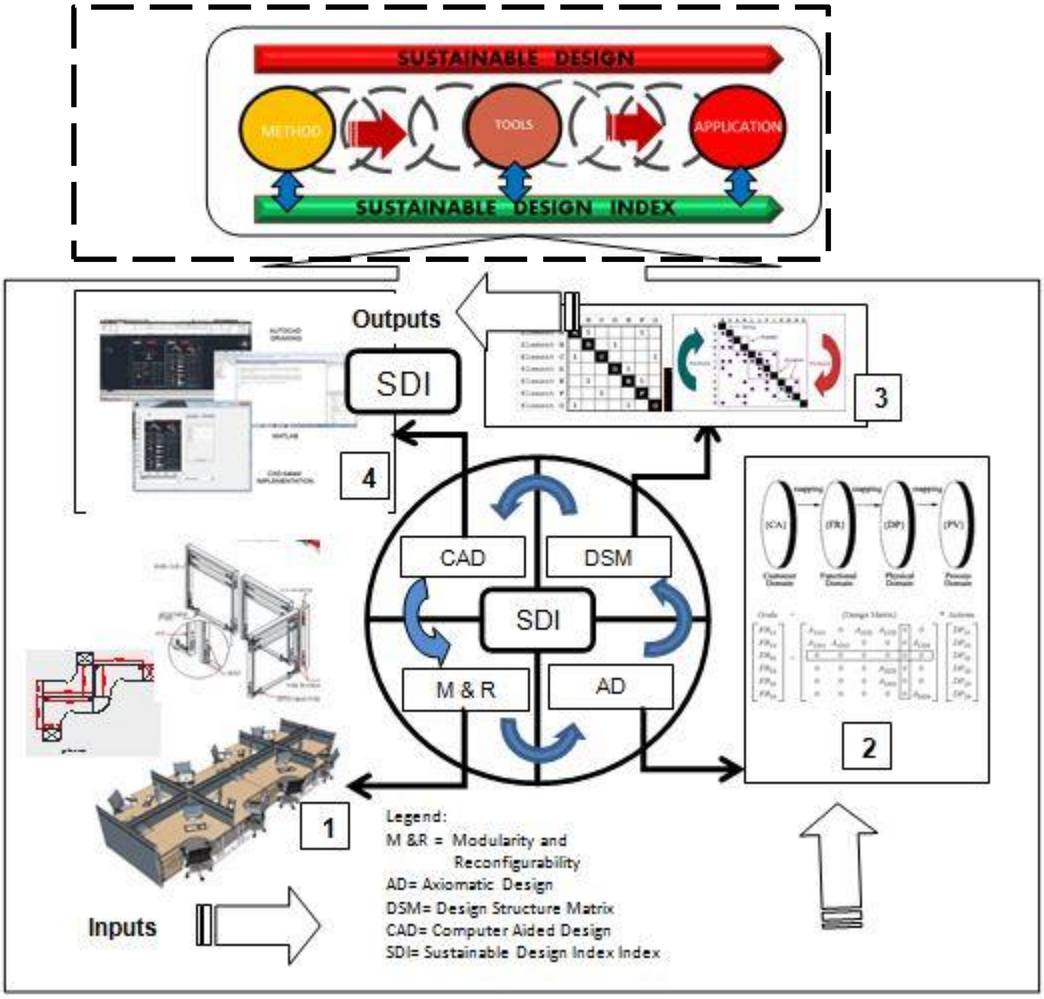


Figure 6-1: The integrated design process and sustainable design index

CAD-programs support the design process in a different way. A traditional CAD-program for drafting allows the designer to document the geometrical properties of the design. A drawing supports both synthesis and analysis, but information captured from the drawing requires human visually-based interpretation. This computer-based model does not require human interpretation for information capture, but may be directly accessed by different application programs (Ekholm, 2001).

The task of the design process is to find solutions to meet the requirements of technical, economic and fashion trends. The design process has a significant impact on customer perceptions and thus the purchasing decision. In this case the processes of decision making for the furniture concept of OPS are transferred into the CAD environment via the sustainable design index (SDI) which is implemented in this study.

6.4 Graphical User Interface

The graphical user interface (GUI) enables the designer make a decision in early design stage by using an engineering model user interface development. A designer's requirements need not become limited by software architecture restrictions once work can be developed from the user interface (Zettlemoyer & St. Amant, 1999). To develop the user interface the following things need to be considered *(Encarnasao et al.*, 1991):

- Easy understanding of the environment's user interface
- Screen layout with an easy organisation, sufficient space for the application, aesthetics, consistency, and stability of the information localisation
- Emphasis on important information
- A graphical user interface to increase the work's acceptance an deficiency, and to reduce the study time
- Consistency of the graphical vocabulary, especially of graphical marks, the icons (symbols) and their logical grouping;
- Using the graphical ability of the hardware and software available. (Encarnasao *et al*.,1991)

A graphic user interface (GUI) is much more user-friendly since people interact better with visually oriented systems, adopting graphics and decisions that allow the user to interact with computer system or devices. The application of the user interface has become popular in various systems and applications, because the user interface makes people happy, satisfied, saves time, and improves efficiency and productivity. To help designers to develop the GUI, a guideline of the characterisation and description, is shown in Table 6-1 below:

Table 6-1: The Characteristic of the GUI

Characteristic	Description
Windows	Multiple windows allow different information to be displayed simultaneously on the user's screen.
Icons	Icons different types of information. On some systems, icons represent files; on others, icons represent processes.
Menus	Commands are selected from a menu rather than typed in a command language.
Pointing	A pointing device such as a mouse is used for selecting choices from a menu or indicating items of interest in a window.
Graphics	Graphical elements can be mixed with text on the same display.

A spiral model was defined when starting the process of designing the user interface for this research. From the framework shown, the activities represent the segment implied by the circuit around the spiral in a clockwise direction, beginning at the centre. The initial rounds around the spiral would be development regarding the product specification; moving through the spiral to design of the sustainable design index (SDI) user interface, made more efficient by the AutoCAD software. Accordingly, typically the initial rounds around the spiral would likely indicate a "concept development project" where it begins centrally from the spiral and proceeds for numerous iterations, until the concept development is completed.

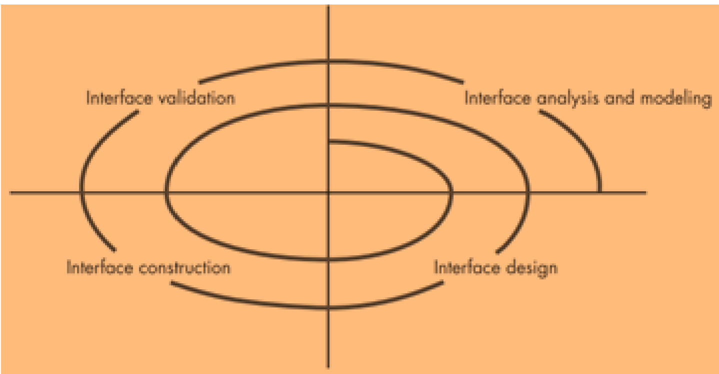


Figure 6-2: The User interface design process

Referring to Figure 6-2, the user interface design process starts with: a) Interface design b) Interface construction c) Interface validation; d) Interface analysis and modelling. The spiral shown in Fig 6-2 indicates that all these steps may happen more than once, each move around the particular spiral addressing further elaboration of specifications and also the resulting design. In many cases, the construction process involves prototyping -the practical method to confirm what has already created.

The evaluation cycle of the user interface design is shown in Figure 6-3. Through the cycle process after the prototype is completed, the next step is to obtain feedback from the user and comments about the efficiency of the interface. Formal evaluation techniques are used in research studies, such as questionnaire and a rating sheet to find the exact information for the input. The process of modification is made based on the input from the user, until the final evaluation of the prototype results in no further comments being made on the interface design.

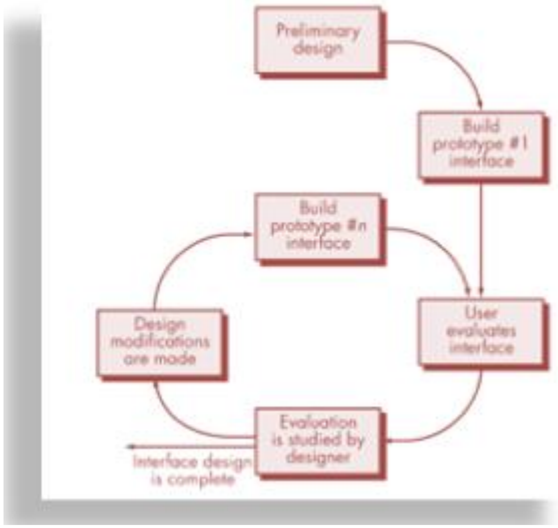


Figure 6-3: The interface design evaluation cycle

The user interface design process as shown in Figure 6-4, is an iterative process involving close connections between the user and designers, in order to know the designer or user activities while making the design process for furniture, namely OPS. The three core activities in the process are:

a) User analysis, aimed at knowing and understanding what the user will do with the system

b) System prototyping, developing processes through which the prototyping experimenting takes place

c) Interface evaluation; after the prototyping is complete, the final stage is to test the validation of the user interface to the end user i.e., the designer in the furniture industry.

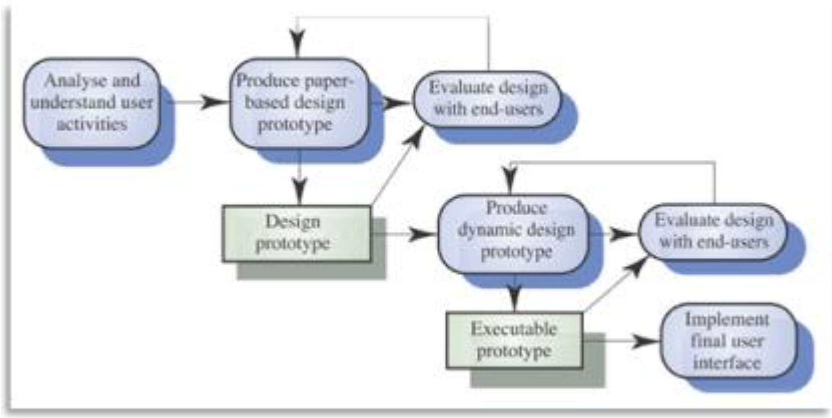


Figure 6-4: The User Interface Design Process

The user feedback is important, especially to understand the user needs for the particular system related to their type of work, well as to help users with high efficiency, but no reasonable possibility of developing user interface programming themselves. The paper-based design prototype is an effective way to save time and effort in the early stage of designing the prototype. The user analyses have to be studied and elaborated to make sure the user and designer can understand the new features to be added in the AutoCAD environment. Furthermore the user interface design also needs to take consideration of the experience, needs, and capabilities of the system for the end users. The most important thing in designing the user interfaces is to be aware of the individual's physical and mental limitations, because people always make mistakes in the justification and decision making stages. While designing the user interface, the designer must take note that even though the user interface has a guideline, not all of the principles are applicable to the end user needs and suitable for the designer's nature of work. Due to that this research only focuses on the furniture industry and specifically on OPS.

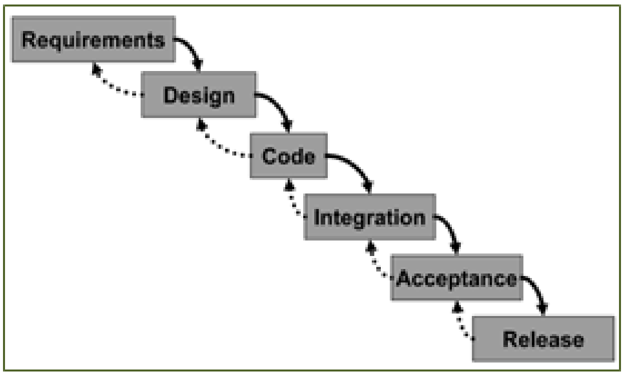


Figure 6-5: The feedback of waterfall model

Figure 6-5 illustrated the waterfall model for the software engineering cycle: the software begins with the systematic analysis of the end user requirement, design coding, integration, acceptance, and releasing the design support. These models are known as waterfalls because they cascade from one to another. The waterfall model is the first published by Royce (Royce, 1970); it is derived more from the general system engineering process. This model shows that any particular process activity should start to plan and have a proper schedule of work. The improvement model using the waterfall model is the discipline it puts on the developer to "think first, and code second." The process of implementation is not always sufficient; the feedback between stages is needed, as shown in Figure 6-5.

6.4.1 The Derivation of Project Appraisal Criteria

The most important impact in recent years on the design process, and on the activities of designers, has come from computer-based data processing. Computer-aided design (CAD) is influencing design methods, organisational structures, and division work, for example, between conceptual designers and detail designers, as well as the creativity and thought processes of the individual designer (Pahl & Beitz, 2013b). To enhance the application of SDI in the CAD environment, new features have developed, which has been written in Visual Basic. To run this program the VBA macro is embedded in a CAD environment where a screen shot of the primary user interface. It is acting as a control panel that was using the Manage menu, which the user needs to be able to measure the purpose of the program.

6.4.2 The Algorithm for the CAD Graphic User Interface

Furthermore, the ability to create macros can be very helpful for enabling automatic sequences of features and actions. The AutoCAD advance package software offers programming language or editors which are VBA, and VB.NET, The integration of these programs into the CAD software enables other CAD files and supports the generation of efficient tools for the particular problem in the development process. An automated handling of problem-oriented mathematical connection, formulas, rules and algorithms can be integrated into the corresponded product model, to provide significant support for the SDI in the design phase. For these studies the AutoCAD 2014 enables programmers to integrate applications written in Visual Basic and loads them into the AutoCAD primary interface. On the Manage menu of the AutoCAD 2014, there are three buttons: Visual Basic Editor, Load Application, and Run VBA Macro buttons. To provide the information to give the user a better understanding of a SDI GUI its can refer in appendix title “CAD and User Interface Design”. It present a detailed explanation of how to run the system and understand how the SDI GUI works, which aims to help the expert to evaluate the sustainability of an open plan system.

The proposed framework has been successfully illustrated to be use during the design selection in the early decision making for sustainable design index selection. The most important stage in the framework is the evaluation and the selection process in order to come out with the best solution.

Therefore, in order to facilitate the use of SDI, a graphic user interface (GUI) has been applied. The GUI of SDI was built with the CAD software. The flowchart for using the

SDI GUI is structured in Figure 6-6. The algorithm show the evaluation process link with two main pages where it begin by determine the weight and score factor for sustainable criteria and then proceed to calculate the sustainability evaluation use SDI as a measure of a differential between the level of sustainability of design option. First of all the designer/expert need to determine the design selection in CAD drawing which is already proposed to customer or requested by customer.

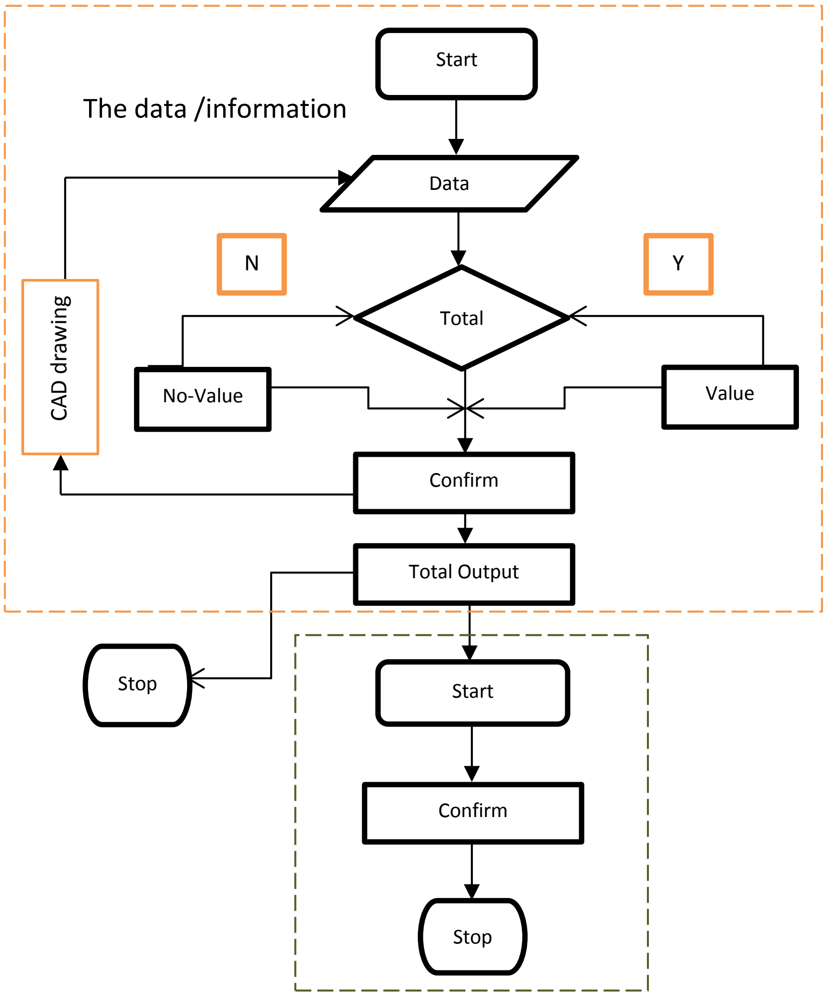


Figure 6-6: The algorithm for the sustainable design index (SDI) using the CAD environment

By starting the CAD environment the SDI GUI is already embedded as features to calculate the best option toward sustainability. Then need to determine the weight value factor of each design option for a target product by setting the weight for BOL, MOL, and EOL. If the displayed sustainability performance is accepted, the evaluation process can proceed into a next phase; otherwise, the process needs to repeat by setting the weights for the BOL, MOL, and EOL at the beginning. To start the evaluation process of the "Life Cycle Oriented Sustainable Design" means the design selection/option the specific data of the alternative are entered regarding the environmental, economic, and social criteria. After the required data are entered, evaluation of the alternative is performing by comparing them with regarding to sustainable design criteria. In the final step, the value is compare and calculated using the sustainable design index table with regards to sustainability performance can be displayed to enable analysis.

With Visual Basic programming language enable the programmer to express many words, which is to instruct the computer in a way that is easier to understand. To represent words and text in Visual basic the series of text characters, such as letters special characters, and space a string variable were used. As show below and also refer to appendix for more detail.

```
Dim eWtotalA_String As String * 5 = "This is a string"
Dim ecoWtotalA_String As String * 5 =""
Dim sWtotalA_String As String * 5
```

To declare the variable, which is the programming language had to decide what to name it and what data type to assign to it. With this design option 'A', 'B' and 'C' had name it as a variable, later it easier to store a value. As the name implies, variables can change the value that they represent as a programing is running.

```
Dim sdiA As Double
Dim sdiC As Double
Dim sdiB As Double
    Dim eWtotalA As Double
    Dim ecoWtotalA As Double
    Dim sWtotalA As Double
            Dim eWtotalB As Double
            Dim ecoWtotalB As Double
            Dim sWtotalB As Double
                 Dim eWtotalC As Double
```

```
Dim ecoWtotalC As Double
Dim sWtotalC As Double
```

In order to determine the best selection each variable must add the score by weight mean for the integer it can store only whole numbers. From programming language the eWtotal mean the weight for environmental, ecoWtotal mean the weight of economic and sWtotal mean the weight for social aspect. Because a number is an **integer**, that only can be used the **Double** data type. And if to store a word, the data type called a **String**. The source code for programming language can be referring to appendix under title "Part of Programming for sustainable design index (SDI) Source Code".

6.4.3 The Conceptual Framework of the Sustainable Design Index

The main GUI generates simple to use input data, in prescribed boxes call, "Life Cycle Oriented Sustainable Design" as shown in Table 6-2, the sustainability criteria for furniture design. As mentioned early in Chapter 2, for the improvement of the product sustainability and the ecological footprint to minimisation the "6R" methodology of Reduce, Reuse, Recycle, Recover, Redesign and Remanufacture was implemented to transform from the conventional "3R" idea of Reuse, Recycle, and Reduce. Most importantly, the proximity of continuous product/material movement might be performed from the point of view of involving several life-cycles (Jawahir *et al., 2006)*.

Both templates for the sustainability criteria and the sustainable design index (SDI) required the information to be feed into the specific box by the design expert or someone responsible for the particular project. The evaluation of the criteria is not provided by the organisation but is instead defined by an expert, based on their prioritisation and according to the importance of the particular material towards sustainability concern. To determine the evaluation criteria of weight function an expert has to decide the suitable rank and criteria to give them the relative weight selection.

Table 6-2: The Sustainability Criteria for Furniture Design

Cycle oriented sustainable design				
Sustainability Criteria		**Beginning of life (BOL)**	**Middle of life (MOL)**	**End-of life (EOL)**
	Environment	Renewable resources	Technology	Reuse
		Non-renewable (durable)	Process	Recycle
		Non-renewable (non-durable)	Energy Used	Re-manufacturing
				Redesign
				Disposal
	Economic	Raw material cost	Production Cost	Reuse Cost
		Procurement	Energy Cost	Recycle Cost
				Re-manufacturing Cost
	Society	Detail design	Transportation Cost	Reuse Cost
		Safety	Worker Health	Recycle
		Conceptual design	Safety	Re-manufacturing
		Part manufacturing		Redesign
				Replacement

There is a three design option, i.e., Design A, Design B, and Design C, as shown in Table 6-3 to determine an index for the selected design option. From the Design A, Design B, and Design C option the user can fill the weight and score base from their expertise to distinguish between the three designs choices. In the case of defining the sustainable criteria for new furniture, i.e., OPS concepts, designer knowledge and expertise have to be taken into account. At the end of this process, a completely automated SDI calculates the design proposal for the series development of generated sustainable design.

Table 6-3: The Sustainable Design Index (SDI)

Sustainable Criteria	Office Furniture (Open plan System)					
	Design A		Design B		Design C	
	Score	Weight	Score	Weight	Score	Weight
Environment						
Economic						
Social						
Sustainable Design Index (SDI)						

The main reason for using the rating and weight factor method is that it allows an expert in the chosen suitable criteria area to be allocated values to some non-quantifiable parameter, and therefore furnishes a foundation that the different kinds of criteria could deduce. The three principles of environmental, social and economic have been collected and calculated as show the example, the result of which is shown in Table 6-3., in which the three criteria were combined with the sustainable design index (SDI).

The weights of the three criteria were derived from the pairwise evaluation matrix, as assessed by the design team member. It is calculated for each option by multiplying each value by the weight, followed by summing the weights score for all criteria using the weight summation method. The weights of the three criteria are derived from the pairwise evaluation matrix. For further conclusive design options, an optimal solution must determine, among the sets of three sustainability criteria, based on the beginning of life (BOL) middle of life (MOL) and end of life (EOL). In this study, the developed an operational decision-making model based on the weight given by an expert.

6.5 CAD-based

The number of CAD tools is growing quickly. From the perspective of an expert, it is essential to use additional tools that are readily available to improve his/her work successfully, yet at the same time, the idea may become more challenging so that an expert would need all the latest tools. That individual won't be able to improve the productivity of one designer only by enhancing the variety of CAD tools. Additionally, we must find a method to deal with the complexity that occurs relating to the latest tools. Most of us require a new CAD platform, which incorporates almost all such tools, as well as covering the complexities involving the use of them.

6.6 Office furniture analysis

In parallel with the literature review, the furniture design scenario for office furniture was analysed by applying the concept of SDI to understand the specific circumstances of the office furniture. The research was conducted in order to fulfil the need for transition towards the sustainability concern. The idea is to incorporate more sustainability, to the product, in order to provide the customer with a significantly lower environmental impact of the furniture product.

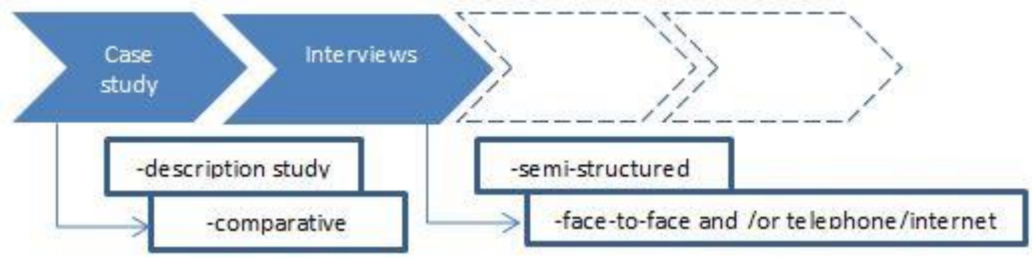


Figure 6-7: Method selection summary

For the purpose of this research, there are a number of factors that have to be considered, which include investigating how sustainability has been practiced within the furniture companies especially the designer. The designer is responsible for making sure that each of the product design for office furniture applies the sustainability, enabling a reduction of the negative impact on the environment. The companies were contacted and after the confirmation as per the scheduling the sequences of the interview meeting were conducted by five experts.

Regarding the research study, Figure 6-7 can be used to make a clear difference between the designer method approach and thinking toward sustainability for comparison through a face-to-face interview. The intention in this case, is to use studies to investigate and provide better understanding of the individual interpretation based on their experiences and perception towards making-decisions and finding solutions throughout the design process (Berg, 2001).

6.6.1 A Data Collected

The companies and the experts participating in this research were chosen within the scope and practices of furniture companies only. The application of these studies' concerns about sustainable design is with reference to the environmental impact of office furniture manufacturers. The inquiry is aimed at designers and the director for each industrial group, concerning their opinion regarding the sustainable design index (SDI) with a new feature of tools are embedded in a CAD-based environment, the various aspects of their design and the sustainability issues. The analysis of this exercise is to determine the perception of an expert of the GUI as a new feature that is embedded within the CAD-based environment as shown in Figure 6-8.

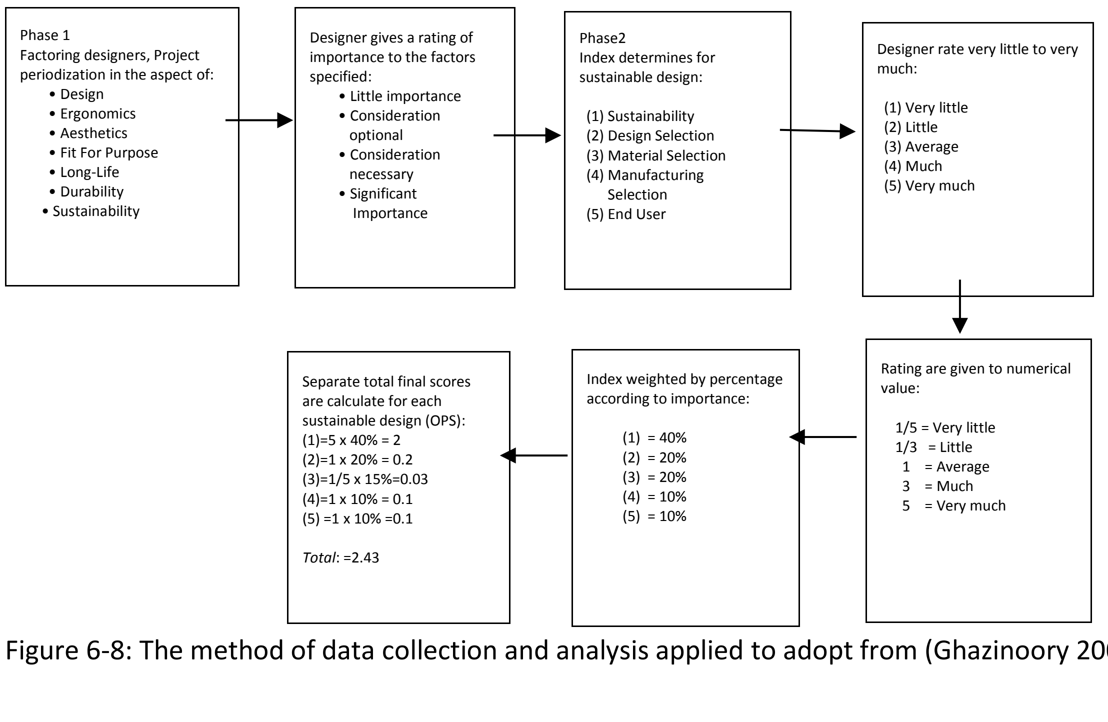


Figure 6-8: The method of data collection and analysis applied to adopt from (Ghazinoory 2005)

In Table 6-4 the designers were asked to determine the area in which they normally work with more priority in the design process and also to determine how the

SDI user interface interacted with the user and the suitableness and user-friendliness of the system to them.

Table 6-4: The priorities, importance of design factor

Please complete the following questions with regard to how your priorities for office furniture design and the suitableness of the Graphical user interface within CAD-based environment				
	Little importance	Consideration optional	Consideration necessary	Significant important
Design				
Ergonomic				
Aesthetic				
Fit for purpose				
Long-life				
Durability/Stabality				
Sustainability issues				

Step 1:

The Table 6-5 shows the index below represents the importance of each section from the design point of view.

In the context of sustainable design, it is necessary to determine how a GUI is embedded in a CAD-based environment in order to consider the sustainability of furniture design (Open Plan System):

(1) Sustainability restricted to the environmental impact

(2) Design selection being the most important part during the design process

(3) Material selection being to determine the product's sustainable factor

(4) Manufacturing selection, with availability of the need technology for the furniture production practice.

(5) End user having satisfaction with every design meeting their needs and requirements

Table 6-5: Rating the importance of score index

Please give a % score of importance to each index in step 1,totalling 100%								
Index	5%	10%	15%	20%	25%	30%	35%	40%
(1)								
(2)								
(3)								
(4)								
(5)								

Step 2:

Designers were asked to aggregate an appropriate index percentage from 5% to 40% (Ghazinoory, 2005). This practice will highlight which aspect the designer considers the most important in order to define the GUI applies for sustainable design of furniture product (OPS).

Table 6-6: The influence of the importance relating to the suitability rate

Using the following indicates the amount of influence a department might have in each index Very little [1/5], Little [1/3], Average [1], Much [3], Very much [5]					
Designer judgement on the particular importance factor	Number of Indices				
	(1)	(2)	(3)	(4)	(5)
Design					
Ergonomic					
Aesthetic					
Fit for purpose					
Long-life					
Durability/Stability					
Sustainability					

Step 3:

Using the system defined in Ghazinoory (2005), designers are asked to rate from 'very little' to 'very much' the impact that the product has on a corresponding index; by doing so the designer's decision will influence the GUI embedded in the CAD-based environment for a sustainable design furniture product (OPS).

The quantitative rating figures were allocated for each qualitative phrase according to the following methods illustrated in Table 6-6:, the rating is defined as follows:

1/5 = Very little

1/3 = Little

1 = Average

3 = Much

5 = Very much

Step 4:

By incorporating these into the decision matrix, for each alternative, the results are multiplied by the weights of the indices, which lead to results being calculated in order to determine the score against each part (Hwang & Yoon, 1981). Score and ratings will be calculated for each part, showing the significance of their influence with the corresponding index. For example, Figure 6-9 shows the method of calculating the weight of importance of each criterion to determine the use of GUI in SDI application. The value of 2.43 indicates the significance of their influence with the corresponding index related to the selected weight of the influence factor of each designer's judgement.

5*40% + 1*20% + 1/5*15% + 1*10% + 1*10% = 2.43

Figure 6-9: The method for calculating the corresponding index

6.6.2 Data Analysis

Figure 6-10 - 6-11 shows a comparison of the expert companies interviewed. The remarks of an expert judgement on this particular tool (GUI) that is embedded in the CAD-based environment will be used to determine the sustainable design index (SDI) for office furniture, namely the OPS. This result shows that most of the designers or experts considered to the aesthetic factor as an important to them.

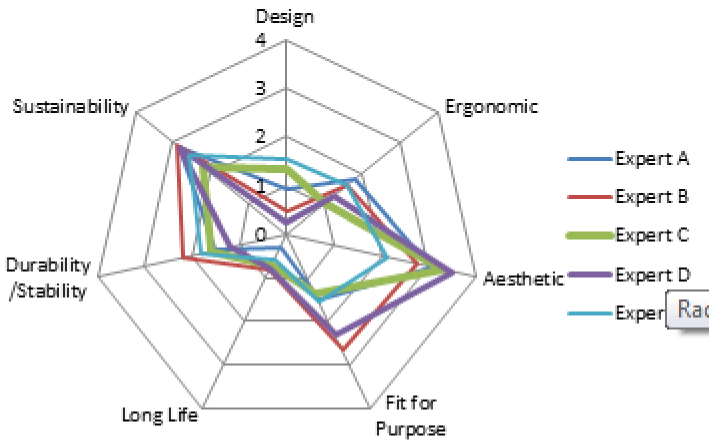


Figure 6-10: The results and expert's perception

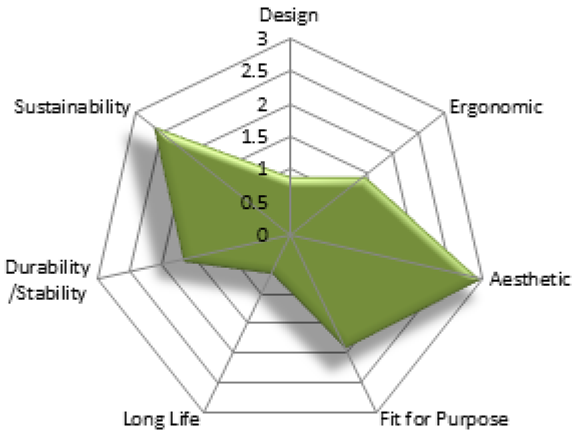


Figure 6-11: The average of the value

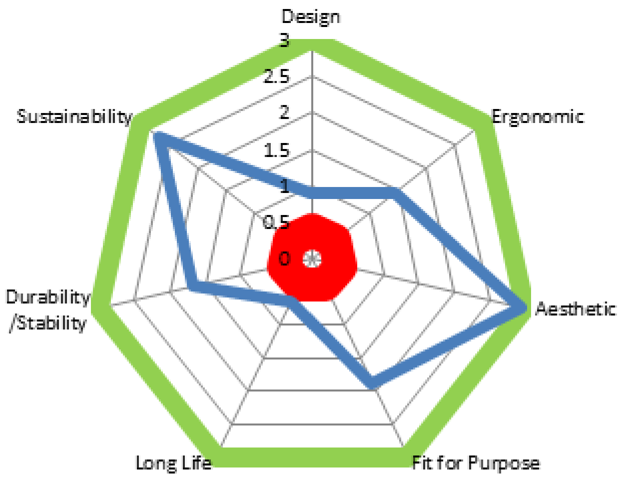


Figure 6-12: The higher values and the lowers values

As Figure 6-12 shows the target of high value and the target of lower value for the designer's perception and their thinking regarding sustainability and the justification of the GUI that is embedded within the CAD-based environment. The designer always thinks about the perfectness and the functionality of a system and how easy it is for them to work with the particular system. Their expectation of the system or any features that enable help for them is considered sustainable.

6.7 Findings from Office Furniture Companies

The aim of this questionnaire study is to collect more information about how a designer's perception and understanding about sustainability is applied in their practices as a designer for furniture companies. The importance of this study is related to the need for a designer or expert to structure their routine work so as to consider the sustainability in the early design stage.

Figure 6-13 provide the additional perspective on the relative designer understanding and application of this method of furniture design. The results of designer experience on modularity and re-configurability, design structure matrix, axiomatic design, computer aided design, and sustainability for designing furniture, and the comparative studies involved therein contain different assumptions and impact assessment factors for the furniture industry.

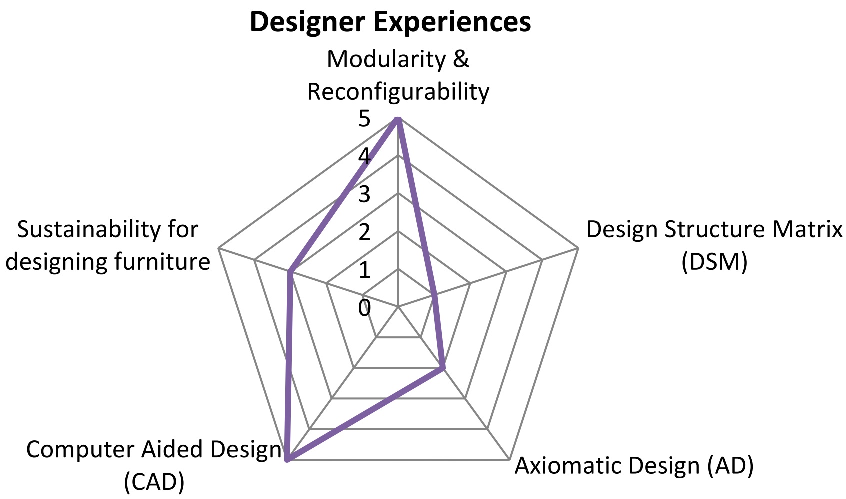


Figure 6-13: The designer experience through the five models

Figure 6-14 gives an overview of the design process and the designer's perception relating to their work, including the investigated cases, the concept decision process in design, influences from team members, the individuals, and the organisation depending on which level they are at, and also the influence factor, which represents a different perspective.

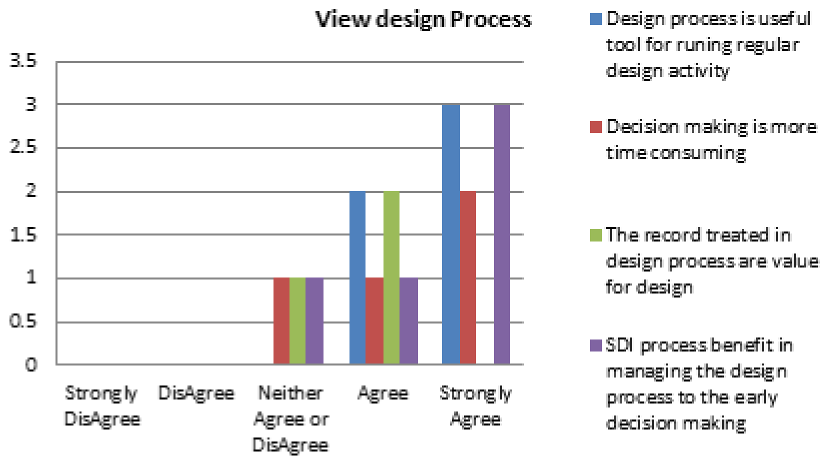


Figure 6-14: View the design process perspective

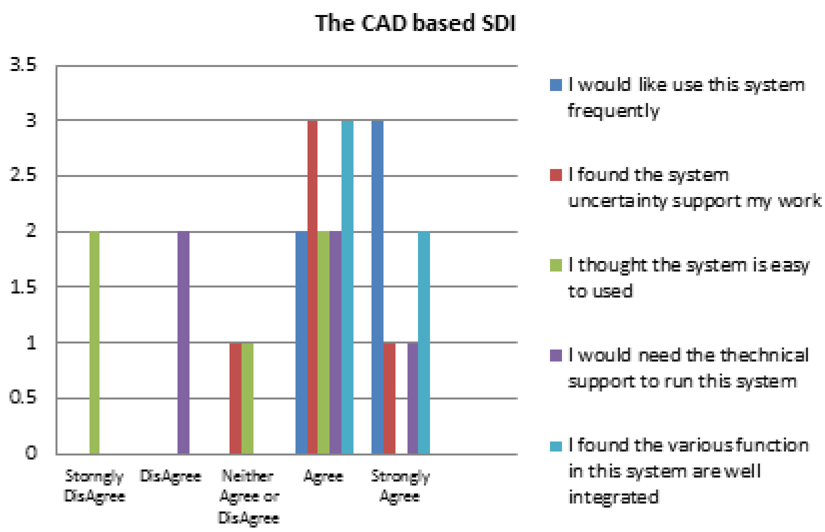


Figure 6-15: The CAD based SDI 'A'

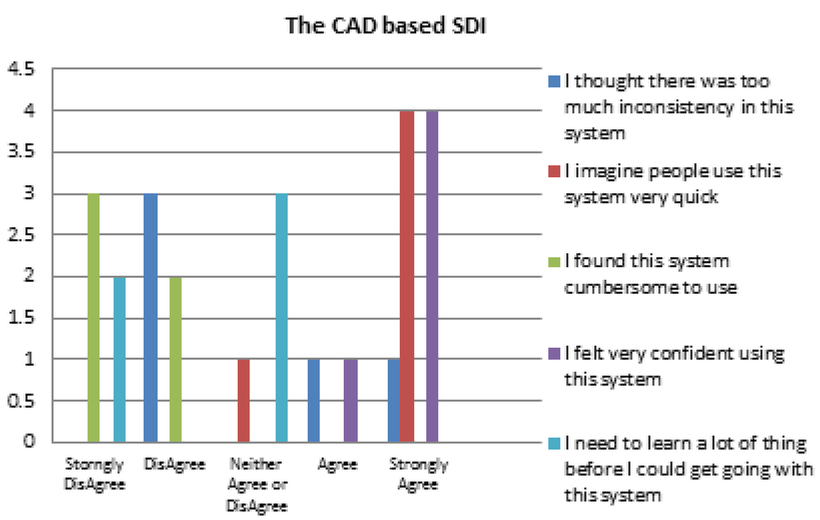


Figure 6-16: The CAD based SDI 'B'

The CAD-based environmental sustainable design index (SDI) tool is a main subject of this study. The development and the effectiveness of application of this tool have been conducted by an expert (designers) in the furniture field. The result showed in Figure 6-15 & 6-16, regarding the CAD based SDI A and B, is that the respondents gave excellent feedback about the SDI tool and also about their daily application of design process development into their work. An application of the (SDI) tools in a CAD-based environment, and also determination the sustainability impact of furniture products, helps the designer to make decisions faster at the early design stage. It also allows the user to run the tool application in an easy way. The result of the section of the questionnaire related to the SDI tool embedded in the CAD environment shows that all of the designers as users agreed and accepted. Most of them strongly agreed that the SDI can be easily learnt and applied in their work with not much problem and is helpful in their work. In the idea generation process, results showed that the system supports technical drawing and the application of new features in the CAD environment working at the same time. This means that the designer or expert is able to see their drawing while the expert filing the important weights for necessary items related to furniture part and components. Using the SDI tool to examine the furniture parts and components, the designer has to consider the three triple bottom lines, i.e., environment, economic, and social factors. Most of the designers, confident enough to use the SDI tool to support their decision making early in the design process.

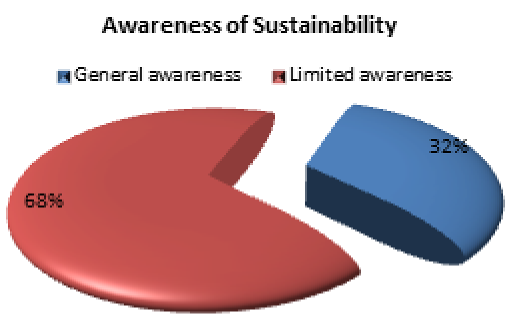


Figure 6-17: General Awareness of Sustainability and Sustainability Design

The participant perception of sustainable design was analyses based on: a) The attitude towards sustainability policies; b) The awareness of sustainability and sustainable design; c) The knowledge about sustainability. The concern and understanding of the concept of sustainability was shaped the documentation and news, including the environmental impact, the awareness about global warming issues and the energy costs in daily life as a designer. The result from Figure 6-17 shows that most of the experts are able to identify recent environmental problems and sustainability issues in the general context. In the practice of initiating and using a process to improve the environment, the expert considers utilising the resource that's best able to create a sustainable adapted solution for their customers. However, as the result shows in Figure 6-17, some of the participants are able to elaborate the meaning of sustainability, and some are not because the awareness and concern about sustainability is dependent on the top management policy maker's education and approach towards the sustainability among their staff.

Table 6-7: The feedback for the conference attended from 2013-2015

	During the conference feedback from the audience (Country)	The comments and suggestion for further action
1	China 2013	- The first presentation mentioned about the sustainable design index applied to the furniture industry to determine sustainable concerns on environmental impact. -That is the first question of how to measure sustainability for furniture production. -The application of new tools that are embedded in CAD is a new intervention for furniture designers, helping them to determine the sustainability of their product; at the same time it's easy to encourage the customer end user those looking for an environmental or green design.
2	United States 2014	-The overall idea and concept are accepted. -The idea of using the CAD tool to measure SDI get a good response from the audience. -No comment on the tool box for the sustainable measure embedded in a CAD environment. -The concern is how the user (designer or expert), determines the sustainability for each material for furniture products. -The need to consider the weight determination by using an appropriate method to support the calculation is necessary.
3	United Kingdom 2015	-The overall idea and concept are accepted. -The application of the SDI tool in CAD is an excellent platform for designers or experts to consider sustainability in furniture products. -No comment on the tool box for the sustainable measure. -An additional suggestion to consider the weight determination and to choose an appropriate method to support the calculation. - This tool application is only for furniture industries.
4	Malaysia 2015	-The overall idea and concept are accepted. -The application of the SDI tool in CAD is easy to use. -The only concern is how to determine the weight in an easy way for designers. -Normally, all designers, especially regarding CAD applications always look for a simple system that is easy to operate and no burden to them in order to consider the importance of the matter and make the justification and also the decision making for short periods. -The simple way is better to solve any problem faced by the designer.

Results from Table 6-7 show the relevant and important concerns from the feedback, regarding the sustainable design index (SDI) discussion present during the conferences from 2013 to 2015 which involved countries such as China, United States, United Kingdom, and Malaysia. The summarised feedback and comments are shown in Table 6-1. The empirical findings summarised in Table 6-1 present the contribution from participants in the conference: opinions and suggestions on the topic of the sustainable design index for office furniture, i.e., OPS through question and answer. Overall, it could be stated that incorporating the sustainable design aspect in furniture companies is important due to environmental awareness and concern of the economic factor, as well as societal concern for the environment. With regards to the implementation of SDI in a CAD-based environment this was considered important. In addition, CAD is considered a great tool for furniture designers to support their work to optimise and minimize errors, and also in decision making to point out the importance of sustainability in environmentally conscious actions.

6.8 Summary

This chapter investigated the integration between CAD-based and sustainable design index (SDI) embedded in a CAD environment. The need for a new feature for a designer to deal with sustainability where a new tool is embedded in a CAD-based environment has been introduced in order to calculate the importance of sustainability for a furniture product. The use of computer-based systems or products is important elements for the user interface to be able to interact with the user. The ability of the computation and the informed application of the interface tell the user of poor design and the implementation of application appropriate to their task. The proper organisation of the design process is conducted in order to achieve effective user interface design.

In modern times, sustainable design of furniture through the environmental impact of manufactured goods can be reduced if designers plan for sustainability through the whole product life cycle. The Sustainable Design Index (SDI) is formulated as a unique design “indicator” to analyse the design sustainability within the design process. SDI and the associated algorithm are investigated in light of the qualitative analysis approach, particularly by taking account of its implementation within CAD environments. Office furniture design is taken as an industrial case study because of its proneness to manufacturing, costs, life cycle, materials, and the societal aspect, although the approach developed aims to be applicable to a wide range of design scenarios. The integrated CAD and SDI; provides the user with a complete visibility of the form without switching into other systems. The software package improves the speed of the calculation of SDI through automation of tasks traditionally done manually, like completing other templates. SDI calculation methods for office furniture, i.e., OPS help designer and marketing easy to convince the customer about the need for environmental concern.

7 Application Case Study on Office Furniture Design

7.1 Introduction

This chapter presents the application of a sustainable design index (SDI), including the tool implementation, and the resultant application design case study, for an Office Furniture Open Plan System (OPS). It firstly introduces a SDI that integrates the sustainable functions of office furniture design and all three pillars of sustainability, i.e. the economic, environmental and societal aspects. SDI represents a novel methodology for integrating sustainability considerations into the design process and working with a computer-aided design (CAD) environment. The case study shows comprehensive application perspectives of SDI, including how to formulate relevant sustainability criteria, and how to integrate and obtain design information that the office furniture for OPS, and thus the design are more sustainable.

7.2 Application and Assessment of Open Plan System

The designer's knowledge and awareness of the environmental impact of office furniture are becoming significant, particularly with OPS. Typically applied to particular end users, this enables companies to improve and expedite the environmental perspective into the market for sustainability. In this respect there has often been a lack of awareness and comprehension of the wider environmental, social and economic impacts of sustainable design in office furniture design and its associated manufacturing industry. It is vital that the designer minimises the environmental and social impacts. A design that minimises environmentally destructive impacts by incorporating itself into the living process is called sustainable design. However, sustainable design should be an evaluation and extension of the traditional design approach, and sustainable design should involve all parties, including designers, suppliers, manufacturers, sales staff, and consumers, in the design process. The design must thus be economical and aesthetical.

The work presented in this chapter will demonstrate how SDI developers can enhance the sustainability of office furniture. This will be accomplished by examining how an SDI can foster and integrate with modularity and re-configurability, the design structure matrix and axiomatic design, and the consequent design decision making at the early design stage to render benefits to the customer and human society. With the use of different decision-making support tools, the result of a comprehensive analysis can be more accurate, convincing and reliable. It is therefore worthwhile investigating the consolidation of functional and commercial perspectives with product sustainability at the early stage of product conceptualisation.

By focusing on office furniture components, it is indicated that OPS is a primary solution in the design process. The driving goal of the manufacturing effort is to satisfy the demand of customers and attain a competitive financial return. The negative environmental consequences would have to be traded off against the financial benefits of increased product marketability. It is widely understood today that most products cause an impact on the environment, as do all manufacturing processes. In this context, sustainable design emerges as a conciliatory alternative among functional, aesthetic, and environmental factors to develop the goods. A product design consists of a creative process where new thoughts or results are synthesised and an analytical process through which a design decision is reached by evaluating the new ideas suggested. The product design method is utilised throughout the entire conception process. To present an additional effective product design process, a concurrent design model with multidisciplinary communication tools based on modularity and re-configurability, axiomatic design, design structure matrix and sustainable design index was developed for the design of office furniture OPSs, as described in the following sections.

Furniture designers make decisions about many design matters. Nonetheless, the design problem is not always clearly defined; problems have to be worded in a manner that enables furniture designers to make conclusions about them. Decision makers must have huge amounts of data to be able to make use of the rational, comprehensive decision-making technique.

Several factors influence the decision making, and understanding these factors and their influence on the decision-making procedure are important in the same way that understanding which decisions are being made is important. Decision makers today must address the topic of sustainability. One of the challenges is the need to assess the level of sustainability in different sectors, in order to ascertain which change of direction is needed in order to steer towards sustainability. From this research as presented, it is found that the designers and design team manager need some design tools to help them with decision making at early design stages especially to improve sustainable design in both qualitative and quantitative ways. To enable this, an SDI tool is conceived and developed for early design decision making towards design sustainability.

7.2.1 SDI-Embedded Design Process

The Sustainable Design Index assessment model developed using the CAD environment tool as a part of this project, could serve as a basic examination of the sustainability of OPSs. The designer uses many types of variables in product development, either dependent or independent, such as the material use of the OPS. In other words, the designer cannot always control the decisions made because some independent decisions may be made by another designer, which will produce such constraints as the proportion or material options. The most useful metric and feedback is the degree to which a product satisfies consumer’s needs.

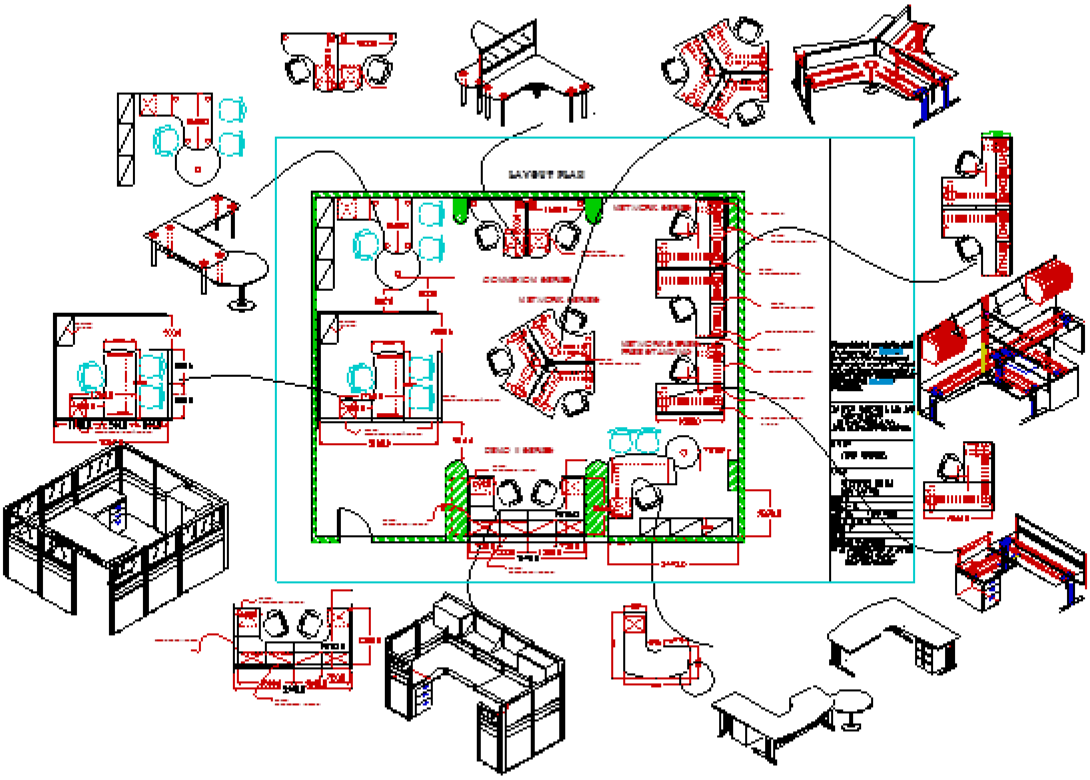
Hence, the designer has to consider these needs during the design process and has to integrate the environmental aspect into the early design process, together with multi-criteria decision-making, in order to achieve sustainable design. The need to measure the environmental performance of products has led to the development of a variety of methods ranging from simple to complex. The design approach to evaluating environmentally sustainable goods, in order to discover the exact trend to follow to enable improvements in design activity, must take into account not only the direct environmental impact of the product but also make their development and ensure that they can be re-used, disassembled and recycle.

User behaviour plays a key role in sustainability and identifies relevant cognitive variables and guidelines to promote sustainable behaviour. Different disciplinary scope and cognitive concepts are important and useful in bringing different perspectives into the sustainable design process, particularly in early decision making and concept generation.

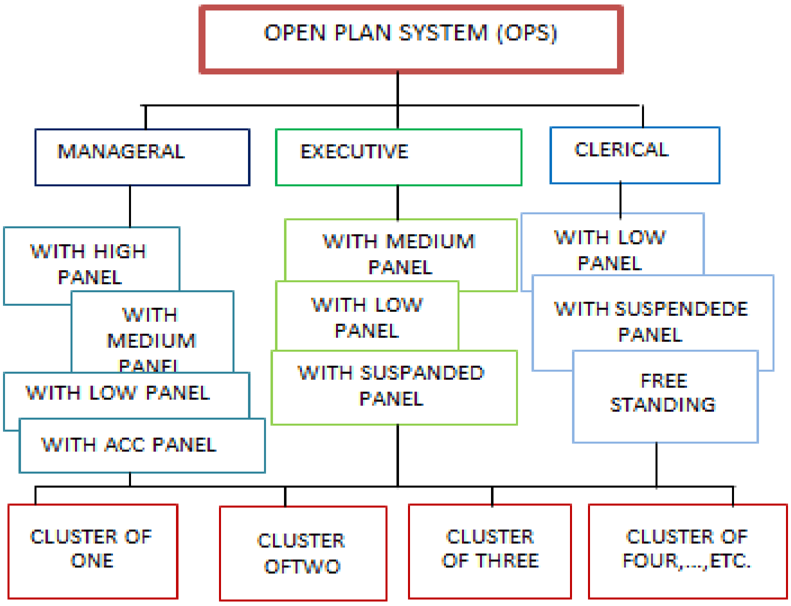
7.2.2 Furniture Modularity and Re-configurability within the Sustainable Design Index (SDI)

The modular product is a key to product success in global competition. Modular product design improves product quality as it calls for firms to determine the relationships between factors at an early phase of the product evaluation process. A design method for improving operations, where similar components sharing common features are used in an item that is of modular design, is frequently recommended. Figure 7-1 shows that by, basing designs on current items for consumption, designers do not need to design products from the starting line every time. They can access existing designs from related products and components, and then revise them to meet specific customers' needs. Modularity and re-configurability can be utilised to create a suitable design solution and achieve new functionalities.

In modular design, a Design Structure matrix (DSM) and Axiomatic Design used to map interdependencies among design parameter and tasks, and to identify interdependent block as modular. The process of identifying appropriate modules in the customer context the AD were apply, the product must analyse the customer's mind set and thought process as consider their needs and modular way of meeting them.



(A)



(B)

Figure 7-1: The modularity and reconfigurable design option for workstations

A hierarchical tree representation of OPS re-configurability, based on modularity is shown in Figure 7-1 (A) & (B). In the evaluation index system of the product configuration scheme, the influencing factors of evaluation objects have multi-levels, and each ingredient has certain 'softness', especially those elements related to humans.

7.2.3 Axiomatic Design

Axiomatic design (AD) can be used for many levels of systems. It can be applied to identify process coupling and complex problems by checking the high-level design matrix. The AD method is explained in detail in Suh (1990). The main objective of AD is to allow the designer to be more creative, and search in a more organized manner, to minimise the interactive trial-and-error method, and to define the best design among the proposed designs. The AD theory consists of four domains: 1) Customer Domain, 2) Functional Domain 3) Physical Domain, 4) Process Domain. (Axiomatic Design) provides a systematic and logical method for driving, and it provides a framework for describing design objects at all levels of detail. The AD, developed by Nam Pyo Suh (2001) is a human-machine interface design tool using matrix methods to systematically analyse and transform customer needs into functional requirements (FRs) and Design parameter (DPs). The relationship between FRs and DPs is represented in a design matrix. A good (decoupled) design can be represented by n x n triangular matrices, in which all entries above the main diagonal are zero. The matrices that are entire of the main diagonal are zero are considered to be the best (uncoupled) designs, and they can be represented by n x n diagonal matrices.

The correlation between Axiomatic Engineering and Total Design Methodology (Refer to chapter three Table 3-1) it can deduced as follows:

CAs = Customer needs/ clarification of task

FRs = Design specification

DPs = Detail design and embodiment/layout design

PVs = Process planning and manufacturing

In order to be able to develop SDI through axiomatic design principle, a correlation will be deduced between weighting factor matrix method used in developing the SDI and axiomatic design formula. Correlation between weighting factor methods in developing the SDI and axiomatic design formula is show below:

Let assume that:

FR=SC (eco+Soc+env)

A= (W) Weight factor (WF) values for each SC

DP= (S) score value for each SC

Form the correlation this implies that the equation (6)(7)(8) therefore, (9)(10) in chapter five.

SDI analysing of the design Open plan system (OPS) will be carried out using the developed axiomatic design formulation. For this purpose of this analysis the first sustainability criteria from table 6-2 will be used.

From the equation excels can be used to compute the matrix for this study. Follow the procedure for assigning weighting factor and rating values as describe as below.

$$SC=\begin{pmatrix} 5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 5 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 5 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 5 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \begin{bmatrix} 5 \\ 5 \\ 5 \\ 0 \\ 5 \\ 0 \\ 4 \\ 0 \\ 0 \end{bmatrix} = \begin{matrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \\ X_6 \\ X_7 \\ X_8 \\ X_9 \end{matrix}$$

From the excel analysis or computation

Weighting factor total = 30

Rating values total = 24

Total sum of $\sum_{i=1}^{n} WF_{ij} R_j$ = 95

Recall equation (6) (7) & (8),

$$SC = \frac{\sum_{i=1}^{n} W_i S_i}{\sum_{i=1}^{n} W_i} \quad = SC = 95/30 = 3.16$$

The SDI value interpretation for the designed Open Plan System of 3.16 means vary good sustainable design index.

AD and DSM are seemingly related, as equally decrease system complexity by exploiting matrices to represent system dependencies. The purpose of using the correlation matrix is to determine the relationships between FRs and DPs. This is important to determine if this positive or negative, so the designer aware what the next step to make a changes or implementation a new design re-configuration.

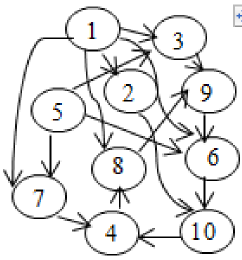
7.2.4 Design Structure Matrix (DSM)

An industrial product development process involves many interrelated engineering design processes. The Design Structure Matrix (DSM) was an accepted method for enhancing and analysing the design of products and systems, and in the 1990s the method received attention and widespread attention. Design reviews and progress assessment are based on the matrix, with a manager ensuring that the required information is transmitted, received and utilised promptly so that critical tasks can be accomplished as efficiently as possible. DSM became a popular representation and analysis tool for system modelling, particularly for purposes of decomposition and integrations. A DSM displays the relationships between the components of a system in an analytical, compact, and, visual, format using a square matrix with identical row and column labels.

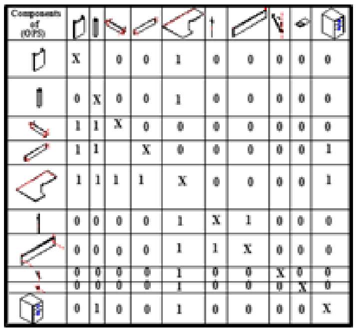
According to graph theory, the relationship between designs elements can be mapped to a Design Structure Matrix as outlined. A DSM associated with a directed graph is a square binary matrix with m rows and n columns and no non-zero elements, where m is the number of nodes and n is the number of directed lines connecting these nodes in the direction graph. If there exists a directed line from node j to node i, then the value of element a_{ij} (column j, row i) is unity (marked with an X). Conversely, the value of the element is zero (left empty) as demonstrated in Figure 7-2 and Figure 7-3 (A) (B) & (C).

$$
\begin{array}{c}
a_1 \\ a_2 \\ \\ a_3
\end{array}
\begin{bmatrix}
a_{11} & a_{12} & \cdots & a_{1n} \\
a_{21} & a_{22} & \cdots & a_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
a_{n1} & a_{n2} & \cdots & a_{nn}
\end{bmatrix}
$$

Figure 7-2: The Design Structure Matrix



	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	1	1	1	1	1	1
2	1	1	0	0	0	0	0	0	0	0
3	1	0	1	0	0	0	0	0	0	0
4	1	0	0	1	0	0	0	0	0	0
5	1	0	0	0	1	0	0	0	0	0
6	1	0	0	0	0	1	0	0	0	0
7	1	0	0	0	0	0	1	0	0	0
8	1	0	0	0	0	0	0	1	0	0
9	1	0	0	0	0	0	0	0	1	0
10	1	0	0	0	0	0	0	0	0	1



(A) (B) (C)

Figure 7-3: The Spaghetti graph, The base DSM, and the DSM of OPS component matrices

To calculate the priorities of the DPs, the importance of the FRs and the relationship between FRs and DPs are utilised. To calculate the weight of a functional requirement, an analytical hierarchy process is used. In conjunction with more detailed concepts, the team may decide to add more detail to the selection criteria. The function of hierarchical relations is a useful means to elucidate the criteria.

7.3 SDI Analysis Algorithm

This analysis considers the environmental life cycle for SDI acquisition. The process of product development starts with the creation of a new product and the concept of sustainability (radical and incremental) for ‘Factor X’ or a sustainable solution. SDI means developing new processes in order to realise those products and services whilst working and co-operating with modularity and re-configurability, DSM and AD as below:

$$SDI \in \sum(PV + DSM + AD)\forall = = \in \sum \left[(1) + \begin{pmatrix} 1 \\ 0 \\ 1 \end{pmatrix} + \begin{pmatrix} 1 \\ 0 \\ 1 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \right] \quad (6)$$

Where : Pv is Polynomial (Modularity, Re-configurability) DSM is Design Structure Matrix and AD is Axiomatic Design

The Analytic Hierarchy method can be used by someone trying to create a direct judgement, or by a set of people trying to examine an additional composite problem. The idea of pair-wise compression is the root for any analysis of a decision-making problem, through the use of the analytical hierarchy process (AHP). This allows the decision maker to incorporate a judgement into a decision. To translate the judgements resulting from the paired comparison, recommended using the scale given within Table 7-1. In this case, there were 15 part components, thus 15 pair-wise comparisons were made. As shown in Table 7-2, the 15x15 reciprocal matrices were built using the average responses of the survey participants. The diagonal elements of the matrix are all equal to 1 since it is assumed that for a component itself, the relative importance is always equal.

Table 7-1: Scale for pair-wise comparisons on sustainability criteria (Saaty 1980)

Type of relation	Interaction	Description
No	0	No relation at all
Weak	1	Loose connection and medium relation
Medium Strong	3	Medium connection and medium relation
Strong	5	Medium connection and high relation
Very Strong	7	Firm connection and high relation
Excellent	9	Strong connection and high relation
Intermediate	2,4,6,8	Intermediate Values

$$R_v \left\{ \frac{0}{extremelylow} \quad \frac{0.1}{verylow} \quad \frac{0.3}{low} \quad \frac{0.5}{medium} \quad \frac{0.7}{high} \quad \frac{0.9}{veryhigh} \quad \frac{1}{extremelyhigh} \right\}$$

AHP is a method that relies exclusively on the judgement of experts to arrive at a decision. The expert judgement enters on the whole during determination of technology impact and weighting scenarios.

7.4 Adapting Weight and Aggregation Indicators

The indicator in the SDI, as shown in Table 7-2, considers the three "pillars" and therefore a set of sustainable design criteria can be defined. This indicator has been developed specifically for OPS. An "index" aggregates a set of indicators; the integration of key sustainability indicators is essential for decision making. Combination indicators are an innovative approach to evaluating sustainable performance. The indicators should be both limited and sufficiently comprehensive to capture the multidimensional nature of sustainability. If too many indicators are applied, the result becomes unwieldy and difficult to interpret. Indicators need to be clear and unambiguous. A conceptual framework for indicators helps to focus and clarify what to measure, what to expect from measurement and what kind of indicators to use. The sustainable development indicator specifies that these are to be developed at the appropriate level of detail to ensure proper assessment of the situation with regard to each particular challenge.

To aggregate the weight of the indicators, it is important to assign the weight and, determine their relative importance to the final SDI to the OPS. A broadly used aggregation technique is the equal weighted average (EWA), in which all the indicators are given the same weight. Weighting is inherent to the system, and when not explicit, all criteria are given an equal weight (Ding, 2008).

The AHP established is a structured technique for organising and analysing complex decisions. A nine-point scale is utilised to rate pair-wise comparisons and their reciprocals, of hierarchy components between levels as an eigenvalue approach. Pair-wise comparison matrices [A] are created for each level-to- level comparison. Each higher level variable has a matrix [A] that is n x n size, with n being the number of the variable in the lower level. Thus, each higher level variable is compared to each alternative or criteria parameter in the lower level. The pair-wise comparisons are judgements. Within an AHP decision maker, preferences are represented by a pair-wise comparison procedure of criteria and alternatives based on a scale and within a hierarchical structure. AHP has been used to determine the weights at various levels. The objective of this paper is to determine the sustainable design on OPS and to present a conceptual decision model, using AHP to assist in evaluating the impact of SDI on office furniture in OPS.

Weight (W) can be expressed as:

$$\sum_{i=1}^{n} Wi = 1 \quad and \quad Wi = (n = 1, \ldots n) \tag{7}$$

Where W_i is the weight assigned to the criteria i, from the decision theory point of view. Importance weighting is needed because not all evaluation criteria are equal. The essential task is determining the relative importance of the criteria.

As in n x n judgement matrix. Firstly, we normalise the column vector in the judging matrix, and then add the normalised matrix in rows. The result should be normalised again to obtain the eigenvector as below.

$$W_i = \frac{1}{n} \sum_{i=1}^{n} \frac{a_{ij}}{\sum_{k=1}^{n} a_{ij}} (i = 1,2,3,\ldots,n)$$

(8)

The Eigenvector method consists of taking as weights the components of the (right) eigenvector of the matrix A. In our notation the eigenvector is defined by Saaty (1980).

$$[A][W] = \lambda_{\max}[W] \tag{9}$$

Where:

[A] = matrix of pair-wise comparison (as described below)

[W] = matrix of vector priorities

7.5 Multi Criteria Decision Making

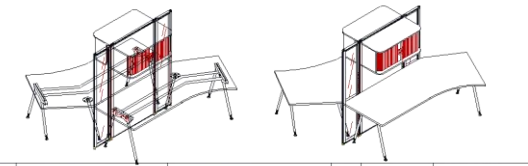
Decision making is an essential part of almost all human life. Making a decision involves a choice among alternatives. A decision is the point at which a choice is made between alternative options. Making decisions involves the processes that include gathering information and generating, complementing, and evaluating alternative courses of action, as well as processes of implementation and evaluation that should be followed once a decision is made. In other words, the problem can be abstracted as how to derive weights, ranking, or importance of a set of activities according to their impact on the situations and the objective of the decision to be made. The assessment itself is carried out with respect to the criteria, the weighting of the criteria and finally the aggregation of the partial assessment on each criterion. MCDM techniques have emerged as a major approach for solving natural resource management problems and integrating the environmental, social, and economic values and preference of stakeholders. Based on the literature reviewed among the numerous alternatives proposed, some of the most commonly used MCDM techniques include AHP and Weighted Sum.

7.6 Application Case Study: Results and Discussion

In this section, to describe how the methodology developed and helped to drive the development process of office furniture towards SDI as shown in Figure 7-4. To construct the SDI development process, a database of all relevant and essential design activities and design parameters along with their interrelationship was constructed. A questionnaire elicited the basic information on every design activity. The design activities and parameters were then evaluated by experts with a working experience of more than ten years; these were the senior designer, project manager and director of the furniture company.

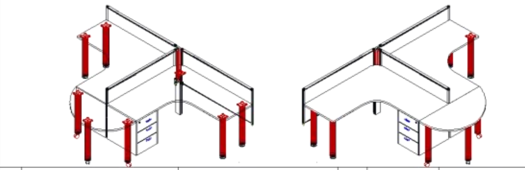
Specifically, the studies were interested in evaluating the experts' understanding of office furniture and its relation to sustainability. Therefore, in order to implement this new approach of SDI application, the authors selected a furniture company such as Bristol Furniture Company and Lozi Furniture Company. The SDI, embedded within the CAD-based environment, was then tested by the furniture design experts as shown in Figure 7-5. The

Delphi method was applied in this study, using an open-ended questionnaire, since the Delphi techniques focuses on eliciting expert opinions over a short period of time. The selection of Delphi subject depends upon the disciplinary areas of expertise required by the specific issue. The Delphi method is a combination of qualitative and quantitative processes that draws mainly upon the opinions of the experts to develop theories and projections for the future. It is best used for a fairly simple assessment of new product and development. The application of the proposed methodology includes all of the design process selection decisions where sustainability considerations are important. Specifically, the methodology can be time and cost-saving when the selected approach to sustainable design includes life cycle assessment for materials and others components. The purpose of establishing the SDI was to allow the authors to offer possible features for the CAD design tool, which would support and educate the designers towards creativity, and sustainability.



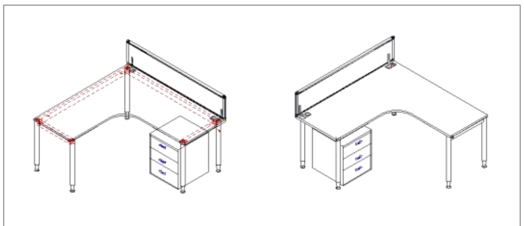
NO	SKETCHES	DESCRIPTION	QTY	UNIT PRICE	TOTAL (USD)
A		CXWC- 16080-30° WORKSURFACE CURVE 2170L X 1140D	2	45.00	90.00
B		CX-LSN-68 METAL LEG WITH SWIVLE GLIDE Ø43 X 715H	4	20.00	80.00
C		CX-LSN-63 METAL LEG WITH SWIVLE GLIDE Ø43 X 715H	2	8.00	16.00
D		METAL BEAM Ø43	4	7.00	28.00
E		CX-PFG-35165 GLASS PANEL 350W X 1650H	2	50.00	100.00
F		CX-PS-90165 PANEL FULL FABRIC 900W X 1650H	1	68.00	68.00
G		HC-90P HANGING CABINET 900W X 400D X 400H	2	50.00	100.00
H		PC1 END CONNECTOR	2	1.80	3.60
I		PC2 2 WAY CONNECTOR	2	2.70	5.40
J		CX-PB-99 L-SHAPE PANEL BRACKET 120L X 50D	4	2.25	9.00
				TOTAL PRICE	500.00

Design A
Managerial workstation



NO	SKETCHES	DESCRIPTION	QTY	UNIT PRICE	TOTAL (USD)
A		CX-WC- 150150P L & R WORKSURFACE CURVE 1500L1 X 600 X 1500L2 X 600	2	41.00	82.00
B		CX-WHR- 12060P WORKSURFACE HALF ROUND 1200L X 600D	1	28.00	28.00
C		CX-LS NA -20A ALUM. CYLINDRICAL LEG W/CLUSTOR 80W X 80D X 715H	3	25.00	75.00
D		CX-LS NA -20 ALUM. CYLINDRICAL LEG 80W X 80D X 715H	4	15.00	60.00
E		CX-LS NT-10 ALUM.COLUMN LEG (TRIANGLE) 100L X 130D X 715H	2	14.00	28.00
F		DFP -503P FIXED PEDESTAL C/W 3 DRAWERS 500D X 468W X 695H	2	45.00	90.00
G		CX-PS-15061 SUSPENDED PANEL W/FULL FABRIC 1500W X 610H	3	51.30	153.90
H		PC1 END CONNECTOR	3	1.80	5.40
I		VVP 610 VERTICAL POLE	1	11.00	11.00
J		CX-PB-99 L-SHAPE PANEL BRACKET 120L X 50D	6	2.25	13.50
K		SH 3 SOCKET HOLDER 56D X 270H	2	10.00	20.00
				TOTAL PRICE	566.80

Design B
Executive workstation



NO	SKETCHES	DESCRIPTION	QTY	UNIT PRICE	TOTAL (USD)
A		CX-WC- 150150 P L & R WORKSURFACE CURVE 1500L1 X 600 X 1500L2 X 600	1	41.00	41.00
B		METAL BEAM	1	35.00	35.00
C		MP-3P MOBILE PEDESTAL C/W 3 DRAWERS 470D X 468W X 574H	1	41.35	41.35
D		C-PKS-15031 STACKABLE PANEL W/FULL FABRIC 1500W X 310H	1	36.00	36.00
E		PC1 END CONNECTOR	2	1.80	3.60
F		PANEL STAND 89L X 15D X 120H	2	3.00	6.00
J		C-PM-150 M1 MODESTY PANEL 1219L X 380D	2	10.80	21.60
				TOTAL PRICE	184.55

Design C
Clerical workstation

Figure 7-4: The Office Furniture Open Plan system (OPS) design options

7.6.1 Furniture, Open Plan System Design and Operations with an SDI-embedded CAD-Environment

A further CAD-based environmental operation is applied, which allows an expert to identify the OPS for the SDI of the design decision Figure 7-5 shows the basic steps in the design process for furniture for an OPS. The SDI approach allows the collection of sustainable designs and sustainable furniture information in an ordered structure that can be analysed to reconfigure OPSs in a manner suitable for developing an SDI software tool. The CAD application with the features is embedded in a CAD software tool used to manage and process the SDI. The furniture expert designers have fixed the relation and the relations weighting. The simplicity and user-friendliness of the SDI tool is important since it allows the experts to focus the attention on the dependency relation between the two parameters. The use of the appropriate CAD tool enables the reduction of the development cycle of the new product. Hence, the selection of a suitable CAD system must be taken into consideration.

For a furniture designer, the software must be capable of producing any technical drawing, which may lead to more innovation, and the design solution. A drawing supports both synthesis and analysis; however, information captured from the drawing requires human visually-based interpretation. This computer-based model does not require human interpretation for information capture, but may be directly accessed by different application programs.

The most important impact on the design process and activities of designers has come from computer-based data processing. CAD is influencing design methods, for example, between conceptual and detail, as well as the creativity and thought processes of the individual designers. The task of the design process is to find the solutions to meet the requirements of technical, economic and fashion trends. The design process has a significant impact on customer perceptions and thus the purchasing decision. In this study, the sustainability decisions for OPS furniture are transferred into the CAD environment via SDI. To enhance the application of SDI in the CAD environment, the authors developed new features, these features contained in a program written in Visual Basic. To run this program, the VBA macro is embedded in a CAD environment as shown in Figure 7-11 a screen-shot of the main user interface. These acts like a control panel, using the management menu that the user needs to assess the functions of the system.

Furthermore, the ability to create macros can be very helpful for enabling automatic sequences of features and actions. The AutoCAD advance package software offers programming language or editors which are VBA and, VB.NET. The integration of these programs into the CAD software enables other CAD files to, support the generation of efficient tools for specific problems in the development process. An automated handling of problem-oriented mathematical connections, formulas, rules and algorithms can be integrated into the corresponded product model, to provide significant support for the SDI at the design phase.

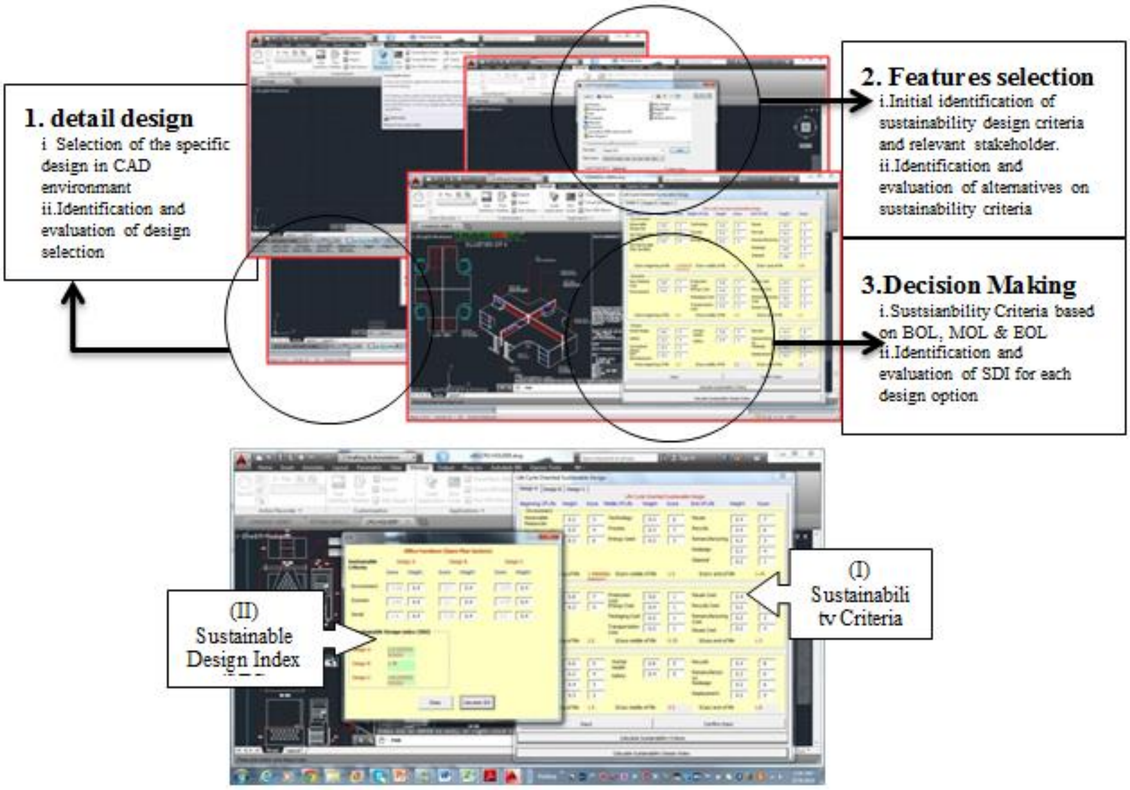


Figure 7-5: The CAD-based environment toward sustainability

An input form expert was required in order to determine the qualified weight of the dimensions of sustainability. Respective members were requested to evaluate a favourite factor of each dimension comparative to a different dimension following a scale of 1 to 9. Considering the issues of sensitivity, the relative weight assessment forms the AHP matrix for each member was compiled and the means of the values calculated. Similarly, pair-wise comparisons of indicators for each category of sustainability were performed to determine the relative weight of the indicators selected. The components of the OPS pair-wise comparison matrix are shown in Table 7-2. The relative weight of the indicators for each category of the OPS was calculated as described in Table 7-3. The normalised score for each indicator was evaluated as shown in Table 7-4. Therefore, expert opinion is required for the ranking of these components of OPS, and these will be incorporated into the SDI model.

Next, the interdependent relationship were calculated for 15 OPS modular components and the DSM to a 15 x 15 square, using the proposed weighting method (Equation 4) which assigns weight to the dependency strength between each pair of product components. This is shown in Table 7-3.

Table 7-2: Component for workstation

	Category	Priority	Rank	Weight
1	Work surface	22.9%	1	0.115
2	Panel	14.7%	2	0.094
3	Wire basket	14.0%	3	0.100
4	Suspended panel	11.4%	4	0.099
5	Fix pedestal	8.3%	5	0.077
6	Mobile pedestal	5.0%	6	0.045
7	Side panel	4.4%	7	0.041
8	Metal leg	3.6%	8	0.034
9	Wood leg	2.8%	10	0.024
10	Hanging cabinet	2.9%	9	0.025
11	Hanging shelve	2.8%	11	0.023
12	Connector	2.3%	12	0.022
13	L bracket	1.7%	13	0.014
14	Glass panel	1.7%	14	0.011
15	Side table	1.4%	15	0.008

Table 7-3: The resulting weight for components of the workstation are based on the principal eigenvector of the decision maker

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	5.00	4.00	4.00	6.00	7.00	7.00	6.00	6.00	4.00	4.00	7.00	7.00	4.00	7.00
2	0.20	1	3.00	3.00	4.00	4.00	5.00	6.00	5.00	4.00	5.00	4.00	6.00	6.00	6.00
3	0.25	0.33	1	4.00	4.00	4.00	6.00	6.00	6.00	6.00	4.00	6.00	5.00	5.00	6.00
4	0.25	0.33	0.25	1	4.00	4.00	4.00	6.00	7.00	6.00	6.00	5.00	6.00	5.00	5.00
5	0.17	0.25	0.25	0.25	1	4.00	5.00	5.00	4.00	4.00	4.00	6.00	6.00	4.00	4.00
6	0.14	0.25	0.25	0.25	0.25	1	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
7	0.14	0.20	0.17	0.25	0.20	0.33	1	3.00	3.00	3.00	3.00	4.00	4.00	3.00	3.00
8	0.17	0.17	0.17	0.17	0.20	0.33	0.33	1	3.00	3.00	3.00	3.00	3.00	3.00	3.00
9	0.17	0.20	0.17	0.14	0.25	0.33	0.33	0.33	1	3.00	3.00	4.00	1.00	1.00	1.00
10	0.25	0.25	0.17	0.17	0.25	0.33	0.33	0.33	0.33	1	3.00	3.00	3.00	3.00	3.00
11	0.25	0.20	0.25	0.17	0.25	0.33	0.33	0.33	0.33	0.33	1	4.00	4.00	3.00	3.00
12	0.14	0.25	0.17	0.20	0.17	0.33	0.25	0.33	0.25	0.33	0.25	1	5.00	5.00	3.00
13	0.14	0.17	0.20	0.17	0.17	0.33	0.25	0.33	1.00	0.33	0.25	0.20	1	3.00	3.00
14	0.25	0.17	0.20	0.20	0.25	0.33	0.33	0.33	1.00	0.33	0.33	0.20	0.33	1	3.00
15	0.14	0.17	0.17	0.20	0.25	0.33	0.33	0.33	1.00	0.33	0.33	0.33	0.33	0.33	1

Table 7-5 shows the normalised sum of the OPS which expresses the relative adequacy of the model to the criterion. The more it outperforms the others, the higher its values. Here the ranking of the OPS is computed from the normalised data.

Table 7-4: Normalised data for the open plan system and the weights for each components

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.273	0.559	0.384	0.282	0.282	0.260	0.209	0.157	0.143	0.103	0.100	0.138	0.128	0.081	0.130
2	0.055	0.112	0.288	0.212	0.188	0.148	0.149	0.157	0.119	0.103	0.125	0.079	0.110	0.122	0.111
3	0.068	0.037	0.096	0.282	0.188	0.148	0.179	0.157	0.143	0.155	0.100	0.118	0.091	0.101	0.111
4	0.068	0.037	0.024	0.071	0.188	0.148	0.119	0.157	0.167	0.155	0.149	0.099	0.110	0.101	0.093
5	0.046	0.028	0.024	0.018	0.047	0.148	0.149	0.131	0.095	0.103	0.100	0.118	0.110	0.081	0.074
6	0.038	0.028	0.024	0.018	0.012	0.037	0.090	0.078	0.072	0.078	0.075	0.059	0.055	0.061	0.056
7	0.038	0.022	0.016	0.018	0.009	0.012	0.030	0.078	0.072	0.078	0.075	0.079	0.073	0.061	0.056
8	0.046	0.019	0.016	0.012	0.009	0.012	0.010	0.026	0.072	0.078	0.075	0.059	0.055	0.061	0.056
9	0.046	0.022	0.016	0.010	0.012	0.012	0.010	0.009	0.024	0.078	0.075	0.079	0.018	0.020	0.019
10	0.068	0.028	0.016	0.012	0.012	0.012	0.010	0.009	0.008	0.026	0.075	0.059	0.055	0.061	0.056
11	0.068	0.022	0.024	0.012	0.012	0.012	0.010	0.009	0.008	0.009	0.025	0.079	0.073	0.061	0.056
12	0.038	0.028	0.016	0.014	0.008	0.012	0.007	0.009	0.006	0.009	0.006	0.020	0.091	0.101	0.056
13	0.038	0.019	0.019	0.012	0.008	0.012	0.007	0.009	0.024	0.009	0.006	0.004	0.018	0.061	0.056
14	0.068	0.019	0.019	0.014	0.012	0.012	0.010	0.009	0.024	0.009	0.008	0.004	0.006	0.020	0.056
15	0.038	0.019	0.016	0.014	0.012	0.012	0.010	0.009	0.024	0.009	0.008	0.007	0.006	0.007	0.019

In order to normalise the reciprocal matrix values into common scale, each elements of vertical columns needs to divided by it sum. The next step is to set priorities for each of criteria by dividing the sum of each row by the total number of criteria that were evaluated see table 7-5.

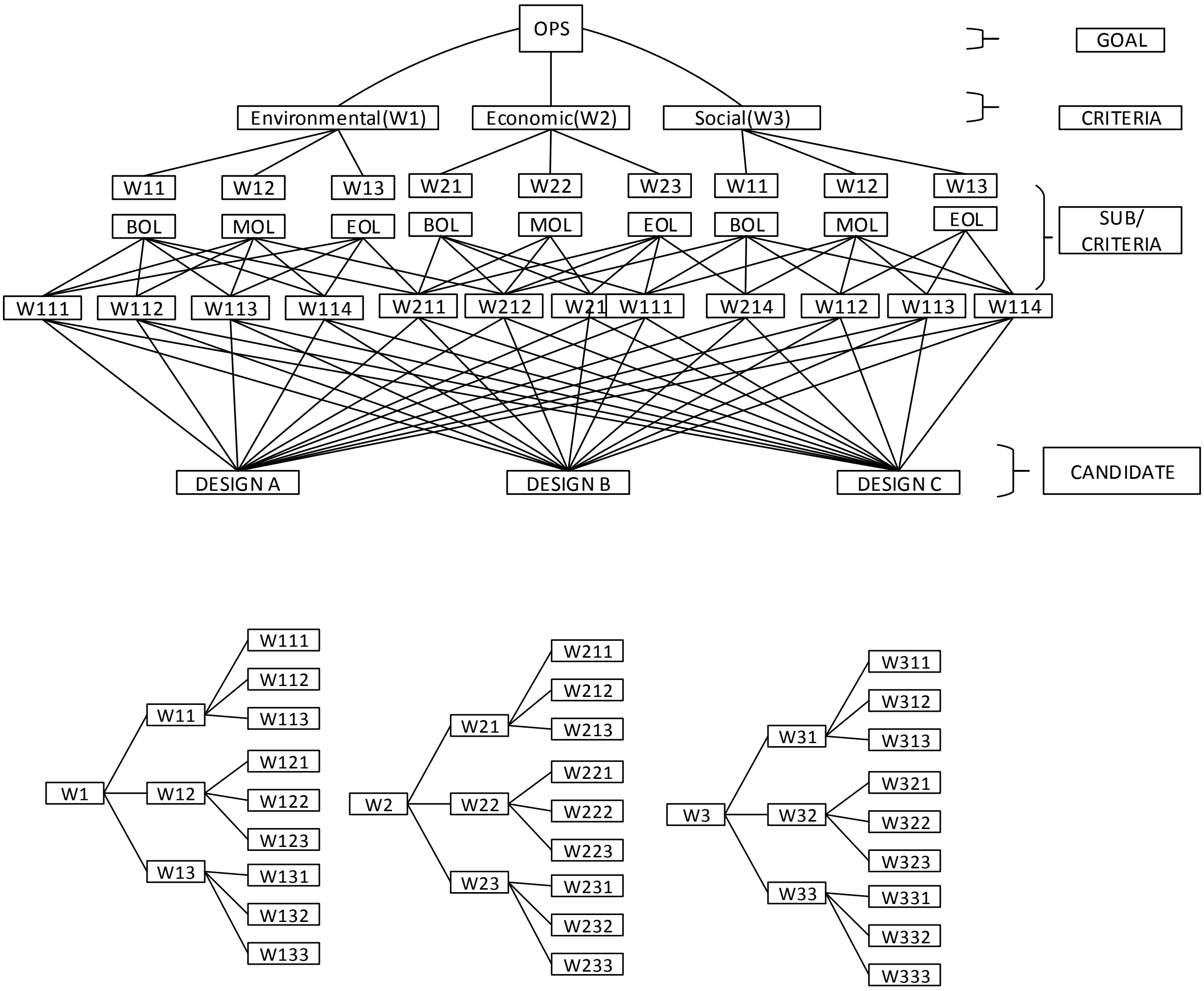


Figure 7-6: The sustainability criteria selection

The Figure 7.6 graphically shows the idea of the sustainable criteria selection within the AHP model. As one can see, it is dividing into four layers, goal definition, three main criteria, twenty one sub-criteria and the final layer of hierarchy is a short list of potential the best design selection. Each criterion is linked to the BOL, MOL, and EOL through its sub-criteria. In the figure one can see that several BOL, MOL, and EOL are going to be evaluated. The overall rating for each individual BOL, MOL, and EOL will be calculated separately with regard to the given priorities.

In order to build a hierarchical tree first the problem need to be defined and a goal needs to be set. The rule is to investigate the best design selection toward sustainability which the final objective is to present the best possible product for the end user especially for office furniture namely open plan system. The bottom list is to list all the alternative options that passed the pre-selection stage. In the case I have selected three design selection that to suit the SDI CAD environment that meet the minimum requirements, after that the final collected information is needed in order to decide the best design toward sustainability.

The criteria for sustainable criteria "Life Cycle Oriented Sustainable Design" all concern quality and aesthetic the office furniture design selection. However, these aspects have be include as sustainability criteria as concern the extending or maximising the lifetime of a furniture, which is can minimising the environmental impact.

7.6.2 SDI Computation

The equation derived from SMART is the simplest of the MAUT methods. The different level of knowledge and the priorities of the group designer and expert are expressed by the voting power, both for weighting the criteria and qualifying (scoring) the alternative against the criteria. The method for calculating the sustainability criteria (SC) of alternative is as follows the equation 6.

Where the symbol (SCenv) denotes the sustainability criteria, Si is the impact factor based on a ranking of 0 to 10 for the environmental elements of the material, and ωi is the weight of every factor at the material stage. The value of the social (SCsoc) and economic (SCeco) elements of the materials can be calculated in a similar procedure as follows recall back the equation 7 and equation 8.

The main reason for using the rating and weight factor method is that it allows an expert to allocate values to non-quantifiable parameters and thus provide a base from which the various types of criteria can be deduced. The three criteria of environmental, social and economic factors were collected and calculated. An example result is shown in Table 7-5 and the three criteria were combined within the SDI. The weights of the three criteria were derived from the pair-wise evaluation matrix as assessed by the design team member. It is calculated for each option by the multiplication of each value by the weight, followed by summing the weight scores for all the criteria using the weight summation method. The best design option has the highest score in the sustainability design index and the higher sustainability index, the better the option. Once the criteria are standardised, they can be incorporated into a decision-making model. The SDI model can be expressed as follows. The higher the sustainability index, the better the option. Once the criteria are standardised, they can be incorporated into a decision-making model. The SDI model can be expressed as follows the equation 9 and equation 10.

Where the symbol SDI denotes the sustainable design index (SDI) and F_{env} is an environmental factor, F_{soc} is social, and F_{eco} is an economic. Each of these factors will be multiplied by the weight. The total is shown in Table 7-7; this example shows that option B has the higher score, meaning that design option B is the better option for the sustainable design index. The SDI values for each design option vary between 0 (most unsustainable) and 10 (most sustainable). The umbrella of sustainability assessment tool consists of indicators and indices. Indicators must be simple to measure, and quantifiable, thus allowing the trend to be determined.

New methods for SDI are the outcome of this study along with an investigation of the areas relevant to the designer's work, and the effectiveness of sustainable design relating to an OPS office furniture system as shown in Table 7-7. Data analysis was carried out with final calculations. The data collection inquiry is aimed at designers whose expertise is in the area of furniture OPSs.

Table 7-5: The sustainability criteria for sustainable design

Sustainability Criteria	Life cycle oriented sustainable design								
	Beginning of life (BOL)	Weight	Score	Middle of life (MOL)	Weight	Score	End-of life (EOL)	Weight	Score
Environment	Renewable resources	0.5	3	Technology	0.4	6	Reuse	0.4	7
Environment	Non-renewable (durable)	0.4	4	Process	0.3	7	Recycle	0.3	6
Environment	Non-renewable (non-durable)	0.3	6	Energy Used	0.2	3	Remanufacturing	0.2	3
Environment		-	-	-	-	-	Redesign	0.9	4
Environment		-	-	-	-	-	Disposal	0.8	1
Environment	*SCenv beginning of life*		1.6	*SCenv middle of life*		1.7	*SCenv end of life*		1.92
Economic	Raw material cost	0.8	7	Production Cost	0.6	7	Reuse Cost	0.4	7
Economic	Procurement	0.2	4	Energy Cost	0.4	5	Recycle Cost	0.2	6
Economic		-	-	Packaging Cost	0.2	3	Remanufacturing Cost	0.2	3
Economic		-	-	Transportation Cost	0.2	2	Redesign Cost	0.2	3
Economic	*SCeco beginning of life*		3.2	*SCeco middle of life*		1.8	*SCeco end of life*		1.3
Society	Detail design	0.6	5	Worker Health	0.6	5	Recycle	0.4	8
Society	Safety	0.3	4	Safety	0.4	5	Remanufacturing	0.3	6
Society	Conceptual design	0.4	3	-	-	-	Redesign	0.2	6
Society	Part manufacturing	0.3	2	-	-	-	Replacement	0.2	5
Society	*SCsoc beginning of life*		1.5	*SCsoc middle of life*		2.5	*SCsoc end of life*		1.8

With regard to the sustainability criteria development table, all the criteria should be considered during the decision making process. Incorporating these factors may take place on a feasibility study case as shown in Table 7-7.

Table 7-6: Partial weight and ranking

	Environmental	Economic	Social	Weight	Ranking
Environmental	1.000	2.000	5.000	0.545	1
Economic	0.500	1.000	6.000	0.370	2
Social	0.200	0.167	1.000	0.085	3

The ranking of these environmental impacts is summarised in Table 7-6. These three issues are considered during the SDI calculation. There is no doubt that the environmental factor is the highest ranking in this study. For the weight used for calculating the SDI, equal weightings seem to be the norm.

Table 7-7: The SDI calculation

Sustainable Criteria	Office Furniture (Open Plan System)					
	Design A		Design B		Design C	
	Score	Weight	Score	Weight	Score	Weight
Environment	5.22	0.545	7.5	0.545	6	0.545
Economic	6.30	0.369	8	0.369	5.55	0.369
Social	5.8	0.084	5.55	0.084	4.55	0.084
Sustainable design index (SDI)	1.885		2.501		1.900	

It can be determined from Figure 7-7 that all the design options (design A, design B, and design C) can be compared with each other based on the SDI formulation given by equation 10. The SDI values for all the design options have the same weight, which 0.545 for environmental, 0.369 economic and 0.084 social. It can be seen in Figure 7-7, that Design B has the highest SDI value (2.501). This is likely to be because design B not only has relatively high sub-indicator values, but also has a better weighting scale among different sub-indicators.

As shown in Figure 7-7, the design options for OPS and comparisons of SDI, values show that design B is the best sustainable design. As described earlier, a verification of the office furniture OPS and the principal SDI are required. Consequently, when a final decision is to be taken, a weighting of each part and component must be conducted. The furniture designer’s call for an expert should thus come in the common weighting procedure, as this could give guidance to the final decision. A weighting procedure could be based on suggested methods for AHP.

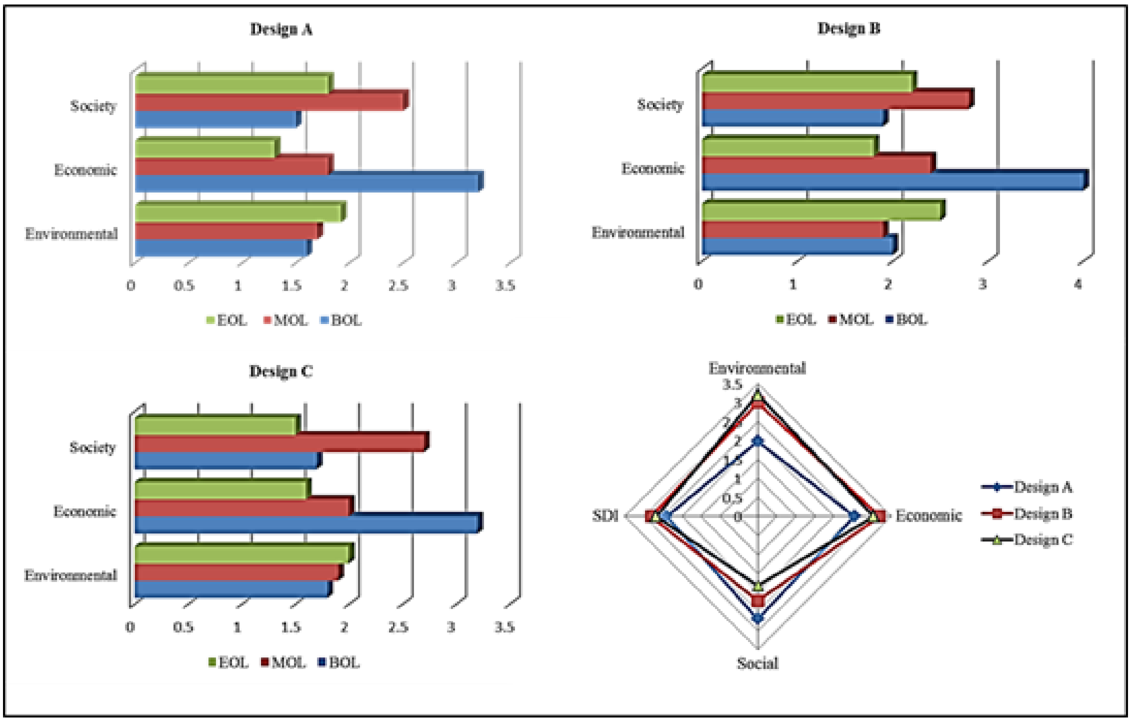


Figure 7-7: The design option calculates using the SDI tool

Another aspect that has been examined is module declarations. In order to avoid the discussion around adding the sustainability criteria for BOL, MOL, and EOL, the weight normalisation is applied and can be used to add the information and thus present updated SC *env*, *eco*, and *soc* accordingly. This ensures that the SDI weightings added are consistent. According to (Ramani *et al*., 2010) early decisions can have a very significant impact on sustainability. This does not just refer to material and manufacturing alternatives, but has a far-reaching effect on the product's entire life cycle, including shipping, circulation, and end-of-life logistics.

7.7 Summary

This research presents the SDI concept by integrating modularity and re-configurability, AD, and DSM to assist the design process for office furniture OPS. The Sustainable Design Index (SDI) is formulated as a unique design "indicator" to analyse the design sustainability within the design process. SDI and the associated algorithms are investigated in light of the qualitative analysis approach, particularly by taking account of their implementation within computer-aided engineering design environments. Office furniture design is taken as an industrial case study because of its sensitivity to mass manufacturing, costs, life cycle, materials, and societal aspects, although the approach developed is applicable to wide design scenarios. The integration of CAD and SDI provides the user with complete visibility of the design process within the CAD environment without switching to other systems. This integration enables computing and analysis of SDI through the automation of design tasks that is traditionally undertaken manually. Using SDI-oriented design methods for designing office furniture OPS substantially helps designers and customers to address environmental and sustainability concerns. Furthermore, the development of an SDI tool and its application in an adaptive smart CAD environment helps to interpret the unique role of sustainability aspects in realizing sustainable office furniture. This in turn can help to enhance the designer's experience, knowledge and creativity by working seamlessly with sustainable design analysis in the design process.

8 Conclusions and Recommendation for Future Work

This chapter presents the main conclusion and summarises the major contributions of this thesis. The future work section highlights those research areas where the findings of this research could be expended upon to further broaden the scope of this research.

8.1 Conclusions

In conclusion, the objective of the research has been successfully achieved the target. For the first objective of this research was to gain the understanding of sustainable design applied to furniture design for the design phase. In the earliest stage of my research, and the research I did fund focused primarily on the effect of sustainable design on the early decision making of design process. The approached used the analytical means the used of analysis to solve the problem. The process is a step of design process series to achieve a goal, where the outcome is almost always more comprehensive and more effective to the furniture manufacturer. The analytical approach is use of an appropriate process to break down a problem into the smaller parts and easier problem to solve.

For the second objective which is to analyse the criteria of sustainable design and applicable to furniture design has been met. The analyses of the criteria selected by the expert in design team and manage sustainability consideration in an early design phase and also in the early decision making. In my literature review on this topic, I have found what I believe to be several significant method that are able to suggest ideas for office furniture that will better promote the sustainable design index.

The third objective was to develop tools for supporting sustainable design and decision making for any design stage across the preliminary furniture design process. The

SDI has been successfully developed as an intuitive decision support tool, which are the tools that embedded in CAD environment for evaluating the office furniture especially open plan system. The SDI system for evaluating and proposed as a solution for sustainable design index that related to the environmental, social, and economic impact to the product proposal. The SDI system operate automatically, the designer is able to make a changes and putting the weighting factor for each sustainable criteria for beginning of life (BOL) middle of life (MOL) and end of life (EOL) accordingly and observe the significance. This make the SDI tool a user friendly and spontaneous aid to sustainable design process.

Finally, for the last objective which is to applying the sustainable furniture design by focusing the tools, analytics, SDI, innovation and industrial implementation. Which is the last objective to validate the practicality and the effectiveness of the SDI tool has been meet by examining through the case study of the office furniture i.e. open plan system for manager work station, executive work station and clerical work station. The case study show the result of the sustainable furniture through the sustainable design index , with regard the sustainability criteria should be consider during the decision making process. The best design showed the highest sustainable design index means the better option for that particular design consider the environmental factor, economic factor and social factor.

This thesis has investigated the issues of sustainability within the furniture product development has been successfully developed and demonstrated through case studies. The research was developed a sustainable design index (SDI) framework for the design phase. The SDI framework was designed to be easily understood the method and applied to the furniture design process and aid in the decision-making stage. The tool for this research and also the application were adapted from the design method, namely modularity and re-configurability, design structure matrix and axiomatic design, computer aided design (CAD), and analytical hierarchy process (AHP) has successfully applied in a part of this research to understand the application.

The thesis presents a sustainable design index (SDI), that attempt to understand the impact of the environment the product life-cycle of furniture design was using an open plan system (OPS). The decision making made in earlier design process is a more effective solution for the entire product life-cycle especially for furniture design innovation. Furthermore the product innovation is essential for any company, especially in furniture industries who need to consider the competitive product in a niche market that also to cater for the environmental issues. Furniture companies that effectively integrate innovation in the product development due to the rapidly changing customer demand are not always facing competition from open market and globalization. Furniture design innovation happens with three types of categorised. From this research found that the companies applied this method which is incremental, radical, and fundamental processes are always depending on the company strategy as needed. Furthermore, furniture companies every year must produce a new range or series of furniture product, to deal with the increasing competition with new markets, new ways of serving customer, national and international market. Due to the demand and request from customer in furniture industries, especially industrial design takes place an innovation effort from both aspects the incremental or radical perspective work as a their main task. Fundamental innovations often take place when a new product range is involved within the research and development (R & D) department, to compete with local and open market. The radical innovation involves when, most of the furniture product know as modular design and needs the arrangement with a variety of configurations.

The importance of sustainability to a furniture product implemented in the product design process has been emphasized in this research. The early decision-making for solving the problems at the conceptual stage under the sustainability concern has been addressed in this research. At the same time, the approach to develop a new tool SDI to help the designer reconsider how to design and produce product to improve the profit and to reduce the environmental impact has been addressed in this research.

As a result, the SDI tool making a sustainable design concern to office furniture design, also to meet and fulfil the consumers need to find the best for environmental, economic, and social impact. Furthermore, for furniture product the drastically changing the design and demand is not promising the designer able to handle and determine the sustainability decision-making without having an appropriate decision tool. The purpose of sustainable design index (SDI) is to ensure that the important aspect of the sustainability criteria, the environmental, economic, and society aspect are included, and that the design expert of office furniture can find a measure that applies. The results of this phase are design criteria that can be ranked and weighted for use in automate SDI.

8.2 Contributions to Knowledge

The initial goal for this research was to determine the method and practices of sustainable design were best suited to promote and effect environmentally to office furniture. The main research contribution made in the process relates to the integration of environmental consideration into each aspect of product design, and manufacturer for office furniture namely open plan system. The proposed sustainable design index (SDI) as the tools fill that important research gap in the field of sustainable design index. The SDI framework can contribute to the body of knowledge in the field by facilitating the application of sustainability criteria in the early design process. Continual exploration and understanding of the design process is necessary to advance and encourage implementation of this valuable tool in the field of office furniture.

From this research a new method has been introduced, that integrating of modularity and re-configurability, design structure matrix, axiomatic design, and computer aided design (CAD) to formulate the sustainable design index (SDI) to help designers make in early decision-making for furniture products. A sustainable design index (SDI) has been developed to assist the designer to make a decision toward sustainability using the new feature within the CAD-based environment is a systematic manner. Based on the standard modules and furniture part and components database, it will help the designer or furniture expert to come up with a variety of configurations for open plan system (OPS) to satisfy the customer requirement and enhance with the sustainability considerations of each of the design proposals. A CAD user interface of a computer SDI tool builds within the CAD interface help the designer make an early decision toward sustainable furniture products. A CAD user interface has been developed to help automated the sustainable design in CAD environment.

8.3 Recommendations for Future Work

Although the sustainability criteria and sustainable design index were identified, the development, evaluation model is only limited to the design stage level. It was through feedback from the interview and conference participants, that the decision-making might be interpreted in different ways even once the final sustainable design index (SDI) was provided. In the development Of SDI, the sustainability criteria that cover three pillars, environmental, economic, and social aspects, throughout the entire product life cycle the beginning of life, middle of life and end of life. However, for some of the criteria, it is difficult to obtain the information to evaluate the weight and score for sustainability assessment. Therefore, there is a need to develop a databased to store sustainability criteria and product information, if needed especially to expedite the time concern.

Furthermore, from the result based on the SDI index the outcome will produce different decision styles; due to the design team have multidisciplinary members with a vast level of experience and expertise. The concern is on the decision–making score as each the hierarchical evaluation takes a detail evaluation criteria, so the weighting among different criteria should be considered, especially involved with different process and also different product. To do that the further research effort need to consider of this matter.

The illustration scheme presented in this thesis is only on step towards capturing information within the design process. Due to that the creation and series of sustainability questions based on expert information sources, however it may possible to expend upon these questions based on the investigation of additional sources. It would also be valuable to explore ways of formally incorporating this matric into the design process in order to ensure the sustainability is a primary driver.

In my research and analysis presented in this thesis, I feel as though I have only scratched the surface of a very complex the axiomatic design and design structure matrix, and I continued study of this topic so that, as a designer or expert in office furniture may progress toward sustainability through the sustainable design index, but also by the people who that involved with the design process. I feel the topic discussed in this research offer the possibilities role that designer can used the sustainable design index as a groundwork for future research on the effect of sustainable design for office furniture on environmental, economic, and social impact. It is my hope that in the pursuit of this understanding, the designer or expert will be able to develop a model of sustainable design to be employed in the built of modularity and re-configurability, axiomatic design, and design structure matrix in order to affect environmentally sustainability activity and helps automate the design process.

References

Adams, W., 2006. The future of sustainability: Re-thinking environment and development in the twenty-first century. *Report of the IUCN renowned thinkers meeting*. [Accessed January 5, 2016].

Adhikaril, I., Kim, S. & Lee, Y., 2006. Selection of Appropriate Schedule Delay Analysis Method : Analytical Hierarchy Process (AHP). , (c), pp.9–13.

Adu, G. et al., 2014. Office Furniture Design – Correlation of Worker and Chair Dimensions. *International Journal of Science and Research (IJSR)*, 3(3), p.7.

Agrawal, A., 2009. Product networks, component modularity and sourcing. *Journal of Technology Management and Innovation*, 4(1), pp.59–81.

Anastas, P. & Zimmerman, J., 2007. Design through the 12 principles of green engineering. *IEEE Engineering Management Review*. [Accessed January 5, 2016].

Anon, jointing design in open plan system for oofice sharizal dollah.pdf.

Application, F. et al., 1989. United States Patent [191 Date of Patent :

Ashby, M. & Johnson, K., 2013. *Materials and design: the art and science of material selection in product design*.[Accessed January 6, 2016].

Azapagic, a., Millington, a. & Collett, a., 2006. A methodology for integrating sustainability considerations into process design. *Chemical Engineering Research and Design*, 84(6), pp.439–452.

Azapagic, a. & Perdan, S., 2000. Indicators of sustainable development for industry: a general framework. *Trans IChemE*, 78(July), pp.243–261.

Bei, F. & Yan, Y., 2011. A perspective of novel design and creativity in the development of furniture. *CCIE 2011 - Proceedings: 2011 IEEE 2nd International Conference on Computing, Control and Industrial Engineering*, 1, pp.109–112.

Besch, K., 2005. Product-service systems for office furniture: barriers and opportunities on the European market. *Journal of Cleaner Production*, 13(10-11), pp.1083–1094. [Accessed November 26, 2015].

Böhringer, C. & Jochem, P.E.P., 2007. Measuring the immeasurable - A survey of sustainability indices. *Ecological Economics*, 63(1), pp.1–8.

Böhringer, C. & Jochem, P.E.P., 2007. Measuring the immeasurable — A survey of sustainability indices. *Ecological Economics*, 63(1), pp.1–8. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0921800907002029.

Bosello, F. et al., 2011. INtegrating MainSTREAM Economic Indicators with Sustainable Development Objectives. Available at: http://in-stream.eu/download/INSTREAM_FSI_final.pdf [Accessed December 11, 2015].

Boughnim, N. et al., 2004a. From Manufacturing Green Office Furniture to providing Sustainable Workplace Services : A necessary change in practices , tools and approaches. *Design*, 2001, pp.1–7.

Boughnim, N. et al., 2004b. From Manufacturing Green Office Furniture to providing Sustainable Workplace Services : A necessary change in practices , tools and approaches. *Design*, pp.1–7.

Boulanger, P., 2008. „Sustainable development indicators: a scientific challenge, a democratic issue", SAPI EN. S 1 (1). *Online since*. [Accessed January 5, 2016].

Boulanger, P.-M. & Bréchet, T., 2005. Models for policy-making in sustainable development: The state of the art and perspectives for research. *Ecological Economics*, 55(3), pp.337–350.

Browning, T.R., 2001. Applying the Design Structure Matrix to System Decomposition and Integration Problems: a Review and New Directions. *Engineering Management, IEEE Transactions on*, 48(3), pp.292–306.

Byggeth, S. & Hochschorner, E., 2006. Handling trade-offs in Ecodesign tools for sustainable product development and procurement. *Journal of Cleaner Production*, 14(15-16), pp.1420–1430

Chandrasegaran, S.K.. et al., 2013. The evolution, challenges, and future of knowledge representation in product design systems. *CAD Computer Aided Design*, 45(2), pp.204–228.

Chandu, R.S., 2012. Skill Acquisition in Engineering Education for Achieving Sustainability. *2012 IEEE International Conference on Engineering Education: Innovative Practices and Future Trends (AICERA)*, pp.1–7.

Chang, D., Lee, C.K.M. & Chen, C.-H., 2014. Review of Life Cycle Assessment towards Sustainable Product Development. *Journal of Cleaner Production*, 83, pp.48–60. Available at: http://www.sciencedirect.com/science/article/pii/S0959652614007690.

Chaves, L.I., 2008. Design for sustainability : A methodological approach for the introduction of environmental requirements in the furniture sector *. *Development*, 6(December), pp.167–171.

Chen, L., Li, S. & Mo, Z., 2011. Sustainable design principles and methods for product development. *Industrial Engineering and Engineering Management (IE&EM), 2011 IEEE 18Th International Conference on*, pp.1937 – 1939.

Chen, L.C. & Chu, P.Y., 2012. Developing the index for product design communication and evaluation from emotional perspectives. *Expert Systems with Applications*, 39(2), pp.2011–2020. Available at: http://dx.doi.org/10.1016/j.eswa.2011.08.039.

Cheng, Q. et al., 2012. A product modular design method based on axiomatic design. *Proceedings of the 2012 IEEE 16th International Conference on Computer Supported Cooperative Work in Design, CSCWD 2012*, pp.282–288.

Cheng, Q. et al., 2015. A product module identification approach based on axiomatic design and design structure matrix.

Cheng, S.-C. et al., 2007. Semantic-based facial expression recognition using analytical hierarchy process. *Expert Systems with Applications*, 33(1), pp.86–95. Available at: http://www.sciencedirect.com/science/article/pii/S0957417406001229.

Chu, C.-H. et al., 2009. Economical green product design based on simplified computer-aided product structure variation. *Computers in Industry*, 60(7), pp.485–500.

Cooper, I., 2002. Transgressing discipline boundaries: is BEQUEST an example of “the new production of knowledge”? *Building Research & Information*, 30(2), pp.116–129.

Coyle, G., 2004. The Analytic Hierarchy Process (AHP). *Principal Strategy. Open Access Material.*, (1980), pp.1–11.

Van Dijk, C.G.C., 1995. New insights in computer-aided conceptual design. *Design Studies*, 16(1), pp.62–80.

Ding, G.K.C., 2008. Sustainable construction—The role of environmental assessment tools. *Journal of Environmental Management*, 86(3), pp.451–464.

DiSano, J., 2002. Indicators of sustainable development: Guidelines and methodologies. *United Nations Department of Economic and Social* . [Accessed December 7, 2015].

Dong, Q. & Whitney, D.E., 2001. Designing a Requirement Driven Product Development Process. *Proceedings of DETC 2001*.

Ebert, U. & Welsch, H., 2004. Meaningful environmental indices: A social choice approach. *Journal of Environmental Economics and Management*, 47(2), pp.270–283.

Economic, U.N.D. of, 2001. *Indicators of sustainable development: Guidelines and methodologi.* [Accessed December 7, 2015].

Economies, D., Design for Sustainability a practical approach for Developing Economies.

Ekholm, A., 2001. Activity objects in CAD-programs for building design A prototype program implementation. , pp.1–14.

Elkington, J., 2001. Enter the Triple Bottom Line. *The Triple Bottom Line: Does it all Add Up?*, 1(1986), pp.1–16.

Encarnasao, J. et al., 1991. User interfaces to support the design process. , 17, pp.317–333.

Eppinger, S. & Browning, T., 2012. *Design structure matrix methods and applications*, [Accessed December 31, 2015].

Erixon, G., von Yxkull, A. & Arnström, A., 1996. Modularity – the Basis for Product and Factory Reengineering. *CIRP Annals - Manufacturing Technology*, 45(1), pp.1–6.

Fargnoli, M., 2003. The assessment of the Environmental Sustainability. *… and Inverse Manufacturing, 2003. EcoDesign'03. …*. Available at: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1322693 [Accessed January 6, 2016].

Farrell, A., 1995. Sustainability theory and the design of knowledge tools. *… of General Science Theory, 1995.'Knowledge Tools …*, pp.120–129.

Felfernig, A., Friedrich, G. & Jannach, D., 2001. Conceptual modeling for con ® guration of mass-customizable products. , 15, pp.165–176.

Fiksel, J., 2006. A Framework for Sustainable Materials Management. *Journal of Management*, 58(8), pp.15–22. Available at: http://www.springerlink.com/index/10.1007/s11837-006-0047-3.

Fiksel, J. et al., 2013. The triple value model: a systems approach to sustainable solutions. *Clean Technologies and Environmental Policy*, pp.691–702.

FIRA International Ltd, 2010. Competitiveness of the UK Furniture Industry. , pp.1 – 60. Available at: http://www.fira.co.uk/document/fira-competitiveness-report-2010.pdf.

Fox, P. et al., 2009. Teaching sustainability: Course, program and degree considerations. *Management of Engineering & Technology, 2009. PICMET 2009. Portland International Conference on*, pp.2240–2245.

Gehin, A., Zwolinski, P. & Brissaud, D., 2008. A tool to implement sustainable end-of-life strategies in the product development phase. *Journal of Cleaner Production*. [Accessed January 6, 2016].

Gemser, G., 2001. How integrating industrial design in the product development process impacts on company performance. *Journal of Product Innovation Management*, 18(1), pp.28–38.

Gershenson, J.K. & Prasad, G., 1997. Modularity in product design for manufacturability. *International Journal of Agile Manufacturing*, 1(1), pp.99–110.

Gershenson, J.K., Prasad, G.J. & Allamneni, S., 1999. Modular Product Design. *A Life-Cycle View*, 3(4), pp.13–26.

Gershenson, J.K., Prasad, G.J. & Zhang, Y., 2003. Product modularity: Definitions and benefits. *Journal of Engineering Design*, 14(3), pp.295–313

Gershenson, J.K., Prasad, G.J. & Zhang, Y., 2004. Product modularity: measures and design methods. *Journal of Engineering Design*, 15(1), pp.33–51.

Gharib, I. & Qin, S., 2013. Integration of sketch-based conceptual design and commercial CAD systems for manufacturing. *The International Journal of Advanced Manufacturing Technology*, 68(9-12), pp.2669–2681.

Ghazinoory, S., 2005. Cleaner production in Iran: necessities and priorities. *Journal of Cleaner Production*, 13(8), pp.755–762.

Golusin, M. & Ivanovic, O.M., 2009. Agriculture , Ecosystems and Environment Definition , characteristics and state of the indicators of sustainable development in countries of Southeastern Europe. , 130, pp.67–74.

Gonçalves-Coelho, a. M. & Mourão, A.J.F., 2007. Axiomatic design as support for decision-making in a design for manufacturing context: A case study. *International Journal of Production Economics*, 109(1-2), pp.81–89.

Grießhammer, R., Buchert, M. & Hochfeld, C., 2007. PROSA – Product Sustainability Assessment. , 49(0).

Guenov, M.D. & Barker, S.G., 2005. Application of axiomatic design and design structure matrix to the decomposition of engineering systems. *Systems Engineering*, 8(1), pp.29–40.

Handfield, R.B. et al., 1997. “Green” value chain practices in the furniture industry. *Journal of Operations Management*, 15(4), pp.293–315.

Harding, R., 2006. Ecologically sustainable development : origins , implementation and challenges. , 187(February 2005), pp.229–239.

Harger, E. & Meyer, M., 1996. DEFINITION OF INDICATORS FOR ENVIRONMENTALLY SUSTAINABLE DEVELOPMENT. , 33(9), pp.1749–1775.

Heijungs, R., Huppes, G. & Guinée, J.B., 2010. Life cycle assessment and sustainability analysis of products , materials and technologies . Toward a scienti fi c framework for sustainability life cycle analysis. , 95, pp.422–428.

Hervani, A., Helms, M. & Sarkis, J., 2005. Performance measurement for green supply chain management. *… : An international journal*. [Accessed January 6, 2016].

Hizsnyik, E., 2011. INtegrating MainSTREAM Economic Indicators with Sustainable Development Objectives SEVENTH FRAMEWORK PROGRAMME WP6 : Costs of sustainability (general equilibrium analysis). , 2009(February), pp.1–49.

Holtta, K.M.M., Suh, E.S. & de Weck, O.L., 2005. Tradeoff Between Modularity and Performance for Engineered Systems and Products. *Int’l Conference on Engineering Design*, pp.1–14.

Hong, E. & Park, G., 2011. Modular design method using the independence axiom and design structure matrix in the conceptual and detailed design stage. *… of 6th International Conference on Axiomatic.* [Accessed November 24, 2015].

Howard, T.J., Culley, S.J. & Dekoninck, E., 2008. Describing the creative design process by the integration of engineering design and cognitive psychology literature. *Design Studies*, 29(2), pp.160–180.

Howarth, G. & Hadfield, M., 2006. A sustainable product design model. *Materials & Design*, 27(10), pp.1128–1133.

Hsu, W. & Liu, B., 2000. Conceptual design: issues and challenges. *Computer-Aided Design*, 32(14), pp.849–850.

Huang, C.C. & Kusiak, A., 1998. Modularity in design of products and systems. *IEEE Transactions on Systems, Man, and Cybernetics Part A:Systems and Humans.*, 28(1), pp.66–77.

Huang, Q. & Zhang, N., 2008. Product conceptual design based on the idea of sustainable design. *9th International Conference on Computer-Aided Industrial Design and Conceptual Design: Multicultural Creation and Design - CAIDCD 2008*, pp.377–379.

Hussey, D.M., Kirsop, P.L. & Meissen, R.E., 2001. Global Reporting Initiative Guidelines: An Evaluation of Sustainable Development Metrics for Industry. *Environmental Quality Management*, 11(1), pp.1–20. Available at: http://dx.doi.org/10.1002/tqem.1200.

Hwang, C.-L. & Yoon, K., 1981. *Multiple Attribute Decision Making: Methods and Applications, A State-of-the-art Survey*,

Ikeda, H., Application, F. & Data, P., 1999. Ulllted States Patent [19].

Inoue, M. et al., 2012. Advanced Engineering Informatics Decision-making support for sustainable product creation. *Advanced Engineering Informatics*, 26(4), pp.782–792. Available at: http://dx.doi.org/10.1016/j.aei.2012.07.002.

Ishii, K., 1998. Modularity: a key concept in product life-cycle engineering. *Handbook of Life-cycle Engineering*, pp.511–530. Available at: http://www.ecodesign.gr/docs/ecodesign/ISHII-98.pdf.

Janthong, N., Brissaud, D. & Butdee, S., 2010. Combining axiomatic design and case-based reasoning in an innovative design methodology of mechatronics products. *CIRP Journal of Manufacturing Science and Technology*, 2(March), pp.226–239.

Jawahir, I. & Rouch, K., 2007. Design for sustainability (DFS): new challenges in developing and implementing a curriculum for next generation design and manufacturing engineers. *International Journal …*. Available at: http://www.ice2007.um.edu.my/~aznijar/shuib/ManufacturingEngineeringEducation/TP05PUB227.pdf [Accessed December 2, 2015].

Jawahir, I.. S. et al., 2006. TOTAL LIFE-CYCLE CONSIDERATIONS IN PRODUCT DESIGN FOR SUSTAINABILITY : A FRAMEWORK FOR COMPREHENSIVE EVALUATION University of Kentucky. *10th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology"*, pp.1–10.

Jenkins, W., 2003. Sustainability theory. *Encyclopedia of Sustainability*, pp.380–384.

Josefstrasse, R.A.G., 2013. Dow Jones Sustainability World Index Guide. , (December).

Joseph, F., Jeff, M. & David, S., 1998. Measuring Product Sustainability. *The Journal of Sustainable Product Design*, (July 1998).

Jr, E.T.K. et al., 2007. Effective Student Engagement with Advanced Manufacturing Concepts – a Case Study. *37th ASEE/IEEE Frontiers in Education Conference*, pp.12–16.

Kang, Y.J., 2004. The method for uncoupling design by contradiction matrix of TRIZ and case study. *Proceedings of ICAD2004 Seoul*, pp.2004–11. Available at: http://www.axiomaticdesign.com/technology/icad/icad2004/icad-2004-11.pdf.

Kates, B.R.W., Parris, T.M. & Leiserowitz, A. a, 2005. What is sustainable development? Goals, indicators, and practice. *Environment*, 47(3), pp.8–21. Available at: http://www.csa.com/partners/viewrecord.php?requester=gs&collection=ENV&recid=6248252.

Kates, R.W., 2001. ENVIRONMENT AND DEVELOPMENT: Sustainability Science. *Science*, 292(5517), pp.641–642. Available at: http://www.sciencemag.org/cgi/doi/10.1126/science.1059386.

Kellett, R., Fryer, S. & Budke, I., 2009. Specification of indicators and selection methodology for a potential community demonstration project. *Retrieved November*. [Accessed December 5, 2015].

Khan, F.I., Sadiq, R. & Veitch, B., 2004. Life cycle iNdeX (LInX): A new indexing procedure for process and product design and decision-making. *Journal of Cleaner Production*, 12(1), pp.59–76.

Kusiak, A., 1999. *Engineering design: products, processes, and systems*, Available at: http://dl.acm.org/citation.cfm?id=519665 [Accessed November 20, 2015].

Kusiak, A., 2002. Integrated product and process design: A modularity perspective. *Journal of Engineering Design*, 13, pp.223–231.

Kusiak, A., 2008. Interface structure matrix for analysis of products and processes. *LCE 2008: 15th CIRP International Conference …*, (March), pp.444–448.

LaBat, K. & Sokolowski, S., 1999. A three-stage design process applied to an industry-university textile product design project. *Clothing and Textiles Research Journal*. [Accessed January 4, 2016].

Lélé, S.M., 1991. Sustainable development: A critical review. *World Development*, 19(6), pp.607–621.

Liu, X., Qian, X. & Zhou, X., 2010. A New Approach to Realize Sustain ability Integrated Design under the Product and Service System Framework. *Ieee*.

Luh, Y., Pan, C. & Lin, W., 2010. A STUDY ON MODULAR DESIGN FOR LCD TV. , 4(5), pp.377–387.

Luisser, F.S. et al., 2010. Feasibility Analysis of Sustainability-Based Measures to Reduce. , pp.624–644.

Malmqvist,J., 2002. A Classification of Matrix-Base Methods for product Modeling. Intrenational design Conference-Design. pp. 203-210.

MacDonald, E. & She, J., 2015. Seven cognitive concepts for successful eco-design. *Journal of Cleaner Production*. [Accessed December 5, 2015].

Malhotra, M.K., Heine, M.L. & Grover, V., 2001. An evaluation of the relationship between management practices and computer aided design technology. *Journal of Operations Management*, 19(3), pp.307–333.

Manzini, E. & Vezzoli, C., 2003. A strategic design approach to develop sustainable product service systems: Examples taken from the "environmentally friendly innovation" Italian prize. *Journal of Cleaner Production*, 11(8 SPEC.), pp.851–857.

Mikkola, J.H., 2007. Management of product architecture modularity for mass customization: Modeling and theoretical considerations BT - Special Issue on Mass Customization Manufacturing Systems. *IEEE Transactions on Engineering Management*, 54(1), pp.57–69.

Mikkola, J.H. & Gassmann, O., 2003. Managing modularity of product architectures: Toward an integrated theory. *IEEE Transactions on Engineering Management*, 50(2), pp.204–218.

Nasr, N. & Thurston, M., 2006. Remanufacturing : A Key Enabler to Sustainable Product Systems. *Proceedings of LCE*, pp.15–18.

Ness, B. et al., 2007. Categorising tools for sustainability assessment. *Ecological Economics*, 60(3), pp.498–508.

Network, G., 1998. Living planet report. [Accessed December 11, 2015].

Newcomb, P., 1998. Implications of modularity on product design for the life cycle. *… Design*. [Accessed November 22, 2015].

Ng, B.K. & Thiruchelvam, K., 2012. The dynamics of innovation in Malaysia's wooden furniture industry: Innovation actors and linkages. *Forest Policy and Economics*, 14(1), pp.107–118..

Pahl, G. & Beitz, W., 2013a. *Engineering design: a systematic approach*. [Accessed November 19, 2015].

Pahl, G. & Beitz, W., 2013b. *Engineering design: a systematic approach*. [Accessed December 3, 2015].

Pan, W. & Wang, Y., 2011. Rapid Assembly Design for Solid Furniture Modeling.

Paper, B., 2012. Sustainable Development : From Brundtland to Rio 2012. *New York*, (September 2010), p.26.

Parikka-Alhola, K., 2008. Promoting environmentally sound furniture by green public procurement. *Ecological Economics*, 68(1-2), pp.472–485..

Pimmler, T., 1994. A development methodology for product decomposition and integration. Available at: http://dspace.mit.edu/handle/1721.1/12068 [Accessed November 28, 2015].

Pope, J., Annandale, D. & Morrison-Saunders, A., 2004. Conceptualising sustainability assessment. *Environmental Impact Assessment Review*, 24(6), pp.595–616.

Program, U.N.E., 2008. Sustainable procurement guidelines for office furniture. *Unep*, (May). Available at: http://www.pnuma.org/industria/esp/documentos/compras sustentables/UNEP Purchasing criteria - furniture - Product Sheet.pdf.

Pugh, S., 1991a. Total design: integrated methods for successful product engineering. [Accessed January 5, 2016].

Pugh, S., 1991b. Total design: integrated methods for successful product engineering. [Accessed December 17, 2015].

Quinn, L. & Baltes, J., 2009. Leadership and the triple bottom line: bringing sustainability and corporate social responsibility to life. *… Center for Creative Leadership Research White Paper. …*. [Accessed November 26, 2015].

Ramani, K. et al., 2010. Integrated Sustainable Life Cycle Design: A Review. *Journal of Mechanical Design*, 132(9), p.091004.

Reay, S.D., Mccool, J.P. & Withell, A., 2011. Exploring the Feasibility of Cradle to Cradle (Product) Design : Perspectives from New Zealand Scientists. *Journal of Sustainable Development*, 4(1), pp.36–44.

Resolution, G., 2005. World Summit Outcome. *A/Res/60/1*. [Accessed January 5, 2016].

Rockström, J. et al., 2009. Planetary boundaries: Exploring the safe operating space for humanity. *Ecology and Society*, 14(2), pp.472–475.

Rosen, M.A. & Kishawy, H.A., 2012. Sustainable Manufacturing and Design: Concepts, Practices and Needs. , pp.154–174.

Royce, D.W.W., 1970. Managing the Development of large Software Systems. *Ieee Wescon*, (August), pp.1–9.

Ruggles, A. & Linder, B., 2012. Guide to sustainable design using solidworks sustainability. [Accessed January 5, 2016].

Saaty, T., 1983. Priority Setting in Complex Problems. *Ieee Transactions on Enigneering Management*, 3(June 1982), pp.140–155.

Saaty, T.L., 1999. Basic Theory of the Analytic Hierarchy Process : How To Make a Decision. *Revista de la Real Academia de Ciencias Exactas, Físicas y Naturales (Esp)*, 93(JANUARY 1999), pp.395–423.

Saaty, T.L., 2008. Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1(1), p.83.

Sagar, A.D. & Najam, A., 1998. The human development index: A critical review. *Ecological Economics*, 25, pp.249–264.

Salhieh, S.M. & Kamrani, A.K., 1999. Macro level product development using design for modularity. *Robotics and Computer-Integrated Manufacturing*, 15(4), pp.319–329.

Salvati, L. & Zitti, M., 2009. Substitutability and weighting of ecological and economic indicators: Exploring the importance of various components of a synthetic index. *Ecological Economics*, 68(4), pp.1093–1099.

Schmidt, W.-P. & Taylor, A., 2006. Ford of Europe ' s Product Sustainability Index. *13th CIRP INTERNATIONAL CONFERENCE ON LIFE CYCLE ENGINEERING*, pp.5–10.

Schwarz, J., Beloff, B. & Beaver, E., 2002. Use sustainability metrics to guide decision-making. *Chemical Engineering Progress*, 98(7), pp.58–63.

Seevers, K.D., Badurdeen, F. & Jawahir, I.S., 2013. Sustainable Value Creation through Innovative Product Design. *Gcsm.Eu*, pp.61–66.

Seliger, G. & Zettl, M., 2008. Modularization as an enabler for cycle economy. *CIRP Annals - Manufacturing Technology*, 57(1), pp.133–136.

Sharifi, A. & Murayama, A., 2013. A critical review of seven selected neighborhood sustainability assessment tools. *Environmental Impact Assessment Review*, 38, pp.73–87.

Shuaib, M. et al., 2014. Product Sustainability Index (ProdSI). *Journal of Industrial Ecology*, 18(4), pp.491–507.

Siche, J. et al., 2008. Sustainability of nations by indices: Comparative study between environmental sustainability index, ecological footprint and the emergy performance indices. *Ecological Economics*. A [Accessed January 6, 2016].

Sims, J., 1997. Us5660120.

Singh, B. et al., 2007. Enabling Design Constraints in. *Assembly*, (August), pp.1–9.

Singh, R.K. et al., 2012. An overview of sustainability assessment methodologies. *Ecological Indicators*, 15(1), pp.281–299. y.

Singh, R.K. et al., 2007. Development of composite sustainability performance index for steel industry. *Ecological Indicators*, 7(3), pp.565–588.

Skerlos, S.J., Morrow, W.R. & Michalek, J.J., 2006. Sustainable Design Engineering and Science : Selected Challenges and Case Studies. *Sustainability Science and Engineering: Defining Principles*, pp.477–525.

Slappendel, C., 1996. Industrial design utilization in New Zealand firms. *Design Studies*, 17(1), pp.3–18.

Smardzewski, J., 2015. *Furniture Design*,

Sosa, M.E., Eppinger, S.D. & Rowles, C.M., 2007. A Network Approach to Define Modularity of Components in Complex Products. *Journal of Mechanical Design*, 129(11), p.1118.

Standards, O.F., 2013. Office Furniture Standards. , (December).

Staniškis, J.K. & Arbačiauskas, V., 2009. Sustainability Performance Indicators for Industrial Enterprise Management. *Institute Environmental Engineering, Kaunas University of Technology, Lithuania*, 2(2), pp.42–50.

Steward, D. V., 1981. Design Structure System: A Method for Managing the Design of Complex Systems. *IEEE Transactions on Engineering Management*, EM-28(3), pp.71–74.

Stone, R.B., Wood, K.L. & Crawford, R.H., 2000. A heuristic method for identifying modules for product architectures. *Design Studies*, 21(1), pp.5–31.

Su, D., 2010. Parametric design for the Furniture based on module. *2010 International Conference on Networking and Digital Society*, pp.422–425.

Subic, A., Mouritz, A. & Troynikov, O., 2010. Sustainable design and environmental impact of materials in sports products. *Sports Technology*, 2(3-4), pp.67–79.

Suh, N., 2001. Axiomatic Design: Advances and Applications (The Oxford Series on Advanced Manufacturing). [Accessed January 5, 2016].

Suh, N., 1990. *The principles of design*, [Accessed January 5, 2016].

Tan, C.L. & Vonderembse, M. a., 2006. Mediating effects of computer-aided design usage: From concurrent engineering to product development performance. *Journal of Operations Management*, 24(5), pp.494–510.

Tovey, M., 1997. Styling and design: intuition and analysis in industrial design. *Design Studies*, 18(1), pp.5–31.

Tseng, H.E., Chang, C.C. & Li, J.D., 2008. Modular design to support green life-cycle engineering. *Expert Systems with Applications*, 34(4), pp.2524–2537.

Ullman, D., 2009. The mechanical design process. [Accessed November 20, 2015].

Ulrich, K., 2003. Product design and development. [Accessed November 19, 2015].

Ulrich, K., 1995. The role of product architecture in the manufacturing firm. *Research Policy*, 24(3), pp.419–440.

Ulrich, K., 1995. The role of product architecture in the manufacturing firm. *Research policy*. [Accessed November 20, 2015].

Ulrich, K. & Eppinger, S., Product design and development. 2004. *Boston, MA: McGraw-Hill/Irwin*. [Accessed November 19, 2015].

Umeda, Y. et al., 2008. Product modularity for life cycle design. *CIRP Annals - Manufacturing Technology*, 57(1), pp.13–16.

Vezzoli, C. et al., 2014. *Product-service system design for sustainability*. [Accessed December 16, 2015].

Villalba, G. et al., 2004. Using the recyclability index of materials as a tool for design for disassembly. *Ecological Economics*. [Accessed December 13, 2015].

Waage, S.A., 2007. Re-considering product design : a practical "' road-map '" for integration of sustainability issues. , 15, pp.638–649.

Wallace, K. & Burgess, S., 1995. Methods and tools for decision making in engineering design. *Design Studies*, 16, pp.429–446.

Wang, H.S., Che, Z.H. & Wang, M.J., 2009. A three-phase integrated model for product configuration change problems. *Expert Systems with Applications*, 36(3), pp.5491–5509. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0957417408004211.

Wang, L. & Lin, L., 2007. A methodological framework for the triple bottom line accounting and management of industry enterprises. *International Journal of Production Research*, 45(5), pp.1063–1088.

Yan, W., Chen, C.H. & Chang, W., 2009. An investigation into sustainable product conceptualization using a design knowledge hierarchy and Hopfield network. *Computers and Industrial Engineering*, 56(4), pp.1617–1626.

Yassine, A., 2004. An Introduction to Modeling and Analyzing Complex Product Development Processes Using the Design Structure Matrix (DSM) Method. *Urbana*, pp.1–17.

Yassine, A., 2004. An introduction to modeling and analyzing complex product development processes using the design structure matrix (DSM) method. *Urbana*. [Accessed January 1, 2016].

Yu, H., Shu, L. & Venter, R., 1998. An enhanced axiomatic design process. *Proceedings of the 1998 ASME Design …* [Accessed November 27, 2015].

Yuan, C. & Wang, W., 2013. Evaluation method of product configuration design integrated customer requirements and application. *African Journal of Business Management*, 7(26), pp.2634–2645.

Zettlemoyer, L.S. & St. Amant, R., 1999. A visual medium for programmatic control of interactive applications. *Proceedings of the SIGCHI conference on Human factors in computing systems the CHI is the limit - CHI '99*, (May), pp.199–206.

Zhang, H. & Xu, J., 2010. On the procedure and methods in modern furniture Green design. *2010 IEEE 11th International Conference on.* [Accessed December 15, 2015].

Zhang, J. & Zhang, Z., 2010. The Knowledge Management of Furniture Product Design and Development Process. *2010 3rd International Conference on Information Management, Innovation Management and Industrial Engineering*, 1, pp.464–467.

Zhang, X., 2012. a New Metric-Based Lca Method for Assessing the Sustainability Performance of Metallic Automotive Components.

Zhang, Y. & Gershenson, J., 2003. An initial study of direct relationships between life-cycle modularity and life-cycle cost. *Concurrent Engineering*. [Accessed November 22, 2015].

Zhou, X. & Kuhl, M., 2010. Design and development of a sustainability toolkit for simulation. *Proceedings of the Winter Simulation Conference*. [Accessed January 5, 2016].

Zhao,H & Cheng,K., 2014. Development of the Sustainable Design index and associated algorithm for furniture deisgn based on the materials costing data and dynamics. KES Transactions on Sustainable Design and manufacturing. Vol 1 No 1, pp.410-418.

Appendices

Publication Resulting from the Research

1) N.Seyajah, K.Cheng and R.Bateman. An Investigation On Method and Tools For Sustainable Design of Office Furniture. The 6th International Conference Design and Manufacturing for Sustainable Development (ICDMSD 2013) April 15-17 2013, pp. 27-34 Hangzhou China. ISBN 978-1-84919-709-0.

2) N.Seyajah, K.Cheng and R.Bateman. Sustainable Design and Innovation for Office Furniture and Its Implementation. The 24th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM) May 20-23 2014, San Antonio Texas.http://dx.org/10.14809/faim.2014.0999. UTSA.libraries digital collections

3) N.Seyajah, K.Cheng, and R.Bateman. Development of Sustainable Design Index For Office Furniture Design and Its CAD-Based Implementation. Proceeding Technical& Computer and Information in Engineering Conference, IDETC/CIE 2014, August 17-20 2014, Buffalo New York USA. Paper No. DET2014-35642,pp V004T06A060;12 pages. doi:10.1115/DET2014-35642

4) N.Seyajah, K.Cheng and R.Bateman. An Investigation on Sustainable Design Index and Its Implementation. CAD15 Proceeding CAD conference An International conference connecting people in CAD research, education and business. 22-25 June 2015 University of Greenwich London, UK . pp 137-142. DOI:10.14733/cadconfP.2015.137-142

5) N.Seyajah. K.Cheng and R.Bateman. Investigation tools for Sustainable Design Index and Its Implementation perspective. The 25th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM) 23-26 June 2015 at the University of Wolverhampton,UK. Vol. 1 pp 184-191. ISBN 978-1-910864-00-5.

6) Norhisham Seyajah, Kai Cheng and Richard Bateman. Sustainable Design Index: A Key Concept in Industrial Design Perspective.2nd SETNC 2015 –Science & Technology National Conference. 26-27th October 2015 Unikl MFI.

7) Norhisham Seyajah, Kai Cheng and Richard Bateman. Sustainable Design Index: A Key Concept in Industrial Design Perspective . Journal of Science and Engineering Technology (JSET).

8) N.Seyajah, K.Cheng, and R.Bateman.The Research the Assessment and Sustainable Design of Office Furniture Design From a Design perspective. ICETE-2015 5th International Conference on Engineering Technologies & Enterpreneurship. 16-18 November 2015. UniKL BMI.

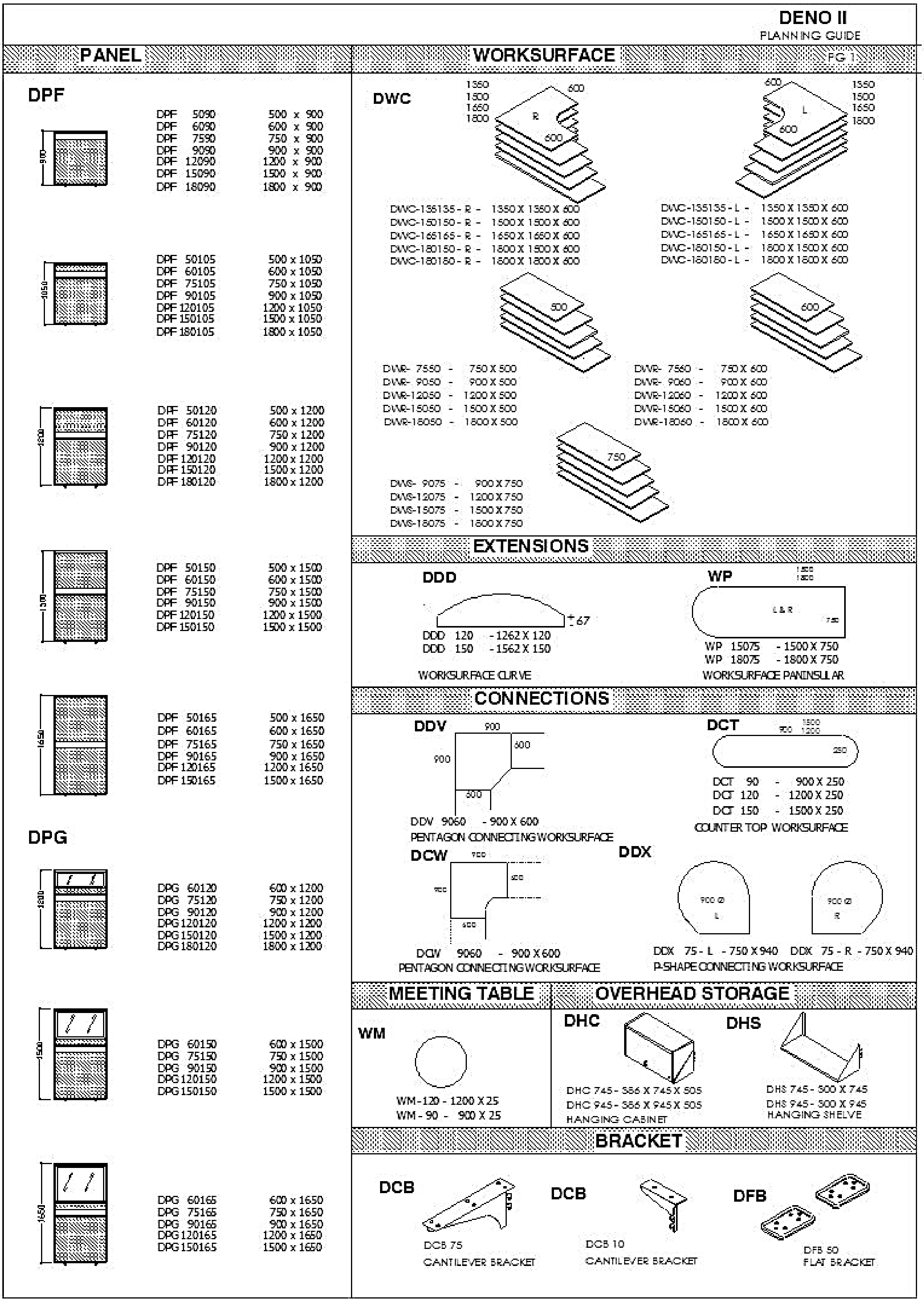
9) N.Seyajah, K.Cheng, and R.Bateman.The Research the Assessment and Sustainable Design of Office Furniture Design From a Design perspective. “Asian Journal of Scientific Research”(ISI Web of Science & SCOPUS Indexes) Journal. (…).

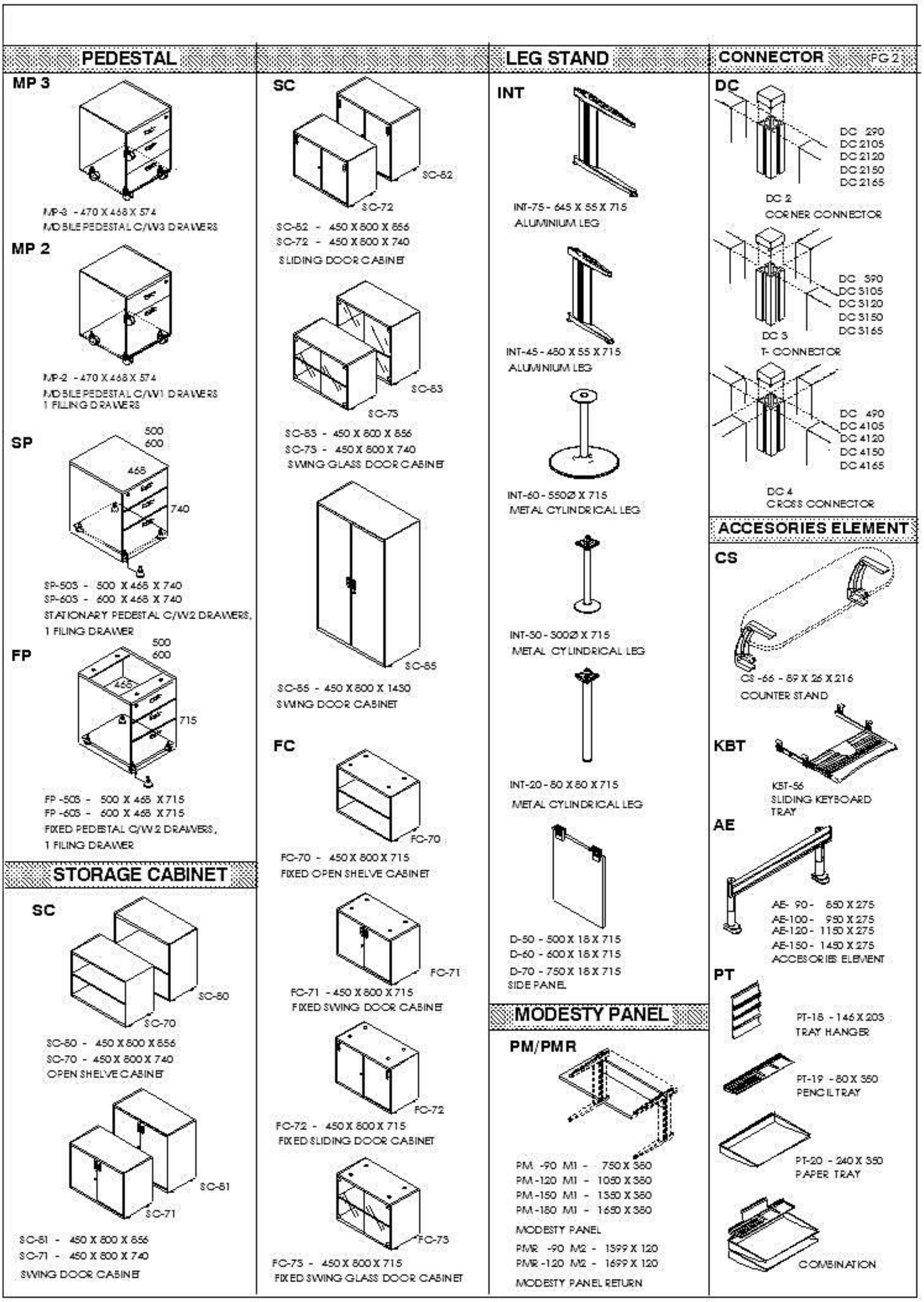
10) N.Seyajah, K.Cheng, and R.Bateman. Office Furniture Design Assessment Using Sustainable Design Index (SDI) and its Application Perspective. Journal of Manufacturing Science and Engineering. MAN-15-1639. (Process of Reviewer)

11) N.Seyajah, K.Cheng .An integrated of sustainable design method for office furniture evaluation. Conference Innovative Design and Manufacturing Engineering Conference (IDMEC 2016)

12) N.Seyajah and K.Cheng .Sustainable design: A furniture design approach and tool during the early design process and decision-making stages. Conference Innovative Design and Manufacturing Engineering Conference (IDMEC 2016)

Furniture Part and Components




PEDESTAL
MP 3
MP-3 - 470 X 468 X 574
MOBILE PEDESTAL C/W3 DRAWERS
MP 2
MP-2 - 470 X 468 X 574
MOBILE PEDESTAL C/W1 DRAWERS
1 FILLING DRAWERS
SP
500
600
468
740
SP-503 - 500 X 468 X 740
SP-603 - 600 X 468 X 740
STATIONARY PEDESTAL C/W2 DRAWERS,
1 FILING DRAWER
FP
500
600
468
715
FP -503 - 500 X 468 X715
FP -603 - 600 X 468 X715
FIXED PEDESTAL C/W2 DRAWERS,
1 FILING DRAWER
STORAGE CABINET
SC
SC-80
SC-70
SC-80 - 450 X 800 X 856
SC-70 - 450 X 800 X 740
OPEN SHELVE CABINET
SC-81
SC-71
SC-81 - 450 X 800 X 856
SC-71 - 450 X 800 X 740
SWING DOOR CABINET
SC
SC-82
SC-72
SC-82 - 450 X 800 X 856
SC-72 - 450 X 800 X 740
SLIDING DOOR CABINET
SC-83
SC-73
SC-83 - 450 X 800 X 856
SC-73 - 450 X 800 X 740
SWING GLASS DOOR CABINET
SC-85
SC-85 - 450 X 800 X 1450
SWING DOOR CABINET
FC
FC-70
FC-70 - 450 X 800 X 715
FIXED OPEN SHELVE CABINET
FC-71
FC-71 - 450 X 800 X 715
FIXED SWING DOOR CABINET
FC-72
FC-72 - 450 X 800 X 715
FIXED SLIDING DOOR CABINET
FC-73
FC-73 - 450 X 800 X 715
FIXED SWING GLASS DOOR CABINET
LEG STAND
INT
INT-75 - 645 X 55 X 715
ALUMINIUM LEG
INT-45 - 450 X 55 X 715
ALUMINIUM LEG
INT-60 - 550Ø X 715
METAL CYLINDRICAL LEG
INT-30 - 300Ø X 715
METAL CYLINDRICAL LEG
INT-20 - 80 X 80 X 715
METAL CYLINDRICAL LEG
D-50 - 500 X 18 X 715
D-60 - 600 X 18 X 715
D-70 - 750 X 18 X 715
SIDE PANEL
MODESTY PANEL
PM/PMR
PM -90 M1 - 750 X 380
PM -120 M1 - 1050 X 380
PM -150 M1 - 1350 X 380
PM -180 M1 - 1650 X 380
MODESTY PANEL
PMR -90 M2 - 1399 X 120
PMR -120 M2 - 1699 X 120
MODESTY PANEL RETURN
CONNECTOR
FG 2
DC
DC 290
DC 2105
DC 2120
DC 2150
DC 2165
DC 2
CORNER CONNECTOR
DC 390
DC 3105
DC 3120
DC 3150
DC 3165
DC 3
T- CONNECTOR
DC 490
DC 4105
DC 4120
DC 4150
DC 4165
DC 4
CROSS CONNECTOR
ACCESORIES ELEMENT
CS
CS -66 - 89 X 26 X 216
COUNTER STAND
KBT
KBT-56
SLIDING KEYBOARD
TRAY
AE
AE- 90 - 850 X 275
AE-100 - 950 X 275
AE-120 - 1150 X 275
AE-150 - 1450 X 275
ACCESORIES ELEMENT
PT
PT-18 - 146 X 203
TRAY HANGER
PT-19 - 80 X 350
PENCIL TRAY
PT-20 - 240 X 350
PAPER TRAY
COMBINATION

Sustainable design (SD) Indices

Böhringer & Jochem (2007) also documented and evaluated the methods of SD indices. They evaluated eleven indices that are utilised to measure national sustainable development. The assessment of these three indices (through normalisation, weighting, and aggregation) was used to determine the critically of their level, as shown in Figure 3-9.

Index	Scale	Normalization	Weighting	Aggregation
Living Planet Index	RNC	$\left(\frac{x_{i,t}}{x_{i,t-1}}\right)$	Equal	$\sqrt[N]{\prod_{i=1}^{N} \frac{x_{i,t}}{x_{i,t-1}}}$
Ecological Footprint	RNC	Transformation in square km	Equal	$\sum_{i=1}^{N} x_i$
City Development Index	RNC	$\frac{x_i - \underline{x}}{\overline{x} - \underline{x}}$	2 steps PCA/experts	$\frac{1}{N}\sum_{i=1}^{N} w_i x_i$
Human Development Index	RNC	$\frac{x_i - \underline{x}}{\overline{x} - \underline{x}}$	Equal	$\frac{1}{N}\sum_{i=1}^{N} x_i$
Environmental Sustainability Index 2005	RNC	Standard deviation	Equal/experts	$\frac{1}{N}\sum_{i=1}^{N} x_i$
Environmental Performance Index	RNC	Best=100 worst=0	PCA and experts	$\sum_{i=1}^{N} w_i x_i$
Environmental Vulnerability Index	RNC/INC	Aim=1 worst=7	Equal	$\frac{1}{N}\sum_{i=1}^{N} x_i$
Index of Sustainable Economic Welfare	RNC	Monetarized	Equal	$\sum_{i=1}^{N} x_i$
Well Being Index	RNC	Best=100 worst=0	Subjective (not derived)	$\frac{1}{N}\sum_{i=1}^{N} (w_i) x_i$
Genuine Savings Index	RNC	Monetarized	Equal	$\sum_{i=1}^{N} x_i$
Environmentally Adjusted Domestic Product (EDP)	RNC	Monetarized	Equal	$\sum_{i=1}^{N} x_i$

Figure 0-1: The types of index (evaluated by normalisation, weighting, and aggregation) (Bohringer & Jochem 2007)

According to Bosello et al., (2011), the normalised score permits a straight comparison concerning the different aspects of sustainability. Different dimensions of sustainable development also contribute to the index for single measure and it is easy to compare across countries. To determine the final composite index it is necessary to assign a weight to the aggregate indicators. This weight is usually obtained through a questionnaire.

CAD and User Interface Design

Many people also have other experience of working with computer programs that are undoubtedly simple as well as spontaneous to work with. Regrettably, additionally, there are plenty of software programs that are so complicated that it takes years to successfully use them, and it will ultimately occur that someone abandons them totally and then attempts to identify an alternative, that is simpler to learn.

In the past, first user interfaces (UI) happened to be basic character-mode command-prompt function, and then a computer user needed to key in commands to be able to execute his or her work. Subsequently, straightforward character-mode pseudo-graphical interfaces came out that will permit computer users to operate much more effectively, removing the requirement concerning the continuous keying in of related instructions. These days, a new, tremendously exciting GUI is essential. The following steps explain how the Visual Basic algorithm application is integrated into the AutoCAD 2014.

Step 1 -Due to the ability of the CAD application link in the CAD environment, the SDI from the template automatically picks from the Manage menu.

Step 2 -By clicking on the Visual Basic Editor Button, the applications are programmed after simulating the formulas, as explained in the equation 1 to 5 to calculate the result.

Step 3 -The code is written in macro function inside the Visual Basic editor.

Step 4 -The user clicks on the Load Application button on the Manage menu and will define the executed file of the Visual Basic application that has been developed.

Step 5 -The AutoCAD 2014 then loads the application into its allocated memory to be ready to run.

Step 6 -The user then clicks on the Run VBA Macro button to select the name of the macro that will run from the Visual Basic application.

Step 7 -The user reads the measurements from the design files in the AutoCAD and then inputs parameters of three different designs, as stated in the GUI.

Step 8 -The Visual Basic application, then calculates the formulas for SDI.

Step 9 -In the future, the VB will be developed to read all the necessary parameters automatically from the design files.

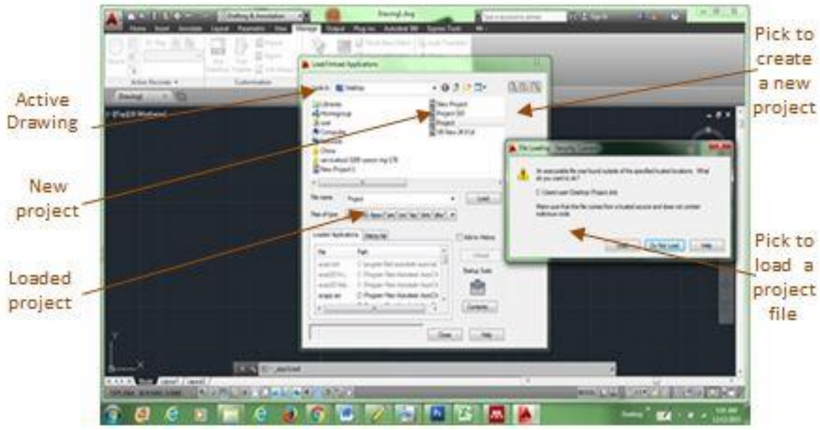


Figure 0-2: The Visual Basic Manager, in Auto CAD

Fig 6-7 shows a Visual Basic Editor in Auto CAD, where the VBA programming is a built-in editor with full features in CAD2014. In CAD the Visual Basic Editor calls the VBAIDE, the command button function to open the Visual Basic editor by picking from the VBA Manager Dialog box.

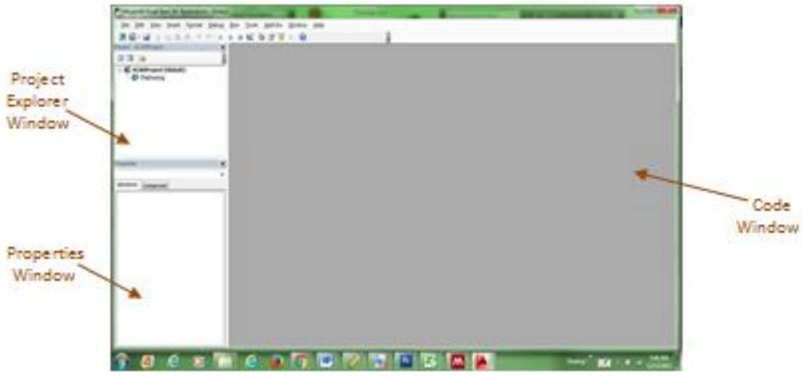


Figure 0-3: The Visual Basic Editor within CAD environment

Figure 6-8 shows the screen shot of Visual Basic, the GUI design. Once computer programming applies VBA, dialog boxes at the center are known as forms. All the properties of form are placed at the left call (toolbox) and right call (box) of the form. The particular order buttons, choice buttons, labeling, text boxes, and many other elements which are located on forms are known as controls. To position any specific items within the form is completed simply by right-clicking the specific item inside the toolbox and after that dragging the item towards the preferred place.

The particular user interface must end up being simple and easy, having minimum hidden selections so that customers can easily conduct work operations. Repeat-ability and also efficiency may improve significantly once features can easily be introduced with the least amount of browsing.

Figure 0-4: The design option for design, create user interfaces

In the AutoCAD project all the files are available to save at two locations: a) in a file; and b) in a drawing. As illustrated in Figure 6-9, below, a new project for a sustainable design index (SDI) is saved in a drawing and is recognised as embedded. The SDI project is automatically loaded since it is a macro and the SDI project is available to open each time in the drawing. The loaded file is a .Dvd file extension, where the SDI project must load in the drawing in order to run in macros. The advantage of this DVD file is that once the SDI project is loaded into a drawing it is considered global, which means that it is available to load into any drawing from any computer to access. The loaded SDI project name is a cad.dvd, where the file search part is located in the AutoCAD file. The SDI project file is open when it is laid in the drawing each time. As long as the SDI project is still open in a drawing file, the macros are accessible to open all drawing files once it is loaded in the drawing file.

Figure 0-5: The SDI user interface

Figure 6-10 shows the template from the page rendered to define the combination of HTML and VBScript for this project's sustainable design index (SDI) programming. This VBScript can also be described, as the variant of a single type of data. A variant is a unique kind of data model which can include a variety of information, depending on what is applied. The only data type in VBScript is a variant, where they both contain invariants such as numeric or string information. The variant function is dependent on the numeric context and string context because it follows what is returned by all functions in VBScript. In the same way, for anyone dealing with data that could just be string data, VBScript considers it as string data. The reason to apply VBScripts compared with JavaScript is because VBScripts is derived from Basic language, which is not like using JavaScript syntax, which is derived from the C language. The file extension in VBScript is .vba or .vbs, while for JavaScript the file extension in JavaScript is .js. Another description about the VBScript is the Active Scripting Language, lightweight and designed for a fast interpreter. When writing the VBScript it is not sensitive to the language, it is easy to handle.

Figure 0-6: The VBScript Language for the SDI programming

The goal of computer-aided design of user interface is to add the constructive and interactive GUI in Auto CAD Version Number 2014 to be used by the end-user. Computer-aided design systems are capable of operating in design, and developing, since they improve the requirements regarding mathematical variables, an activity that is challenging for individuals to actually achieve while using, visual images, and also in modifying graphic representations regarding digital objects, which is considerably more usual for individuals to perform. Computer-aided design systems could be useful for operating in user interface design because they improve the specification of programming language constructs, which are hard for individuals to achieve efficiently while using visualisation and modifying of visual representations of virtual interfaces, which are significantly more usual for individuals to make.

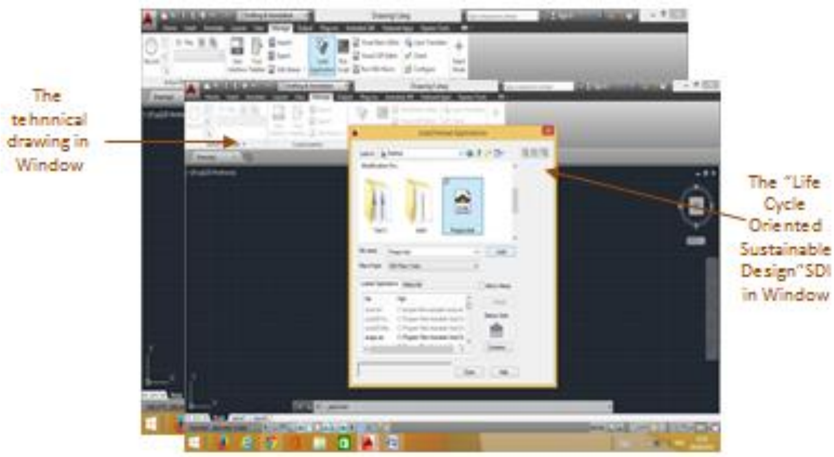


Figure 0-7: The CAD User Interface 'A'

As shown in Figure 6-12 A, the page is rendered to define the loan/unload application by using the pull-down menu, choosing Manage and then loading the application, which will appear and define the applications to load at start-up.

The start-up option loads the specified files or it can be dragged from the files list, or from any application with dragging capabilities. Then the file must be applied the file from the 'look in file': such a desktop file then loads the file name selected "Project SDI" which is the file type AUTO CAD Apps (*,arx,*orx,*lsp,*drb,dbx).

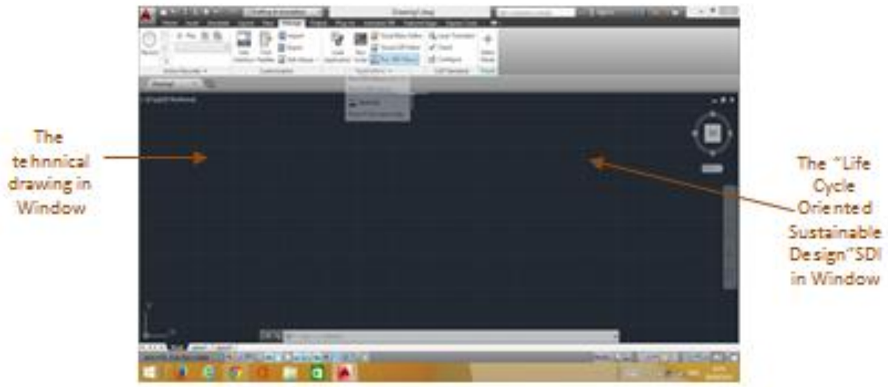


Figure 0-8: The CAD-based User Interface 'B'

Close the 'look in file', and then open the VBA using Run VBA Macros and run the Macros name file: click run the macro name, and the file VB interface will appear in the CAD environment as shown in Figure 6-13 B.

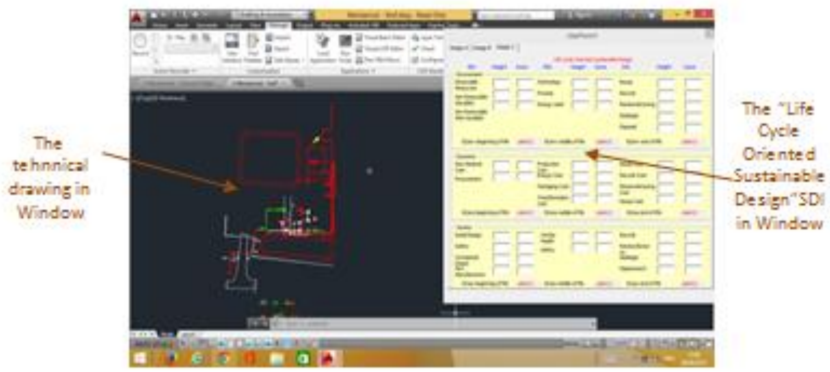


Figure 0-9: The CAD-based User Interface 'C'

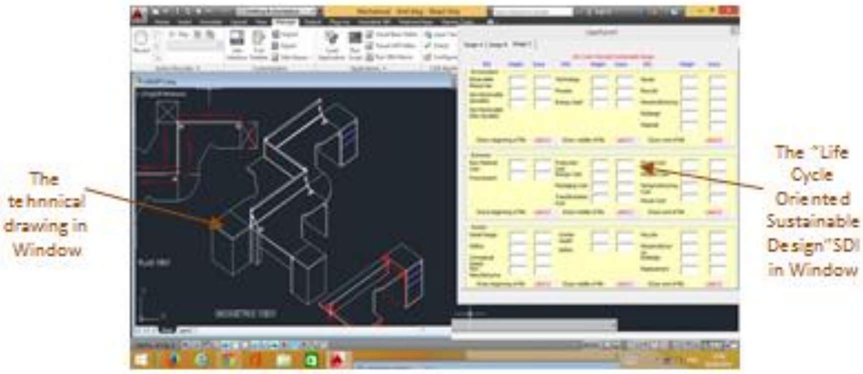


Figure 0-10: The CAD-based User Interface 'D'

Figure 6-14 C, and Figure 6-15 D, show the “Life Cycle Oriented Sustainable Design” graphical user interface which has a three design option, i.e., Design A, Design B, and Design C

From the Design A, Design B, and Design C option the user can fulfil the weight and score base from their expertise in order to distinguish between the three design options as shown In Figure 6-16 E.

Figure 0-11: The CAD-based User Interface 'E'

Fig 6-16 E, shown after the three design options A,B, and C already satisfies the user or designer need to choose the button calculate the sustainable design index in order to arrive at the final calculation for the sustainable design index as shown in a small tool box.

Case Studies at Office Furniture Design and Manufacturing Companies

There are two companies that have been chosen for this study a) Lozi Design Ltd UK and) Bristol Technology Sdn Bhd Malaysia.

1. Industrial Design Case Study 1 Lozi Design Ltd UK

Lozi Design Ltd (www.lozidesign.com)

Brief Company Background

Lozi Design Ltd was found by Soroush Pourhashemi in 2012 and was incorporated on 5th September 2013. Souroush Pourhashemi currently holds the positions of director/CEO. Lozi (in Persian) –means a rhombus. The term is used in describing traditional woodworking techniques, textile designs and architecture. Lozi (adj. Zambian)-means 'plain'.

Lozi draws influence from both organic and geometric shapes to create unique pieces of furniture. Everything they produce reflects the three basic elements of design: point, line and surface. The pieces are created by carefully shaping and bending wood-reducing the need for joints and augmenting the simplicity and elegance of the furniture (Soroush, 2012).

Lozi focus on design and manufacturing furniture for the UK market, ranging from tables, chest drawers, coat hangers, bedside cabinets, etc. The company's target market is mostly young professionals.

Every item is handcrafted at Lozi's workshop, and is of the highest quality. Lozi combines modern technology with traditional woodworking methods to deliver an element of soul to every product and give it personality in a way no factory can. Lozi care about how things feel. That is why they use only natural, sustainable products, from Latvian birch plywood and veneers, to organic glue and milk-based paint. They believe that beauty should be compatible with maintaining the world around us, and so strive to make all their product carbon neutral.

Aims and Objective of at Lozi Design

Lozi fuses traditional woodwork with modern technology and elegance with sustainability, creating pieces with personality at prices everyone can afford. The company focuses intensively on lean methods of manufacturing during product design and manufacturing, leading to a high waste reduction.

The distinct objectives of Lozi Design are:

-Use of sustainably sourced material in the manufacturing process as in the use of Latvian birch plywood and veneers, to organic glue and milk-based paint

-Waste reduction in product manufacturing and design: material reduction is achieved by cutting the plywood in such a way that every part of the plywood is used during the manufacturing process. Waste reduction in design is achieved by reducing unnecessary corners, edges, joints etc.

-Incorporating product aesthetics, product rigidity, and materials, sustainability together, therefore creating products that are a stylish, aesthetic, durable and reliable, and which are quite affordable.

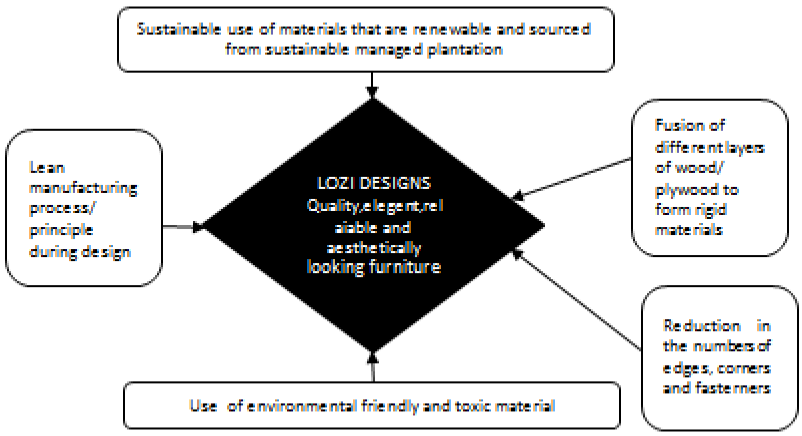


Figure 0-12: Lozi design ideology/objective

Lozi Design Methodology

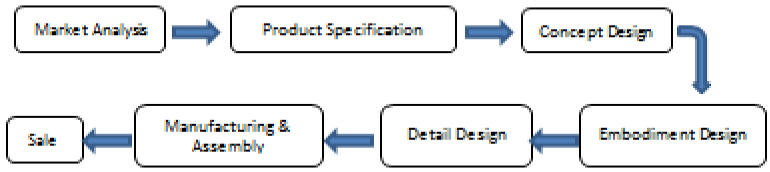


Figure 0-13: Lozi design methodology

Design, Manufacturing and Assembly of Product

Product –Candleholder

For the market analysis, the candle holder will be designed and manufactured.

Product specification

The design specification was developed from the customer requirements as stated below:

-The candle holder should be made from three different layers of plywood bonded together with non-toxic substance.

-It should be able to hold four candles that are not than 40mm in diameter

-The plywood should come from a sustainable forest plantation

-The product should target young UK professional, in cost, reliability, durability and aesthetics

-The candle holder should be light and should not be more than 420 X 80 X 100mm in dimension

Concept Design

After generating different concept drawings for the candle holder, the candle holder shown in Figure 6-23 was chosen as the concept to design, manufacture and assemble.

Embodiment Design

An embodiment design that aimed to meet all the specification and satisfy the customer requirements was created. The embodiment design for the chosen candle holder was made with corrugated cardboard paper.

Detail design

Detail dimensioning of the candle holder in 2D and material allocation

2. Case Study 2 at Bristol Technology Sdn Bhd

Bristol is a Malaysian group of companies that creates great design concepts for products and services. Bristol has a brand name that is connected with higher quality and functionality, modern and innovative design.

Bristol has been a leading and highly regarded the office furniture and seating manufacturer since 1983. Bristol produces products for office type furniture, such as meeting tables, executive desks, system furniture and storage. Bristol provides such items as office furniture and office seating products, the end product being produce to the high standard and delivered in conducive working environments for local and overseas markets. The core business is office furniture products, with strong support for research and development divisions, and it uses the highest quality and standard materials such as metal and wood-based product in order to meet the customer desires. (Bristol Office Furniture Manufacturer Workstation.., http://www.bristol.com.my/About/The-Bristol-Story.aspx (accessed December 24, 2015).) Bristol web site

Figure 0-14: Bristol Vision of the Business (Bristol Website)

2.1.1.1. Value and Vision of Bristol Design

The Growth

They predict which constant development in the organization is essential and also the motivation behind this growth is related to the next level of thinking.

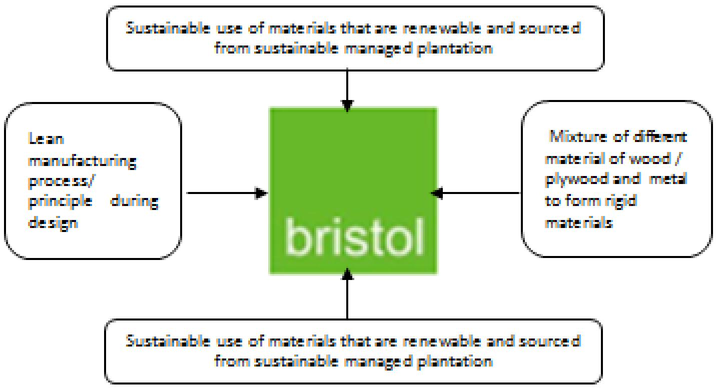


Figure 0-15: Bristol design ideology/objective

2.1.1.2. Bristol Design Methodology

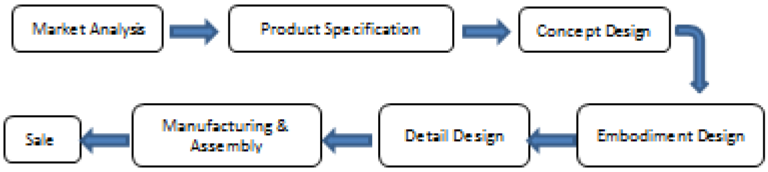


Figure 0-16: Bristol design methodology

Focus on the Core Business Venture

Bristol believes that their core business is to satisfy the end user's needs and requirements with good quality office furniture. In order to produce a better product for office furniture and seating the effort and focus is important. In Bristol, their slogan "the more you thought, you know, the less you know" is their aim and drives the process of improvement in their products. The process of learning is the primary activity for development to provide good office furniture and seating to meet consumer needs and to follow the trend by incorporating new technology.

Entrepreneurship in Business Handling

The team member is a principal actor in their activities, which means the participation of all the people helping the owner to run the company. The synchronisation of every department helps smoothen the company to run the operation with perfect results. The role of the staff and management contribute to improving the product quality through their understanding and helping to value-add the product, as well as cost-efficiency for the enriched attractiveness of their products.

Constant Change in Business Environment

Their focus and efforts are aimed at the customer requirements towards business, including the design process, product pricing, project management and project financing, marketing material, and space planning consultancy. The establishment of the product in the market segment, and also, the demand and mature market for the professional project, redirects the company to serve the project and contract sales. Their challenge is to handle the globalisation of the marketplace and attract customers from countries like India, Pakistan, Kuwait, and Dubai.

Sustainability

Bristol is committed to preventing pollution and continually improving the product while sustaining the energy and other resources with environmental implementation. Their objective is to involve everyone to care for the environment with various environmental management programs:

-To confirm having the actual local environmental legal specifications as well as consumer specifications.

-To dedicate themselves to being able to recycle as well as recover waste, as well as transforming trash into useful material and products where possible.

-To preserve energy and also to decrease the use of chemical substance and gas.

Part of Programming for SDI Source Code

SUSTAINABLE DESIGN INDEX (SDI) (SOURCE CODE)

```
Private Sub Label15_Click()
  End Sub
Private Sub CommandButton1_Click()
 UserForm2.Hide
  End Sub
Private Sub CommandButton2_Click()
                    Dim sdiA As Double
             Dim sdiC As Double
   Dim sdiB As Double
      Dim eWtotalA As Double
   Dim ecoWtotalA As Double
Dim sWtotalA As Double
       Dim eWtotalB As Double
  Dim ecoWtotalB As Double
Dim sWtotalB As Double
    Dim eWtotalC As Double
 Dim ecoWtotalC As Double
Dim sWtotalC As Double
     Dim sdiA_String As String * 5
   Dim sdiB_String As String * 5
   Dim sdiC_String As String * 5

On Error GoTo errMyErrorHandler:
 Dim eWtotalA_String As String * 5
Dim ecoWtotalA_String As String * 5
Dim sWtotalA_String As String * 5
       Dim eWtotalB_String As String * 5
     Dim ecoWtotalB_String As String * 5
  Dim sWtotalB_String As String * 5
Dim eWtotalC_String As String * 5
  Dim ecoWtotalC_String As String * 5
     Dim sWtotalC_String As String * 5
```

```
Dim eStotalA_String As String * 5
Dim ecoStotalA_String As String * 5
Dim sStotalA_String As String * 5
Dim eStotalB_String As String * 5
Dim ecoStotalB_String As String * 5

Dim sStotalB_String As String * 5
Dim eStotalC_String As String * 5
Dim ecoStotalC_String As String * 5
Dim sStotalC_String As String * 5

Dim X As String * 10
Dim Y As String * 10
Dim z As String * 10
Dim sFile As String, lFile As Long
Dim filePath As String

eWtotalA = eWA.Text
ecoWtotalA = ecoWA.Text
sWtotalA = sWA.Text
eWtotalC = eWC.Text
ecoWtotalC = ecoWC.Text
sWtotalC = sWC.Text

eWtotalB = eWB.Text
ecoWtotalB = ecoWB.Text
sWtotalB = sWB.Text
sdiA = ((Round(eStotalA, 1) * eWtotalA) + (Round(ecoStotalA, 1) *
ecoWtotalA) + (Round(sStotalA, 1) * sWtotalA)) / 3
sdiA_String = sdiA
sdiB = ((Round(eStotalB, 1) * eWtotalB) + (Round(ecoStotalB, 1) *
ecoWtotalB) + (Round(sStotalB, 1) * sWtotalB)) / 3
sdiB_String = sdiB
sdiC = ((Round(eStotalC, 1) * eWtotalC) + (Round(ecoStotalC, 1) *
ecoWtotalC) + (Round(sStotalC, 1) * sWtotalC)) / 3
sdiC_String = sdiC
```

```
                  sdiAlabel.Caption = sdiA
         sdiBlabel.Caption = sdiB
sdiClabel.Caption = sdiC
eWtotalA_String = Round(eWtotalA,
ecoWtotalA_String = Round(ecoWtotalA, 1)
sWtotalA_String = Round(sWtotalA, 1)
eWtotalC_String = Round(eWtotalC, 1)
eWtotalB_String = Round(eWtotalB,
ecoWtotalB_String = Round(ecoWtotalB, 1)
ecoStotalA_String = Round(ecoStotalA, 1)
sStotalC_String = Round(sStotalC, 1)
eStotalB_String = Round(eStotalB, 1)
eStotalA_String = Round(eStotalA, 1)
sWtotalC_String = Round(sWtotalC, 1)
sWtotalB_String = Round(sWtotalB, 1)
sStotalA_String = Round(sStotalA, 1)
ecoStotalC_String = Round(ecoStotalC, 1)
eStotalC_String = Round(eStotalC, 1)
sStotalB_String = Round(sStotalB, 1)
ecoWtotalC_String = Round(ecoWtotalC, 1) eStotalA_String =
Round(eStotalA, 1)

ecoStotalA_String = Round(ecoStotalA, 1)
ecoStotalB_String = Round(ecoStotalB, 1)
sStotalA_String = Round(sStotalA, 1)
X = "ABC"
Y = "AB"
z = sdiC
filePath = "C:\Test.txt"
Kill filePath
    sFile = "C:\Test.txt"

    lFile = FreeFile
    Open sFile For Append As lFile
```

```
    Print #lFile, "                    *******  Office Furniture (Open
Plan System)  ********"
    Print #lFile, "Sustainable Criteria       Design A
Design B                       Design C"
 Print #lFile, "" Print #lFile, " Score      Weight              Score
Weight              Score     Weight"
 Print #lFile, " Environment " & eStotalA_String & " " &
eWtotalA_String & " " & eStotalB_String & " " & eWtotalB_String & "   "
& eStotalC_String & " " & eWtotalC_String
    Print #lFile, " Economic " & ecoStotalA_String & "         " &
ecoWtotalA_String & " " & ecoStotalB_String & " " & ecoWtotalB_String &
" " & ecoStotalC_String & "  " & ecoWtotalC_Strin
    Print #lFile, " Social " & sStotalA_String &  " & sWtotalA_String &
" " & sStotalB_String & "  " & sWtotalB_String & " " & sStotalC_String
& " " & sWtotalC_String
    Print #lFile, ""

    Print #lFile, "*****  Sustainable Design index (SDI)  *****"
                      Print #lFile, "Design A = " & sdiA_String
    Print #lFile, "Design B = " & sdiB_String
                       Print #lFile, "Design C = " & sdiC_String
      Close lFile
 Exit Sub
errMyErrorHandler:
           MsgBox "Please inputnumbers only", _
  vbExclamation + vbOKCancel, _
             "Error: " & CStr(Err.Number)
End Sub

Private Sub ecoWtotalB_Change()

End Sub

Private Sub UserForm_Click()

End Sub
```

SUSTAINABLE DESIGN CRITERIA (SOURCE CODE)

```
Private Sub CommandButton1_Click()
'Unload Me
'UserForm1.hide
'UserForm1.show
ThisDrawing.Activate
End Sub
Private Sub TabStrip1_Change()
End
Private Sub TabStrip4_Change()
End Sub
Private Sub CommandButton2_Click()
Dim eW1value As Double
   Dim eW2value As Double
      Dim eW3value As Double
         Dim eW4value As Double
             Dim eW5value As Double
                   Dim eW6value As Double
                Dim eW7value As Double
      Dim eW8value As Double
         Dim eW9value As Double
            Dim eW10value As Double
                 Dim eW11value As Double
Dim eS1value As Double
     Dim eS2value As Double
           Dim eS3value As Double
               Dim eS4value As Double
                   Dim eS5value As Double
                  Dim eS6value As Double
           Dim eS7value As Double
  Dim eS8value As Double
            Dim eS9value As Double
                    Dim eS10value As Double
```

```
    Dim eS11value As Double
Dim cS1value As Double
  Dim cS2value As Double
      Dim cS3value As Double
          Dim cS4value As Double
             Dim cS5value As Double
              Dim cS6value As Double
                  Dim cS7value As Double
            Dim cS8value As Double
         Dim cS9value As Double
Dim cS10value As Double
          Dim cW1value As Double
             Dim cW2value As Double
                Dim cW3value As Double
                   Dim cW4value As Double
                      Dim cW5value As Double
                        Dim cW6value As Double
                  Dim cW7value As Double
           Dim cW8value As Double
Dim cW9value As Double
Dim cW10value As Double
   Dim sW1value As Double
       Dim sW2value As Double
           Dim sW3value As Double
               Dim sW4value As Double
                  Dim sW5value As Double
                     Dim sW6value As Double
                   Dim sW7value As Double
                Dim sW8value As Double
            Dim sW9value As Double
Dim sW10value As Double
           Dim sS1value As Double
               Dim sS2value As Double
                  Dim sS3value As Double
                    Dim sS4value As Double
                        Dim sS5value As Double
```

```
Dim sS6value As Double
Dim sS7value As Double
Dim sS8value As Double
Dim sS9value As Double
Dim sS10value As Double
Dim test As Double

Dim SCenvvalue1 As Double
Dim SCenvvalue2 As Double
Dim SCenvvalue3 As Double

Dim SCecovalue1 As Double
Dim SCecovalue2 As Double
Dim SCecovalue3 As Double

Dim SCsocvalue1 As Double
Dim SCsocvalue2 As Double
Dim SCsocvalue3 As Double
On Error GoTo errMyErrorHandler:

eW1value = eW1.Text
eS1value = eS1.Text
eW2value = eW2.Text
eS2value = eS2.Text
eW3value = eW3.Text
eS3value = eS3.Text

eW4value = eW4.Text
eS4value = eS4.Text
eW5value = eW5.Text
eS5value = eS5.Text
eW6value = eW6.Text
eS6value = eS6.Text

eW7value = eW7.Text
eS7value = eS7.Text
```

```
eW8value = eW8.Text
eS8value = eS8.Text
eW9value = eW9.Text
eS9value = eS9.Text
eW10value = eW10.Text
eS10value = eS10.Text
eW11value = eW11.Text
eS11value = eS11.Text

cW1value = cW1.Text
cS1value = cS1.Text
cW2value = cW2.Text
cS2value = cS2.Text
cW3value = cW3.Text
cS3value = cS3.Text
cW4value = cW4.Text
cS4value = cS4.Text
cW5value = cW5.Text
cS5value = cS5.Text
cW6value = cW6.Text
cS6value = cS6.Text
cW7value = cW7.Text
cS7value = cS7.Text
cW8value = cW8.Text
cS8value = cS8.Text
cW9value = cW9.Text
cS9value = cS9.Text
cW10value = cW10.Text
cS10value = cS10.Text

SCenvvalue1 = ((eW1value) * (eS1value) + (eW2value) * (eS2value) +
(eW3value) * (eS3value)) / 3
SCenvvalue2 = ((eW4value) * (eS4value) + (eW5value) * (eS5value) +
(eW6value) * (eS6value)) / 3
```

```
SCenvvalue3 = ((eW7value) * (eS7value) + (eW8value) * (eS8value) +
(eW9value) * (eS9value) + (eW10value) * (eS10value) + (eW11value) *
(eS11value)) / 5

SCenv1.Caption = SCenvvalue1
        SCenv2.Caption = SCenvvalue2
                  SCenv3.Caption = SCenvvalue3
SCecovalue1 = ((cW1value) * (cS1value) + (cW2value) * (cS2value)) / 2
          SCecovalue2 = ((cW3value) * (cS3value) + (cW4value) *
(cS4value) + (cW5value) * (cS5value) + (cW6value) * (cS6value)) / 4
           SCecovalue3 = ((cW7value) * (cS7value) + (cW8value) *
(cS8value) + (cW9value) * (cS9value) + (cW10value) * (cS10value)) / 4
SCeco1.Caption = SCecovalue1
            SCeco2.Caption = SCecovalue2
                       SCeco3.Caption = SCecovalue3

sW1value = sW1.Text
     sS1value = sS1.Text
            sW2value = sW2.Text
                    sS2value = sS2.Text
               sW3value = sW3.Text
        sS3value = sS3.Text
sW4value = sW4.Text
        sS4value = sS4.Text
               sW5value = sW5.Text
        sS5value = sS5.Text
sW6value = sW6.Text
sS6value = sS6.Text
            sW7value = sW7.Text
                     sS7value = sS7.Text
                                sW8value = sW8.Text
                        sS8value = sS8.Text
                    sW9value = sW9.Text
          sS9value = sS9.Text
     sW10value = sW10.Text
sS10value = sS10.Text
```

```
SCsocvalue1 = ((sW1value) * (sS1value) + (sW2value) * (sS2value) +
(sW3value) * (sS3value) + (sW4value) * (sS4value)) / 4
              SCsocvalue2 = ((sW5value) * (sS5value) + (sW6value) *
(sS6value)) / 2
SCsocvalue3 = ((sW7value) * (sS7value) + (sW8value) * (sS8value) +
(sW9value) * (sS9value) + (sW10value) * (sS10value)) / 4

SCsoc1.Caption = SCsocvalue1
            SCsoc2.Caption = SCsocvalue2
SCsoc3.Caption = SCsocvalue3
Exit Sub
          errMyErrorHandler:
 MsgBox "Please inputnumbers only", _
             vbExclamation + vbOKCancel, _
   "Error: " & CStr(Err.Number)
End Sub

Private Sub Frame1_Click()

End Sub

Private Sub CommandButton3_Click()
Dim eW1value As Double
    Dim eW2value As Double
       Dim eW3value As Double
           Dim eW4value As Double
             Dim eW5value As Double
                  Dim eW6value As Double
                  Dim eW7value As Double
           Dim eW8value As Double
      Dim eW9value As Double
   Dim eW10value As Double
Dim eW11value As Double
   Dim eS1value As Double
       Dim eS2value As Double
```

```
Dim eS3value As Double
Dim eS4value As Double
Dim eS5value As Double
Dim eS6value As Double
Dim eS7value As Double
Dim eS8value As Double
Dim eS9value As Double
Dim eS10value As Double
Dim eS11value As Double
Dim cS1value As Double
Dim cS2value As Double
Dim cS3value As Double
Dim cS4value As Double
Dim cS5value As Double
Dim cS6value As Double
Dim cS7value As Double
Dim cS8value As Double
Dim cS9value As Double
Dim cS10value As Double
Dim cW1value As Double
Dim cW2value As Double
Dim cW3value As Double
Dim cW4value As Double

Dim cW5value As Double
Dim cW6value As Double
Dim cW7value As Double
Dim cW8value As Double
Dim cW9value As Double
Dim cW10value As Double
Dim sW1value As Double
Dim sW2value As Double
Dim sW3value As Double
Dim sW4value As Double

Dim sW5value As Double
```

```
Dim sW6value As Double
Dim sW7value As Double
Dim sW8value As Double
Dim sW9value As Double
Dim sW10value As Double
Dim sS1value As Double
Dim sS2value As Double
Dim sS3value As Double
Dim sS4value As Double

Dim sS5value As Double
Dim sS6value As Double
Dim sS7value As Double
Dim sS8value As Double
Dim sS9value As Double
Dim sS10value As Double
Dim test As Double

Dim SCenvvalue1 As Double
Dim SCenvvalue2 As Double
Dim SCenvvalue3 As Double

Dim SCecovalue1 As Double
Dim SCecovalue2 As Double
Dim SCecovalue3 As Double

Dim SCsocvalue1 As Double
Dim SCsocvalue2 As Double
Dim SCsocvalue3 As Double

On Error GoTo errMyErrorHandler:

eW1value = eW1B.Text
eS1value = eS1B.Text
eW2value = eW2B.Text
eS2value = eS2B.Text
```

```
eW3value = eW3B.Text
eS3value = eS3B.Text

eW4value = eW4B.Text
eS4value = eS4B.Text
eW5value = eW5B.Text
eS5value = eS5B.Text
eW6value = eW6B.Text
eS6value = eS6B.Text

eW7value = eW7B.Text
eS7value = eS7B.Text
eW8value = eW8B.Text
eS8value = eS8B.Text
eW9value = eW9B.Text
eS9value = eS9B.Text
eW10value = eW10B.Text
eS10value = eS10B.Text
eW11value = eW11B.Text
eS11value = eS11B.Text


cW1value = cW1B.Text
cS1value = cS1B.Text
cW2value = cW2B.Text
cS2value = cS2B.Text
cW3value = cW3B.Text
cS3value = cS3B.Text
cW4value
= cW4B.Text
cS4value = cS4B.Text
cW5value = cW5B.Text
cS5value = cS5B.Text
cW6value = cW6B.Text
cS6value = cS6B.Text
cW7value = cW7B.Text
```

```
cS7value = cS7B.Text
cW8value = cW8B.Text
cS8value = cS8B.Text
cW9value = cW9B.Text
cS9value = cS9B.Text
cW10value = cW10B.Text
cS10value = cS10B.Text

SCenvvalue1 = ((eW1value) * (eS1value) + (eW2value) * (eS2value) + (eW3value) * (eS3value)) / 3
SCenvvalue2 = ((eW4value) * (eS4value) + (eW5value) * (eS5value) + (eW6value) * (eS6value)) / 3
SCenvvalue3 = ((eW7value) * (eS7value) + (eW8value) * (eS8value) + (eW9value) * (eS9value) + (eW10value) * (eS10value) + (eW11value) * (eS11value)) / 5

SCenv1B.Caption = SCenvvalue1
SCenv2B.Caption = SCenvvalue2
SCenv3B.Caption = SCenvvalue3

SCecovalue1 = ((cW1value) * (cS1value) + (cW2value) * (cS2value)) / 2
SCecovalue2 = ((cW3value) * (cS3value) + (cW4value) * (cS4value) + (cW5value) * (cS5value) + (cW6value) * (cS6value)) / 4
SCecovalue3 = ((cW7value) * (cS7value) + (cW8value) * (cS8value) + (cW9value) * (cS9value) + (cW10value) * (cS10value)) / 4

SCeco1B.Caption = SCecovalue1
SCeco2B.Caption = SCecovalue2
SCeco3B.Caption = SCecovalue3

sW1value = sW1B.Text
sS1value = sS1B.Text
sW2value = sW2B.Text
sS2value = sS2B.Text
sW3value = sW3B.Text
sS3value = sS3B.Text
```

```
sW4value = sW4B.Text
sS4value = sS4B.Text
sW5value = sW5B.Text
sS5value = sS5B.Text
sW6value = sW6B.Text
sS6value = sS6B.Text
sW7value = sW7B.Text
sS7value = sS7B.Text
sW8value = sW8B.Text
sS8value = sS8B.Text
sW9value = sW9B.Text
sS9value = sS9B.Text
sW10value = sW10B.Text
sS10value = sS10B.Text

SCsocvalue1 = ((sW1value) * (sS1value) + (sW2value) * (sS2value) +
(sW3value) * (sS3value) + (sW4value) * (sS4value)) / 4
SCsocvalue2 = ((sW5value) * (sS5value) + (sW6value) *
(sS6value)) / 2
SCsocvalue3 = ((sW7value) * (sS7value) + (sW8value) * (sS8value) +
(sW9value) * (sS9value) + (sW10value) * (sS10value)) / 4

SCsoc1B.Caption = SCsocvalue1
SCsoc2B.Caption = SCsocvalue2
SCsoc3B.Caption = SCsocvalue3
Exit Sub
errMyErrorHandler:
MsgBox "Please inputnumbers only", _
vbExclamation + vbOKCancel, _
"Error: " & CStr(Err.Number)
End Sub

Private Sub CommandButton4_Click()
Dim eW1value As Double
Dim eW2value As Double
Dim eW3value As Double
```

```
Dim eW4value As Double
Dim eW5value As Double
Dim eW6value As Double
Dim eW7value As Double
Dim eW8value As Double
Dim eW9value As Double
Dim eW10value As Double
Dim eW11value As Double
Dim eS1value As Double
Dim eS2value As Double
Dim eS3value As Double
Dim eS4value As Double
Dim eS5value As Double
Dim eS6value As Double
Dim eS7value As Double
Dim eS8value As Double
Dim eS9value As Double
Dim eS10value As Double
Dim eS11value As Double
Dim cS1value As Double
Dim cS2value As Double
Dim cS3value As Double
Dim cS4value As Double
Dim cS5value As Double
Dim cS6value As Double
Dim cS7value As Double
Dim cS8value As Double
Dim cS9value As Double
Dim cS10value As Double
Dim cW1value As Double
Dim cW2value As Double
Dim cW3value As Double
Dim cW4value As Double
Dim cW5value As Double
Dim cW6value As Double
Dim cW7value As Double
```

```
Dim cW8value As Double
Dim cW9value As Double
Dim cW10value As Double
Dim sW1value As Double
Dim sW2value As Double
Dim sW3value As Double
Dim sW4value As Double
Dim sW5value As Double
Dim sW6value As Double
Dim sW7value As Double
Dim sW8value As Double
Dim sW9value As Double
Dim sW10value As Double
Dim sS1value As Double
Dim sS2value As Double
Dim sS3value As Double
Dim sS4value As Double
Dim sS5value As Double
Dim sS6value As Double
Dim sS7value As Double
Dim sS8value As Double
Dim sS9value As Double
Dim sS10value As Double
Dim test As Double

Dim SCenvvalue1 As Double
Dim SCenvvalue2 As Double
Dim SCenvvalue3 As Double

Dim SCecovalue1 As Double
Dim SCecovalue2 As Double
Dim SCecovalue3 As Double

Dim SCsocvalue1 As Double
Dim SCsocvalue2 As Double
Dim SCsocvalue3 As Double
```

```
On Error GoTo errMyErrorHandler:

eW1value = eW1A.Text
              eS1value = eS1A.Text
                           eW2value = eW2A.Text
                 eS2value = eS2A.Text
          eW3value = eW3A.Text
eS3value = eS3A.Text

eW4value = eW4A.Text
               eS4value = eS4A.Text
                                 eW5value = eW5A.Text
                        eS5value = eS5A.Text
             eW6value = eW6A.Text
eS6value = eS6A.Text

eW7value = eW7A.Text
   eS7value = eS7A.Text
     eW8value = eW8A.Text
       eS8value = eS8A.Text
            eW9value = eW9A.Text
       eS9value = eS9A.Text
                            eW10value = eW10A.Text
                      eS10value = eS10A.Text
          eW11value = eW11A.Text
eS11value = eS11A.Text


cW1value = cW1A.Text
   cS1value = cS1A.Text
      cW2value = cW2A.Text
         cS2value = cS2A.Text
              cW3value = cW3A.Text
                  cS3value = cS3A.Text
                      cW4value = cW4A.Text
```

```
cS4value = cS4A.Text
cW5value = cW5A.Text
cS5value = cS5A.Text
cW6value = cW6A.Text
cS6value = cS6A.Text
cW7value = cW7A.Text
cS7value = cS7A.Text
cW8value = cW8A.Text
cS8value = cS8A.Text
cW9value = cW9A.Text
cS9value = cS9A.Text
cW10value = cW10A.Text
cS10value = cS10A.Text

SCenvvalue1 = ((eW1value) * (eS1value) + (eW2value) * (eS2value) +
(eW3value) * (eS3value)) / 3
SCenvvalue2 = ((eW4value) * (eS4value) + (eW5value)
* (eS5value) + (eW6value) * (eS6value)) / 3
SCenvvalue3 = ((eW7value) * (eS7value) + (eW8value)
* (eS8value) + (eW9value) * (eS9value) + (eW10value) * (eS10value) +
(eW11value) * (eS11value)) / 5

SCenv1A.Caption = SCenvvalue1
SCenv2A.Caption = SCenvvalue2
SCenv3A.Caption = SCenvvalue3
SCecovalue1 = ((cW1value) * (cS1value) + (cW2value) * (cS2value)) / 2
SCecovalue2 = ((cW3value) * (cS3value) + (cW4value) *
(cS4value) + (cW5value) * (cS5value) + (cW6value) * (cS6value)) / 4
SCecovalue3 = ((cW7value) * (cS7value) + (cW8value)
* (cS8value) + (cW9value) * (cS9value) + (cW10value) * (cS10value)) / 4
SCeco1A.Caption = SCecovalue1
SCeco2A.Caption = SCecovalue2
SCeco3A.Caption = SCecovalue3
sW1value = sW1A.Text
sS1value = sS1A.Text
sW2value = sW2A.Text
```

```
sS2value = sS2A.Text
sW3value = sW3A.Text
sS3value = sS3A.Text
sW4value = sW4A.Text
sS4value = sS4A.Text
sW5value = sW5A.Text
sS5value = sS5A.Text
sW6value = sW6A.Text
sS6value = sS6A.Text
sW7value = sW7A.Text
sS7value = sS7A.Text
sW8value = sW8A.Text
sS8value = sS8A.Text
sW9value = sW9A.Text
sS9value = sS9A.Text
sW10value = sW10A.Text
sS10value = sS10A.Text

SCsocvalue1 = ((sW1value) * (sS1value) + (sW2value) * (sS2value) +
(sW3value) * (sS3value) + (sW4value) * (sS4value)) / 4
SCsocvalue2 = ((sW5value) * (sS5value) + (sW6value) * (sS6value)) / 2
SCsocvalue3 = ((sW7value) * (sS7value) + (sW8value) * (sS8value) +
(sW9value) * (sS9value) + (sW10value) * (sS10value)) / 4

SCsoc1A.Caption = SCsocvalue1
SCsoc2A.Caption = SCsocvalue2
SCsoc3A.Caption = SCsocvalue3
Exit Sub
errMyErrorHandler:
MsgBox "Please inputnumbers only", _
vbExclamation + vbOKCancel, _
"Error: " & CStr(Err.Number)
End Sub
Private Sub CommandButton5_Click()
Dim eStotalA As Double
Dim eStotalB As Double
```

```
Dim eStotalC As Double
Dim ecoStotalA As Double
Dim ecoStotalB As Double
Dim ecoStotalC As Double
Dim sStotalA As Double
Dim sStotalB As Double
Dim sStotalC As Double

On Error GoTo errMyErrorHandler:

eStotalA = CDbl(SCenv1A.Caption) + CDbl(SCenv2A.Caption) +
CDbl(SCenv3A.Caption)
ecoStotalA = CDbl(SCeco1A.Caption) + CDbl(SCeco2A.Caption) +
CDbl(SCeco3A.Caption)
sStotalA = CDbl(SCsoc1A.Caption) + CDbl(SCsoc2A.Caption) +
CDbl(SCsoc3A.Caption)
eStotalB = CDbl(SCenv1B.Caption) + CDbl(SCenv2B.Caption) +
CDbl(SCenv3B.Caption)
ecoStotalB = CDbl(SCeco1B.Caption) + CDbl(SCeco2B.Caption) +
CDbl(SCeco3B.Caption)
sStotalB = CDbl(SCsoc1B.Caption) + CDbl(SCsoc2B.Caption) +
CDbl(SCsoc3B.Caption)

eStotalC = CDbl(SCenv1.Caption) + CDbl(SCenv2.Caption) +
CDbl(SCenv3.Caption)
ecoStotalC = CDbl(SCeco1.Caption) + CDbl(SCeco2.Caption) +
CDbl(SCeco3.Caption)
sStotalC = CDbl(SCsoc1.Caption) + CDbl(SCsoc2.Caption) +
CDbl(SCsoc3.Caption)

UserForm2.eStotalA.Text = eStotalA
UserForm2.ecoStotalA.Text = ecoStotalA
UserForm2.sStotalA.Text = sStotalA

UserForm2.eStotalB.Text = eStotalB
UserForm2.ecoStotalB.Text = ecoStotalB
```

```
UserForm2.sStotalB.Text = sStotalB

UserForm2.eStotalC.Text = eStotalC
               UserForm2.ecoStotalC.Text = ecoStotalC
UserForm2.sStotalC.Text = sStotalC

UserForm2.show
                Exit Sub
errMyErrorHandler:
              UserForm2.Hide
 MsgBox "Please inputnumbers only", _
                   vbExclamation + vbOKCancel, _
           "Error: " & CStr(Err.Number)
End Sub

Private Sub eW1B_Change()
                   UserForm1.show False
End Sub
          Private Sub Frame11_Click()
                      End Sub
           Private Sub Frame4_Click()
End Sub
             Private Sub Label2_Click()
                         End Sub
                 Private Sub Label24_Click()
End Sub
                 Private Sub Label92_Click()
                             End Sub
                   Private Sub MultiPage1_Change()
End Sub
                    Private Sub TextBox3_Change()
            UserForm1.show (Modal)
                                       End Sub
Private Sub UserForm_Click()
                              End Sub
```

******* Office Furniture (Open Plan System) ********

Sustainable Criteria	Design A		Design B		Design C	
	Score	Weight	Score	Weight	Score	Weight
Environment	3	1	3	2	3	3
Economic	3	1	3	2	3	3
Social	3	1	3	2	3	3

***** Sustainable Design index (SDI) *****

Design A = 3

Design B = 6

Design C = 7